Air Quality Benefits of Nighttime Construction in Texas Non-attainment Counties—Technical Report

Technical Report 0-6864-1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
http://tti.tamu.edu/documents/0-6864-1.pdf

Technical Report Documentation Page

1. Report No. FHWA/TX-17/0-6864-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle AIR QUALITY BENEFITS OF NIGHTTIME CONSTRUCTION IN TEXAS NON-ATTAINMENT COUNTIES—TECHNICAL REPORT		5. Report Date Published: December 2017 6. Performing Organization Code
7. Author(s) Reza Farzaneh, Tara Ramani, Madhusudan Venugopal, Suriya Vallamsundar, Geza Pesti, Jason Crawford, Andrew Birt, Chaoyi Gu, Mohammad Askariyeh, Gabriel Valdez, Jeff Shelton, Melisa Finley, Sushant Sharma, Jeremy Johnson, Robert Huch, and Nick Wood		8. Performing Organization Report No. Report 0-6864-1
9. Performing Organization Name and Address Texas A&M Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-6864
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483		13. Type of Report and Period Covered Technical Report: September 2015–July 2017 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Investigate the Air Quality Benefits of Nighttime Construction in Non-attainment Counties

URL: http://tti.tamu.edu/documents/0-6864-1.pdf

16. Abstract

The practice of performing some work zone activities at night has existed in the United States since at least the 1960s. Night work is most commonly initiated where it is impractical to close traffic lanes on certain high-volume roadways during normal daylight hours. Currently, there is no comprehensive evaluation of the changes in emissions associated with moving construction activities to the nighttime. It is commonly expected that when construction activities are shifted to the nighttime, reduced congestion levels could result in fewer vehicle emissions. The extent and scale of this impact has not been studied in detail. This research project investigated the air quality impacts of nighttime construction through case studies and developed a decision-support framework to help the stakeholders put the findings on air quality impacts in the larger context of other factors that are of importance when making a decision to pursue nighttime construction.

17. Key Words Nighttime Construction, Emissions, Nonattainment Counties, National Ambient Air Quality Standards, Clean Air Act Amendments, Decision-Support Framework, Air Quality Impacts		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia http://www.ntis.gov	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 190	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

AIR QUALITY BENEFITS OF NIGHTTIME CONSTRUCTION IN TEXAS NON-ATTAINMENT COUNTIES—TECHNICAL REPORT

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Report 0-6864-1
Project 0-6864
Project Title: Investigate the Air Quality Benefits of Nighttime Construction in Non-attainment Counties

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published: December 2017

TEXAS A&M TRANSPORTATION INSTITUTE
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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors wish to thank the Project Committee (Tim Wood, Jamie Zech, Sonya Badgley, Mike Graham, Pat Henry, Jackie Ploch, Jeffery Riley, and Ray Umscheid) for their guidance and oversight during the course of this project. The authors would also like to thank the TxDOT area engineers and contractors who participated in the state-of-the-practice interviews and provided case study data as part of this research project, as well as John Habermann of the Texas A&M Transportation Institute (TTI) for data collection assistance and Gary Lobaugh of TTI for editorial assistance on this report.

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LIST OF ACRONYMS

AADT	Average Annual Daily Traffic
ASOS	Automated Surface Observing Stations
CAA	Clean Air Act
CFR	Code of Federal Regulations
CMAQ	Congestion Mitigation and Air Quality
CMEM	Comprehensive Modal Emissions Model
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DCE	Diesel Construction Equipment
DNL	Day/Night Noise Level
DOT	Department of Transportation
EF	Emission Factor
EIS	Environmental Impact Statement
ENV	Texas Department of Transportation Environmental Affairs Division
EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
GHG	Greenhouse Gas
HC	Hydrocarbon
HDV	Heavy-Duty Vehicle
HPMS	Highway Performance Monitoring System
I/M	Inspection/Maintenance
LDV	Light-Duty Vehicle
MCDM	Multi-Criteria Decision-Making
MM	Mile Marker
MOVES	Motor Vehicle Emission Simulator
MSAT	Mobile Source Air Toxic
MTP	Metropolitan Transportation Plan
NAAQS	National Ambient Air Quality Standards
NCDC	National Climatic Data Center
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act
NIOSH	National Institute of Occupational Safety and Health
NO_2	Nitrogen Oxide
NO_x	Oxides of Nitrogen
NOAA	National Oceanic and Atmospheric Administration
NSR	New Source Review
NWS	National Weather Station
NYSDOT	New York State Department of Transportation
O_3	Ozone
Pb	Lead
PBL	Planetary Boundary Layer
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter of 2.5 microns or less
PM_{10}	Particulate Matter of 10 microns or less

PSD	Prevention of Significant Deterioration
SIP	State Implementation Plan
SO_2	Sulfur Dioxide
TCEQ	Texas Commission on Environmental Quality
TexN	Texas NONROAD Model
THC	Total Hydrocarbons
TIP	Transportation Improvement Program
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
UFP	Ultrafine Particles
USGS	U.S. Geological Survey
VDOT	Virginia Department of Transportation
VIN	Vehicle Identification Number
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
VT-Micro	Virginia Tech Microscopic Energy and Emissions Model
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

In urban areas in Texas and the United States, roadway work zone and construction activities are often conducted at night to reduce the disruptions to traffic and to prevent congestion caused by lane closures during peak hours. The reduced traffic delays due to nighttime construction have the potential to reduce traffic emissions. However, the emissions and air quality impacts associated with moving these activities from the daytime to the nighttime have not been studied in detail. Further, there are several other factors that may affect the decision to shift construction activities to the nighttime. These include safety, cost, and noise issues, and local factors specific to nighttime construction.

This research project developed an understanding of emissions and air quality impacts of shifting work zone and construction activities to the nighttime. These findings were then discussed in the broader context of other factors that generally influence the decision to pursue nighttime construction. As a first step, the research team conducted an extensive state-of-the-practice assessment to investigate the advantages and disadvantages of nighttime construction, technical methods to model and estimate emissions impacts, and relevant air quality issues. A survey of practitioners in Texas was also conducted to gain an understanding of current practices.

Following the state-of-the-practice review, the research team developed and implemented a case-study-based approach to assess the emissions impact of nighttime construction. The case studies were designed to study the differences between daytime and nighttime construction in terms of two main components: (a) the difference in emissions from construction activity and equipment, and (b) the difference in emissions from traffic. Further, the researchers also investigated the differences in impact of the dispersion of emissions during the daytime and nighttime, attributable to the differences in prevailing metrological factors.

To study the differences in construction emissions, researchers collected construction activity information from two nighttime construction sites in Texas and obtained further information on the usage of construction equipment from the contractors. After a review of information provided, it was concluded that the use of lighting equipment during nighttime construction is the single major difference between nighttime and daytime construction practices, with most other activities being comparable between daytime and nighttime. Diesel-powered light plants are most commonly used for providing on-site lighting, and the TexN emissions model was used to develop estimates of emissions impacts of these plants based on typical operational conditions.

Understanding the differences in traffic emissions requires understanding the traffic impacts that form the basis for estimating the emissions impacts. The research team developed a methodology to estimate the traffic operation and emissions impacts of nighttime versus daytime work zones. First, traffic impacts were assessed using a microsimulation model, and the MOVES emissions model was then applied for emissions estimation. The methodology was applied to three case studies (two freeways and an arterial) in Texas. The analysis results suggest that nighttime work zones result in lower total emissions than daytime work zones, though a part of the lower emissions is attributable to overall reduced traffic levels. However, the impact depends on the pollutant of interest and the specific change in average vehicle speeds that is expected to occur because of the work zone and factors such as the proportion of heavy-duty versus light-duty vehicles.

The assessment of the impact of metrological conditions on the dispersion of pollutants indicated that for the same amount of emissions, the nighttime period could result in higher pollutant concentration levels. However, given that traffic congestion and overall traffic volumes are generally substantially lower in the nighttime period, the findings do not imply that nighttime construction activities result in worse air quality in terms of pollutant concentrations.

Based on the findings from the case studies and state-of-the-practice assessment, a decision-support framework was developed. The framework identified criteria in addition to air quality that were relevant to the decision to pursue nighttime construction. These factors included aspects such as noise impacts, light impacts, safety impacts, congestion levels, need for lane closures, cost impacts, access to worksite, and other project-specific factors. A spreadsheet-based decision-support tool was developed and included a screening checklist along with a quantitative calculator. The quantitative calculator can be used to generate sketch-level assessments of the emissions impacts for a lane closure under nighttime and daytime construction scenarios.

While air quality is not necessarily a primary consideration in the decision to pursue nighttime construction, this study conducted a systematic analysis of air quality impacts of nighttime construction covering three major areas: (a) construction emissions impacts, (b) traffic emissions impacts, and (c) potential impacts on dispersion of pollutants. Overall, the findings indicate the potential for emissions reduction (primarily from traffic emissions) when construction activities are moved to the nighttime in congested urban areas.

CHAPTER 1. INTRODUCTION

BACKGROUND AND RESEARCH GOAL

In many urban areas in Texas, especially on high-volume roadways, roadway work zone and construction activities are commonly conducted at night to reduce the impacts on congestion and mobility. The practice of performing some work zone activities at night has existed in the United States since at least the 1960s (*1*). As is the case today, early attempts at nighttime work were initiated because officials considered it impractical to close traffic lanes on certain high-volume roadways during normal daylight hours.

Nighttime roadway construction leads to reduced traffic delays and has the potential to reduce associated emissions around work zones. However, the emissions and air quality impacts associated with moving these activities from the daytime to the nighttime have not been studied in detail. This is of particular importance to areas that are currently in violation of federal air quality standards (i.e., nonattainment or maintenance areas), where transportation conformity provisions apply. Apart from congestion-related issues and potential air quality impacts, there are several other factors that may affect the decision to shift construction activities to the nighttime. These include safety, cost, and noise issues. Public agencies need a systematic approach to understand and account for potential air quality impacts and other factors while making decisions about whether to undertake nighttime construction.

This research project, *Investigate the Air Quality Benefits of Nighttime Construction in Non-attainment Counties*, was conducted by the Texas A&M Transportation Institute (TTI) for the Texas Department of Transportation (TxDOT) to address this issue. The project goal is to provide TxDOT with guidance and information on the emissions and air quality impacts of shifting work zone and construction activities to the nighttime in Texas' nonattainment, attainment maintenance, and near-nonattainment areas. Additionally, the project also placed the findings related to air quality into the broader context of other factors relevant to making a decision on nighttime construction. This was accomplished through the development of a decision-support framework for stakeholders that will consider these emissions and air quality benefits in the broader context of other costs and benefits of nighttime construction.

PROJECT SCOPE AND CONTEXT

This project focused on the air quality impacts of nighttime construction activities, specifically potential impacts of shifting from daytime to nighttime construction. This was conducted in the broader context of decision making on nighttime construction, where other factors such as safety and operational considerations are also important. Several TxDOT districts currently conduct construction and maintenance activities on high-volume facilities at night to reduce adverse traffic impacts (i.e., congestion resulting in unacceptable queues and delays) that typically occur when the same work is performed during the day. Depending on the type of project or activity, work may be performed exclusively at night or may include a combination of nighttime and daytime activity (hybrid projects).

Table 1 contains a list of the various maintenance and construction activities commonly conducted on roadways that were covered in the scope of this project. As Table 1 shows, the types of activities range from small routine activities such as filling potholes and street sweeping to large-scale construction projects such as bridge and road construction. This report uses the collective terms “construction” or “work zone activities” for all these types of projects. However, the main focus was on larger-scale, longer-duration projects that have greater likelihood of impacting local air quality.

Table 1. Examples of Common Construction and Maintenance Activities.

Common Construction Activities	**Common Maintenance Activities**
Earthwork: excavation/embankment/backfill	Reworking shoulders
Subgrade	Maintenance of earthwork/embankment
Subbase and base course	Drainage structures maintenance and rehabilitation
Bituminous surfaces and pavements	Sidewalks repair and maintenance
Concrete sawing	Milling and removal
Bridge construction	Repair of concrete pavement
Shoulders: bituminous and Portland cement concrete	Resurfacing
Highway signing	Bridge decks rehabilitation and maintenance
Pavement marking: striping and markers	Pothole filling
Electrical wiring and cables	Waterproofing/sealing
Culverts and sewers	Crack filling
Drainage structures	Sweeping and cleanup
Electrical poles/lighting/traffic signals	Surface treatment
Guardrail and fences	
Erosion control: riprap/ditch lining	
Landscaping: seeding/mulch/sodding/planting	
Concrete pavement and sidewalks	
Work traffic control	

While congestion reduction is the primary driver for undertaking nighttime construction, several other factors such as safety, productivity, work quality, and cost are also relevant to the decision-making process. Concerns about these issues include premium worker wages and material costs, added traffic control costs, reduced visibility, coordination with supervisors and/or technical staff that work during the day, and reduced availability of materials and equipment parts (i.e., most plants and repair shops are not open). Conversely, potential benefits include longer work times, easier access to the worksite for material delivery, and cooler temperatures. These are discussed in further detail in Chapter 2.

Both daytime and nighttime construction and maintenance projects have the potential to impact air quality. For effective decision making, a comparative approach is needed to understand the differences in the total emissions likely to occur if a project is undertaken at nighttime versus daytime. The total emissions generated by a project or activity can be partitioned into emissions that are a result of changes in traffic activity in and around the worksite, and emissions from equipment used in construction and maintenance activities. Although the drivers of the emissions and air quality impacts of daytime versus nighttime projects can be identified intuitively, there is no comprehensive evaluation of differences between emissions and air quality for daytime versus nighttime construction and maintenance projects. Understanding the magnitude of differences in emissions and potential impacts in terms of emissions dispersion is important for a number of reasons.

FRAMEWORK OF KEY ISSUES

Figure 1 provides a summary diagram illustrating the organization of information relevant to this project. The elements can be broadly viewed as air quality, traffic congestion, and construction practice aspects. The figure illustrates that the decision to undertake a project in the daytime or nighttime can have implications for traffic congestion around the worksite. In turn, a daytime-nighttime decision will potentially affect a number of construction-related factors such as the cost of the project, worker health and safety, traffic safety, and the types of equipment needed to complete the project. The reciprocal arrow between congestion impacts and construction factors suggests that it is possible that elements of the construction process have the ability to impact traffic activity (e.g., the duration of the project), and that congestion impacts may also affect construction factors (e.g., worker safety). The diagram illustrates that the emissions and air quality impacts of a transportation project during the daytime or nighttime will be driven by both construction factors (e.g., the types and quantities of machinery used during a project) and traffic activity around the worksite (congestion). Finally, these absolute air quality impacts must be considered in a broader regulatory and health context that assesses whether any absolute impact on emissions and air quality associated with a daytime or nighttime project justifies other costs associated with this key decision.

As the diagram shows, the intent of this project was to bridge the two elements by studying the air quality impacts of nighttime versus daytime construction and to understand these impacts in a broader decision-making context.

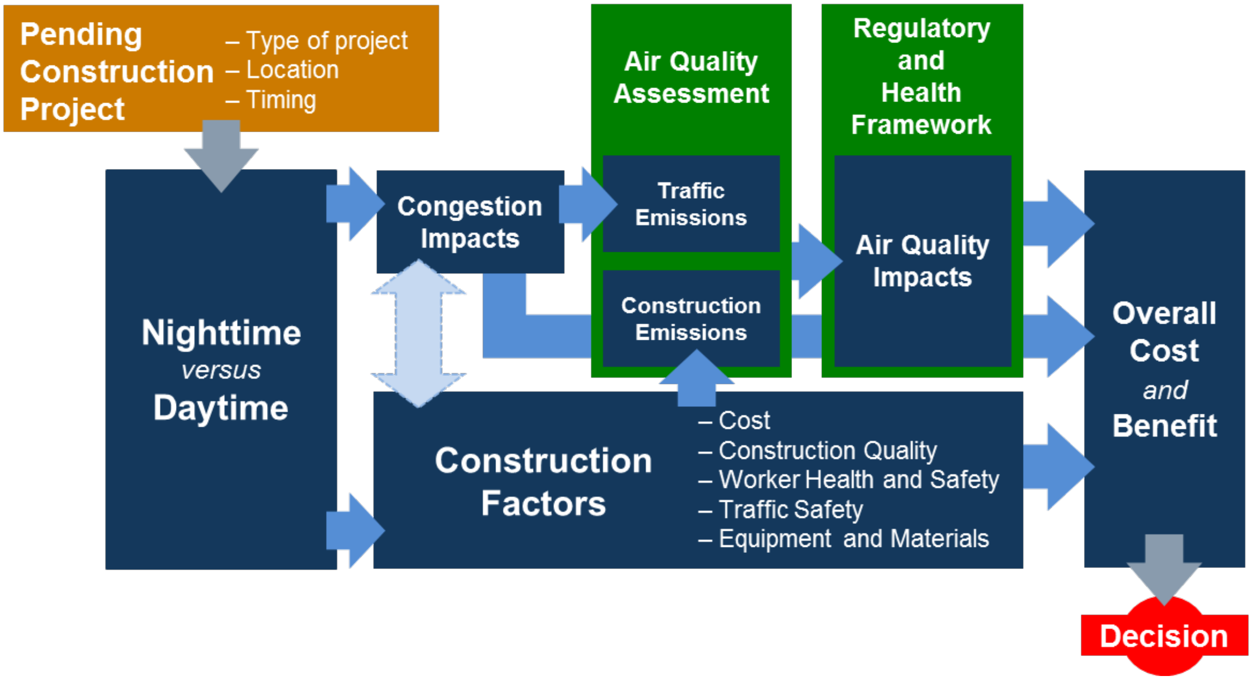

Figure 1. Framework of Key Issues.

RESEARCH PLAN

Figure 2 shows the research plan and the task flow for the project. Task 1 was a state-of-the-practice assessment, which was followed by the development of a case study protocol in Task 2. Case studies to characterize the air quality impacts of nighttime construction were conducted in Tasks 3 through 5, which focused on construction emissions, traffic emissions, and emissions dispersion, respectively. Finally, a decision-support framework that can be used by stakeholders to make decisions about whether to undertake nighttime construction activities was developed in Task 6.

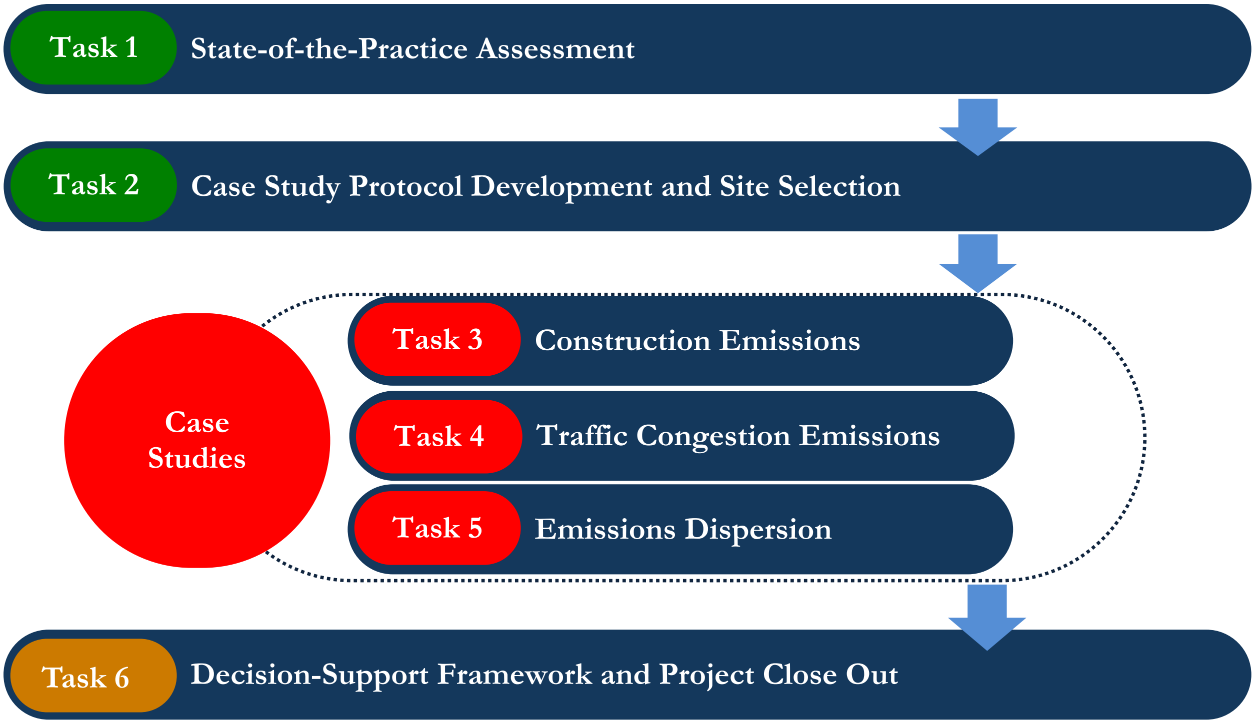

Figure 2. Project Tasks.

ORGANIZATION OF REPORT

The project tasks are discussed in the following seven chapters. Chapter 2 is a comprehensive assessment of the state of the practice including a discussion on the regulatory framework of air quality issues and an assessment of emissions and air quality impacts. Chapter 3 outlines the case study design and preliminary case study considerations. Chapter 4 discusses the development of an analytical methodology to estimate the emissions differences from construction activity between daytime and nighttime activities. Chapter 5 discusses methods used to develop a methodology for estimating emissions from traffic activities, and Chapter 6 provides a discussion on the impacts of meteorological factors on pollutant concentrations. Chapter 7 presents the development of the decision-support framework, and Chapter 8 discusses the findings and conclusions for the work performed in this project.

CHAPTER 2. LITERATURE AND STATE OF THE PRACTICE

An extensive literature review and state-of-the-practice assessment was conducted as part of this project, covering the following topics.

- Advantages and disadvantages of nighttime construction.
- Current practice in Texas (which included a survey of practitioners).
- Current practice in other states.
- Regulatory framework of air quality issues.
- Assessment of emissions and air quality impacts.
    - Traffic modeling.
    - Emissions modeling.
    - Dispersion modeling.
- Decision-making frameworks and approaches for nighttime construction.

This section provides a summary of key findings from the literature review and state of the practice.

ADVANTAGES AND DISADVANTAGES OF NIGHTTIME CONSTRUCTION

As mentioned in Chapter 1, nighttime construction is mostly conducted to alleviate issues associated with traffic. However, there are a number of other factors that also impact the feasibility and suitability of night work. These factors can be grouped into four broad categories: construction, safety, mobility, and environmental.

Construction-Related Factors

The three main construction-related factors that need to be considered for nighttime versus daytime construction projects are productivity, quality, and cost. Negative issues associated with nighttime projects include premium worker wages and material costs, added traffic control costs, reduced visibility, coordination with supervisors and/or technical staff that work during the day, and reduced availability of materials and equipment parts (i.e., most plants and repair shops are not open). Conversely, potential benefits include longer work times, easier accessibility to the worksite for material delivery, and cooler temperatures.

Although reduced visibility, longer setup/removal time for traffic control and lighting, greater difficulty communicating with supervisors and technical support, and worker fatigue are potential factors that could negatively affect work quality and productivity during nighttime projects, a number of studies have found that it is possible to achieve levels of work quality and productivity at night that are comparable to those achieved under daylight conditions if effective work procedures and adequate lighting are used (*1*, *2*, *3*, *4*, *5*, *6*, *7*, *8*, *9*, *10*, *11*, *12*). Some of the productivity and quality advantages of nighttime work can be attributed to longer working hours, less interference from traffic at night, and cooler temperatures.

Studies have also found that although nighttime construction costs can be higher under certain circumstances, in most cases they are comparable to or even lower than daytime construction costs (*1, 4, 10, 13*). However, additional costs are sometimes incurred for specific work items such as traffic control, lighting, worker wages, material delivery, inspection, and operating material plants outside of normal work hours.

Safety-Related Factors

The safety impact of nighttime construction practice can be divided into two distinct categories: traffic safety and worker safety. Several studies investigated the effects of work zones on nighttime traffic crashes. However, because information about whether a work zone was active at the time of a nighttime crash was often not available, some studies concluded that nighttime crashes increase substantially in work zones (*14*, *15*, *16*), whereas other studies concluded the opposite (*17*, *18*, *19*). Many studies specifically examined the safety of nighttime work activities and concluded that the crash rate on sections of roadways near work activities was higher than normal nighttime crash rates, and that crash rates were higher when lane closures were required compared to those when no lane closures were required (*20*, *21*, *22*). However, researchers noted that the overall number of crashes at night might still have been lower than would have been expected if the work had been performed during the day because of much higher vehicle exposure levels present during the day (*23*). More recently, a National Cooperative Highway Research Program (NCHRP) study (*24*) on nighttime and daytime work zone crashes concluded the following:

- The overall safety impacts to the motoring public at night tend to be less or about the same as during the day dependent upon whether or not work is active and a lane closure is present.
- Crashes that occur in nighttime work zones are not necessarily more severe than those that occur in similar daytime work zones.
- Although the increased risk of a crash is similar, differences do exist in the types of crashes that occur in nighttime and daytime work zones.
- For work activities that require temporary lane closures, the total safety impacts to the motoring public are less if the work is performed at night.

In addition to traffic safety, nighttime versus daytime projects may have differential effects on worker health and safety. Lower overall illumination levels in the work zone coupled with potential degradations in worker attention levels, reaction times, and motor skills caused by the disruption of the body’s natural circadian rhythms could negatively impact worker safety. Intuitively, drivers (both the general public and project workers) may be more fatigued at night, leading to increased accident rates at the worksite. Working at night also impacts the quality of life of highway workers since it tends to reduce social and family interactions. While these considerations are intuitive, the actual safety impacts of performing roadwork at night (relative to daytime operations) on highway workers has not been thoroughly examined mainly because of the limited amount of accident data available. A study by the National Institute of Occupational Safety and Health (NIOSH) examined fatal occupational injuries for highway construction workers between 1992 and 2000 (*25*). Based on their assessments, NIOSH researchers concluded that "working at night is not responsible for the overall increase in highway worker deaths." However, there were not sufficient data to actually compare highway worker accident rates at night versus day. An analysis of fatal accidents in highway work zones from 1996–2001 in Illinois (*26*) found no indication that nighttime construction was more hazardous than daytime construction. Due to insufficient data, the NCHRP study mentioned previously (*24*) was unable to determine whether worker construction accidents were more frequent at night. However, the data did show that the severity of worker construction accidents was the same when working at night or day.

Mobility-Related Factors

Severe congestion, long delays, and vehicle queues are common at work zones where one or more lanes are closed and traffic demand exceeds the reduced roadway capacity. One of the most important advantages of nighttime operations is the reduction in congestion, delay, and queue lengths. In addition to generally reducing delays around worksites, nighttime operations have the potential to avoid disruptions to nearby businesses that operate primarily during the day. On the other hand, in some areas, especially freeway segments in metropolitan areas and along major freight corridors, even nighttime projects can cause congestion. In such cases, roadway- and worksite-related traffic activities may negatively impact local residents and businesses that operate primarily at night.

Environmental Factors

The environmental impacts of nighttime versus daytime construction include noise and vibration from equipment, light pollution from work zone lighting at night, and air quality impacts from construction equipment and traffic congestion.

Although noise and vibration may be a cause to avoid nighttime construction in some residential areas, noise and vibration can also be detrimental during the day, especially if the construction activities are near schools or hospitals (*3*). Noise is specifically undesirable during nighttime because of the increased annoyance associated with noise at a time when residents and hospital patients are most likely to be sleeping. Weighted decibel metrics such as day/night noise level (DNL) have been developed to reflect this issue. Noise mitigation measures include, but are not limited to, installing temporary sound shields, locating material storage away from residential areas, and using less-offensive vehicle alarms (*3*). Work zone lighting is critical for safety, quality, and productivity but can result in complaints if the light/glare spills into residential areas.

In addition, recent research (*27*) found that improperly implemented work zone lighting that produces glare conditions for motorists can severely limit the ability of drivers to detect low-contrast objects, such as debris, immediately after they have moved out of an illuminated area such as a nighttime work zone.

From an emissions and air quality perspective, when construction activities are shifted to the nighttime, congestion will be lower compared to the same project undertaken during the daytime. In turn, this is thought to reduce fuel consumption and vehicle emissions associated with nighttime versus daytime projects. However, the actual construction activities themselves also generate emissions, regardless of whether the activities occur in the daytime or nighttime, and this also needs to be considered. The emissions of major concern from common construction activities include particulate matter (PM) and oxides of nitrogen (NO_x) from vehicles and equipment. Additionally, PM is also produced on a construction site in the form of fugitive dust and contributes to the air quality impacts. Dust is generated by ground excavation, earthmoving operations, wind erosion, and equipment and vehicles traveling along unpaved roads. Dust emissions can vary day to day, depending on the level of construction activity and weather conditions. The most common construction activities that generate dust include site preparation, earthmoving (including hauling of material), paving of roadway surfaces, and erection of structures. Earthmoving activities usually consist of grading, trenching, soil compaction, and cut and fill operations. Site preparation includes activities such as general land clearing and grubbing.

Summary of Advantages and Disadvantages

Table 2 provides a summary of the potential advantages and disadvantages of nighttime construction discussed previously and the conclusions drawn by researchers based on the literature review and common practice. The findings highlight that there are many interdependent factors that must be considered when determining whether or not it would be advantageous to undertake construction activities at night, as discussed further in the section on decision-making frameworks and approaches.

Table 2. Potential Advantages and Disadvantages of Nighttime Construction.

Factors	Advantages	Disadvantages	Conclusions
Construction Related			
Quality	- Longer work periods - Easier access for material delivery - Less interference from traffic - Cooler temperatures	- Reduced visibility - Limited access to staff that works during the day - Worker fatigue	Can achieve levels comparable to, or better than, daytime work with adequate lighting and contingency planning
Productivity	- Longer work periods - Easier access for material delivery - Less interference from traffic - Cooler temperatures	- Increased traffic control/ lighting setup/removal time - Reduced visibility - Reduced availability of materials and equipment parts - Limited access to staff that works during the day - Worker fatigue	Can achieve levels comparable to, or better than, daytime work with adequate lighting and contingency planning
Cost	- Shorter project duration	- Premium worker wages - Premium material costs - Extra traffic control costs - Illumination costs	Comparable or less than daytime work
Safety Related			
Motorists	- Reduced congestion - Reduced vehicle queues	- Reduced visibility - Driver fatigue - Degraded attention levels, reaction times, and motor skills	Crash risk and severity similar to daytime work Total safety impacts less for work performed at night
Workers	- Cooler temperatures	- Reduced visibility - Worker fatigue - Degraded attention levels, reaction times, and motor skills	Severity of accidents similar to daytime work
Mobility Related			
Motorists	- Reduced congestion - Reduced delay - Decreased road user costs	- May increase road user costs for commercial vehicle industry	Primary reason for conducting night work Offsets extra construction costs
Local Residents	- Reduced disruption during the day	- Could negatively impact at night	Conduct public outreach
Nearby Businesses	- Reduced disruption to daytime businesses	- Could negatively impact nighttime businesses	Conduct public outreach
Environment Related			
Emissions	- Lower vehicle emissions - Reduced fuel consumption - Reduced air emissions	- Construction activity emissions - Dust	
Noise	- Reduced daytime noise impact specifically to daytime businesses	- Could negatively impact local residences and nighttime businesses	Implement mitigation measures
Vibration	- Reduced disruption to local residences and daytime businesses	- Could negatively impact local residences and nighttime businesses	Implement mitigation measures
Light Trespass (Glare)	N/A	- Could negatively impact local residences and nighttime businesses - Could limit drivers' ability to detect low-contrast objects	Implement mitigation measures

CURRENT PRACTICES IN TEXAS

Prior Studies

According to a Texas study conducted in 2003–2004, seven TxDOT districts (i.e., those in major urban areas such as Austin, Dallas, El Paso, Fort Worth, Houston, San Antonio, and Waco) conducted a significant amount of nighttime work because unacceptably high traffic congestion would result if the work were undertaken during the day (*23*). An additional nine TxDOT districts used night work occasionally. Projects involving nighttime activities generally fell into one of two categories:

- Projects that were performed almost exclusively at night on the travel lanes (e.g., paving and striping).
- Projects that involved work activity during the day and at night (i.e., continuous projects). Daytime activities involved some work on the travel lanes during non-peak periods, but a majority of the daytime work was conducted off the travel lanes. Nighttime activities primarily occurred on the travel lanes (e.g., bridge work, paving, and overhead sign installation).

A sample of 280 TxDOT projects showed that 30 percent were exclusively conducted at night and 70 percent involved both daytime and nighttime work. The research team's experience in more recent years has been that even more TxDOT districts are conducting reconstruction, rehabilitation, and maintenance operations on high-volume facilities at night to reduce adverse traffic impacts (i.e., congestion resulting in unacceptable queues and delays) that typically occur when the same work is done during the day.

Survey of TxDOT Practice

This task developed a comprehensive documentation of the state of the practice for making nighttime construction decisions in the state of Texas. Another objective was to document the overall cost, construction quality, safety, mobility/congestion, noise, and other relevant factors associated with nighttime construction, and to identify types of work most suited for nighttime construction. The Texas A&M Transportation Institute (TTI) research team conducted interviews with TxDOT staff to assess the state of the practice in Texas. As a first step, TTI researchers developed a detailed interview questionnaire, which was then finalized based on review and input from TxDOT.

In coordination with TxDOT, the researchers selected six urban districts (Austin, Dallas, Fort Worth, El Paso, San Antonio, and Houston) for the interviews. Appendix A includes the questionnaire used, details of each interviewee, and the dates of the interviews. The highlights of the information gathered from interviews with TxDOT staff are included in the following paragraphs.

Nighttime construction is common. Nighttime construction is common in urban districts. All districts that participated in the interviews perform nighttime construction operations. Nighttime construction operations are preferred for particular activities such as pouring bridge decks and hanging beams, or at locations where lane closure is not possible during the daytime due to heavy traffic. Nighttime construction is preferred during summers if concrete temperature needs to be controlled, mostly while pouring concrete on bridge decks.

The nighttime construction decision is made during the design phase. Most of the districts reported that the nighttime construction decision is made at the 30 percent mark of the project design phase. The San Antonio District also reported that at the 60 percent mark of the design phase, the final decision is communicated to the contractor and team. However, for some construction projects, the area engineer can consider the possibility of nighttime construction based on the contractor's requests during the construction phase. The project location, type of activity, and schedule govern the nighttime construction decision rather than the project size or type (i.e., small versus large, or construction versus maintenance project).

The area engineer is responsible for nighttime construction. In most of the districts, the area engineer is responsible for making nighttime construction decisions. The flexibility for nighttime construction in terms of when, where, and what operations is based on the area engineer's judgment of the area. The area engineer considers major events and businesses before making a nighttime construction decision. For complex decisions, the district engineer may play a role and may overrule the area engineer's decision.

External stakeholders' input depends on location and affected streets. The urban districts coordinate their efforts for nighttime construction with the cities. For example, in the Houston District, city staff provides input into lane closures that may affect city roads. Additionally, during the design process, the City of Houston approves the traffic control plan if city streets are used. Most districts also obtain special event information from the cities so that the nighttime construction does not affect traffic adversely. Districts conduct public meetings before nighttime construction; however, public input to TxDOT is limited and mostly informational.

No formal process for nighttime construction decision making exists. There is lack of a documented formal process (i.e., flowchart, checklist) for nighttime construction decision making. The San Antonio District has a checklist for nighttime or weekend construction activities. Dallas has a formal document for lane closures for nighttime construction operations. Appendix B includes these documents.

Many factors influence nighttime construction decision making. The major factors that influence nighttime construction decisions are traffic impacts, lane closure requirements, project schedule (accelerated versus normal), location (commercial or residential), material availability, worker safety, TxDOT inspection staff availability, weather, and noise. The most important factor that influences nighttime construction is the traffic impact caused by lane closures. Where daytime lane closure would result in severe congestion, closures are directed to occur during the nighttime.

Air quality is not considered in nighttime construction decision. None of the districts reported considering air quality as a factor for nighttime construction decision making.

Major impediments to performing nighttime construction exist. The major impediments to nighttime construction are worker safety, insufficient illumination, unavailability of materials, noise, and complaints by nighttime businesses. Worker safety is the biggest impediment because of the higher number of impaired and speeding drivers on the road during the nighttime. Lack of sufficient lighting and material availability also affects the nighttime construction decision.

Differences in operation between daytime and nighttime work exist. The major difference between daytime and nighttime construction is installation of light plants for illumination. From the contractor's standpoint, worker safety, material availability, and costs are major factors for the nighttime construction. For TxDOT, safety and availability of inspectors/staff are important. There was not much consensus on the productivity impacts of nighttime construction.

Researchers also asked the participants to rank construction and maintenance activities based on their suitability for nighttime operations as highly suitable (H), moderately suitable (M), and least suitable (L). Table 3 shows various construction activities and the distribution of ranking under each category. Two participants did not provide rankings of the categories, so the total of responses in Table 3 is 12 instead of 14. The following paragraphs provide a summary of the suitability of different projects for nighttime construction.

Highly suitable nighttime construction operations. Most pavement surfacing and signing related work such as bituminous surfaces, concrete sawing, concrete pavements, and pavement signing are considered highly suitable for nighttime construction. This is mostly because of the requirement for multiple lane closures and quick production and turnaround time for such projects. Bridge construction is also considered highly suitable for nighttime construction, mostly because of the advantages of pouring concrete at lower temperatures.

Moderately suitable nighttime construction operations. Most of the moderately suitable construction operations for nighttime are those that can be performed at either time (day or night) depending on the location and schedule of the project. For accelerated projects, these activities can be performed continuously throughout the daytime and nighttime.

Least suitable nighttime construction operations. Landscaping, erosion control, and electrical wiring are considered least suitable for construction operations. Often these operations are longitudinal and require continuous illumination along a road section, or are performed behind traffic barriers and do not impact traffic.

For some construction activities, such as installation of highway signing or electrical poles/lighting/traffic signals, there was lack of consensus on their suitability for nighttime construction, with large variation in responses.

Table 3. Response Distribution Based on Suitability of Maintenance Activities at Nighttime (H=Highly Suitable, M=Moderately Suitable, and L=Least Suitable).

Construction Activity	No. of H Responses	No. of M Responses	No. of L Responses
Earthwork: excavation/embankment/backfill	1	5	6
Subgrade	0	6	6
Subbase and base course	1	6	5
Bituminous surfaces and pavements	9	2	1
Concrete sawing	5	5	2
Bridge construction	11	1	0
Shoulders: bituminous and Portland cement concrete	5	5	2
Highway signing	5	2	5
Pavement marking: striping and markers	10	1	1
Electrical wiring and cables	1	2	9
Culverts and sewers	0	7	5
Drainage structures	1	6	5
Electrical poles/lighting/traffic signals	4	2	6
Guardrail and fences	1	6	5
Erosion Control: riprap/ditch lining	1	2	9
Landscaping: seeding/mulch/sodding/planting	1	2	9
Concrete pavement and sidewalks	6	3	3
Work traffic control	8	2	1

Table 4 shows various maintenance activities and distribution of ranking received under each category. Following is a summary of the ranking information.

- **Highly suitable nighttime maintenance operations.** Maintenance activities such as milling, concrete pavement repair, pothole filling, resurfacing, and bridge deck rehabilitation and maintenance are most suitable for nighttime operations. This is mostly because they either require a lane closure or specific temperature conditions.

- **Moderately suitable nighttime maintenance operations.** Relatively less intrusive maintenance activities such as waterproofing/sealing are moderately suitable for nighttime maintenance operations.
- **Least suitable nighttime maintenance operations.** Activities such as maintenance of earthwork/embankment and sidewalk repair are least suitable for nighttime operations. This is because these activities do not require a lane closure or would require illumination of extended road segments if performed at night.

Some activities such as surface treatment and crack filling have a large variation in responses on suitability ranking for nighttime construction. This also represents the diversity of practice in nighttime maintenance operations for these activities.

Table 4. Response Distribution Based on Suitability of Maintenance Activities at Nighttime (H=Highly Suitable, M=Moderately Suitable, and L=Least Suitable).

Maintenance Activity	No. of H Responses	No. of M Responses	No. of L Responses
Reworking shoulders	1	4	7
Maintenance of earthwork/embankment	0	2	10
Drainage structures maintenance and rehabilitation	0	4	8
Sidewalks repair and maintenance	2	3	7
Milling and removal	9	3	0
Repair of concrete pavement	12	0	0
Resurfacing	10	2	0
Bridge decks rehabilitation and maintenance	10	2	0
Pothole filling	9	1	2
Waterproofing/sealing	4	5	2
Crack filling	5	5	2
Sweeping and cleanup	7	3	1
Surface treatment	7	0	4

GUIDELINES AND EXAMPLES OF PRACTICE FROM OTHER STATES

A general review of guidelines and practices from state departments of transportation (DOTs) and other agencies was conducted by studying agency websites and other published material. In general, congestion is cited as the primary driver of the decision to pursue nighttime construction. An NCHRP project conducted in 2002 developed guidelines for nighttime road work to improve safety and operations (*28*). In addition, it provided formulated procedures to facilitate decision making for undertaking nighttime work. The report encourages a systematic comparison of alternative traffic control strategies, including traffic control plans, traffic management plans, and work schedule alternatives. It provides a comprehensive, quantitative basis for selecting the most cost-effective plan for ensuring the safety of the public and workers, maintaining capacity, minimizing the impact on the community, and completing the work on schedule.

The California North Region Construction Guide identifies lower volumes of traffic during the nighttime compared to daytime as a major factor in favor of nighttime construction (*29*). In Washington State, nighttime construction is typically undertaken in areas of high traffic volumes, as outlined in Washington State Department of Transportation's (WSDOT's) work zone and traffic control guidelines (*30*). However, a major concern for WSDOT is construction noise, with any work generating high noise levels limited between 7 a.m. and 10 p.m. (*31*). This limitation can serve as a barrier to shifting certain types of work to the nighttime.

The Illinois Department of Transportation sponsored a study to investigate the effects of nighttime construction on worker safety (*26*) and found nighttime construction to be a good option from an efficiency perspective because it leads to shorter project durations with fewer interruptions to construction activities.

Initially, the Virginia Department of Transportation (VDOT) only performed construction during the nighttime in urbanized areas, but it has increased the number of nighttime construction projects in non-urbanized and rural areas because of increasing traffic volumes. A 1999 study commissioned by VDOT did not find conclusive evidence that safety was adversely impacted by nighttime construction (*32*).

The New York State Department of Transportation (NYSDOT) conducted a comprehensive study focusing on understanding the state of the practice of nighttime road construction projects (*7*). NYSDOT found that nighttime construction reduces traffic congestion, does not affect the quality of work, and reduces user costs because of the elimination of delays. This study also observed that air quality could be improved because there is no disruption in traffic.

Ohio DOT opts for nighttime construction to avoid congestion issues associated with lane closures and provides guidelines for the same (*33*). However, similar to WSDOT, nighttime noise and disruption in residential areas is an issue that can limit nighttime work.

REGULATORY FRAMEWORK FOR AIR QUALITY

This project focused on the air quality implications of nighttime versus daytime construction activities. This focus involved understanding the regulatory aspects of air quality and how it may influence assessment of work zones.

The Clean Air Act and Criteria Pollutants

The 1970 Clean Air Act (CAA) was the initial comprehensive federal law that regulates air emissions from area, stationary, and mobile sources. CAA requires the U.S. Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for chemical compounds considered harmful to public health and the environment. NAAQS are set for six principal chemical compounds referred to as criteria pollutants. These have been based on studies that have shown a relationship between pollutant emissions and adverse health (*34*). Further, NAAQS are divided into primary standards established to protect public health, especially of vulnerable population subgroups and secondary standards set to protect public welfare that includes aesthetics, damage to wildlife, vegetation, and buildings. Table 5 provides a summary of NAAQS for criteria pollutants. In addition to these criteria pollutants, EPA has also identified a set of chemical compounds known as mobile source air toxics (MSATs). EPA's list of MSATs contains over 425 identified compounds emitted from highway vehicles. The Federal Highway Administration's (FHWA's) 2016 Interim MSAT guidance (*35*) lists the priority MSATs as acrolein, acetaldehyde, benzene, 1,3-butadiene, diesel particulate matter, ethylbenzene, formaldehyde, naphthalene, and polycyclic organic matter.

Table 5. NAAQS for Criteria Air Pollutants.

Chemical Compound		**Averaging Time**	**NAAQS**	**Impact**
Carbon Monoxide (CO) An odorless, colorless gas resulting from incomplete fossil fuel combustion		1 hour	35 parts per million (ppm)	Regional and project level
		8 hours	9 ppm	
Nitrogen Dioxide (NO_2) A brownish gas that forms quickly during high temperature combustion of fossil fuels		1 hour	100 parts per billion (ppb)	Regional level
		Annual	53 ppb	
Particulate Matter (PM) Mixture of solid particles and liquid droplets in the air	**$PM_{2.5}$**	24 hours	35 μg/m^3	Project level
		Annual (Primary)	12 μg/m^3	
	PM_{10}	24-hours	150 μg/m^3	
Sulfur Dioxide (SO_2) A highly reactive colorless gas formed when fuel containing sulfur is burned		1 hour	75 ppb	Regional level
		3 hours	0.5 ppm	
Lead (Pb) A heavy metal found naturally in the environment and in manufactured products		Rolling 3-month average	0.15 μg/m^3	Regional level
Ground Level Ozone (O_3) A colorless gas that forms as a result of chemical reactions between volatile organic compounds, nitrogen oxides, and oxygen in the presence of heat and sunlight		8 hours	0.070 ppm	Regional level

Note: Transportation conformity applies to CO, PM, NO_2, and ground level ozone. Source: (*36*).

Nonattainment Areas and the Transportation Conformity Process

In Texas, TxDOT and the Texas Commission on Environmental Quality (TCEQ) are the two state government agencies responsible for ensuring that transportation plans and projects do not violate existing air quality regulations. The air quality data collected by TCEQ air monitoring stations for different chemical compounds and averaging periods are compared with NAAQS. Based on this comparison, EPA designates areas in Texas into the following categories:
(a) nonattainment areas if they do not meet NAAQS; nonattainment areas are further designated as marginal, moderate, serious, severe, or extreme as a function of deviation from standards;
(b) maintenance areas if a previous nonattainment area has been subject to a state implementation plan (SIP) revision and maintenance plan that has been approved by EPA; and
(c) attainment area if the area is meeting NAAQS. Figure 3 shows the areas in Texas that are currently designated as nonattainment or maintenance.[1]

Once nonattainment designations take effect, state and local governments must develop a SIP to demonstrate how each area will attain and maintain NAAQS and improve air quality (*37*). The SIP covers emissions reductions for different criteria pollutants classified by source, such as on-road motor vehicles, non-road equipment and vehicles, and stationary and area sources. Requirements for SIP may vary based on the nonattainment classification of an area—for example, in marginal ozone nonattainment areas, national-level controls are considered to be sufficient to bring the area into attainment.

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[1] The ozone nonattainment areas indicated are per the 2008 ozone standard of 0.075 ppm. Designations for the current 2015 standard of 0.070 ppm are not yet in effect.

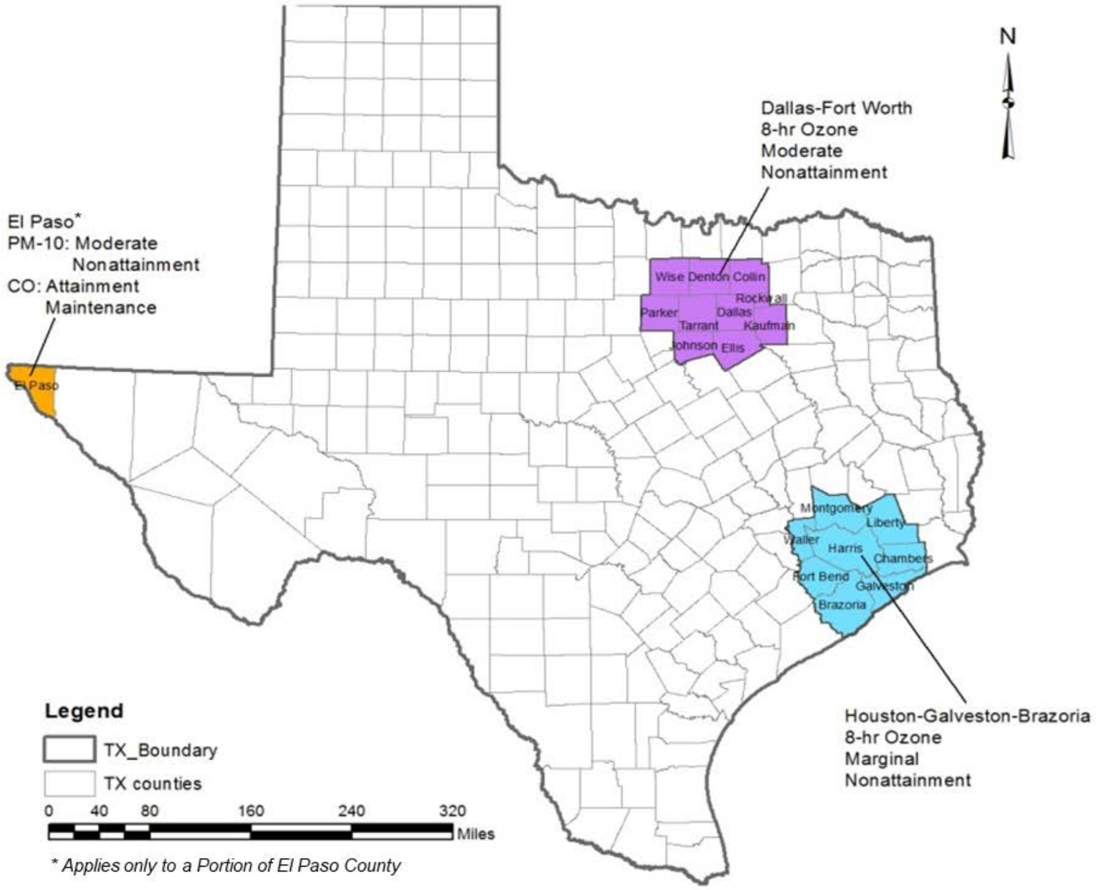
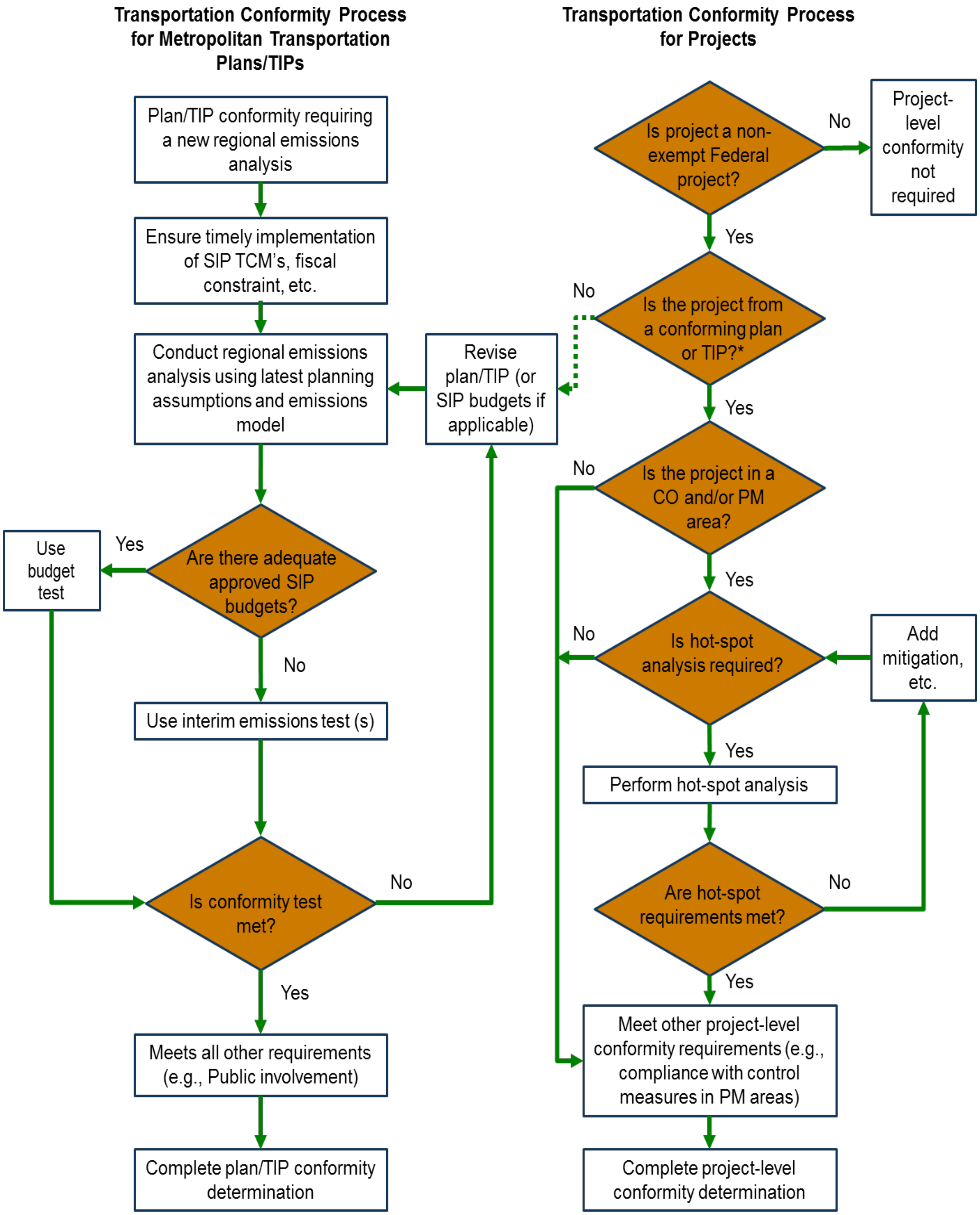


Figure 3. Nonattainment and Maintenance Areas in Texas.

The transportation-related elements of the SIP are governed by regulations pertaining to transportation conformity, which regulates on-road mobile source emissions. Transportation conformity is a complex process that involves several actions to be taken collaboratively by multiple stakeholders. It can be viewed as the process by which transportation planning is linked to air quality planning (*38*). The conformity procedure applies at two levels: regional and project. Figure 4 shows a simplified version of the transportation conformity process for both the regional and project levels. The transportation conformity requirements applicable to on-road mobile sources are described in more detail in the following subsections.

Regional-Level Transportation Conformity

At the regional level, conformity is concerned with the regional transportation system as a whole, specifically whether regional plans and programs are consistent with the goal of attaining NAAQS. The SIP identifies emissions budgets (termed as the motor vehicle emissions budget) for each criteria pollutant for which the region is in nonattainment. This budget represents the maximum allowable amount of emissions to ensure future compliance with NAAQS. The regional conformity process involves developing emissions inventories based on travel activity for all projects in a transportation plan or program, and assessing if the implementation of these projects conforms to the emissions budgets. Regional conformity applies to regional transportation plans/metropolitan transportation plans (MTPs) with a 20-year planning horizon and to the Transportation Improvement Program (TIP), and conformity requirements must be met in order for most projects to advance in a region. In certain cases, such as for areas in marginal nonattainment for ozone, emissions budgets do not apply.



Source: (*38*).

Figure 4. Transportation Conformity Process.

Project-Level Transportation Conformity

Besides the requirement that all non-exempt projects come from a conforming TIP/MTP, project-level conformity requirements specifically apply to CO and PM (chemical compounds found to cause localized impacts when in excess of NAAQS standards) in nonattainment and maintenance areas. Project-level conformity is performed by the project sponsor as part of the project's environmental review process. The process may also involve a project-level air quality analysis (hot-spot analysis) to assess the localized impacts of individual projects using an emission model and an air quality dispersion model. A hot-spot analysis is an estimation of likely future localized CO and PM emissions concentrations, and a comparison of the estimated, future localized CO and/or PM concentrations with the NAAQS. Hot-spot analysis assesses impacts on a smaller scale than the entire nonattainment or maintenance area (e.g., congested roadway intersections and highway or transit terminals) and uses an air quality dispersion model to determine the effects of emissions on air quality.

In accordance with 40 Code of Federal Regulations (CFR) 93.109(b) and (d), a CO hot-spot analysis is only required as part of project-level conformity in a CO nonattainment or maintenance area. In contrast, a CO traffic air quality analysis (TAQA; worst-case screening analysis) is performed under the National Environmental Policy Act (NEPA), specifically FWHA's T-6640 guidance document. Projects requiring a quantitative analysis must use applicable air quality models, databases, and other requirements (*39*). All other nonexempt projects can undertake either a quantitative or qualitative analysis. In 2008, EPA included a provision that allowed the U.S. Department of Transportation (U.S. DOT), in consultation with EPA, to make categorical hot-spot findings in CO nonattainment and maintenance areas if appropriate modeling showed that a type of highway or transit project would not cause or contribute to a new or worsened air quality violation of the CO NAAQS or delay timely attainment of the NAAQS or required interim milestone(s), as required under 40 CFR 93.116(a) (*39*).

In nonattainment areas for PM, hot-spot analyses are required for projects of air quality concern. Projects of air quality concern are generally highway and transit projects that involve significant levels of diesel traffic, or any other project that is identified by the SIP as a localized air quality concern. An additional consideration is to identify if the projects fall under the exempt category for conformity determinations. Such projects may proceed toward implementation even in the absence of a conforming transportation plan. Projects that fall into this category generally correspond to non-federal-aid system roads, hazard identification programs, crossings, shoulder improvements, etc. A detailed list can be found in 40 CFR 93.126 (*39*).

Until 2010, project-level transportation conformity for PM was based on a qualitative analysis of PM hot spots, with methods including comparison with location of similar characteristics, or by the use of air quality studies at the proposed project location. The qualitative analysis was replaced in 2010 by quantitative analysis requirements, which involve the estimation of project-level emissions using the Motor Vehicle Emission Simulator (MOVES) model, followed by the use of an appropriate dispersion modeling (CAL3QHCR or AERMOD models) to assess localized concentrations. Additional measures or control strategies may be required based on the findings of the quantitative analysis.

Project-Level Mobile Source Air Toxic Requirements

While not directly related to transportation conformity, as part of NEPA documentation, FHWA requires a project-level quantitative MSAT analysis to identify the air quality effect of major transportation projects. There are nine chemical compounds commonly known as priority MSATs, including acrolein, acetaldehyde, benzene, 1,3-butadiene, diesel particulate matter, ethylbenzene, formaldehyde, naphthalene, and polycyclic organic matter. FHWA provided interim guidance for project-level MSAT analysis and developed a tiered approach for analyzing MSAT in NEPA documents. Depending on the potential MSAT effects, no analysis may be required, or a qualitative analysis may be required for projects with low potential MSAT effects, or quantitative analysis may be required for projects with higher potential MSAT effects.

Reducing the effects of MSAT should be considered for projects with substantial construction-related MSAT emissions that are likely to occur over an extended building period, and for post-construction scenarios where the NEPA analysis indicates potentially meaningful MSAT levels. Such mitigation efforts should be evaluated based on the circumstances associated with individual projects, and they may not be appropriate in all cases (*40*). A number of available mitigation strategies and solutions for countering the effects of MSAT emissions can be found in the Construction and Post-Construction Emission Reduction Strategies section of TxDOT's Air Quality Environmental Standards of Uniformity (*41*).

Regulations Applicable to Emissions from Construction Activities

The previous section discussed transportation conformity regulations that mostly apply to on-road mobile source emissions. Additionally, there are regulations that specifically apply to emissions from construction activities at work zones; these include those within the conformity process (regional and project level) and other state or federal regulations. Table 6 summarizes these regulations.

Table 6. Regulations Specific to Construction Activities.

Description	Implementing Rule/Guidance	Summary
Project-Level Conformity (PM, CO Hot-Spot Analysis)	40 CFR 93.109, 40 CFR 93.123(c)	Emissions from construction-related activities are not required to be included in PM and CO hot-spot analyses if such emissions are considered temporary as defined in 40 CFR 93.123(c) (*39*). Temporary increases are defined as those that occur only during the construction phase and last five years or less at any individual site.
MSAT Analysis, NEPA	NEPA Review Process for Highway Projects; FHWA's Updated Interim MSAT guidance (October 2016)	MSAT emissions should be considered for the construction phase of a project and for post-construction scenarios. TxDOT's guidance documents provide additional information on potential mitigation measures (*42*).
Regional-Level Conformity	40 CFR 93.122(f)	Construction-related fugitive PM emissions are to be included as part of the regional conformity process in PM nonattainment and maintenance areas with a SIP that identifies construction-related fugitive PM as a contributor to the nonattainment problem, based on regulations in 40 CFR 93.122(f) (*43*).
Material Handling during Construction	Title 30 on Environmental Quality, Chapter 111, Subchapter A, Division 4, Texas Administrative Code Requirements	The Texas Administrative Code Requirements, Title 30 on Environmental Quality (*42*) have regulations for material handling during construction of roads, alleys, streets, and parking lots* to reduce the amount of dust emissions.
General Construction Impacts, NEPA Requirement	NEPA 42 USC 4332; CO TAQA	NEPA 42 USC 4332, Guidance for Preparing and Processing of Environmental and Section 4(f) Documents (General Construction Projects) (*44*) outlines the requirements for including construction impacts in Environmental Impact Statements (EISs). This is applicable to any projects involving construction activities, including transportation projects. The potential adverse impacts (particularly air, noise, water, traffic congestion, detours, safety, visual, etc.) associated with construction of each alternative of the project have to be included in the draft EIS along with appropriate mitigation measures.

* Regulations apply if the area of land affected by construction activities is more than 1 acre in size, except for the city of El Paso, where restrictions apply regardless of the size of the area of land affected.

MODELING OF EMISSIONS

This section discusses emissions modeling around construction zones and the air quality impacts of these emissions. Figure 5 shows the general modeling framework for the process of assessing the emissions and air quality impacts of construction zones. First, traffic and construction equipment activity data are used to characterize the total emissions generated by a specific work project. In turn, these total emissions estimates can then be used to model the dispersion of specific emissions into the atmosphere to understand the localized impacts of these emissions on local air quality. This general approach was followed in the case study assessments conducted as part of this research project, which investigated construction emissions, traffic emissions, and emissions dispersion aspects.

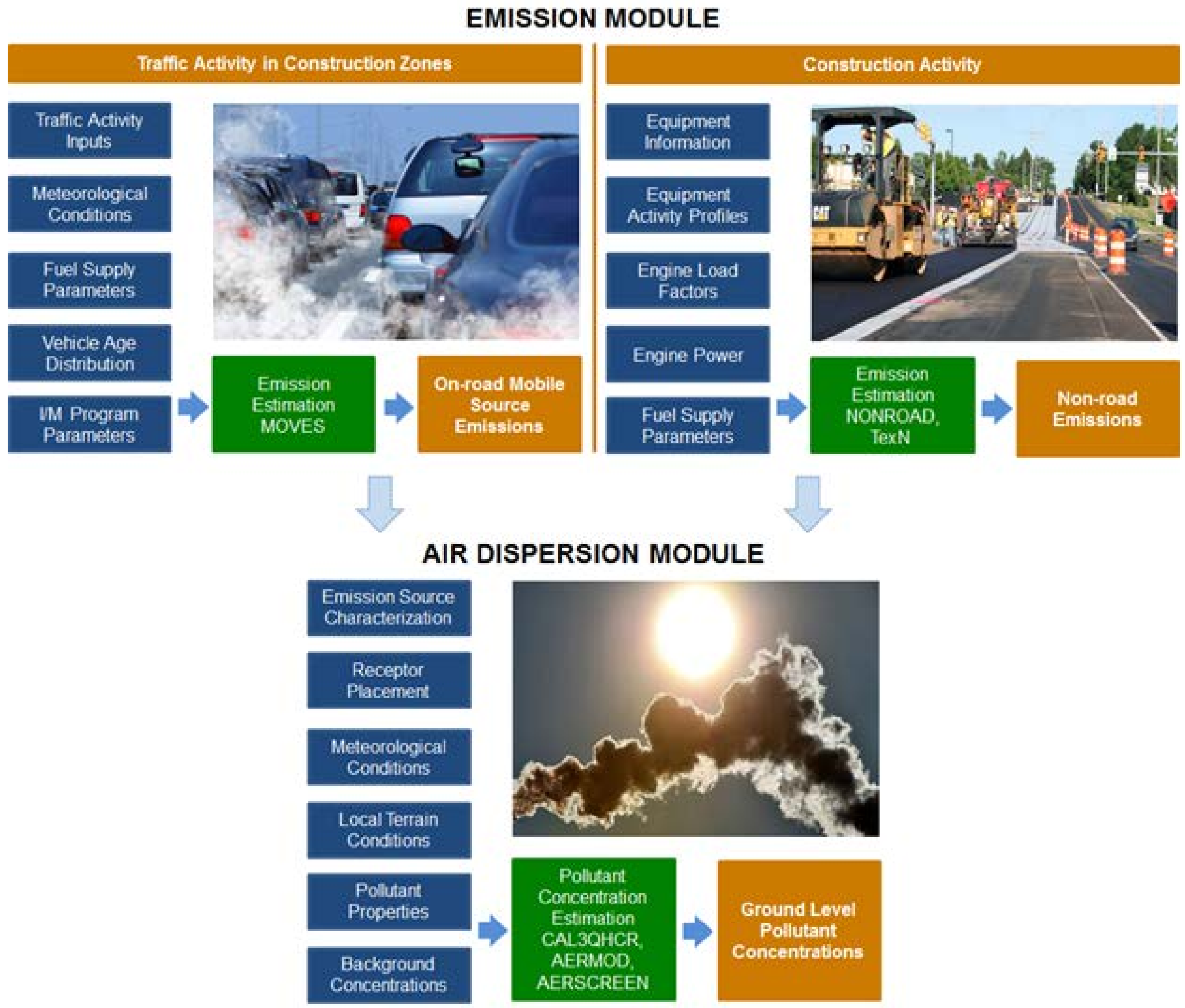


Figure 5. Emissions Estimation and Dispersion Modeling Framework.

Modeling Traffic-Related Emissions

Emissions modeling for assessing on-road mobile source emissions is broadly classified into macroscopic and microscopic models and takes into account factors related to traffic and roadway conditions; vehicle characteristics; and specific local meteorological and fuel supply conditions. Macroscopic models estimate emissions at the regional level using average aggregate network parameters. Microscopic models are used to estimate emissions at a finer resolution using instantaneous speed and acceleration values. Microscopic models estimate emissions using base emission rates developed from both laboratory and real-world testing. Some of the early microscopic models are the Comprehensive Modal Emissions Model (CMEM) (*45*) and the Virginia Tech Microscopic Energy and Emission Models (VT-Micro) (*46*). EPA has developed its next generation microscopic emissions model, called MOVES. The latest version of MOVES is MOVES2014a, released by EPA in November 2016. MOVES has improved capabilities compared to the CMEM and VT-Micro and has replaced EPA's MOBILE macroscopic emissions model for regulatory emissions estimation purposes (*47*).

The key distinctive features of MOVES that are perceived superior to its predecessors are (a) it uses a modal-based approach rather than an average speed-based approach for emission rate estimation; (b) it uses a MySQL database management instead of an external spreadsheet data management system; (c) it has the capability to estimate emissions at a geographical scale ranging from national, regional, or county level to a single roadway link; (d) it can be used to estimate both emissions and emission rates; and (e) it includes more sophisticated greenhouse gas (GHG) and energy consumption estimation methods. This section focuses on MOVES since it was the model used in this study.

MOVES uses a modal-based approach to estimate emissions compared to the average speed-based driving cycle approach used in MOBILE. A modal-based approach refers to developing emissions rates for a unique combination of modes (or bins) based on vehicle operating conditions and vehicle characteristics. The bins that classify vehicle activities according to vehicle characteristics are called source bins. These characteristics correspond to weight class, fuel type, technology, standard, and horsepower range. The bins that classify vehicle activities according to vehicle operating conditions are called operating mode bins. These characteristics correspond to speed and vehicle-specific power. Vehicle-specific power refers to the power demand placed on the engine. After distributing the vehicle activities into source and operating mode bins, MOVES estimates the fraction of vehicle activities in each of these bins and then develops a unique emissions rate for each combination of bins. The total emissions are estimates according to Equation 1 (*48*):

$$\mathbf{Total\ Emissions}_{\mathbf{emission\ process,vehicle\ type}} = \left(\sum \mathbf{Emission\ Rate}_{\mathbf{emission\ process,bin}} \mathbf{\ x\ Activity}_{\mathbf{bin}}\right) \mathbf{x\ Adjustments}_{\mathbf{process}}$$

(Eq. 1)

Equation 1 illustrates that the emissions rate for each emission process is estimated based on an emissions source, the operating mode bin allocation, and the fraction of activity in each bin. Adjustments are made to the emissions rates based on local specific conditions (meteorology, fuel supply, age distribution).

A significant feature available in MOVES is the ability to support quantitative project-level emissions assessments using detailed travel activity data. The MOVES project-scale analysis function is the most spatially explicit modeling level in MOVES because it calculates emissions from a single roadway link, a group of specific roadway links, and an off-network common area (e.g., transit terminal or park-and-ride lot). Total emissions (Equation 2) are calculated as a product of emissions factors (EFs) and vehicle activity. The type of vehicle activity depends upon the emission process; for example, to model running exhaust emissions, the relevant vehicle activity is vehicle miles traveled (VMT), while start exhaust emissions are modeled using the number of vehicle starts, and emissions from idling are modeled using vehicle idle time.

$$\mathbf{Total\ Emissions} = \mathbf{Emission\ Factors} \times \mathbf{Vehicle\ Activity\ Measure} \qquad \text{(Eq. 2)}$$

Two types of emission outputs are generated by MOVES: (a) emissions inventories with quantity of emissions and energy consumption (e.g., grams); and (b) emissions rates with quantity of emissions per unit of activity (e.g., grams per mile). MOVES requires inputs from the two broad categories illustrated in Figure 6: (a) traffic inputs corresponding to traffic activity, fleet composition, and roadway link characteristics; and (b) inputs that correspond to local meteorology, fuel supply, vehicle age distribution, and inspection/maintenance (I/M) parameters.

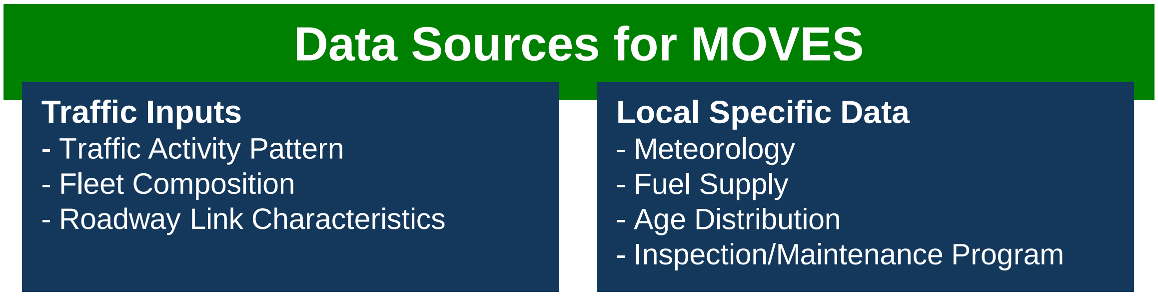


Figure 6. Input Data Sources for MOVES Project-Level Analysis.

Table 7 summarizes the input data requirements and possible sources for project-level analyses using MOVES. Table 7 provides a summary of possible data sources for each of the input parameters. The traffic volume and length of the simulated road will determine VMT for all through traffic. Then, fleet composition factors will be applied to divide total VMT into an estimate of VMT for each vehicle type. The fleet composition factors can be obtained through the Highway Performance Monitoring System (HPMS) database or other sources. This process can be implemented for various scenarios of work zone activity and ambient traffic conditions, such as those that might occur during daytime construction or nighttime construction, or for work zones located on either major/minor urban/rural arterial/collector roads. The total on-road mobile source emissions for each scenario can then be compared to evaluate the differences in emissions that occur when shifting daytime construction to nighttime construction.

Table 7. Input Data Requirements for MOVES Project-Level Analysis.

Data Item	Description	Source
Link	Roadway link characteristics.	User defined.
Link Drive Schedule	Vehicle trajectory or speed/time trace.	Traffic microsimulation models.
Operating Mode Distribution	Amount of time spent by vehicle fleet in different operating modes.	Optional for roadway links if the speed-time trace data table is provided. Required for off-network links. Data derived for each traffic analysis zone, quantifying how many trip starts or number of trips are associated with each traffic analysis zone.
Link Source Type Fraction	Link-specific percentage of link traffic volume driven by each vehicle type.	HPMS. Texas Department of Transportation Traffic Count Database.
Source Type Age Distribution	Vehicle age distribution.	Texas Department of Transportation. Department of Motor Vehicles vehicle registration.
Meteorology	Temperature and humidity.	Texas Commission on Environmental Quality data.
Fuel Supply	Fuel supply parameters and associated market share.	EPA's latest available (2013) summer season retail outlet reformulated gas survey data in major Texas metropolitan area.
I/M Program	I/M program parameters for nonattainment areas.	Texas state I/M rules. I/M parameters from MOVES database.
Off-Network Link	Vehicle start, short-term idling, and extended idling emissions.	Local specific data. Travel demand models.

Modeling Construction Equipment Emissions

Currently, few models are available for estimating emissions from non-road equipment used in construction activities. Non-road equipment is defined by EPA as self-propelled or portable equipment that is moved to a different location at least once a year on average, and is not registered for on-road operation. California's CalEEMod, EPA's MOVES (which integrates the EPA's NONROAD2008 model into it), and Texas's NONROAD (TexN) model are the emissions models that can estimate construction-specific non-road vehicle emissions.

CalEEMod is California's land use emissions model designed to quantify potential criteria pollutant and GHG emissions associated with both construction and operations from various land use projects. The model quantifies direct emissions from construction, operations (including vehicle use), and indirect emissions (such as GHG emissions from energy use). The mobile source emissions factors used in the model include the EPA standards into the mobile source emissions factors. CalEEMod was developed in collaboration with the air districts of California and contains default data (e.g., emissions factors, trip lengths, meteorology, source inventory) provided by the districts to account for local requirements and conditions. Although CalEEMod is an accurate tool for quantifying air quality impacts from land use projects throughout California, it does not explicitly model emissions from roadway construction projects. The Sacramento Metropolitan Air Quality Management District has developed the Roadway Construction Emission Model to assess the emissions of linear construction projects such as roadway construction as an offshoot of CalEEMod. The Roadway Construction Emission Model considers roadway project-specific inputs and equipment characteristics, and leverages emission factors used by CalEEMod including non-road emissions factors to quantify roadway-related emissions. However, the emission factors are specific to California, though they can be modified indirectly by entering project-specific information.

The MOVES emissions model developed by EPA provides, in addition to on-road sources, emissions rates per unit of non-road activity and estimates total non-road construction equipment emissions. MOVES collects emissions factors and other default data at the nationwide level and allocates the data to various states and counties based on allocation factors. These allocation factors do not incorporate local specific conditions such as age distribution or fuel supply that are found to vary between states. MOVES is also consistent with EPA's AP-42: Compilation of Air Pollutant Emission Factors Volume II, Section II standards (*49*), has the ability to estimate regional non-road emissions rates, and consists of emissions inventories for construction equipment. MOVES can be used for modeling emissions in any state, whereas the default emission factors in the Roadway Construction Emission Model are specific to Sacramento Valley in California.

MOVES estimates emissions for non-road equipment based on the following input parameters (*50*):

- Equipment population distributed by age, power, fuel type, and application.
- Average load factor expressed as average fraction of available power.
- Available power in horsepower.
- Activity in hours of use per year.
- Emissions factor with deterioration by model year for the appropriate emissions standard.

The total emissions are calculated according to Equation 3:

$$\boldsymbol{Emissions} = \sum \boldsymbol{Pop} \times \boldsymbol{A} \times \boldsymbol{Power} \times \boldsymbol{LF} \times \boldsymbol{EF} \qquad \text{(Eq. 3)}$$

Where:

Pop = population of equipment with a given engine size (horsepower).

A = average hours of operation per equipment during the time frame of interest.

Power = engine horsepower.

LF = engine load factor (percentage of rated power while under load).

EF = emission factors (specific to horsepower rating and engine model year).

While TCEQ's TexN model uses input files and post-processing routines to estimate Texas-specific emissions estimates, it retains the NONROAD2008 model that has now been incorporated into MOVES2014 to conduct the basic emissions estimation calculations. The TexN model provides emissions estimates for most of the non-road mobile source equipment categories operating in Texas (including construction and mining equipment). The TexN model calculates emissions estimates for the same equipment categories included in EPA's NONROAD model, such as excavators, generator sets, forklifts, and various recreational and lawn and garden equipment.

The TexN model contains 25 distinct sectors, such as residential construction, commercial construction, highway construction, etc.. Each sector has distinct equipment population and activity profiles, with most of them being classified as diesel construction equipment (DCE). Two sectors within TexN—miscellaneous equipment having less than 25 horsepower and all non-DCE—use the default profiles from EPA's NONROAD model. The remaining 23 sectors represent independent DCE profiles developed specifically for TCEQ. Table 8 compares the characteristics of the Roadway Construction Emission Model, MOVES, and TexN model.

Table 8. Comparison of Roadway Construction Emission Model, MOVES, and TexN.

Roadway Construction Emission Model	**MOVES**	**TexN**
Quantify emissions associated with both construction and operations for roadway projects	*Can provide emissions for non-road vehicles used during construction operations*	*Provides emissions estimates for a large number of non-road equipment categories operating in Texas*
INPUTS		
- Equipment types per activity and count - Hours per day of equipment usage - Construction project phase, activity, type, dates - Trip length	- Equipment types, population, and age distribution of each type - Activity in hours of use per year - Average load factors - Available power in horsepower	- Equipment type and subsector - Activity level (in hr/yr) - Analysis year, season, and region - Diesel and gasoline fuel parameters - Retrofit data
DEFAULT		
- Emission factors (EMFAC, OFFROAD) specific for Sacramento Valley air basin for specific construction equipment - Load factors and horsepower for various equipment types - Fuel type	- Emissions factor based on location (county level) and specific attributes (temperature, humidity, etc.) for non-road equipment	- Emissions factor based on region-specific adjustment for Texas
OUTPUT		
- Emission estimates by: o Various project phases (such as land clearing, grading subgrade, paving, etc.) for various chemical compounds of interest o Chemical compounds: CO, PM, NO_x, carbon dioxide (CO_2)	- Total on-road and non-road emissions by: o Construction activities for various chemical compounds of interest o Chemical compounds: CO, PM, NO_x, CO_2	- Emissions estimates by the following categories: o County or region o Time period o Analysis year o Equipment/fuel type o Chemical compounds: sulfur dioxide (SO_2), PM hydrocarbons (HC), NO_x, CO, CO_2

Air Dispersion Modeling

Air dispersion models (air quality models) are used for assessing near-field impacts of mobile source emissions. These models predict how airborne pollutants emitted from stationary or mobile sources disperse in the atmosphere and how their concentrations vary over time and space. Because emissions concentrations from mobile and non-road sources tend to peak near the emissions source (roadways and work zones) and decay quickly within a few hundred meters to background concentration levels (*51*, *52*), it is important to understand their dispersion characteristics in addition to their contribution to regional emissions.

An air dispersion model can be viewed as a mathematical simulation that describes the transportation and dispersion of air pollutants in the atmosphere, producing a set of concentration estimates that vary spatially in the analysis area. These concentration estimates are often used as proxies for assessing localized air quality and human health impacts. Pollutant dispersion depends on a number of factors that include the fate and transport properties of the specific pollutant, meteorology, terrain, and strength of the emission source. Accordingly, an air dispersion model requires inputs from a number of data sources, namely (a) emissions estimates, (b) meteorological and land use conditions, and (c) fate and transport properties of pollutants. The air dispersion model produces pollutant concentration estimates for specific average time periods, and for any number of predefined receptor locations (placed at an average human breathing height) located within and around a work zone.

Air dispersion models have regulatory applications to ensure that federally supported projects comply with National Ambient Air Quality Standards as set forth by EPA. These models also have a significant effect on the human environment within the context of NEPA. Other regulatory applications include New Source Review (NSR) and Prevention of Significant Deterioration (PSD) regulations. These models are addressed in Appendix A of EPA's Guideline on Air Quality Models (also published as Appendix W of 40 CFR Part 51) (*53*). Among the different dispersion models, CALINE3 models and AERMOD are designated as preferred models for project-level transportation conformity and NEPA applications. These models estimate dispersion with a Gaussian-like equation, which incorporates factors that account for the rate the plume disperses in each direction, reflection from the ground, and plume rise (*54*). Table 9 compares the differences between the various air dispersion models and their applicability to this research, and Table 10 lists the input parameters required for air dispersion modeling.

Table 9. Comparison of CAL3QHCR, AERMOD, and AERSCREEN Models.

Description	CAL3QHCR	AERMOD	AERSCREEN
Model Formulation	Gaussian-based model designed to model vehicular queues at signalized intersections.	Gaussian-based model based on recent atmospheric science with planetary boundary layer parameterization.	Gaussian-based screening model based on AERMOD model formulation. AERSCREEN produces estimates of worst-case 1-hour concentrations for a single source, without the need for hourly meteorological data.
Modeling Options	Represents all sources as line sources.	Flexible in representing different types of sources as point, line, area, and volume sources.	Flexible in representing sources as point, line, area, and volume sources. However, only one source can be modeled in one run.
	Option to vary EFs by different time scales.	Option to vary EFs by different time scales.	Requires only one source-specific EF.
	A single year of meteorological data can be incorporated at a time.	Multiple years of meteorological data can be processed simultaneously.	Does not require hourly meteorological data. Requires site-specific basic meteorological parameters such as max and min temperature.
Modeling Components	Meteorological preprocessor for CAL3QHCR is MPRM.	Meteorological preprocessors AERMET, AERSURFACE, and AERMINUTE. Terrain preprocessor AERMAP. Multi-building dimension program BPIPRIME.	Meteorological preprocessor, MAKEMET. Ability to interface with AERMOD, AERMAP, and BPIPRIME.
Regulatory Application	Quantitative analysis for highway and intersection projects. Not appropriate for modeling refined PM hot-spot analyses.	Quantitative analysis for highway, intersection, transit, freight, or terminal projects, and combination of projects that involve both on-road and off-network sources.	Screening models are often applied before applying a refined air quality model to determine if refined modeling is needed.

Table 10. Input Data Parameters for Air Dispersion Modeling (CAL3QHCR, AERMOD).

Air Dispersion Modeling Parameters	Inputs
Source Characterization	Sources are defined based on: (1) Travel activity. (2) Physical dimensions. (3) Orientation.
Emission Factor	Combined EFs from: (1) Traffic activity at construction zones from MOVES model. (2) Construction activity obtained from CalEEMod, TexN models. EFs are normalized with reference to time and source dimensions.
Receptor Characterization	Receptors are placed at a finer spacing near the sources, and the spacing is increased with distance from the source. Receptors are placed at an average human breathing height.
Meteorology	Three types of data required for processing meteorological data consist of: (1) Surface data that measure characteristics of lower layers of the atmosphere. (2) Upper air data that measure characteristics that change with height in the atmosphere. (3) Land use data that represent surface characteristics. The raw data are processed using meteorological preprocessors.
Dispersion Parameters	Initial vertical dispersion to account for effects of vehicle-induced turbulence. Release height is the height at which wind effectively begins to affect the plume. Urban/rural representativeness of the project site to account for the effect of Urban Heat Island Effect, a term used to describe urban areas that are hotter than nearby rural areas, especially at night, mainly as a result of heat retention by urban materials.

TRAFFIC AND CONSTRUCTION ACTIVITY DATA NEEDED FOR AIR QUALITY MODELING

The previous section discussed the modeling process and the available models for assessing traffic-related emissions, construction equipment emissions, and dispersion of chemical compounds. Traffic and construction activity data serve as the basic input to these emissions and air dispersion models. This section discusses approaches for obtaining traffic and construction activity data for use in the emissions and air dispersion modeling processes.

Measuring and Modeling Traffic Activity in and around Constructions Zones

The operational and mobility impacts of traffic activities in construction zones are typically assessed by determining the delays and vehicle queues experienced by travelers passing through the work zone. The two key input data required to estimate traffic delays and queue lengths are traffic demand and work zone capacity. Traffic demand is the traffic flow rate (typically expressed as hourly volume) that is trying to pass through the work zone at any given time, and work zone capacity is the maximum flow rate that can be served by a given work zone configuration.

When traffic demand is less than the work zone capacity, vehicles travel through the work zone without experiencing congestion and delays. However, as traffic demand increases and exceeds the capacity of the work zone, then congestion occurs and vehicle queues begin to form upstream of the work zone. An additional challenge in assessing construction zone impacts is that in addition to temporal changes in traffic demand, work zone capacity also varies through time. Usually, a reduction in work zone capacity occurs when one or more lanes are closed, but depending on the worksite activity near the traveled lane, capacity can be further reduced by additional lane closures or modifications, trucks entering or exiting the roadway, or other obstructions.

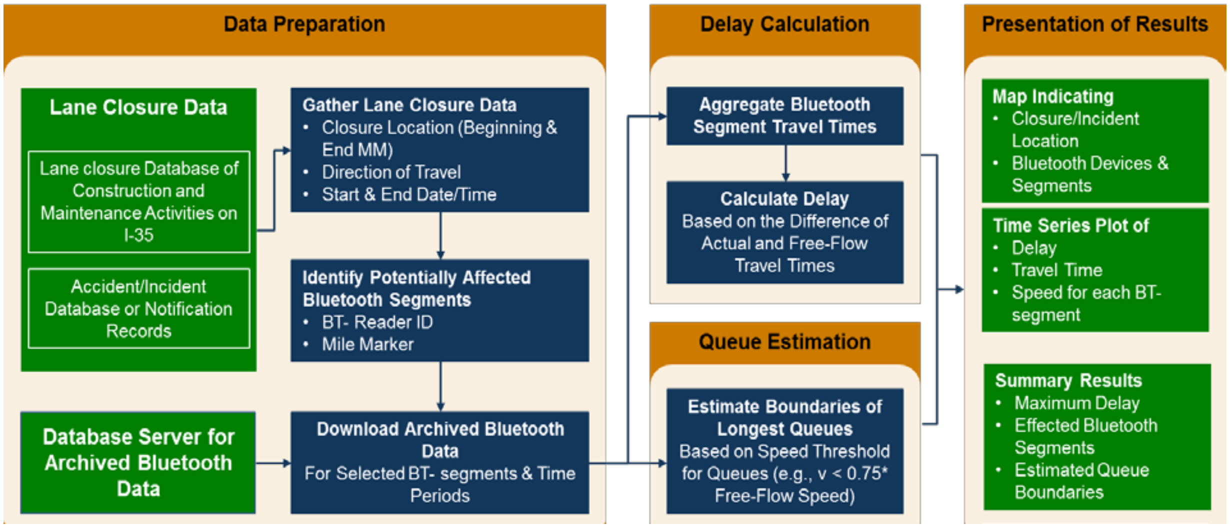
The traffic impacts of the reduction in capacity of work zones can be estimated using delay or queue length measurement, or using modeling/simulation to assess changes in vehicle activity. The following sections discuss the measurement and modeling approaches that can be used to assess the traffic activity impacts in work zones.

Measuring Traffic Activity

Measuring the impacts of construction zones on traffic activity generally follows methods similar to measuring impacts of congestion or traffic incidents. The most common approaches include delay measurement and queue length measurement.

Delay Measurement. Delay is defined as the difference between actual and free-flow travel times. The most common travel time measurement methods are point-to-point travel time estimates. They can be obtained from travel time runs using global positioning system (GPS)-equipped vehicles or more advanced technologies such as Bluetooth address matching, automated vehicle identification, or license plate recognition systems.

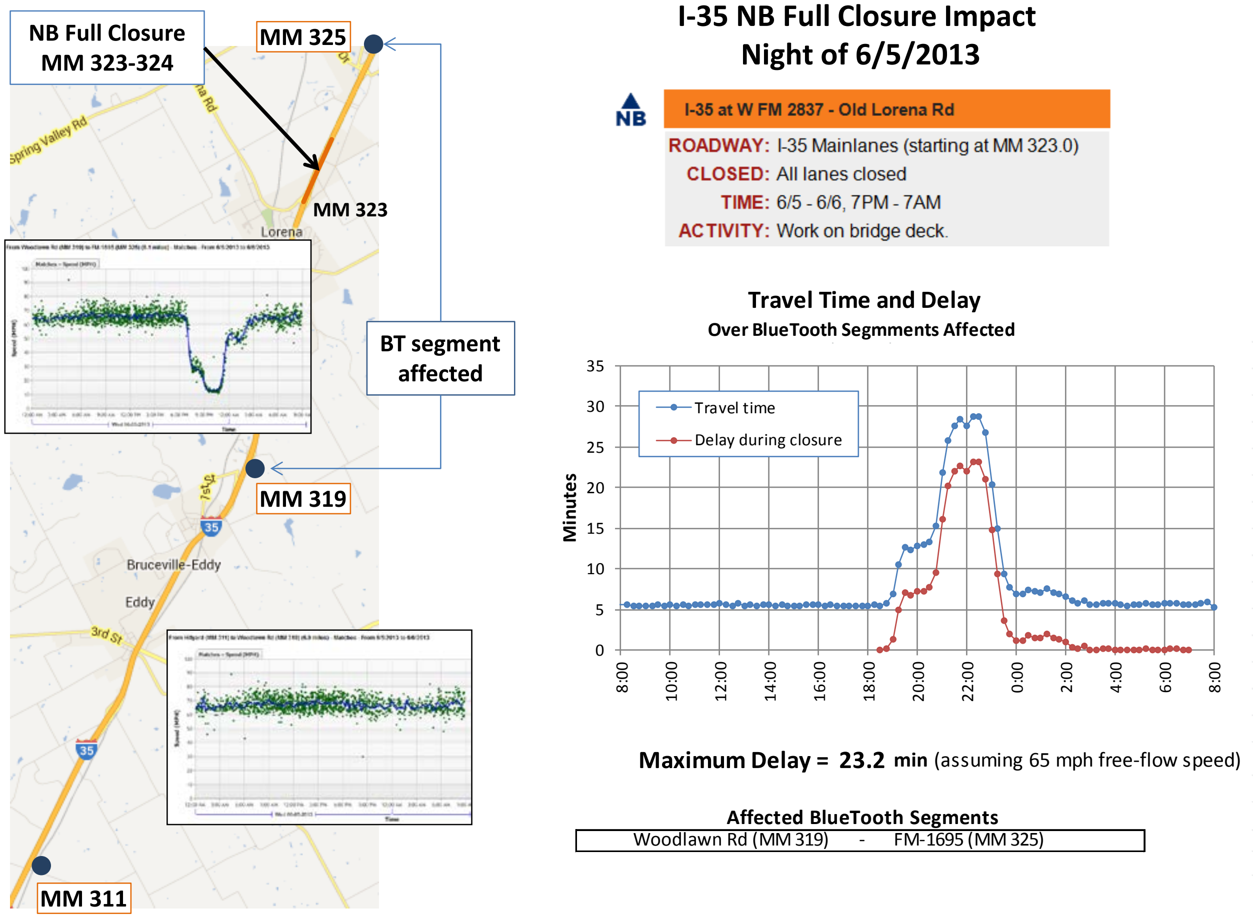
A significant example of the use of Bluetooth address matching for estimating delays is provided by a joint project between TxDOT and TTI that monitors traffic delays on Interstate 35 (I-35) in Central Texas and reports this travel information to the general public. The project was implemented to assist TxDOT in meeting the challenges of a $2 billion reconstruction of I-35. TTI has designed, deployed, and implemented a traveler information system to keep the public informed about construction work and delays, enhance safety, and facilitate mobility during the eight-year construction horizon. This system uses Bluetooth readers that detect vehicles carrying enabled Bluetooth networking devices such as cellular phones, mobile GPS systems, telephone headsets, and in-vehicle navigation systems. Each Bluetooth device can be identified by a unique code or identifier (Mac address). As devices carried within a vehicle move along a roadway, they are detected at successive readers and transmitted to a central host computer that uses the data to obtain speed information for that roadway segment. Across the I-35 corridor, Bluetooth readers are deployed at an average of 4-mi spacing with a minimum distance of 0.9 mi and maximum distance of 11.5 mi between consecutive readers (*55*). To monitor and provide feedback on the performance of the system, a component was developed to assess the impacts of construction activities and incidents based on travel times, delays, and queue lengths calculated from Bluetooth address matching. Figure 7 summarizes the major steps of performing an impact analysis of work zone lane closures or incidents.



Source: (*55*).

Figure 7. Steps of Post-Event Work Zone and Incident Impact Analysis.

Figure 8 illustrates an example of the application of the tool to delays associated with work zones. This example shows the delays associated with a nighttime bridge project that required the closure of all I-35 main lanes in the northbound direction. The freeway was closed at 7 p.m. and reopened at 7 a.m. the next morning. During the closure, I-35 traffic was diverted to the frontage road. In Figure 8, the bold orange line on the map shows the segment of freeway that was closed in the northbound direction between mile marker (MM) 323 and 324. The locations of the Bluetooth readers used in the analysis are marked by three blue dots. The two scatter plots over the map show the average speed of individual vehicles over time as they traveled through the Bluetooth segments. The considerable drop in vehicle speeds between the Bluetooth readers at MM 319 and 325 indicates that there was significant congestion in this segment. The fairly constant speed profile on the second scatter plot indicates that vehicles were traveling at free-flow speeds in the Bluetooth segment between MM 311 and 319, so traffic was not affected by the construction upstream of MM 319 (*56*).



Source: (*55*).

Figure 8. Impact of a Freeway Closure on I-35.

The line graph to the right of the map shows how travel times (blue line) and delays (red line) changed over time. The maximum delay caused by the freeway closure was about 23 minutes, occurring at approximately 10 p.m. There was some queuing between 6:30 p.m. and midnight, with the maximum queue length less or equal to 4 mi (i.e., the queue never extended beyond the first Bluetooth reader upstream of the freeway closure). The spacing of the Bluetooth segments did not allow more refined queue length estimates at this location. There was no delay after midnight.

In addition to evaluating the impacts of single construction projects or incidents, the method has also been used to determine the combined impact of all concurrent construction projects and incidents for specified segments and for the entire corridor of I-35 between Salado and Hillsboro. For example, a daily analysis of the past 24-hour period is routinely performed to determine travel times and delays in 15-minute intervals between the major population centers of Hillsboro, Waco, Temple, and Salado (*56*).

Queue Length Estimation. Although queues are mostly considered to be a performance metric that reflects congestion levels, they are also safety concerns because of the high potential of rear-end crashes at the back of queues (i.e., the boundary between stopped/slow queues and the upstream traffic approaching at high speed).

The most common techniques for estimating the length and duration of queues are based on spot speed data collected using relatively densely spaced sensors. The steps involved in estimating the length and duration of a queue using spot speed data are described below and illustrated in Figure 9 (*56*):

1. Divide the roadway into regions with uniform speed.
2. Examine speeds and volumes hour by hour at each sensor location.
3. Compare hourly speeds across sensors to identify the extent of queue propagation.
4. Sum region lengths where speeds are below the threshold.

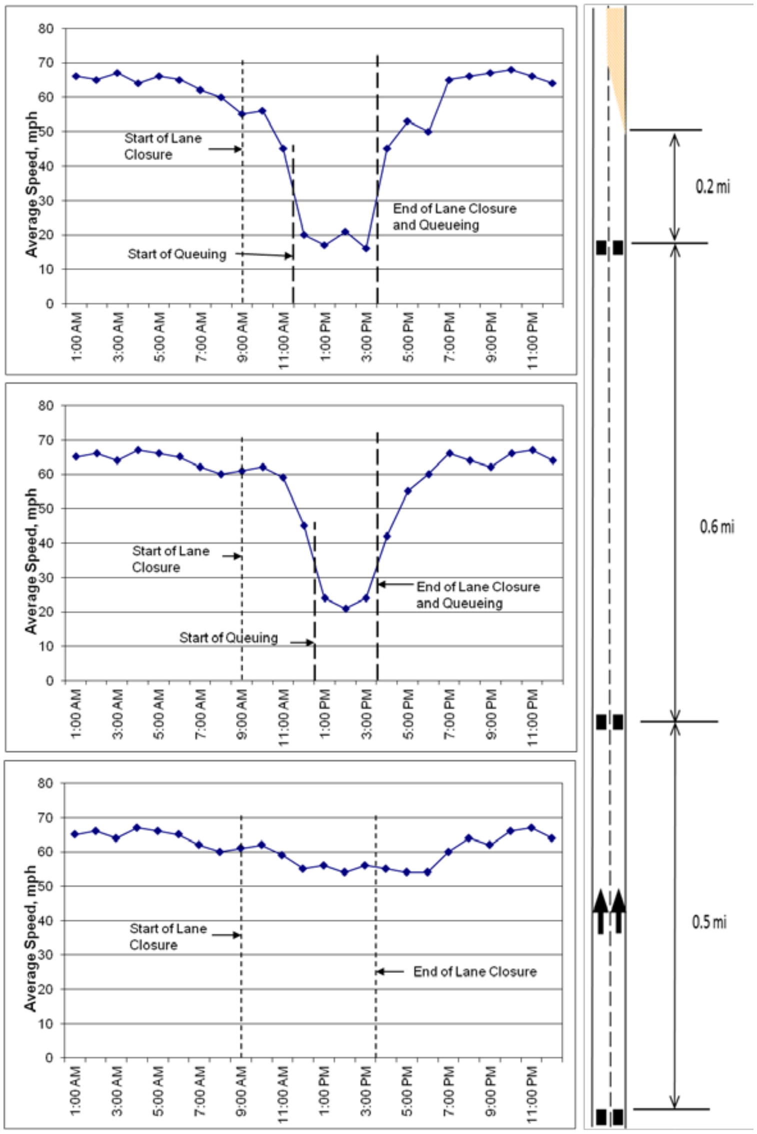


Figure 9. Estimation of Length and Duration of Queue from Spot Speed Sensors.

Modeling Traffic Activity

Drivers traveling through work zones may experience a range of traffic conditions. They may travel at free-flow speed, in slow-moving queues, or in stop-and-go conditions, or they may be stuck in a stopped queue for an extended period. In addition to frequent speed changes, they may also need to merge into a designated open lane if the work zone requires a lane closure. In some cases, a construction or maintenance project will require a complete closure of the roadway/freeway, and possibly detours to an alternate route/frontage road. For work zones located on a signalized arterial, vehicle behavior can become even more complicated.

These complex traffic operations and driver behavior scenarios can be modeled using a calibrated microscopic simulation model. There are a number of microscopic simulation packages available for this purpose, such as VISSIM, AIMSUN, PARAMICS, and TRANSMODELER. VISSIM is a microscopic traffic simulation model developed by Planung Transport Verkehr (PTV) AG, and is one of the most widely used models in the United States. The TTI research team has conducted several research projects with VISSIM, making it the model of choice for this study.

VISSIM or other simulation models can be used to analyze traffic activity under different work zone scenarios and to understand the differences in traffic activity for specific construction and maintenance projects undertaken during the day or the same projects undertaken at night. The first step in the process is to develop a simulation testbed for the roadway section or network representing a case study work zone. The testbed replicates the exact roadway geometry, posted speed, work zone lane closure, and traffic control at the work zone location. The testbed generally includes the entire work zone and a sufficiently long (e.g., 8–10 mi) roadway segment upstream of the work zone to ensure that potential vehicle queues are accurately modeled.

The next step in the modeling process is to calibrate the key model parameters (i.e., driver behavior parameters related to car following and lane changing). This step ensures that the model conforms to realistic traffic activity. Model calibration is typically an iterative process in which model parameters are systematically adjusted and fine-tuned to match the simulated vehicles' throughput, speeds, travel times, and queue lengths with field observations.

Finally, the calibrated simulation testbeds can be used to simulate traffic activity under different work zone scenarios. These scenarios can include manipulations of travel demand by changing traffic volumes and truck percentages to represent typical nighttime and daytime conditions at the case study sites, and of work zone capacity by simulating different lane closure scenarios. In addition to common mobility performance measures, such as vehicle throughput, travel time, delay, and queue length, VISSIM can also output vehicle trajectory data (i.e., location, speed, acceleration, and deceleration). This vehicle activity data can then serve as the input for models that estimate and aggregate vehicle emissions.

Construction Impact Data

As illustrated in the introductory section, road construction and maintenance projects encompass a broad range of project types. In turn, different project types use different equipment and have different equipment activity patterns. All of these factors impact the emissions generated by the construction activity. In some cases, different equipment and activities may also be deployed for the same type of project undertaken during the nighttime versus daytime.

Measurement and modeling of construction activity and emissions impacts generally involve understanding the activities, equipment and usage associated with particular types of work or projects, and potential differences between operations when the same work is being performed during the daytime versus nighttime.

One of the significant challenges in measuring and modeling worksite construction activity is to ensure that data are collected at an appropriate resolution that is consistent with the inputs for the selected emissions model. A majority of these data can be obtained using on-site observation and surveys with construction site staff. The various emissions models that can be applied for measuring emissions from construction equipment activity were discussed in a previous section.

In general, the data required include equipment types, population, age distribution of each equipment type at each study site, and equipment characteristics such as average load factors, power, and equipment refueling activities including fuel type. The equipment activity recorded in terms of engine hours of use at the site is the primary input that serves as the basis for almost all emissions models.

ASSESSING AIR QUALITY IMPACTS OF WORK ZONES AND NIGHTTIME CONSTRUCTION

A number of existing studies have investigated the impacts of work zones from various aspects, including environmental, monetary, and traffic impacts. Within these studies, there is a recent trend of assessing the environmental impacts of these construction zones, and although many of these studies have focused on emissions impacts from construction-related equipment, more recent studies have begun to assess the additional impacts of traffic activities around construction zones.

Crawford conducted an assessment of emissions from highway construction projects at five study sites in Dallas/Fort Worth, Texas (*57*). Four large-scale, multiyear construction projects and one small pavement maintenance project were observed. Materials trucks and construction equipment were observed and their activities recorded. The activity measures recorded were engine starts, operating hours, and the frequency and duration of throttles (transient events). Activity from field trucks, materials trucks, and construction equipment was used to estimate the emissions produced at each study site. These emissions estimates were then placed in perspective by comparing their equivalent VMT for the general vehicle fleet in the region.

González and Echaveguren developed a dynamic modeling framework based on discrete-event simulation to describe the sustainability in roadway constructions (*58*). They simulated a hypothetical project and estimated fugitive emissions (volatile organic compounds [VOCs], $PM_{2.5}$, PM_{10}) and exhaust emissions (CO, NO_x, SO_2, VOC) generated by production and traffic conditions. The construction operations of interest mainly involved the schedule of trucks entering, loading, and exiting the construction site. They used the VISSIM model to conduct microsimulations of traffic delays outside of the construction site caused by these truck activities. By applying different truck operation scheduling (including number of trucks, location of loading zone, etc.) into their simulations, they showed that the total fugitive and exhaust emissions from a site could be significantly affected by changes in truck schedules, and that emissions could be minimized by using an optimum number of trucks and loaders.

Avetisyan et al. conducted a study focusing on quantifying the effects of vehicle technology, traffic volume, and work zones on emissions production from on-road traffic (*59*). Microscopic traffic simulations were performed to assess the on-road mobile source emissions impact of single-lane closure work zones. The study corridor was a 7-mi interstate freeway and emissions effects of 15, 30, 45, and 60 minutes of single-lane closure work zone were studied. A microscopic emissions estimation model was established that estimated the production of airborne chemical compounds of interest as a function of modal vehicular parameters (e.g., velocity, acceleration, stops, starts, and idling), vehicle composition categories (e.g., passenger cars, trucks, and buses), and class (age and tier level). They found that lane closures cause a decrease in the speed of passing vehicles and an increase in emissions rates per mile driven. However, because the work zone caused a reduction in overall traffic through the corridor, the study found that the total emissions from on-road traffic were also reduced.

Zhang et al. adopted a microscopic approach to estimated vehicle emissions from light-duty and heavy-duty vehicles in a work zone under rush hour conditions and compared the results with emissions under free-flow traffic conditions (*60*). They collected second-by-second vehicle speed and acceleration data based on field experiments on typical weekdays. They used vehicle speed and acceleration data as inputs to CMEM to generate second-by-second emissions. Total emissions from on-road traffic were obtained through summation of all second-by-second emissions. They found that CO_2, CO, HC, and NO_x emissions rates (grams per mile) reach their highest level during a transitional period when traffic changed from free-flow to congested or congested to free-flow conditions. These findings were attributed to increased acceleration or deceleration activities during the transition period. The exception to this finding was for heavy-duty vehicles where NO_x emissions rates did not change significantly under different traffic conditions. The total on-road traffic emissions almost doubled under congested conditions when compared with a free-flow work zone scenario.

Huang et al. set out to understand which road maintenance projects have the least overall environmental impact based on both construction activities and disrupted traffic (*61*). A particular focus of the study was the additional fuel consumption and emissions caused by delayed traffic. They built a life-cycle assessment model that evaluated the environmental impacts of roadwork in terms of material production, material transportation, material placement, and traffic delay due to the work zone. The environmental impacts of delayed traffic were calculated through a microsimulation platform used to simulate construction activities under different scenarios of project duration. The results showed that by reducing construction time from eight to five days, substantial reductions in traffic-related emissions can be achieved. The savings in CO and PM due to the reduced construction project times were comparable to the total amount of emissions generated by the work zone activities. However, smaller reductions were seen for NO_x, HC, and CO_2.

Carr developed a construction congestion cost model to simulate traffic volumes and speeds under normal and work zone conditions (*62*). The focus of the study was to understand the cost implications of diverting or canceling traffic operations. The model calculated travel cost (per mile), delay cost (per delayed hour), and the cost of canceled trips (per canceled trip). By summing all of the costs, the model provided a detailed view of the economic impacts of construction activities. Although this study did not address the environmental impact of construction activities, it does raise an interesting question about whether diversions or canceled trips should be considered when the impacts of construction activities are evaluated.

Cass and Mukherjee adopted a hybrid life-cycle assessment approach to evaluate GHG emissions for highway construction operations (*63*). GHG emissions were evaluated from construction operations only (i.e., delayed traffic-related emissions were not considered). Their approach emphasized the emissions from construction phases and focused on-site collection of material and equipment usage data during the construction or rehabilitation operations.

In addition to studies that investigate the emission impacts of construction projects, many studies have examined the impact of work zone emissions on human health. The primary chemical compounds that affect human health are NO_x, CO, and PM that are often associated with diesel engines. While stringent regulations from EPA regulate the amount of emissions from new non-road equipment (2008 or newer), much of equipment in the current non-road diesel fleet consists of older equipment. Epidemiological studies have indicated a link between vehicular emissions and adverse health impacts such as premature deaths, increased hospital admissions for respiratory and cardiovascular diseases, asthma attacks, and lost productivity through and missed work or school days (*64*). In addition, emissions concentrations from mobile and non-road sources have a tendency to peak near the emission source (roadways and work zones) and decay quickly within a few hundred meters to the background concentration levels (*2*, *3*). These health impacts are especially relevant to construction workers or individuals that live or work near these sources. In a study by the Union of Concerned Scientists (*64*), EPA and CARB methods were used to quantify the health and economic damage from construction equipment emissions in California. While the focus of the study was beyond transportation, they reported total impacts of over $9 billion for the construction equipment sector as a whole, which includes a large amount of transportation infrastructure-related activity. The report documented that 90 percent of the health and economic damage occurred in California's five most populous air basins (South Coast, San Francisco, San Diego, San Joaquin, and Sacramento).

Given the significant body of research that has examined the impacts of construction activity on emissions and the impacts of these emissions on human health, it is unsurprising that studies have focused on strategies to reduce the emissions from non-road construction equipment. Many of these studies highlight how changes to equipment type, fuel type, and operational efficiency can significantly reduce emissions. For example, a report by EPA identified low cost strategies to reduce emissions and health effects from non-road construction equipment (*65*). The report grouped low cost activities into three categories: (a) operating strategies include reducing unnecessary idling, improving preventive maintenance, and training equipment operators; (b) fuel strategies that focus on the use of cleaner fuels, including ultra-low sulfur diesel and biodiesel; and (c) equipment strategies such as retrofits, repowering/engine upgrades, and electrification. The Union of Concerned Scientists study suggests cost-effective technology solutions that include adopting retrofit technologies and cleaning up existing construction equipment to reduce construction emissions (*64*). Similarly, a NCHRP 25-25 project report suggested that DOTs can reduce emissions from non-road equipment by reducing the amount of equipment activity, improving fuel economy by changing equipment type or increasing operational efficiency, and using alternative fuel technologies (*66*).

None of these studies have explicitly explored the potential emissions and air quality impacts of shifting the construction activities from daytime to nighttime in a systematic manner. In addition to the overall potential air quality benefits, shifting the work schedule of construction workers to nighttime from daytime could help in reducing their exposure to chemical compounds due to a reduction in traffic volumes and congestion. Quantifying the potential benefits of time period shift in construction activities along with other equipment and fuel technology strategies can help address several environmental, regulatory, and public health objectives.

DECISION-MAKING FRAMEWORKS AND APPROACHES TO NIGHTTIME CONSTRUCTION

There are a few studies that systematically surveyed transportation practitioners to identify the factors that influence the decision to pursue nighttime construction. In 1990, a study asked state highway agencies to rate 12 factors used when considering nighttime construction on a scale from one to seven, where seven represented the highest level of importance (*67*). Table 11 shows that traffic congestion (i.e., mobility) was considered to be the most important factor (6.72), followed by safety (5.93). In contrast, agency cost was rated the lowest (3.07). For environmental factors, only noise (5.31) and light glare (4.66) were included in the list of rated factors.

Table 11. Importance of Decision-Making Factors as Reported by State Highway Agencies in 1990.

Factor	Average Rating
Congestion	6.72
Safety	5.93
Noise	5.31
Work Time Available	5.21
User Cost	5.14
Quality	4.93
Light Glare	4.66
Productivity	4.29
Agency Experience	3.79
Contractor Experience	3.43
Temperature	3.38
Owner Cost	3.07

Source: (*26*).

In 2001, a study surveyed 32 state transportation departments, 20 Kentucky highway contractors, and 23 Kentucky resident engineers (*8*). Table 12 contains the top five issues contributing to the decision to conduct work at night identified by these three groups or respondents. Again, congestion was the primary concern.

Table 12. Top Five Issues Contributing to Decision to Work at Night.

Issue Rank	Department of Transportation	Highway Contractor	Kentucky Resident Engineers
1	High daytime traffic	High daytime traffic	High daytime traffic
2	Traffic control	Contract issues	Temperature concerns
3	Road user costs	Schedule issues	Traffic control
4	Longer work periods	Traffic control	Schedule issues
5	Schedule issues	Safety	Longer work periods

Source: (*6*).

In 2003, researchers conducted a survey of Oregon DOT employees involved with nighttime construction and maintenance activities and private contractors to identify the level of importance of 19 factors researchers identified as being relevant to the decision of whether or not to conduct nighttime work activities (*4*). The survey respondents were asked to rate each factor from one to seven, where one was the lowest and seven the highest based on importance. The survey respondents also ranked all 19 factors relative to each other. Table 13 shows the overall survey results for these two tasks (rating and ranking). For both the rating and the ranking, safety, traffic control, and congestion were the most important factors affecting the decision to conduct night work. Air quality and fuel consumption were ranked and rated the least important factors.

Table 13. Oregon Study Overall Survey Results (n=446).

Group	Rating		Ranking	
	Factor	Average	Factor	Average
1	Safety	6.44	Safety	2.08
	Traffic Control	6.07	Traffic Control	4.05
	Congestion	5.98	Congestion	4.83
2	Lighting	5.84	Quality	6.64
	Quality	5.40	Productivity	7.32
	Public Relations	5.32	Worker Condition	7.90
	Worker Condition	5.19	Driver Condition	8.76
	Productivity	5.11	Lighting	9.12
	Scheduling	5.07	Public Relations	9.42
	Driver Condition	5.04	Construction Cost	10.16
	Construction Cost	4.94	Scheduling	10.23
	Accident Cost	4.92	Accident Cost	11.13
3	Availability of Material/Equipment Repair	4.70	Noise	11.74
	Communication Supervision	4.64	User Cost	11.91
	Noise	4.57	Maintenance Cost	12.16
	User Cost	4.52	Availability of Material/Equipment Repair	12.20
	Maintenance Cost	4.46	Communication Supervision	12.61
4	Air Quality	3.27	Air Quality	15.24
	Fuel Consumption	2.89	Fuel Consumption	16.43

Source: (*2*).

Studies indicate that congestion and safety are the most important factors for nighttime construction decision making. However, other factors are also relevant. From a theoretical perspective, this decision-making activity is an application of multicriteria decision making (MCDM), often also termed as multicriteria decision analysis or multivariate decision analysis. The field of MCDM deals with creating a means for translating qualitative attributes into a framework that can enable choosing between various alternatives in a scientific manner. The advantage of MCDM is its ability to account for a wide range of different, but relevant criteria or objectives. Even if these criteria cannot be expressed in monetary or quantitative terms, comparisons can still be based on relative priorities or other assessments (*68*). Commonly used MCDM include the analytical hierarchy process, multi-attribute utility theory, and the outranking method (*69*). While there are several examples of general transportation decision-making frameworks and processes that are used for a range of applications, from transportation planning to operations, this section discusses decision-making approaches and frameworks specifically developed in the nighttime construction area.

As early as 1986, Shepard and Cottrell discussed the advantages and disadvantages of night work, and provided a step-by-step algorithm to determine the feasibility of nighttime construction (*21*). Elrahman and Perry also proposed a similar step-wise approach to the assessment of nighttime construction (*70*).

Hancher and Taylor developed a questionnaire-based form and scoring system for the Kentucky Transportation Cabinet to use in identifying projects that are good candidates for nighttime construction (*8*). Rebholz et al. developed a decision-making tool (EVALUNITE) for the Illinois DOT, which included a cost module (taking into account user delay costs and construction costs) and an effectiveness module that took into account construction-related factors, safety-related factors, and social and environmental issues (*13*). Al-Kaisy and Nassar also presented an application example of the same tool in 2009 (*71*). Similarly, a 2003 study by Douglas and Park in Oregon also developed a decision-making model for nighttime construction, based on a theoretical model that aggregated the weighted values of various factors (*4*). This model considered safety, quality of construction, public relations, worker conditions, productivity, scheduling, and congestion. The data input included a series of questions used to elicit responses to generate scores for various criteria. Bryden provided an assessment procedure that can be used to evaluate nighttime construction against other alternative plans (*28*).

As the literature illustrates, the decision to undertake nighttime construction should account for a range of factors, including congestion, safety, cost, worker conditions, and environmental impacts. Researchers anticipate that any MCDM process developed as part of this research project will incorporate these factors, with performance measures developed to quantify them. The critical difference between the model developed in this research and the examples discussed in this section is the emphasis on the emissions and air quality impacts when comparing nighttime and daytime construction activities.

SUMMARY

This chapter summarized the state-of-the-practice; provided background information on key subjects including current nighttime construction practices, advantages and disadvantages, measurement and modeling issues, existing studies, data, performance measures, and decision-making frameworks; and serves as the foundation for the remainder of this report.

CHAPTER 3. CASE STUDY APPROACH

INTRODUCTION

Tasks 3–5 of this research project employed a case-study-based approach to characterize the air quality impact of nighttime construction. This chapter briefly discusses the initial process of identifying candidate case study sites during the development of the study protocol. As the research project progressed, researchers found the assessment of traffic emissions impacts, construction emissions impacts, and understanding of dispersion/local air quality impacts each required unique approaches to compare nighttime versus daytime scenarios. Due to this, it was not feasible to employ the same case study sites for all the analyses conducted. The individual case studies for each analytical component are discussed in detail in following chapters.

SELECTION CRITERIA

For the purposes of this research, a case study is defined as a simulated or observed construction work zone that affects traffic flow, is eligible for nighttime construction, and occurs in a nonattainment, attainment maintenance, or near-nonattainment county in Texas.

The evaluation criteria, broadly listed in order of importance, provided the research team with a set of considerations for the selection of case studies:

- **Nighttime Construction That Could Be Performed during Daytime Hours—**The primary goal of this study was to develop a tool that helps distinguish between the emissions produced for a similar construction activity during the daytime versus nighttime. Hence, it is critically important that the selected location have nighttime construction activity. Additional value would be gained if the same nighttime activity was also performed during the daytime for comparison.
- **Congested Conditions—**It is necessary to calibrate traffic simulation models for both uncongested and congested conditions. At least some time period during both day and night, traffic demand should exceed the available capacity (V/C>1).
- **Cooperation from Area Office and Contractor—**Support and cooperation of the area office is *key* to the success of the case studies. The area office was used to help identify and reinforce support for the research effort. Support at the project office encouraged better participation by the prime general contractor and the subcontractors. Contractors were asked to provide equipment inventory and usage information to the research team in lieu of the research team directly collecting this information from the contractor equipment.
- **Work Zone and Traffic Data Availability—**The change in vehicle emissions due to night versus day construction activity was assessed using simulation models that were calibrated using real-world data observed at the case study sites. The data required for model calibration included traffic demand and throughput, travel time or delay, queue

length, vehicle compositions (classifications), work zone configurations, and speed limits. Availability of sensors/detectors to measure traffic volumes, vehicle speeds, travel times, and queue lengths were desirable. If these sensors were not available, TTI staff performed field data collection and observations to gather some of these data.

- **Proximity to Air Quality Monitors—**Identifying case study sites in close proximity to near-road monitors helped in the comparison of the magnitude and dispersion pattern of pollutants between daytime and nighttime periods. Near-road monitors served as a time-saving alternative to air dispersion modeling, but were not a critical requirement. Project types, such as construction versus maintenance and large versus small, were helpful in understanding the period of data collection and selection of diverse projects for the case study. Large construction projects provided researchers with a larger window of data collection, given the amount of coordination required with contractors and the area engineer, in addition to mobilizing internal resources and equipment for data collection.
- **Project Scope—**Project scope is critical to understanding the construction activities during the daytime and nighttime. Based on the interviews, typical projects with nighttime construction have scope such as roadway resurfacing, installation or upgradation of a safety barrier, construction of a direct connection ramp, new lane construction, bridge repair to construct an overpass/underpass, and road widening. The project scope also assisted in selecting a diverse set of projects for the case studies.
- **Area Type—**Projects in rural locations have a different traffic volume and composition than projects in the urban areas. Researchers anticipated the location of the project would provide different estimates of emissions for the same construction activities during daytime and nighttime.
- **Roadway Classification—**The interstate road has a different traffic volume, traffic speeds, and composition than a state highway or business road. Similar to the project location, roadway classification also results in different emissions estimates for daytime and nighttime construction activities. This classification assisted in selecting diverse projects for the case study.

IDENTIFICATION OF POTENTIAL LOCATIONS

The research team sought the input from TxDOT urban district area engineers to identify candidate case study locations. TTI staff contacted area engineers to identify the projects that have nighttime construction (or expected to have nighttime construction) between August 2015 and December 2015. The researchers used this information shortlist potential case study candidates from the complete list of projects collected (see Appendix C). These projects mostly meet the criteria set by the researchers for the project. Current road construction projects along a 100-mi section of the I-35 corridor in Central Texas (see Figure 10) met many of these criteria and data requirements. For this particular corridor, TTI researchers had access to a work zone database with detailed data (excluding construction equipment inventory and activity data) for all nighttime and daytime construction and maintenance projects performed over the past three years. The traffic data set has a high-resolution of traffic data, vehicle classification data, travel time data, and speed data. The richness of the traffic data and lane closure data sets made this corridor an attractive candidate for a case study.

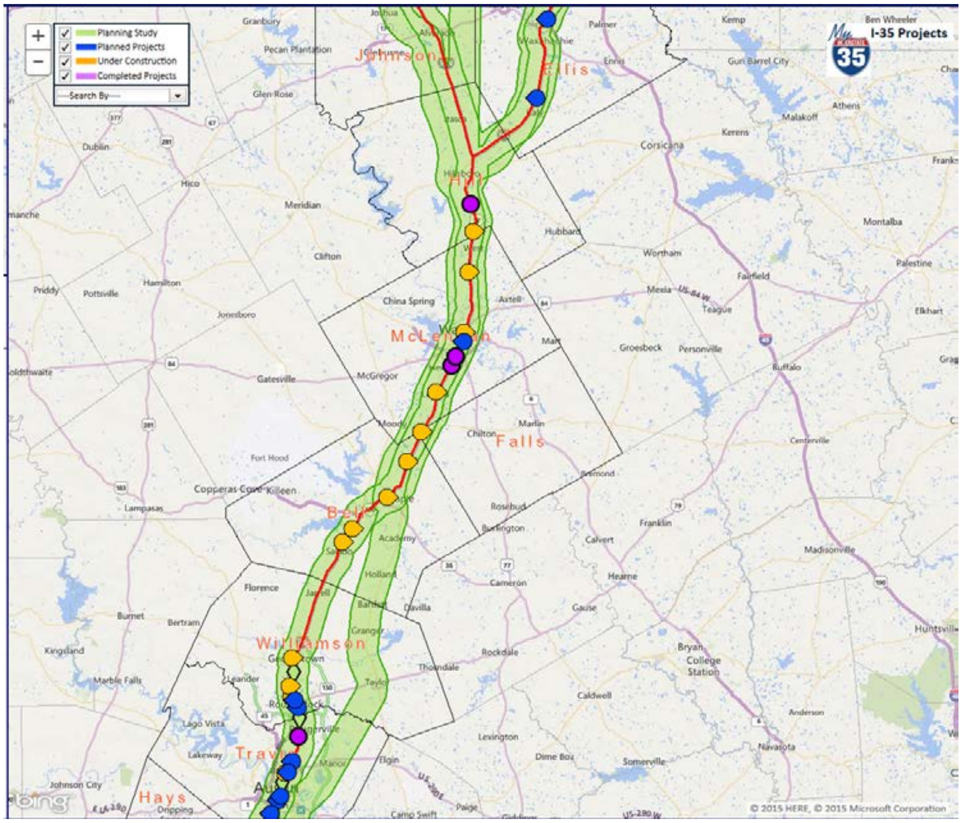


Figure 10. Multiple Construction Projects on I-35 Corridor Central Texas.

SUMMARY

The selection of case studies took into account different factors. The case studies for characterizing emissions differences in daytime and nighttime construction from construction equipment (Task 3), traffic (Task 4), and potential impact of meteorological conditions on dispersion (Task 5) each employed different case study locations and approaches suited to the needs and data of individual tasks. The following chapters cover each task in further detail.

CHAPTER 4. CHARACTERIZING EMISSIONS DIFFERENCES FROM CONSTRUCTION ACTIVITIES

INTRODUCTION

Work in this task developed an analytical methodology to estimate the changes in emissions from construction-related activities at nighttime work zones compared to daytime construction, and demonstrate its applicability through case studies.

There are limited studies providing information on emissions differences from construction activities performed at night versus daytime, with most studies qualitatively attributing emissions reductions to improvements in traffic flow. However, some literature mentioned concerns with the impacts of nighttime work on productivity and efficiency of construction activity. The research team examined studies that explicitly outlined the quality and/or productivity of nighttime construction work. The findings of these studies strongly suggest that, in general, nighttime construction does not result in reduced productivity and quality. This chapter developed and applied a methodology to estimate differences in emissions attributable to construction emissions due to daytime and nighttime construction.

METHODOLOGY

This section outlines the methodology the research team used to collect field data and estimate the differences in construction-related emissions between daytime and nighttime construction. Figure 11 illustrates the conceptual overview approach used for this task. This approach consists of four major elements:

1. Conduct field study and data collection.
2. Identify and characterize activity changes (i.e., construction activity) between daytime and nighttime.
3. Estimate emissions factors for relevant construction equipment types.
4. Estimate overall emissions changes between nighttime and daytime construction.

The following sections describe the specific methodologies and efforts for these items.

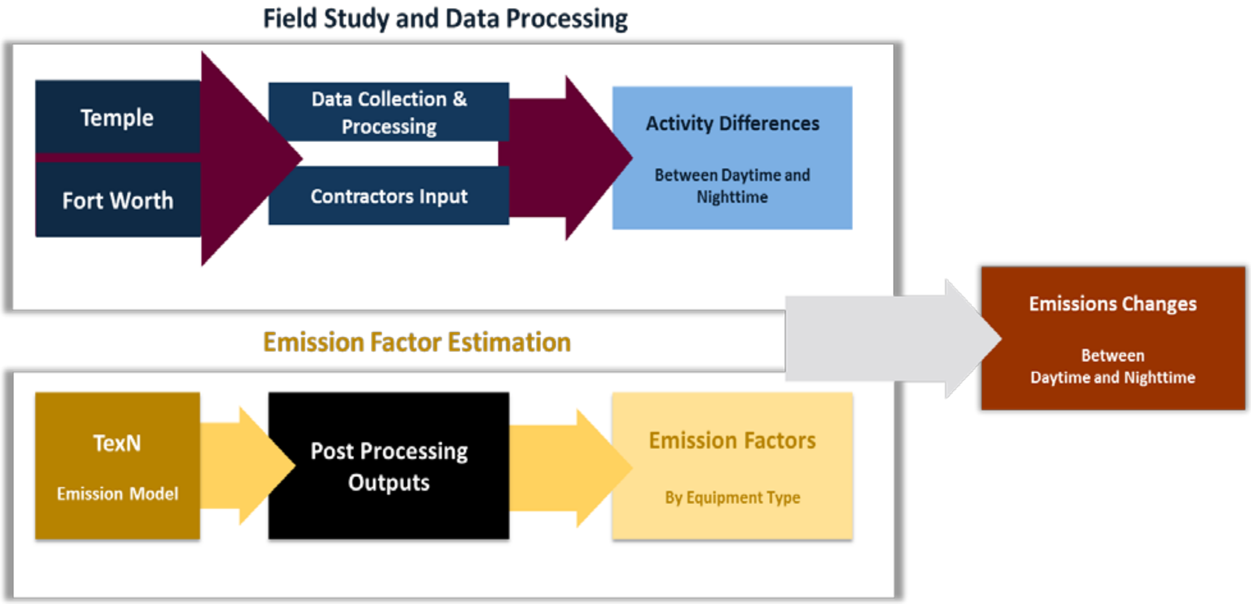


Figure 11. Conceptual Methodology for Characterizing Construction-Related Emissions Differences between Nighttime and Daytime.

FIELD STUDY AND DATA COLLECTION

Since the primary goal is to compare differences in the emissions produced for a similar construction activity during the daytime versus nighttime, the research team examined the possibility of collecting data for the same task when performed during both daytime and nighttime. However, it is very rare to have the same activity performed at the same location during both daytime and nighttime, and the final data collection and analysis approach accounted for this fact. The approach is based on collecting the necessary observations using a combination of data collection from nighttime construction activities and input from the construction contractors performing those activities. The initial data collection was planned for case study sites identified in Chapter 3, but changes to the construction work schedule and other factors contributed to the inability to collect data as originally envisioned.

The data collection was then conducted at other construction sites between March 2016 and August 2016, with the cooperation of TxDOT’s Environmental Affairs Division (ENV). TTI staff prepared a data collection form for recording the equipment activity during nighttime construction. This form was shared by the general contractor and their subcontractors and included the following fields: date, project, contractor equipment ID, equipment type, engine model year, engine horsepower (hp), engine/fuel type, and engine hours of use start/end by day and night period. In addition, there was a field to indicate if the equipment for the specific activity could have been used in daytime hours if the activity was performed in daytime. Appendix D provides the data collection forms used for recording the equipment activity information.

Figure 12 and Figure 13 show the locations of the data collection efforts in Fort Worth and Temple. Both locations offered activities as part of major reconstruction projects on limited-access freeways. The Fort Worth project consisted of grading a subbase, bridge painting, placement of precast structural concrete, and placement of crushed stone. The Temple project primarily consisted of pouring and placement of concrete for a roadway. Both projects were observed for a single night, with the Fort Worth observation occurring during June 2016 and Temple occurring during August 2016.

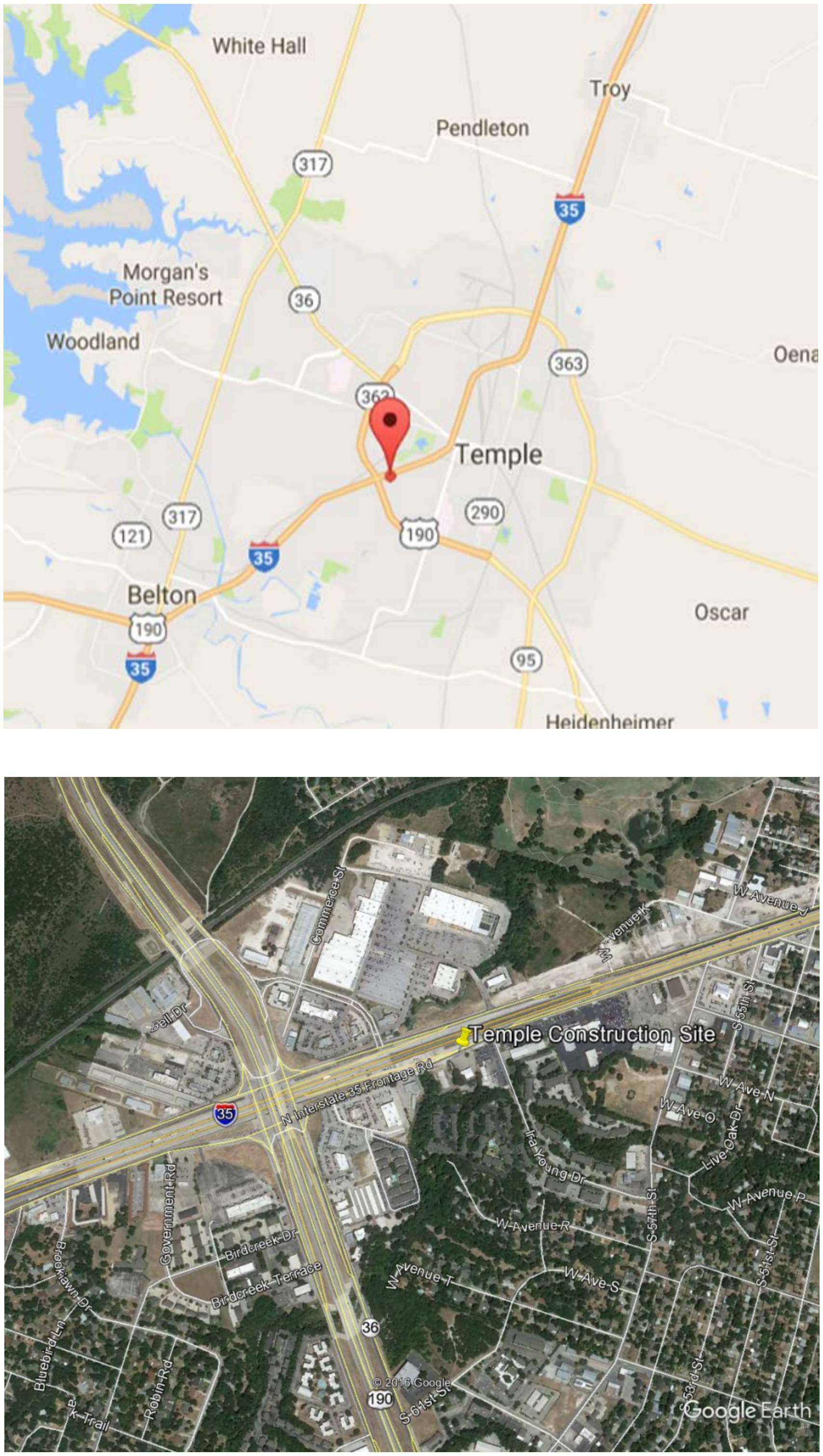


Figure 12. Map Showing Temple Construction Site.

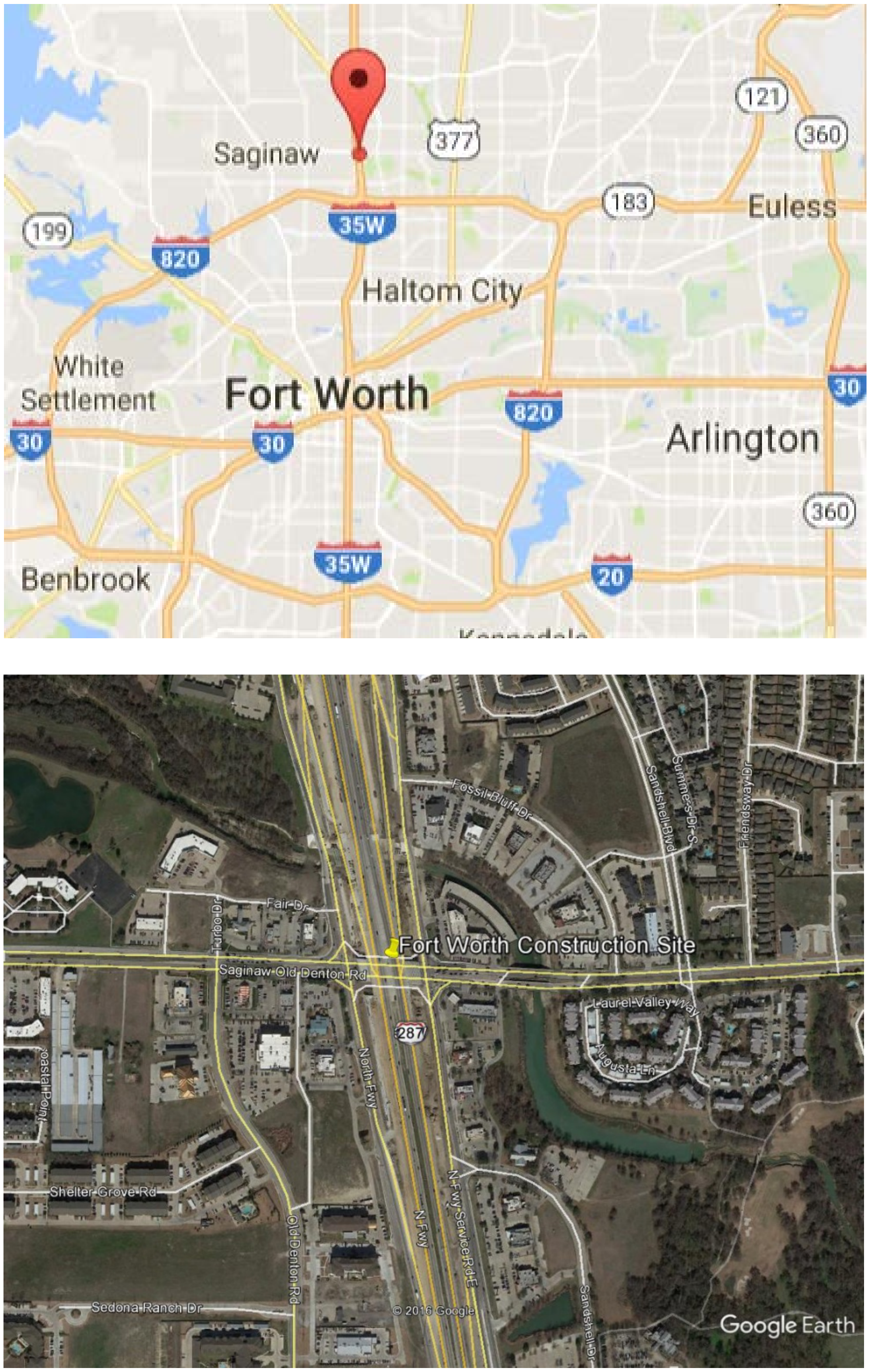


Figure 13. Map Showing Fort Worth Construction Site.

On the day before the observation, the research team arrived at the construction site during the later afternoon hours, usually between 4 p.m. and 6 p.m. The research team met with a representative from the on-site contractor and took a tour of where construction activity was likely to occur during that evening. Figure 14 and Figure 15 show examples of the types of activities from the Fort Worth location, and Figure 16 and Figure 17 show examples from Temple.

Figure 14. Placement of Precast Concrete for Mechanically Stabilized Earth Wall in Fort Worth.

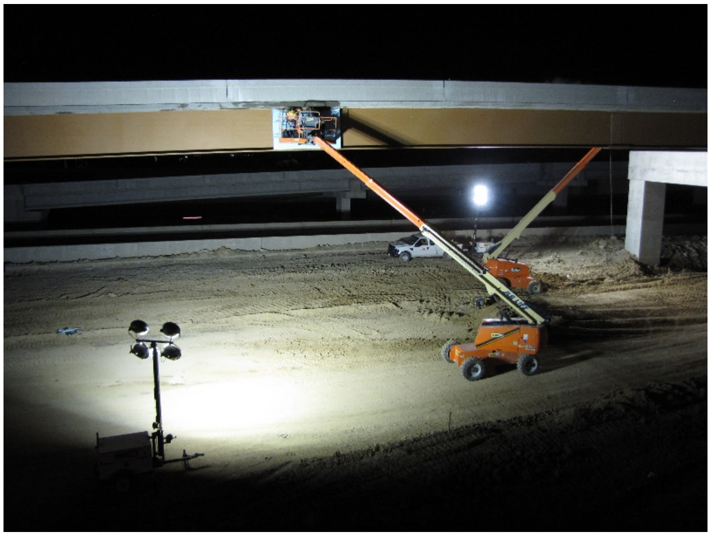


Figure 15. Workers on Hydraulic Lift in Fort Worth.

Figure 16. Workers on Setting Forms for Concrete Pour in Temple.

Figure 17. Concrete Slip Paver in Temple.

When nighttime construction work began, the research team drove across the construction site looking for vehicles and heavy equipment likely to be used that night. The earlier meeting with the contractor's representative helped to identify the location, number, and types and equipment slated for use that night. At the beginning of the night, researchers worked with contractors to record the vehicle make/model, equipment type, vehicle identification number (VIN), and the mileage. Engine hour readings were recorded for heavy-duty equipment. The data collection team also took pictures of all active vehicles and equipment on each construction site.

Near daybreak, the research team took another recording of the mileage or engine hour reading. The second reading allowed the research team to calculate either the number of hours or miles of activity for each night of observation. Field notes were recorded for vehicles with significant idling during the overnight period to mark instances when an odometer reading would not appropriately measure engine activity. For each study site, the research team asked the contractor to provide a reasonable estimate of the change in operational time if any, if the same work were to be performed during the day. The contractor responses were that the change in operational time is subjective and it depends on the activity such as pouring concrete, demolition, or earthwork. The contractors confirmed that overall the change in the operational time is negligible if the same work were to be performed during the day.

In a follow-up conversation with the contractor working at the Temple location, the contractor choose to work overnight because of cooler temperatures specifically during the summer months. Cooler temperatures improve the proper concrete placement. The contractor also will change the schedule from overnight construction to daytime in the fall when temperatures are cooler. The research team followed up with other contractors and they provided additional reasons for choosing to work overnight, including less impact on the traffic flow as the result of lane closure.

IDENTIFYING ACTIVITY CHANGES BETWEEN DAYTIME AND NIGHTTIME

Researchers processed and analyzed the information collected in the previous step to identify the activity changes between nighttime and daytime. Researchers grouped the equipment activity records by equipment type based on the on-road and non-road operations. On-road vehicle operations such as travel to and from construction site hauling materials, or equipment, were not included in this analysis as the VMT of these trips do not change between daytime and nighttime. Although the operational speeds of these vehicles may vary from daytime to nighttime, the emissions impacts may be minimal with nighttime being the favorable condition. Furthermore, the on-road operation is captured as the larger traffic impact (discussed in the next chapter). The research team evaluated and analyzed the following two construction activity information items from the two sites:

- Non-road/construction equipment usage.
- Truck idling.

The following describes the procedure and assumptions researchers used to estimate the necessary activity changes needed for emissions estimation.

Construction Equipment Usage

The research team combined the additional information from contractors and the literature with the field observation to develop a method of capturing the emissions differences between nighttime and daytime construction activities. The research team asked the contractors at the case study sites to provide a list of the equipment they would use for each of the construction activities during daytime and nighttime construction. Table 14 summarizes this information.

Based on the information from Table 14, literature, and feedback from the contractors, the research team concluded that it is safe to assume there is no difference in quality and productivity of construction work between daytime and nighttime, and the use of light plants is the single most important differentiator between daytime and nighttime construction.

Table 14. Construction Equipment Employed Night and Day.

Equipment Type	Construction Timing	
	Night	Day
Aerial Lift	√	√
Dump Truck	√	√
Excavator	√	√
Fork Lift	√	√
Freight Truck	√	√
Front Loader	√	√
Light Plant	√	X
Pickup Truck	√	√
Rear Loader	√	√
Roller	√	√
Sweeper	√	√
Track Loader	√	√
Water Truck	√	√
Wheel Loader	√	√

Adequate lighting is one of the most important factors affecting safety, quality, productivity, and cost of nighttime construction and to ensure safety of workers and travelers. The conversation with the contractors and the collected data from the construction sites indicate that the majority of lighting systems used on construction sites are diesel-powered and designed to enable the simultaneous optimization of four major objectives:

- Maximize average illuminance.
- Maximize lighting uniformity.
- Minimize glare.
- Minimize lighting costs.

The optimal number of lighting equipment or light plants used during nighttime construction projects depends on the project length and the type of construction activities performed at night (*72*). The research team observed that 6–8 light plants were in use at the Fort Worth case study site, of which only two light plants were used for active construction; other light plants were used for traffic signage and overall illumination of construction site to assist in delivery of materials. The light plants used at the two case study sites were diesel-powered systems made by

Multiquip (Model Multiquip LT12) and Magnum. Figure 18 shows one of the light plants at the Temple case study site.

Figure 18. Light Plant (Magnum) Used at the Temple Construction Site.

Truck Idling

Potential change in engine idle time for medium-duty and heavy-duty diesel trucks that haul material and equipment to and away from the construction site can cause differences in emissions between nighttime and daytime construction. The research team also included the truck idling activity in the information collection effort from the case study sites.

Medium-duty and heavy-duty trucks are extensively used in the construction activities. These trucks include dump trucks, water trucks, concrete trucks, utility trucks, and small pickup trucks. Figure 19 shows a dump truck delivering material to the construction site. During the data collection effort, researchers specifically asked the contractors about any potential differences in trucks activities between daytime and nighttime. The feedback from the contractors indicated that there may be increases in raw material and equipment delivery time as a result of traffic conditions during daytime when compared to nighttime. On the other hand, during nighttime, when lighting is not optimal and there is poor communication among the working crew, higher than normal truck idling durations might happen during drop off and pick up of material and equipment.

The idling duration whether day or night varies from site to site, and the idling duration difference between day and night may be negligible when averaged with overall construction in the region. The research team evaluated all the information from the case study sites and contractors to determine how significant this activity is in characterizing the emissions differences between daytime and nighttime construction. Researchers concluded that differences in truck idling and operations did not need to be taken into account, due to the following reasons:

- Increased idling in traffic and higher travel times during daytime as the result of traffic congestion is accounted for as part of the traffic emissions impact, discussed in the next chapter.
- Good coordination among construction crew members and existence of proper illumination at drop-off and pick-up points are the norm for experienced contractors. It is safe to assume that any differences in regional average truck idling durations between daytime and nighttime are marginal. Therefore, this activity is not included in the assessment of differences between nighttime and daytime construction emissions.

Figure 19. Dump Truck Unloading Crushed Stones during the Nighttime.

ESTIMATION OF EMISSION FACTORS FOR CONSTRUCTION EQUIPMENT

Two main parameters are required for estimating total emissions for non-road equipment—the activity (in terms of hours of vehicle/equipment operation per day or per year) and population (number of equipment pieces of a certain type). The research team developed a methodology to estimate construction-related emissions differences between daytime and nighttime. As described previously, the research team concluded that the major differences between nighttime and daytime construction activities are the light plants. Therefore, the developed methodology considers only the lighting equipment and uses the TexN model to capture the Texas-specific input parameters to generate a statewide average emission factor. The TexN model contains the Texas-specific usage patterns and population information of non-road equipment belonging to the relevant categories including generators/lighting equipment. The model also contains other local data such as meteorology, fuel supply, and control programs.

The developed methodology for estimating changes in construction-related emissions between daytime and nighttime involves generating representative EFs using the TexN model and then combining it with the difference in equipment activity between daytime and nighttime operations.

Figure 20 illustrates the conceptual design of generating the EFs. Appendix E provides further details of the process, by which a population-mix normalized composite emissions factors were developed for the light plants, as shown in Table 15.

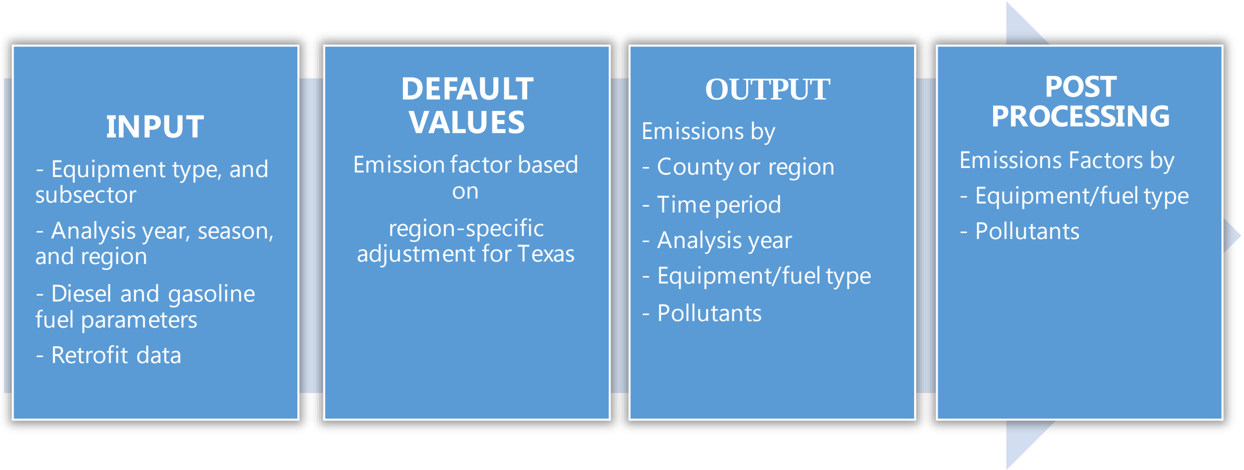


Figure 20. Emissions Factors Estimation for Construction Equipment.

Table 15. Population-Mix Normalized Composite Emissions Factor Estimation for Light Plant Equipment.

Pollutant	EF (g/hr)
NO_x	20.80
VOC	3.28
PM_{10}	2.21
CO	16.38

ESTIMATION OF EMISSION CHANGES FROM NIGHT VERSUS DAYTIME ACTIVITIES

As described in a previous section, the research team concluded that the main changes in the equipment or construction activity between daytime and nighttime construction operations are light plants used for illumination during the nighttime operation. From the data collected at the two case study sites with corroboration from conversation with contractors, researchers concluded that:

- On average 6 to 8 diesel-powered light plants[2] are used at each construction site during the nighttime construction activities.
- These light plants are used for an average of 10 to 11 hours per night.

To avoid overestimating the benefits of the nighttime construction, the research team chose 11 hours of operation per day to estimate the emissions of lighting equipment operating during nighttime. Table 16 summarizes the final results in the form of total emissions results for the light plants. Assuming the use of 6 to 8 per night, a daily emissions increase of 0.48 to 0.64 lb for VOC, 3.03 to 4.04 lb for NO_x, 0.32 to 0.43 lb for PM_{10}, and 2.38 to 3.18 lb for CO from construction activities at nighttime would occur.

Table 16. Statewide Applicable Average Emission Changes from Shifting Daytime Construction Activity to Nighttime.

No. of Light Plants	NO_x (lb/day)	VOC (lb/day)	PM_{10} (lb/day)	CO (lb/day)
1	0.50	0.08	0.05	0.40
2	1.01	0.16	0.11	0.79
3	1.51	0.24	0.16	1.19
4	2.02	0.32	0.21	1.59
5	2.52	0.40	0.27	1.99
6	3.03	0.48	0.32	2.38
7	3.53	0.56	0.37	2.78
8	4.04	0.64	0.43	3.18
9	4.54	0.72	0.48	3.58
10	5.04	0.80	0.54	3.97

SUMMARY

This task developed and applied a methodology for assessing the construction-related emissions impact of shifting daytime construction activities to nighttime. The research team collected activity data from two nighttime construction sites in Texas and obtained further information on the usage of construction equipment from the contractors. After careful evaluation of all the information, researchers concluded that the use of lighting equipment during nighttime construction is the single major difference between nighttime and daytime constructions.

The research team developed a methodology to estimate the emissions changes as a result of using the lighting equipment during nighttime construction operations. The methodology uses the TexN model developed by TCEQ to generate emissions factors for representative counties in

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[2] Number of light plants vary by the construction activity and the project length.

Texas. The field observations and inputs from the contractors indicated an average of 6–8 light plants operating for 10–11 hours per night at each nighttime construction site. Researchers developed a simplified lookup table showing the estimated total emissions from the operation of light plants.

Researchers acknowledge the limitations of the results as they were based on limited site observations. However, a review of the literature shows the conclusions and findings of this task, for the construction activity differences between daytime and nighttime construction, are consistent with other studies.

CHAPTER 5. ESTIMATING EMISSIONS FROM TRAFFIC ACTIVITIES

INTRODUCTION

This chapter discusses the methods used to develop an analytical methodology to estimate the changes in the traffic operation and emissions of vehicles at nighttime versus daytime work zones. This methodology was developed and tested using three case study work zones. For each case study, different lane closure scenarios were simulated (i.e., lane closures during daytime versus nighttime). The analytical methods were designed to develop quantitative metrics of traffic activity and emissions associated with nighttime and daytime lane closures for each case study.

METHODOLOGY

A modeling approach combining microscopic traffic simulation with an enhanced emissions estimation model was developed and applied to estimate the mobility and vehicle emissions impacts of traffic at three work zone locations in Texas. The flowchart in Figure 21 summarizes the modeling steps.

A simulation test bed was developed for each case study. The test bed replicated roadway and work zone geometry, posted speed, and other relevant traffic control (e.g., signal timing on the arterial) at each study site. Each test bed covered the entire work zone plus upstream roadway segments long enough to capture queue propagation during both nighttime and daytime conditions. Model parameters were calibrated using a data set available from previous field studies conducted on the I-35 Central Texas corridor. The calibration process involved fine-tuning driver behavior parameters that describe car-following and lane-changing maneuvers. Calibration was objectively guided by a process that minimized the difference between measured and model-predicted values of throughput, travel times, and queues.

The calibrated simulation test beds were then used to model daytime and nighttime work zone lane closure scenarios using traffic volumes and truck percentages representative of the case study sites.

Simulation results were post-processed to extract data for common mobility performance measures (e.g., travel times, delays, and queue lengths), and detailed vehicle trajectory and link-based data that provided inputs to an emissions analysis.

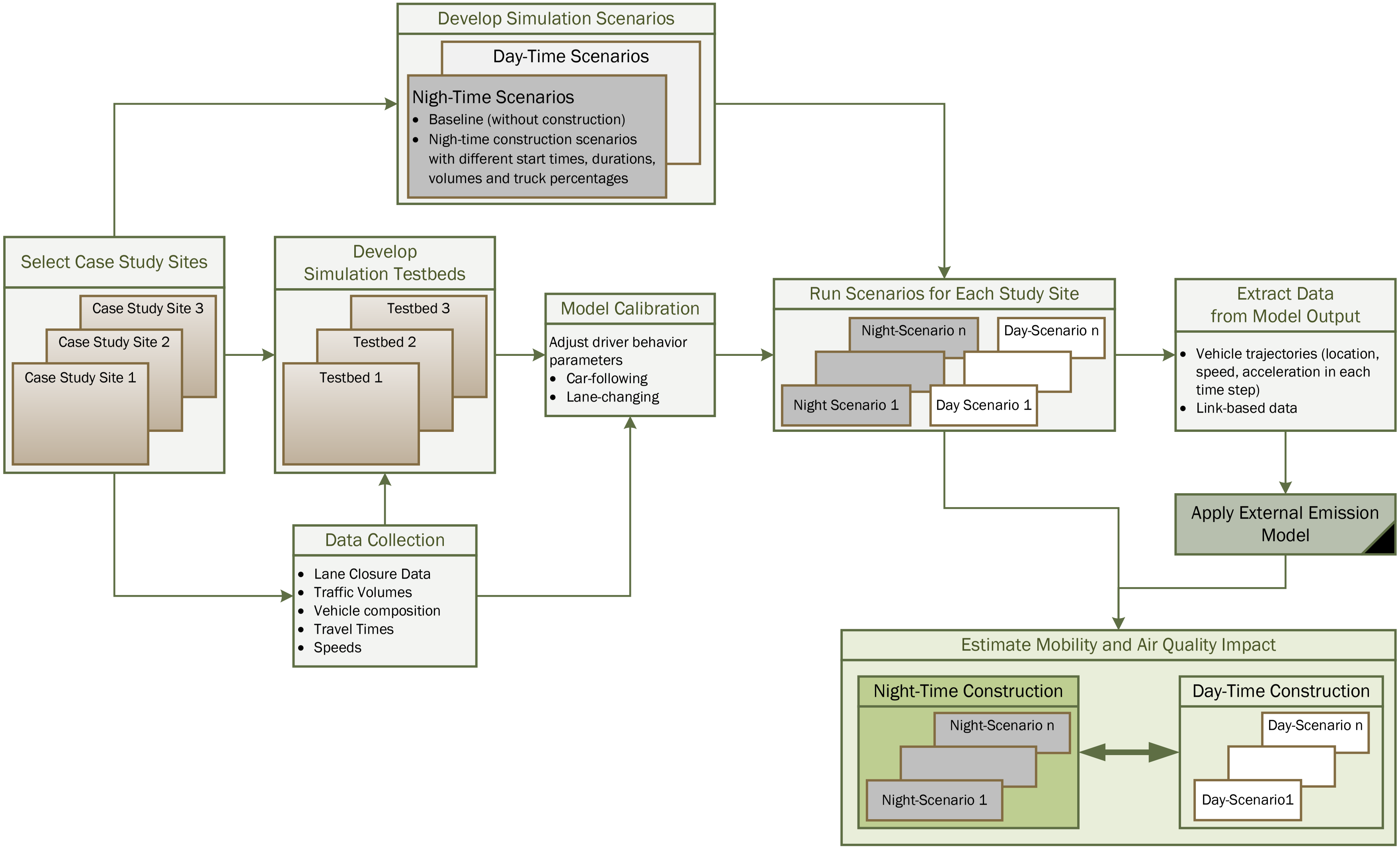


Figure 21. Modeling Activity to Assess the Mobility and Air Quality Impacts of Nighttime and Daytime Work Zones.

CASE STUDY SITES

Three case study sites were selected to include three different types of roadways: urban and suburban freeway segments and an arterial corridor. The case study sites were also selected to encompass different traffic volumes, vehicle compositions, lane configurations, posted speeds, and traffic control. The site selection criteria also included the availability of reliable data required for model calibration and for the simulation of various daytime and nighttime lane closure starting-time scenarios. The following sections describe each case study site.

Case Study 1: Freeway Work Zone on I-35 near Waco, Texas

Case Study 1 is an approximately 15-mi freeway segment in Waco. It is located on the Central Texas corridor of I-35 in between Salado and Hillsboro (see Figure 22). Figure 23 shows the expected time periods for lane closures, and Figure 24 shows the locations of volume sensors and Bluetooth readers. In 2010, TxDOT began a $2 billion reconstruction project at the site. The 96-mi corridor carries more than 100,000 vehicles per day and more than 30 million vehicle trips per year, and it is expected to carry an estimated total of more than 250 million vehicle trips over the eight-year period of 2010–2018. Two-thirds of vehicles travel to final destinations outside the corridor to the north or south. When complete, this section of I-35 between Hillsboro and Salado will be expanded from four lanes to six lanes in rural areas and to eight lanes in urban areas, with continuous one-way frontage roads.

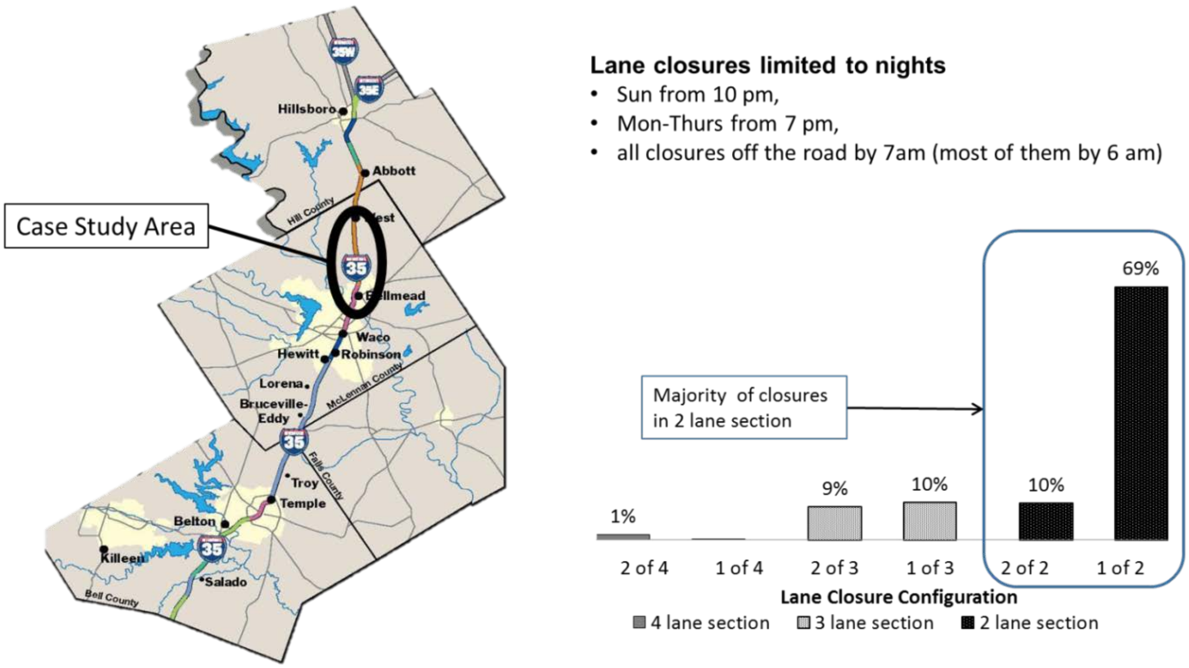


Figure 22. Case Study Site on I-35.

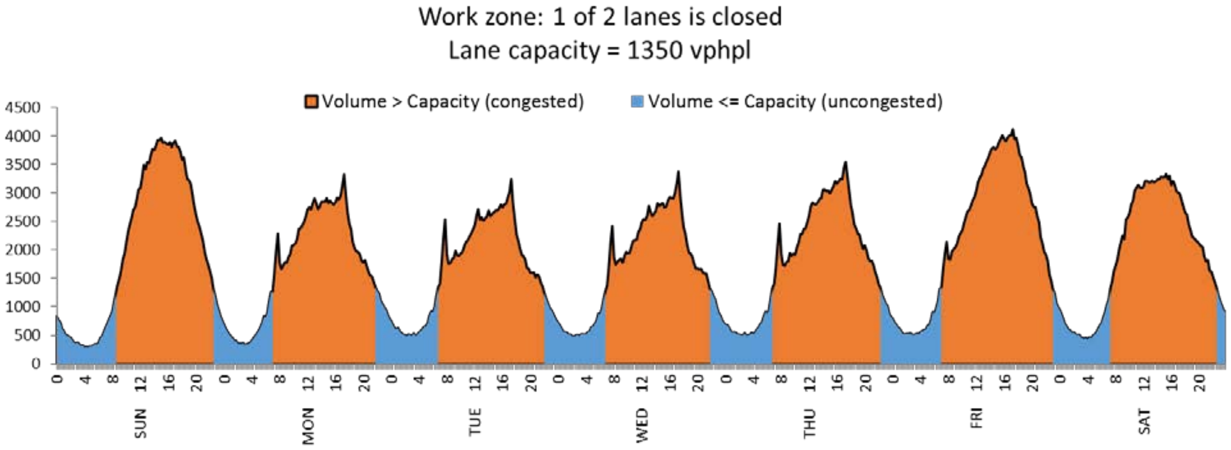
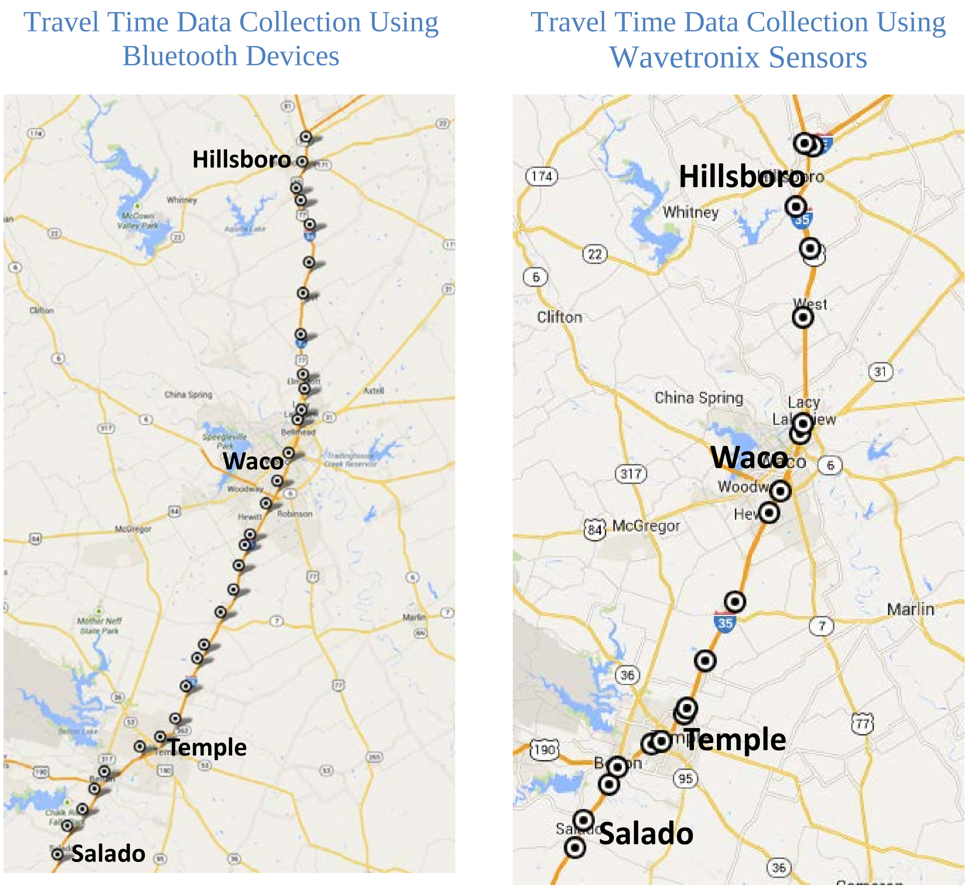


Figure 23. Time Periods of Expected Congestion at the I-35 Case Study Site.


Travel Time Data Collection Using Bluetooth Devices

Travel Time Data Collection Using Wavetronix Sensors

Figure 24. Volume Sensor and Bluetooth Reader Locations.

Case Study 2: Freeway and Arterial Work Zone in El Paso, Texas

The second case study site is located on the central-west side portion of the border region where I-10 and W. Paisano Drive experience heavy traffic congestion during peak hours due to the proximity of a college campus, the central business district, and shopping centers.

The segment of I-10 considered for this study has three lanes in each direction and no frontage road or direct connectivity to other alternative routes such as N. Mesa Drive or W. Paisano Drive. The site is currently undergoing construction to build collector-distributor lanes and frontage roads (i.e., 5.94 mi total) between N. Mesa Drive and Executive Center Boulevard to improve traffic flow on I-10. The expected completion date for the project is 2019.

Case Study 3: Arterial Work Zone in El Paso, Texas

The W. Paisano Drive segment evaluated in this study is parallel to I-10 (Figure 25) and consists of two lanes per direction. An ongoing project called Border Highway West Extension is being undertaken at this site to provide additional capacity and connectivity to the university and downtown. A proposed 7-mi tolled lane facility will run parallel to W. Paisano Drive to provide other alternatives to daily commuters.

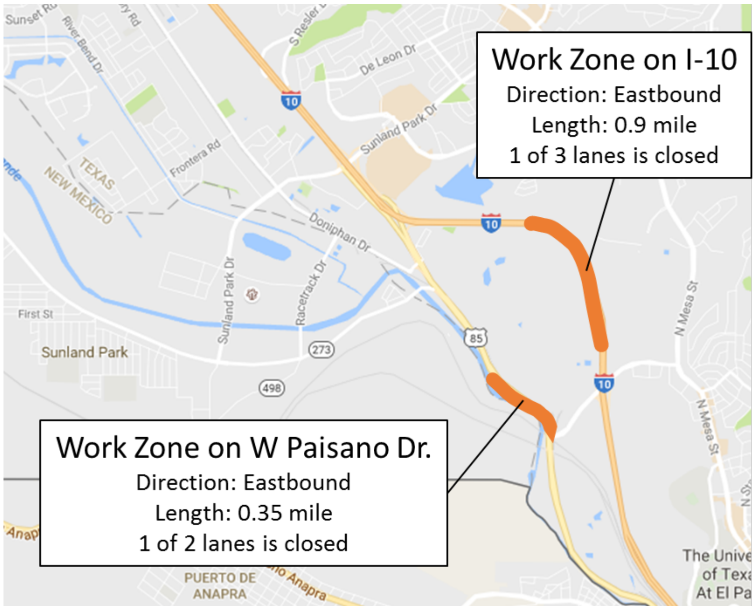


Figure 25. Case Study Sites in El Paso.

MICROSCOPIC TRAFFIC SIMULATION

A simulation test bed was set up for each of the case study sites in VISSIM. A simulation test bed is a model representation of a selected roadway system in which network elements (e.g., links that define roadway geometry and lane configuration) and model parameters (e.g., driver behavior parameters) are fixed, while some model input (e.g., traffic volume, vehicle composition, desired speed distribution, and routing decisions) can be varied. The test bed development involved the following steps:

- Coding the network.
- Defining vehicle classes/types and their attributes, routing decisions, and traffic control.
- Specifying/configuring virtual data collection locations and model output for evaluation purposes.

For each of the three case studies (I-35, I-10, and W. Paisano Drive), daytime and nighttime work zone scenarios were simulated with appropriate lane close configurations and lane closure timings. In the case of the I-35 test bed, three different nighttime lane closure timings (i.e., three alternative scenarios) were assessed. The test bed development process, the simulation scenarios, and the simulation runs and results are discussed in further detail in Appendix F.

EMISSIONS MODELING

The results from the traffic simulation were used to calculate the emissions attributable to daytime and nighttime construction projects for each scenario of all three case study work zones. The objective of the emissions modeling was to use the traffic simulation outputs described in the previous section to estimate emissions of all vehicles passing through the case study construction zones during each daytime and nighttime scenario (defined as a case study scenario). The following pollutants were analyzed: total hydrocarbons (THC), CO, NO_x, CO_2, VOC, $PM_{2.5}$, and PM_{10}. The following is an overview of the emissions estimation process for each modeled case study scenario:

1. Second-by-second traffic data (from the microsimulation model) were converted to hourly VMT and hourly average speed for each link of the modeled work zone road network. Average hourly speeds and hourly VMT per link were calculated for cars and trucks (i.e., the two vehicle types used in the traffic simulations). Because each case study scenario was replicated 10 times, this process was repeated for each simulation to yield average hourly VMT and speeds for each link of each modeled case study scenario.
2. EPA's MOVES was used to generate speed and link type (i.e., arterial or interstate) specific emissions rates for all MOVES vehicle types. El Paso–specific emissions rates, representing winter conditions, were used for each case study to enable results to be compared irrespective of their location in Texas and to isolate the effects of traffic activities on total emissions.
3. The emissions rates for each of the 13 MOVES vehicle types (source types) were aggregated into composite emissions rates representing (a) all light-duty vehicles (i.e., passenger cars, passenger trucks, light commercial trucks); and (b) all heavy-duty vehicles (i.e., long- and short-haul combination trucks). The composite emissions rates were specific to speed and road type. Aggregate emissions rates were calculated using El Paso–specific fleet distributions.
4. The outputs from Steps 1 and 3 were used to calculate hourly total vehicle emissions for each simulated case study scenario. Total emissions for each case study scenario were calculated by summing the hourly emissions on each link of the modeled work zone.

Further details of the process are provided in Appendix G.

RESULTS

This section provides a description of the results for each of the case studies investigated in this task. The results are divided into two categories—traffic operation impacts and emissions impacts.

Case Study 1: I-35

Traffic Operation

Figure 26 and Figure 27 show vehicle speeds and percentage delays for the daytime and nighttime work zone scenarios on I-35. During daytime construction, vehicles experience up to 85 percent reduction in speeds and up to five times longer travel times than during free-flow conditions. During the early hours of nighttime construction, drivers still experience up to 50 percent speed reduction and about twice as long travel times than during free-flow conditions.

However, if work zone activity is initiated at 9 p.m. (21-7 scenario in the figure), vehicles travel at near-free-flow speeds and experience almost no delays during the entire nighttime construction period.

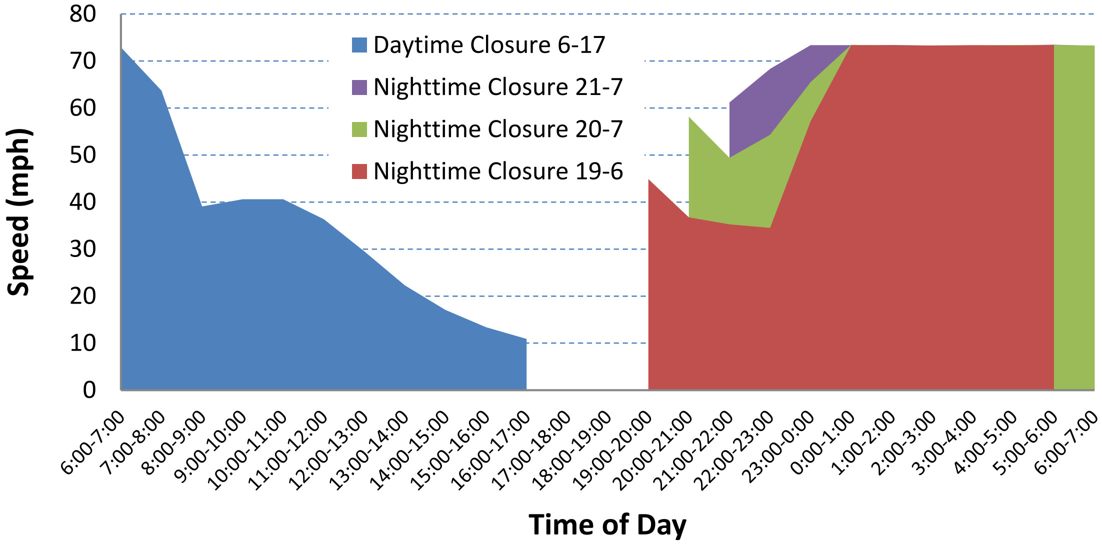


Figure 26. Vehicle Speeds—Nighttime vs. Daytime Work Zones on I-35.

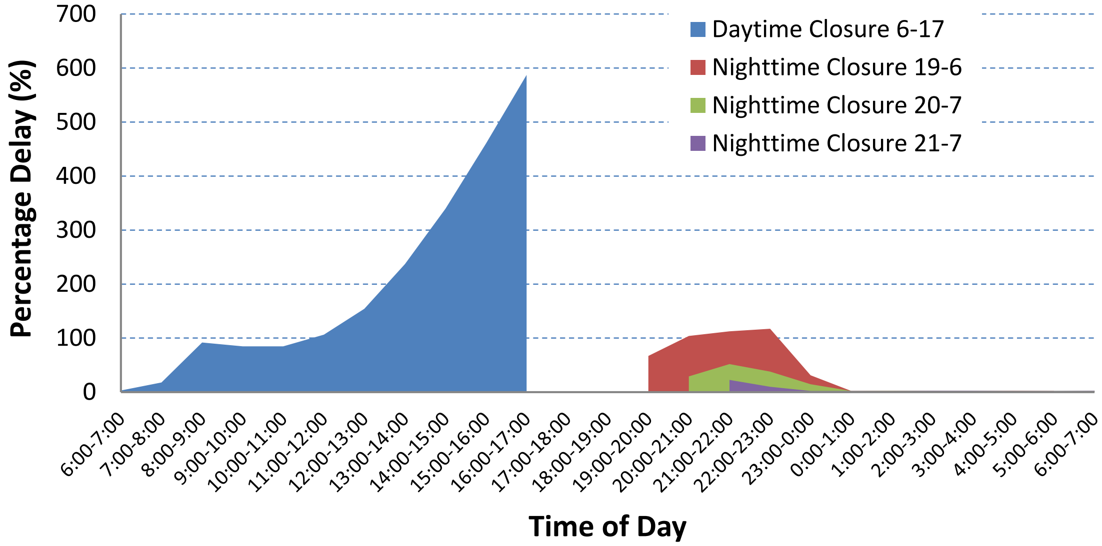


Figure 27. Percentage Delay—Nighttime vs. Daytime Work Zones on I-35.

Emissions Impacts

Table 17 shows the average speed, VMT, and total emissions generated by vehicular traffic estimated for daytime and nighttime construction scenarios. The table illustrates large differences between total daytime and nighttime vehicle emissions for all pollutants. However, care must be taken in interpreting these results as emissions impacts because nighttime VMT is also much lower than daytime VMT—and total VMT is the most significant driver of total emissions.

For this reason, the average emission rates per vehicle per mile (expressed in grams per VMT [g/VMT]) is a more reliable metric for understanding the impacts of nighttime versus daytime construction. For each pollutant, this metric represents the efficiency of an average vehicle traveling through a work zone for a specific scenario. For all pollutants, the average emissions rate per mile was significantly different for daytime versus nighttime scenarios. However, the direction of change in emissions rates (i.e., whether nighttime construction resulted in higher or lower rates relative to daytime construction) depended on the specific pollutant. For example, average emissions rates for gasoline-dominated pollutants THC, CO, and VOC all decreased under the nighttime scenarios, suggesting the possibility of a positive emissions impact. In contrast, average emissions rates for NO_x, PM_{10}, $PM_{2.5}$, and CO_2 increased for nighttime construction scenarios relative to daytime construction scenarios.

This complex emission response can be explained by the average speeds of the vehicles during daytime or nighttime construction, the mix of vehicles assumed for each scenario, and the speed-specific emissions rates for each pollutant (Table 17 and Table 18). Average vehicle speeds were slower during the daytime scenario compared to the nighttime scenarios. However, for diesel-dominated pollutants (i.e., NO_x, PM_{10}, $PM_{2.5}$, and CO_2), the reduction in speed during the daytime scenario resulted in reduced emissions rates because of reduced engine load at lower speeds.

Table 18 summarizes the percentage impact of nighttime versus daytime work zones and categorizes these impacts into those arising from light-duty vehicle (LDV) versus heavy-duty vehicle (HDV) activities. A more detailed breakdown of LDV- and HDV-specific total emissions and emissions rates can be found in Appendix H. In line with the results shown in Table 17, nighttime construction resulted in much lower total emissions when compared directly to daytime construction. However, these impacts were largely the result of significant reductions in VMT.

By categorizing total impacts into light-duty and heavy-duty sources, Table 17 illustrates that any assessment of emissions impacts must consider the mix (i.e., proportion of LDV and HDV) of vehicles using the corridor. For example, for NO_x, LDVs had a larger percent reduction in emissions rate between daytime and nighttime than HDVs (58 percent for LDVs versus 31 percent for HDVs). Because HDVs represent a larger proportion of nighttime traffic, and because of their intrinsically high emissions rates (relative to LDVs), the overall reduction in emission rate of 38 percent is close to the percentage reduction in HDV VMT. In contrast, CO’s overall reduction more closely follows changes in LDV parameters because CO is a gasoline-dominated pollutant.

Table 17. Total Vehicle Emissions for Daytime and Nighttime Work Zones on I-35.

			Speed (mph)	VMT	Emissions (kg)						
					THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
Daytime	6 AM–5 PM	Total		287,036	56.61	1,257.59	731.78	20.26	22.13	55.48	219,291.86
		Hourly Average	35.12	26,094	5.15	114.33	66.53	1.84	2.01	5.04	19,935.62
		Ave. Rate* (g/VMT)			0.20	4.38	2.55	0.07	0.08	0.19	763.99
Nighttime	7 PM–6 AM	Total		140,157	23.08	528.77	469.79	12.32	13.44	22.79	118,364.22
		Hourly Average	58.97	12,741	2.10	48.07	42.71	1.12	1.22	2.07	10,760.38
		Ave. Rate* (g/VMT)			0.16	3.77	3.35	0.09	0.10	0.16	844.51
	8 PM–7 AM	Total		130,415	18.79	483.97	420.81	10.69	11.66	18.52	105,992.10
		Hourly Average	67.36	11,856	1.71	44.00	38.26	0.97	1.06	1.68	9,635.65
		Ave. Rate* (g/VMT)			0.14	3.71	3.23	0.08	0.09	0.14	812.73
	9 PM–7 AM	Total		109,679	15.14	407.69	350.14	8.76	9.55	14.91	88,162.77
		Hourly Average	71.63	10,968	1.51	40.77	35.01	0.88	0.96	1.49	8,816.28
		Ave. Rate* (g/VMT)			0.14	3.72	3.19	0.08	0.09	0.14	803.83

* Average rate is the average emissions rate for the entire period.

Table 18. Reduction in Total Vehicle Emissions for Nighttime vs Daytime Construction on I-35.

		Percent Reduction								
		Travel Time	**VMT**	**THC**	**CO**	**NO$_x$**	**PM$_{2.5}$**	**PM$_{10}$**	**VOC**	**CO$_2$**
7 PM–6 AM	**Overall**	**40%**	**51%**	**59%**	**58%**	**36%**	**39%**	**39%**	**59%**	**46%**
	LDVs	40%	59%	66%	60%	58%	59%	59%	67%	66%
	HDVs	43%	16%	53%	43%	31%	36%	36%	53%	28%
8 PM–7 AM	**Overall**	**48%**	**55%**	**67%**	**62%**	**42%**	**47%**	**47%**	**67%**	**52%**
	LDVs	47%	62%	70%	63%	60%	62%	62%	71%	70%
	HDVs	51%	22%	64%	53%	39%	45%	45%	63%	35%
9 PM–7 AM	**Overall**	**51%**	**62%**	**73%**	**68%**	**52%**	**57%**	**57%**	**73%**	**60%**
	LDVs	50%	68%	75%	68%	66%	68%	68%	76%	75%
	HDVs	54%	35%	72%	62%	49%	55%	55%	71%	46%

Case Study 2: I-10 El Paso, Texas

Vehicle Speeds and Delays

Figure 28 and Figure 29 show vehicle speeds and percentage delays for the daytime and nighttime work zone scenarios on I-10. During daytime construction, vehicle speeds were approximately 80 percent lower than during nighttime construction and experienced up to seven times longer travel times than under free-flow conditions. During nighttime construction, vehicles traveled at near-free-flow speeds and experienced minimal delays.

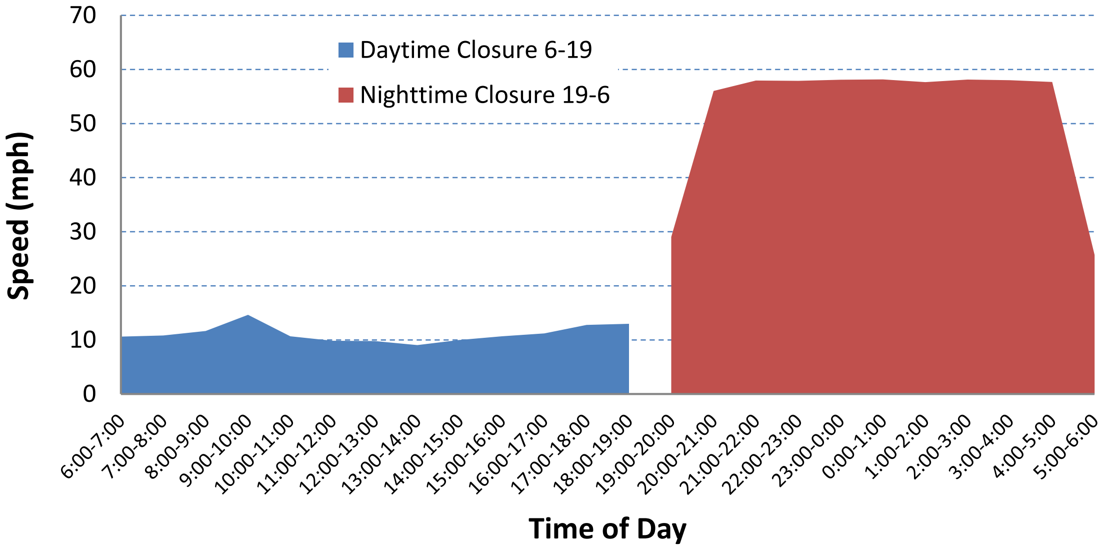


Figure 28. Vehicle Speeds—Nighttime vs. Daytime Work Zones on I-10.

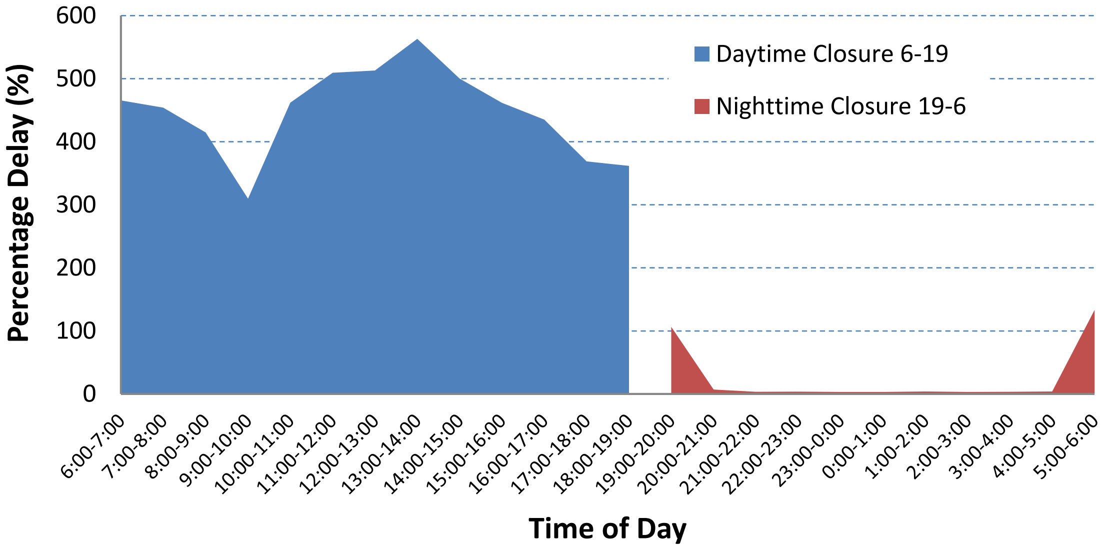


Figure 29. Percentage Delay—Nighttime vs. Daytime Work Zones on I-10.

Emissions Impacts

Table 19 shows the average speed, VMT, and total emissions generated by vehicular traffic estimated for daytime and nighttime construction scenarios. Similar to the I-35 case study, the table illustrates large differences between total daytime and nighttime vehicle emissions for all pollutants, with the change in total VMT being the significant driver of the change in total emissions. For all pollutants, the average emissions rate per mile was significantly different for daytime versus nighttime scenarios. In contrast to Case Study 1, nighttime construction reduced the average emissions rate of all pollutants.

Table 20 summarizes the percentage impact of nighttime versus daytime work zones and categorizes these impacts into those emitted from LDV versus HDV activities. Appendix H presents a more detailed breakdown of light-duty- and heavy-duty-specific total emissions and emissions rates. The NO_x numbers show that in this case study, nighttime lane closures had a large impact on heavy-duty pollutant; for example, while nighttime VMT was 68 percent of daytime VMT, this had the effect of reducing emissions by between 81 and 90 percent. This large reduction highlights a substantial improvement (i.e., reduction) in average NO_x emissions rates as the result of the difference in the daytime average speed of 11.14 mph and the nighttime average speed of 52.22 mph.

Table 19. Total Vehicle Emissions for Daytime and Nighttime Work Zones on I-10.

			Speed (mph)	VMT	Emissions (kg)						
					THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
Daytime	6 AM–7 PM	Total		255,182	72.72	1,255.57	657.98	20.07	21.91	71.72	233,907.81
		Hourly Average	11.14	19,629	5.59	96.58	50.61	1.54	1.69	5.52	17,992.91
		Ave. Rate (g/VMT)*			0.28	4.92	2.58	0.08	0.09	0.28	916.63
Nighttime	7 PM–6 AM	Total		95,636	10.14	270.17	131.27	3.13	3.43	9.88	46,959.39
		Hourly Average	52.22	8,694	0.92	24.56	11.93	0.28	0.31	0.90	4,269.04
		Ave. Rate (g/VMT)*			0.11	2.83	1.37	0.03	0.04	0.10	491.02

* Average rate is the average emissions rate for the entire period.

Table 20. Reduction in Total Vehicle Emissions for Nighttime vs. Daytime Construction on I-10.

		Percent Reduction								
		Travel Time	VMT	THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
7 PM–6 AM	**Overall**	**79%**	**63%**	**86%**	**78%**	**80%**	**84%**	**84%**	**86%**	**80%**
	LDVs	79%	62%	82%	77%	66%	75%	75%	82%	79%
	HDVs	79%	68%	90%	87%	83%	86%	86%	90%	81%

Case Study 3: W. Paisano Drive, El Paso, Texas

Vehicle Speeds and Delays

Figure 30 and Figure 31 show vehicle speeds and percentage delays for daytime and nighttime work zone scenarios on W. Paisano Drive. During daytime construction, vehicle speeds were approximately 10 percent lower than during nighttime construction. These observations indicate the lower impact of the construction-related lane closure for this urban arterial.

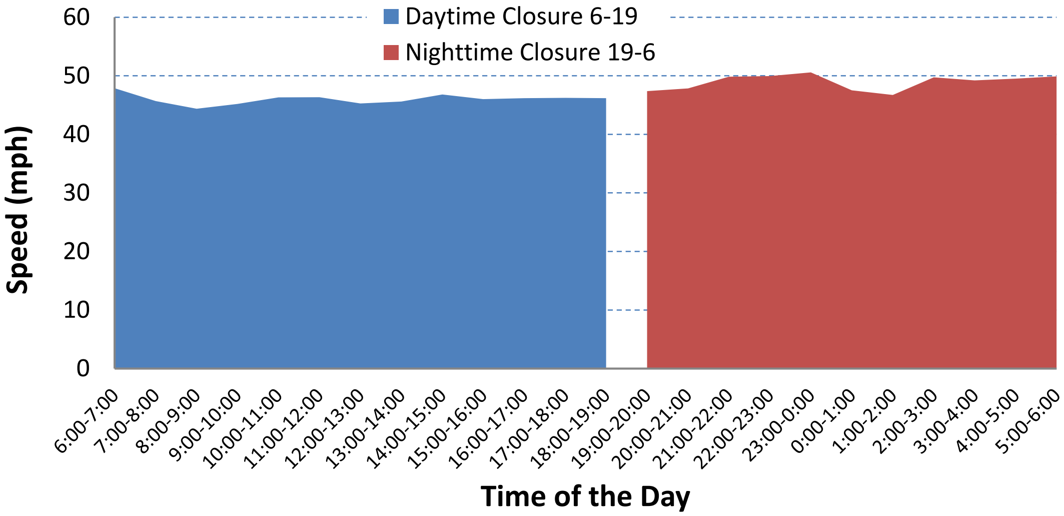


Figure 30. Vehicle Speeds—Nighttime vs. Daytime Work Zones on W. Paisano Drive.

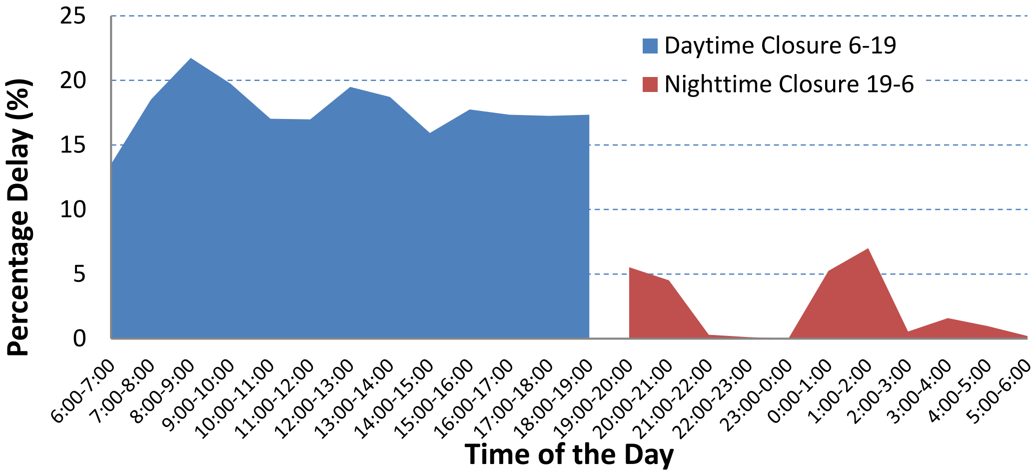


Figure 31. Percentage Delay—Nighttime vs. Daytime Work Zones on W. Paisano Drive.

Emissions Impacts

Table 21 shows the average speed, VMT, and total emissions generated by vehicular traffic estimated for daytime and nighttime construction scenarios. Consistent with the previous case studies, the results in the table illustrate large differences between total daytime and nighttime vehicle emissions for all pollutants. In line with the previous case studies, nighttime VMT was much lower than daytime VMT, and total VMT was the significant driver of total emissions.

In line with Case Study 1 (and in contrast to Case Study 2), nighttime construction had a negative impact on NO_x and CO_2 emissions rates, and minimal or no effect on PM_{10}, $PM_{2.5}$, THC, and VOC. The nighttime work zone scenario showed a reduction of CO emissions rates.

Cars represented most of the traffic activity on this corridor, so their emissions rate behavior (i.e., emissions rate curves) was the main driver of the observed changes.

Table 22 summarizes the percentage impact of nighttime versus daytime work zones and categorizes these impacts into those arising from car versus truck activities. Appendix H presents a more detailed breakdown of light-duty- and heavy-duty-specific total emissions and emissions rates. In this case study, the nighttime work zone scenario had much lower impacts on all emissions than in the freeway case studies (Case Study 1 and Case Study 2). For example, overall, the decrease in VMT of cars and trucks (77 percent) resulted in percentage decreases in emissions of between 75 and 77 percent. This trend can be explained by the relatively low traffic volumes at this location, so minimal delays under the daytime work zone scenario.

Table 21. Total Vehicle Emissions for Daytime and Nighttime Work Zones on W. Paisano Drive.

			Speed (mph)	VMT	Emissions (kg)						
					THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
Daytime	6 AM–7 PM	Total		26,229	2.23	67.55	24.28	0.60	0.66	2.15	10,587.34
		Hourly Average	46.01	2,018	0.17	5.20	1.87	0.05	0.05	0.17	814.41
		Ave. Rate (g/VMT)*			0.08	2.58	0.93	0.02	0.03	0.08	403.65
Nighttime	7 PM–6 AM	Total		6,105	0.51	15.34	5.98	0.15	0.16	0.50	2,490.31
		Hourly Average	48.93	555	0.05	1.39	0.54	0.01	0.01	0.05	226.39
		Ave. Rate (g/VMT)*			0.08	2.51	0.98	0.02	0.03	0.08	407.93

* Average rate is the average emissions rate for the entire period.

Table 22. Reduction in Total Vehicle Emissions for Nighttime vs. Daytime Construction on W. Paisano Drive.

		Percent Reduction								
		Travel Time	**VMT**	**THC**	**CO**	**NO_X**	**$PM_{2.5}$**	**PM_{10}**	**VOC**	**CO_2**
7 PM–6 AM	**Overall**	**6%**	**77%**	**77%**	**77%**	**75%**	**76%**	**76%**	**77%**	**76%**
	LDVs	6%	77%	78%	77%	77%	77%	77%	78%	77%
	HDVs	7%	74%	75%	75%	74%	75%	75%	75%	74%

Discussion

This task developed an analytical methodology to estimate the traffic operation and emissions impacts of nighttime versus daytime work zones. Traffic and emissions modeling was used to simulate the traffic flow and emissions impacts arising from lane closures at three different case study locations. To investigate the effects of nighttime versus daytime construction, different lane closure scenarios (i.e., daytime or nighttime) were simulated at each case study location.

The analytical methodology presented above was designed to be used in a more complete decision-making process to ascertain the benefits of nighttime versus daytime work zone scenarios. As such, the methods were developed to: (a) provide key metrics (i.e., traffic speed, delay, total emissions, and emissions rates) that are required for this decision-making process; and (b) investigate and understand how roadway, traffic, and emissions factors interact to impact total emissions in a work zone.

When applied to the selected case studies, the analysis methodology illustrated that undertaking nighttime construction has a significant impact on traffic activities and emissions when directly compared to a daytime work zone scenario. This was true for each of the selected case studies, which differed considerably in terms of road types (i.e., arterials versus interstates), corridor lengths, travel demand (i.e., the volume of traffic entering the corridor), and mix of cars and heavy-duty trucks using the corridor. However, most of these impacts are directly attributable to the significant reductions in traffic volume that occur during nighttime compared to daytime. As such, care should be taken when interpreting these savings as an emission impact in the context of deciding whether to switch work zone activities from the daytime to nighttime.

Figure 32 provides an overview of the difference in total emissions that occur when undertaking daytime versus nighttime work. When directly compared to the emissions resulting from daytime construction, nighttime work zones show reduced emissions between 50 and 85 percent depending on the type of pollutant and the specific case study. Figure 33 and Figure 34 break down these impacts into those attributable to LDVs compared to HDVs. In general, large emissions impacts occur for the portion of emissions generated by LDVs (between 65 and 85 percent depending on case study and pollutant). The impacts from HDVs are lower (typically between 50 and 90 percent depending on case study and pollutant) but remain significant. These results occur because across all scenarios, the decrease in nighttime LDV volume is greater than the decrease in HDVs relative to daytime conditions (i.e., throughout a 24-hour period, the volume of HDVs tends to fluctuate less than the volume of LDVs).

The direct influence of changes in vehicle volume on nighttime emissions impacts is also illustrated in Figure 35, Figure 36, and Figure 37, which show the impacts of the three different nighttime scenarios (each defined by different timing of lane closures). Compared to the daytime scenario, each nighttime scenario results in considerable emissions reductions. However, the absolute impact is driven by differences in the total number and relative proportion of LDVs and HDVs passing through the construction zone. The analysis methodology highlights that the timing of lane closures has the potential to impact emissions.

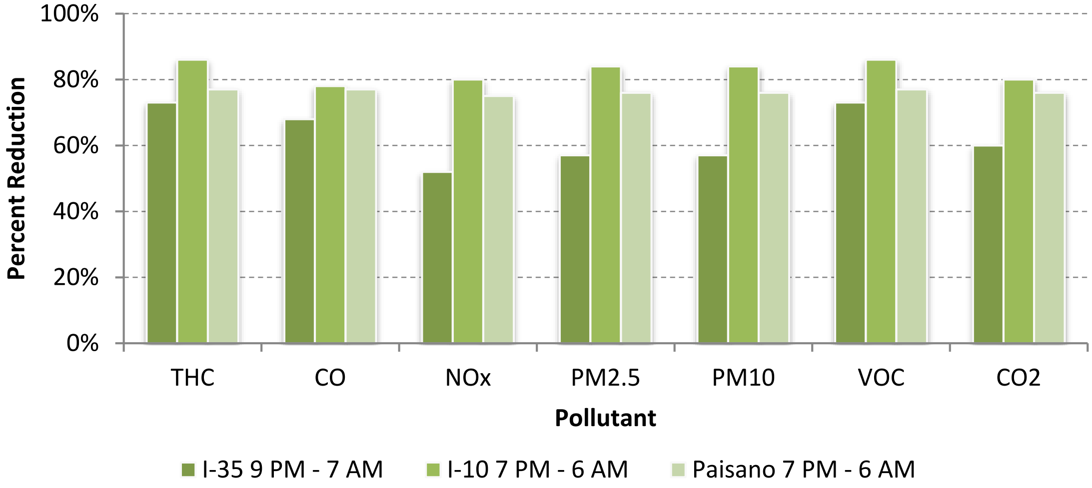


Figure 32. Reduction in Total Vehicle Emissions for Nighttime vs. Daytime Work Zones.

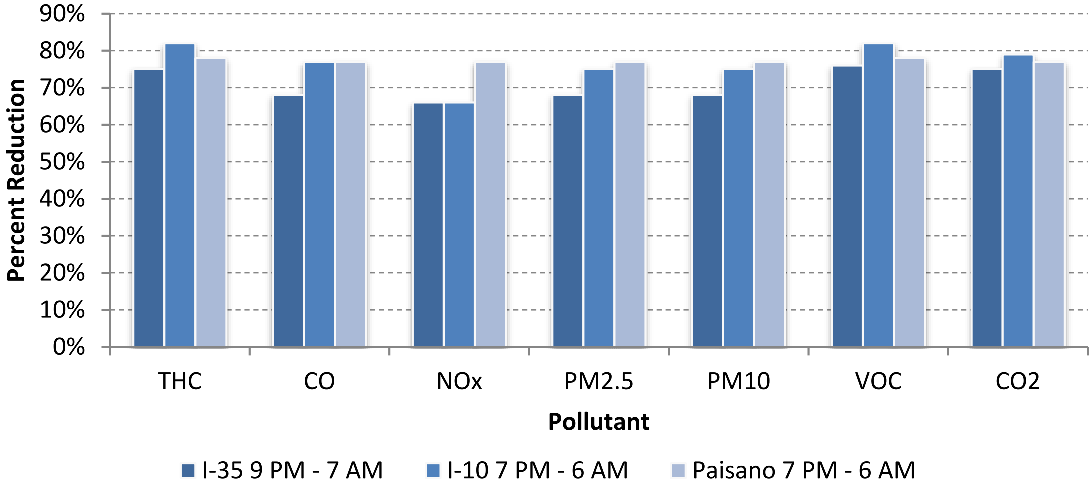


Figure 33. Reduction in Light-Duty Vehicle Emissions for Nighttime vs. Daytime Work Zones.

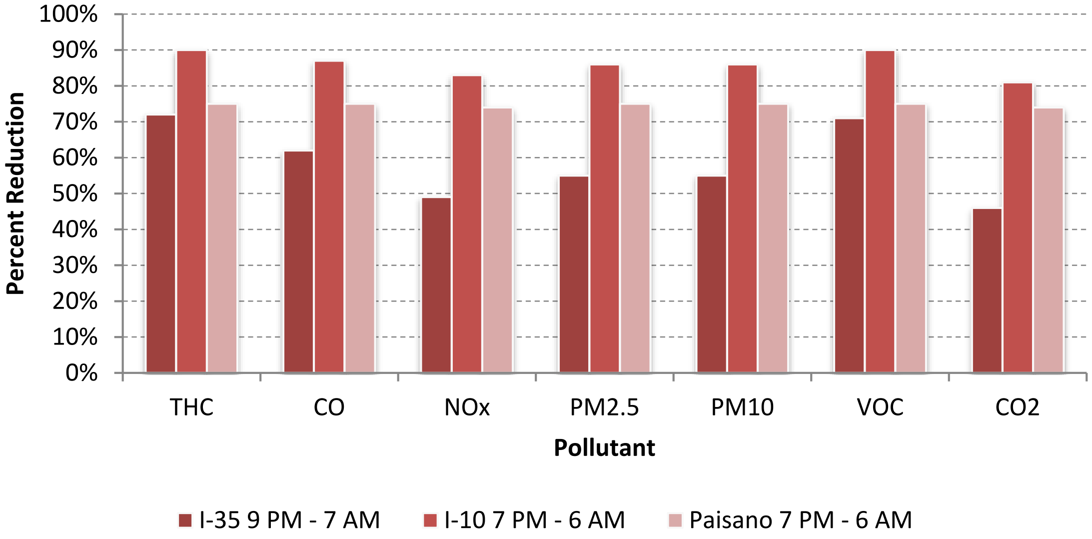


Figure 34. Reduction in Heavy-Duty Vehicle Emissions for Nighttime vs. Daytime Work Zones.

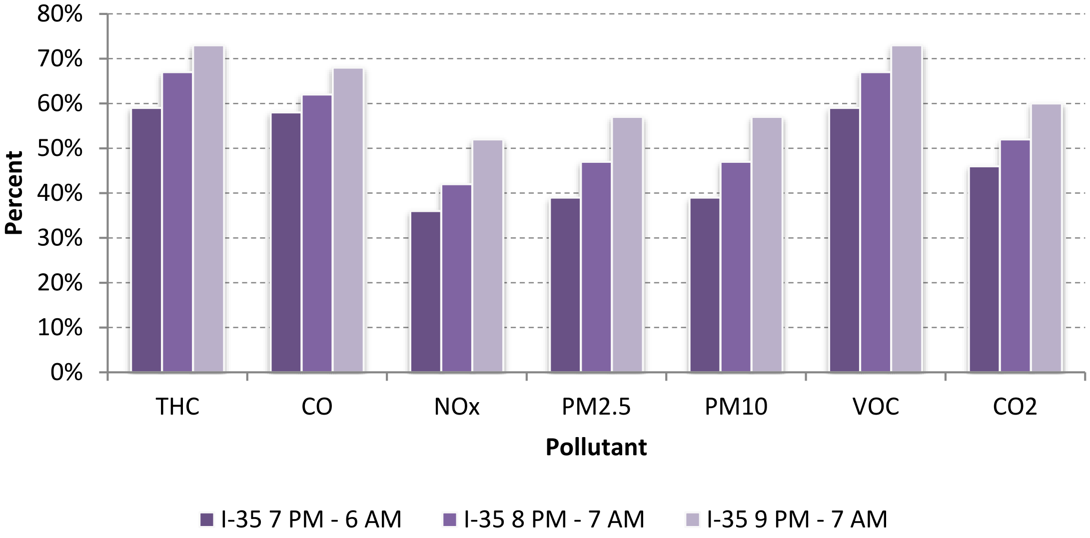


Figure 35. Total Vehicle Emissions for Different Nighttime Work Zone Scenarios Relative to Daytime Scenario (I-35 Case Study).

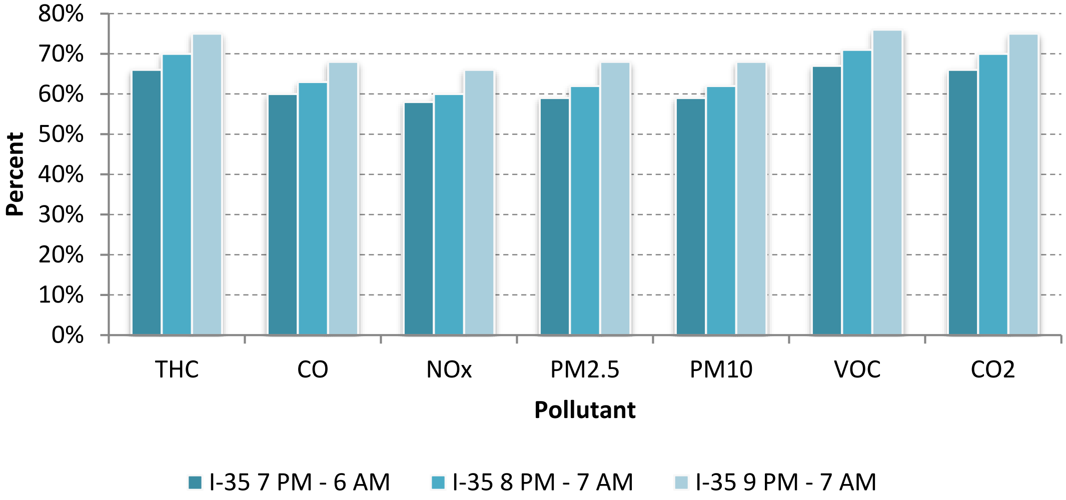


Figure 36. Light-Duty Vehicle Emissions for Different Nighttime Work Zone Scenarios Relative to Daytime Scenario (I-35 Case Study).

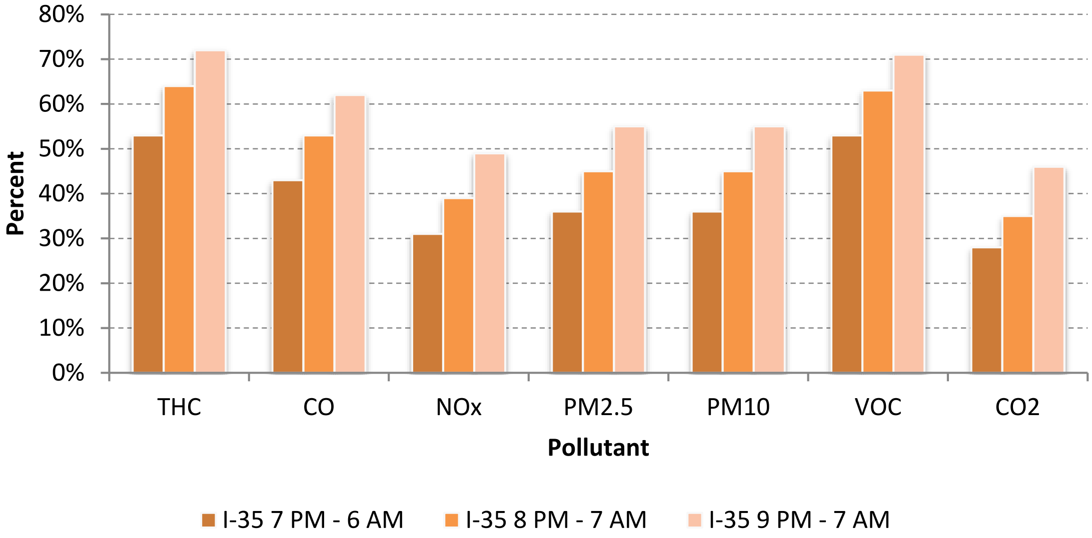


Figure 37. Heavy-Duty Vehicle Emissions for Different Nighttime Work Zone Scenarios Relative to Daytime Scenario (I-35 Case Study).

The research team emphasizes that most of the difference between daytime and nighttime emissions is driven by the general reduction in traffic volumes during the nighttime. However, important effects also occur because of the average behavior of vehicles through a work zone under different scenarios. In the analysis methodology described in this report, these effects are accounted for by the speed-specific emission rates of vehicles (more accurately, these speed-specific emissions rates correspond to the average speeds of LDVs or HDVs moving through the work zone). The speed-specific emission rates, illustrated in Figure 35 through Figure 37, incorporate the effect of acceleration and deceleration movements (i.e., the specific drive cycles) of vehicles moving through work zones. In turn, these drive cycles and average speeds are driven by congestion that occurs as vehicle demand approaches roadway capacity.

Figure 35 through Figure 37 illustrate that each pollutant exhibits different responses to the average speed and drive cycle of vehicles. Notably, the emissions rates of nearly all pollutants are lowest at intermediate speeds that correspond to vehicles moving slowly but relatively steadily through heavy traffic. For vehicles moving at very low speeds, repeated acceleration and deceleration movements cause high emissions rates per vehicle per mile. At high speeds (i.e., above 60 mph), emissions rates increase because aerodynamic resistance places increasing demands on engine power. This non-linear relationship between emissions rates and speed suggests two important factors that affect the emissions impacts of daytime versus nighttime construction.

First, the impacts of nighttime versus daytime work zones must be judged in the context of one or more specific pollutants. In many areas of Texas (e.g., nonattainment counties), nighttime work zones offer a potential strategy for mitigating existing air quality problems. Existing air quality issues are most often centered upon one or a small subset of all vehicle pollutants. The results presented in this task suggest that because the rates of each vehicular pollutant behave differently to changes in vehicle activity (speed and drive cycle), the value of nighttime construction work should be assessed in line with the specific air quality challenges of a region.

Second, impacts of nighttime work zones will critically depend on the level of congestion and the average speed of vehicles moving through the work zone. In other words, emissions rates do not linearly increase with reduced average vehicle speed (as caused by congestion), so increased congestion does not always result in increased emissions. This is clearly shown in Case Study 1, where the average emissions rates per vehicle per mile for NO_x, PM_{10}, $PM_{2.5}$, and CO_2 were all lower for the daytime compared to nighttime scenarios, despite moderate daytime congestion. Effectively, moderate congestion during the daytime resulted in a reduction in average vehicle speeds (to approximately 35 mph), which resulted in lower emissions rates relative to the nighttime scenario where vehicles moved at average speeds between 58 and 72 mph. In contrast, nighttime work in Case Study 2 had a decreasing impact on emissions rates because daytime work zone congestion was higher, resulting in stop-start driving conditions, vehicle speeds of only 11 mph, and consequently higher average emissions rates compared to the rates of vehicles traveling through an uncongested nighttime work zone.

SUMMARY

In this task, the research team developed a methodology to estimate the traffic operation and emissions impacts of nighttime versus daytime work zones. The methodology was applied to three case studies to understand the factors that determine whether, and under what circumstances, undertaking nighttime versus daytime construction will result in a positive emissions impact.

The analysis suggests that nighttime work zones result in much lower total emissions than daytime work zones. However, the TTI research team strongly advises that this does not constitute a true impact of nighttime versus daytime work zone practices because these effects are driven directly by the reduced traffic during the nighttime versus daytime.

True emissions impacts are driven by fundamental differences in emissions rates per vehicle per mile driven by changes in the way that vehicles move through a work zone (i.e., the average speed and drive cycle). The analysis suggests that it is not correct to assume that reductions in average speed will always result in lower emissions rates. For some pollutants, emissions rates are lower at intermediate speeds such as those that occur as vehicles move through a moderately congested work zone. As such, in some circumstances, by allowing vehicles to move at free-flow speeds, nighttime work zones can have a negative emissions impact. More generally, the impact of nighttime versus daytime construction depends on the pollutant of interest and the specific change in average vehicle speeds that is expected to occur because of the work zone.

The mix of LDV and HDV types at a location has the potential to have a large emissions impact. Per unit, HDVs have higher NO_x, PM, THC/VOC, and CO emissions rates than their light-duty counterparts. Additionally, on many corridors (specifically intercity freight corridors such as I-35), HDV volumes remain relatively high at night compared to the volume of LDVs. If congestion causes speeds to drop to levels where emissions rates increase, corridors with high proportions of HDVs may experience large emissions impacts.

CHAPTER 6. THE IMPACT OF METEOROLOGICAL FACTORS ON POLLUTANT CONCENTRATIONS

INTRODUCTION

Two major factors that affect the dispersion of pollutants into the atmosphere are emissions rates (rate at which the emissions are released from the emissions source) and meteorological conditions (wind speed, wind direction, atmospheric stability, and surface roughness, etc.). Task 5 evaluated the effect of meteorological conditions on pollutant concentration levels between daytime and nighttime. This was achieved by conducting a sensitivity analysis for the same set of emissions rates using meteorological data inputs corresponding to different time periods in a dispersion model. The sensitivity analysis-based approach was selected over the use of a single case study data to allow for more robust and generalizable findings. The results of this analysis provide an understanding of the impact of factors that affect pollutant dispersion.

This chapter presents the methodology used to assess the relative difference in pollutant concentrations between daytime and nighttime periods due to meteorological conditions. The chapter presents the results, findings obtained from the series of sensitivity analyses, a summary, and conclusions.

AIR DISPERSION MODELING WITH AERMOD

Chapter 2 introduced the AERMOD dispersion model. Among the different air dispersion models, EPA approves AERMOD for a wide range of regulatory applications including roadways and off-road networks (i.e., construction sites) in all types of terrain. For PM hot-spot modeling required for project-level conformity, AERMOD is listed as an approved dispersion model for highway, intersection, transit, terminal, and projects that involve a combination of project types (*73*). The AERMOD model is used for the sensitivity analyses conducted in this project.

AERMOD is a steady state Gaussian plume model based on recent advances in atmospheric science, and incorporates the parameterization of the planetary boundary layer (PBL). PBL is the turbulent air layer next to the Earth’s surface that has an important effect on the spatial distribution of pollutants. In the stable boundary layer, it assumes the concentration distribution to be Gaussian in both the vertical and horizontal directions. In the convective boundary layer, the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function. AERMOD uses an advanced method to characterize stability compared to its processor models. AERMOD uses a continuous function called Monin-Obukhov length to characterize atmospheric stability. AERMOD is capable of modeling a number of sources and receptors, handling multiple years of meteorological data simultaneously and gives the option of varying emissions rates by different time scales, such as by season, month, hour-of-day, and wind speed. The two regulatory components of AERMOD include the meteorological preprocessor (AERMET) and the terrain data preprocessor (AERMAP). AERMET processes the meteorological data from the National Weather Station (NWS) and on-site data. AERMET produces output files containing the surface scalar parameters and the vertical profile of meteorological data. AERMAP preprocesses complex terrain data and generates receptor grids, using USGS digital elevation data. Other non-regulatory components of AERMOD include AERSCREEN, the screening version of AERMOD, AERSURFACE, the surface-characteristics preprocessor and BPIPRIME, and the multibuilding dimensions program for PRIME applications (*74*).

AERMOD can be downloaded from the EPA website (*75*). Each component of the AERMOD modeling system (AERMAP, AERSURFACE, and AERMET) should be stored in its own subdirectory. The outputs from these subcomponents are required to be copied to the subdirectory where AERMOD will be executed. The input and output file to each subcomponent model has to be renamed or copied to the basic file name of the executable. For example, when executing an AERMOD run, myinputfile.inp has to be renamed to AERMOD.INP and myoutputfile.out has to be renamed to AERMOD.OUT. Once the AERMOD.OUT file has been produced, it has to be renamed back to myoutputfile.out; otherwise, AERMOD.OUT will be over written the next time AERMOD is run. AERMOD is executed by double-clicking the AERMOD.exe. One of the basic inputs to AERMOD is the run stream setup file, which contains the selected modeling options, as well as source location and parameter data, receptor locations, meteorological data file specifications, and output options. Another basic type of input data needed to run the model is the meteorological data, which is provided by the AERMET preprocessor. For applications involving elevated terrain effects, the receptor and terrain data are obtained from the AERMAP preprocessor. The process of air dispersion modeling using AERMOD consists of three steps as shown in Figure 38.

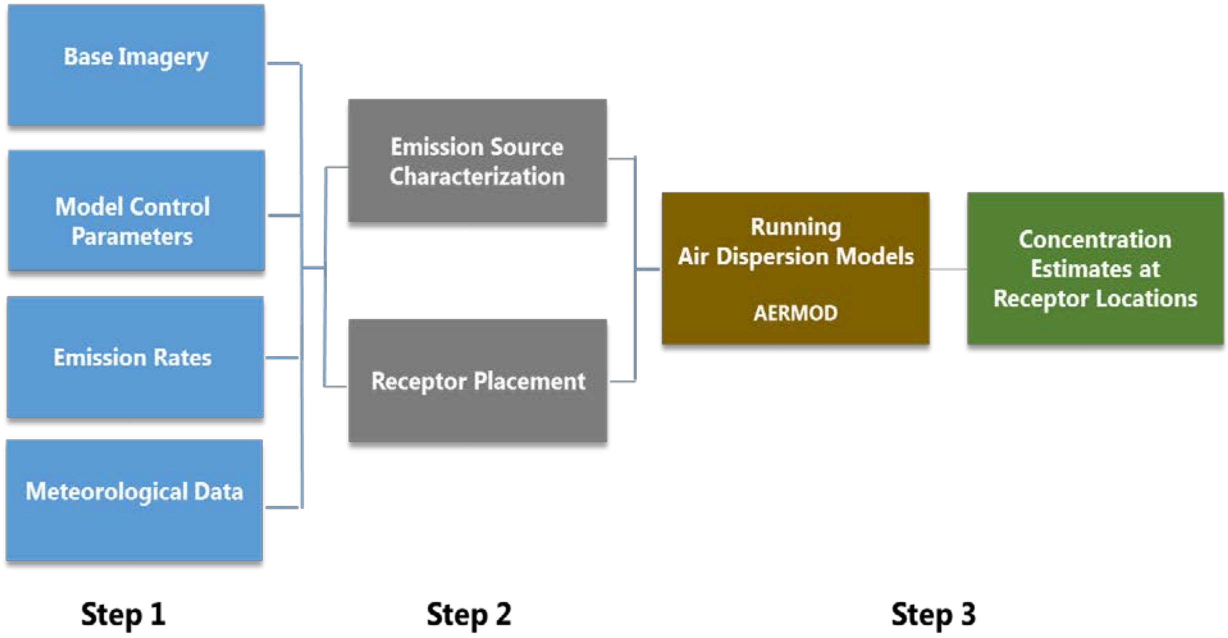


Figure 38. Air Dispersion Modeling.

Step 1

This step consists of assembling the base imagery, obtaining emission factors, processing meteorological and land use conditions specific to case study, and specifying model control parameters:

- Base imagery helps in the coding of the sources and receptors geographically on the roadway links. Base images often required for case study sites can be obtained from Google Earth maps, aerial photographs, and CADD drawings.
- Model control parameters are used to specify the pollutant type, pollutant properties, land use type (urban or rural), and averaging period for which the concentration estimates are required to be modeled. AERMOD is a steady state air dispersion model that models the dispersion of any primary non-reacting pollutant into the atmosphere. The dispersion is governed by the pollutant emissions rate and meteorological and land use conditions. For the same set of meteorology and land use conditions, the dispersion patterns for different pollutants are dependent on the emissions rates.
- Emissions rates are one of the major driving factors for determining the dispersion pattern of pollutant concentrations. For transportation applications, emissions rates are obtained from the MOVES emissions model based on traffic activity characterization, fleet mix, and other factors related to fleet age distribution, temperature and humidity, and fuel supply parameters.
- Meteorological conditions are a major factor that affects pollutant dispersion in the atmosphere. Three types of data are required for processing the meteorological data—

surface data that measure characteristics of lower layers of the atmosphere, upper air data that measure characteristics that change with height in the atmosphere (such as temperature), and land use data that represent surface characteristics. The raw meteorological and land use data are obtained from the following sources:

- Automated Surface Observing Stations (ASOS).
- NWS.
- USGS land use database.

The ASOS and NWS databases are owned and maintained by the National Climatic Data Center (NCDC) and National Oceanic and Atmospheric Administration (NOAA) under the U.S. Department of Commerce (*76*). The U.S. Geological Survey (USGS) land use database is a national archive for remotely sensed images of Earth's land surface maintained by the U.S. Department of the Interior (*77*). The raw data are processed using meteorological preprocessors—AERMINUTE, AERMET, and AERSURFACE—to produce data in a format compatible for AERMOD. Figure 39 shows the process of meteorological data processing. High-resolution wind data are processed by AERMINUTE preprocessor in the first step. One of the main concerns in using NWS surface data directly for AERMOD is the presence of high incidence of calm and missing wind data. AERMOD cannot accurately simulate dispersion with calm/missing winds. To reduce this, NCDC started archiving raw one-minute data logged by automated stations (*78*). AERMINUTE is used to process the one-minute data to produce hourly wind speed and direction averages to improve the quality of surface data obtained from the NWS. The second step consists of obtaining the land cover surface characteristics from the AERSURFACE preprocessor. AERSURFACE processes the land cover data (specific to the case study location) from the USGS database and produces surface characteristics. These surface characteristics relate to the albedo (fraction of total incident solar radiation that is reflected back to space without absorption), Bowen ratio (amount of surface moisture conditions), and surface roughness (height of obstacles to the wind flow).

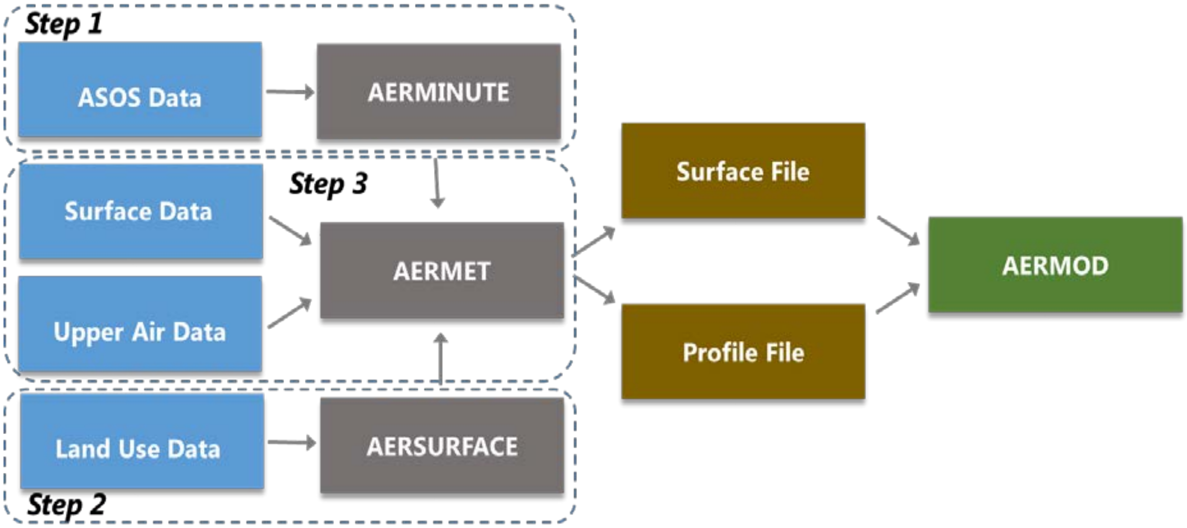


Figure 39. Meteorological and Land Use Processing for AERMOD Model.

In the third step, AERMET incorporates surface and upper data from the NWS database and combines it with the hourly wind speed and direction averages produced by AERMINUTE and land cover surface data (albedo, surface roughness, and Bowen's ratio) from AERSURFACE to produce output files for AERMOD. The two files produced by AERMET consist of a boundary layer parameter file, which includes turbulence parameters, mixing height, and friction velocity. The second file contains the vertical profile of winds, temperature, and standard deviation of the fluctuating components of the wind. These two files are directly incorporated into AERMOD. TCEQ produces preprocessed meteorological data (*79*) in one-year and five-year data sets for all 256 counties in Texas using AERMET Version 12345.

Step 2

This step involves characterizing the emission sources (i.e., roadway links) and placing receptors:

- Characterization of emissions sources consists of defining the dimensions of the sources (roadway links) and designating the rate at which the source produces emissions. For dispersion modeling, source (roadway link) dimensions are defined based on the following key parameters:
  - Roadway link orientation.
  - Physical dimensions of roadway links.
  - Travel activity that corresponds to volume and speed.
  - The physical dimensions of the roadway links define the source area. The vertical component of the model is defined by the initial vertical dispersion height and the source release height. AERMOD can model the roadway line source as a series of volume or area sources (*74*). Volume sources are more appropriate for line sources,

which have some initial plume depth (rail lines, conveyor belts) and area sources are more appropriate for near-ground-level sources with no plume rise (viaduct, storage piles). In addition to defining the source dimensions, source-specific dispersion parameters, namely initial vertical dispersion and release height are also specified in this step. Initial vertical dispersion height is assumed to be about 1.7 times the average vehicle height, to account for the effects of vehicle-induced turbulence. Source release height is the height at which wind effectively begins to affect the plume and is estimated from the midpoint of the initial vertical dimension.

- Receptor placement consists of placing receptors as proxies to measure the concentration levels experienced by people at a specific location. The placement is based on the publicly accessible areas where high emission concentrations would be expected. Typically, these are in areas of vulnerable populations and are placed at an average human breathing height of 1.8 m above the ground. Since pollutant concentrations are known to be higher near the roadway links (source areas), receptors are placed with a finer resolution near the roadway links and the spacing between the receptors are increased with distance away from the roadway links.

Step 3

This step consists of multiple runs of the AERMOD model using files prepared in Steps 1 and 2. Model outputs from air dispersion modeling will include the pollutant concentration estimates for the desired averaging time period at all receptors.

SENSITIVITY ANALYSIS METHODOLOGY

This section outlines the methodology that the research team used to assess the relative difference in pollutant concentrations between daytime and nighttime periods. This was accomplished by performing a sensitivity analysis that varied key input parameters (for same set of emission rates) to represent differences in nighttime and daytime conditions that may influence pollutant dispersion.

Hourly meteorological parameters and emissions source-specific emissions rates are used as inputs to dispersion models, which produce hourly variations in dispersion from emissions sources. The dispersion modeling approach in this task focuses on the relative change in concentration estimates using generic assumptions for traffic and emission rates (i.e., examining differences in dispersion between daytime and nighttime periods for the same levels of traffic). This is performed to eliminate the differences in pollutant concentrations attributable to differences in traffic volumes typically seen when comparing daytime and nighttime scenarios. Therefore, the effect of meteorological data on pollutant concentrations between daytime and nighttime periods is evaluated through a series of sensitivity analyses for the same set of emissions rates.

This approach is in line with the overall project objectives of assessing the *relative difference* in air quality levels as a result of shifting construction activities from daytime to nighttime periods rather than quantifying the expected concentrations based on predicted traffic levels (which typically conducted in a hot-spot analysis). A sensitivity analysis is used to determine how different values of an independent variable (meteorological data) will impact the dependent variable (concentration estimates) maintaining the other independent variables (emission rates) constant.

Figure 40 illustrates the conceptual overview approach used for this task. This approach consists of the following major elements:

1. Case study setup.
2. Assess key input parameters for sensitivity analysis.
3. Perform air dispersion modeling and obtaining results.

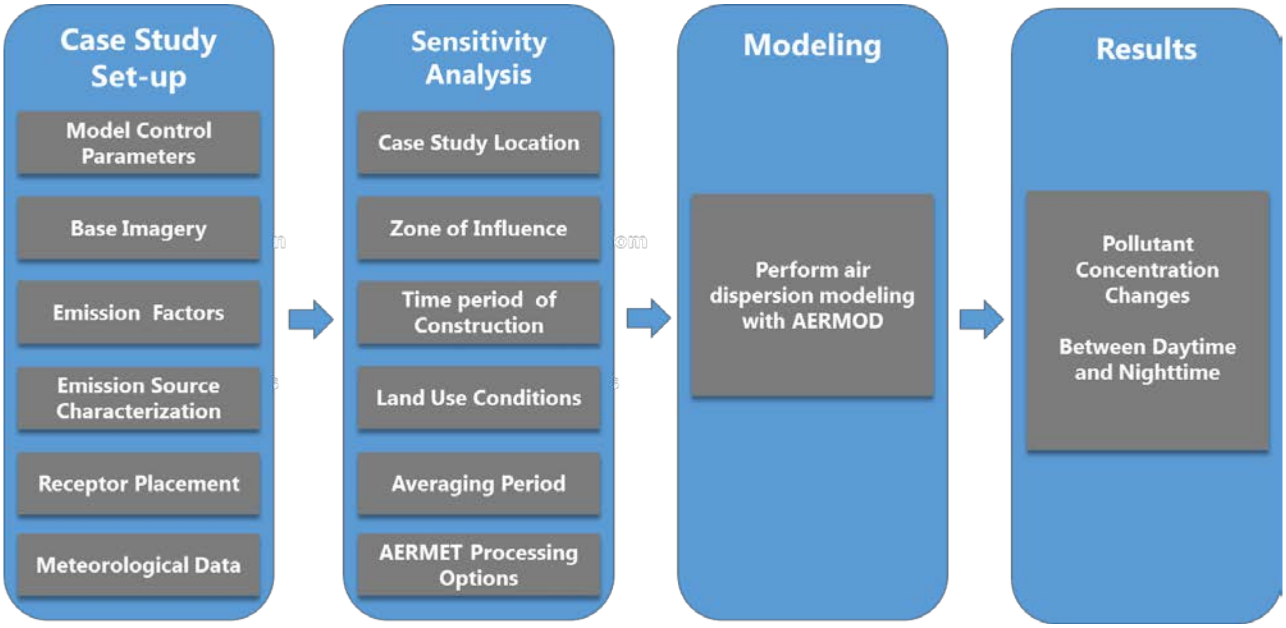


Figure 40. Conceptual Methodology for Task 5.

Further details of the sensitivity analysis methodology are provided in Appendix I.

RESULTS

This section presents the results obtained from the series of sensitivity analyses performed by the research team to assess the impact of meteorological factors on pollutant concentrations between daytime and nighttime periods.

To evaluate and compare the effects of different time periods, time period designations, land use, areas, and zones of influence from the roadway edge on pollutant concentrations, different combinations of these factors are defined to model pollutant dispersion using AERMOD. Figure 41 shows the variation in normalized concentration predictions as a function of time period designation, zone of influence or distance from the roadway, and land use. Results shown in Figure 41 are based on the default regulatory option in AERMOD. These figures indicate that the concentration estimates are the highest near the roadway link (or near-road) and then gradually decrease with distance from roadway links. The rate of decline in concentration estimates is steep for a distance of 250 m and the concentration estimates flatten for distances beyond 250 m.

These findings are consistent with the literature (*80*, *81*, *82*, *83*, *84*). Karner et al. analyzed 41 roadside monitoring studies between 1978 and 2008 and concluded that almost all pollutants decay to background levels at a distance of 115 m to 570 m from the edge of the road and the decay rate varies from one pollutant to another (*84*). Venkatram et al. analyzed data from three near-road pollution measurements and the AERMOD dispersion model, and showed that the concentration of an inert pollutant decays rapidly to less than one-fifth of its initial strength from roadway edge (*85*). For a short-lived pollutant (due to evaporation, photolysis, chemical reaction, deposition, among other mechanisms), the concentration would be reduced to 1/10 of its initial strength.

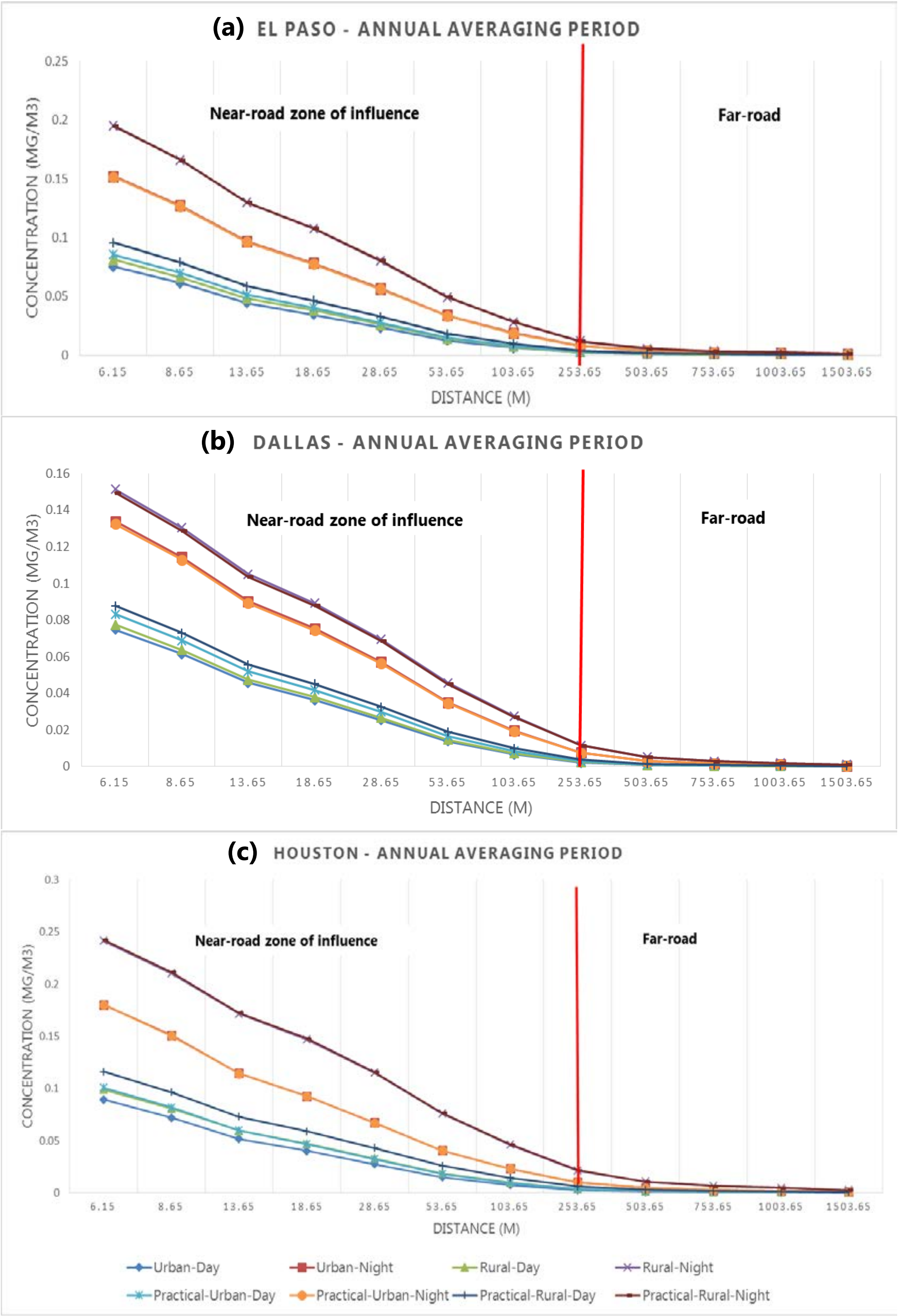


Figure 41. Normalized Concentrations with Distance from Roadway Edge, Land Use, and Time Period Designation for (a) El Paso, (b) Dallas, and (c) Houston.

For all the case study areas (El Paso, Dallas, and Houston), concentration estimates are found to be higher for nighttime periods compared to daytime and rural land use compared to urban land use conditions. The reason for high concentration estimates during nighttime compared to daytime periods is because of the stable atmospheric conditions during nighttime periods. Sunlight during the daytime helps in the mixing/dispersion of pollutants in the atmosphere. When the sunlight strikes the Earth's surface during the day, it heats up more quickly and the heat is transferred to the air immediately above the ground, causing the warm air to rise and mix with the cooler air above. When the sun sets during evening and nighttime periods, the Earth's surface cools down much faster than air, resulting in cooler (heavier) air near the ground and warmer (lighter) air staying on top. This fairly stable atmospheric condition during nighttime periods leads to much reduced mixing and dispersion of pollutants, and thereby higher concentrations. Thus, the low atmospheric transport and dispersion characteristics during nighttime periods lead to higher concentration estimates (*54*).

Lower concentration estimates observed in an urban land use setting compared to a rural setting are because of the urban heat island effect, a term used to describe urban areas that are hotter than nearby rural areas, especially at night due to the heat retention by urban materials. In this regard, buildings, roads, and structures in urban areas absorb more radiation and energy compared to almost flat terrain conditions in rural areas. Because of this heat retention, the vertical motion of the air is increased through convection, yielding better mixing, stronger vertical air flux, and eventually better dilution resulting in increased dispersion of pollutants (*54*). Considering all combinations of input parameters, concentration estimates are found to be higher for the rural nighttime period, followed by the urban nighttime, rural daytime, and urban daytime periods.

In addition to the default regulatory option, the research team re-ran the model with the BETA option (meteorological data processed with LOWWIND option in AERMOD and use of ADJ_U* in AERMOD). Concentration estimates obtained with meteorological data processed using BETA options (LOWWIND and ADJ_U*) in AERMET and AERMOD are compared with the concentration estimates obtained with preprocessed meteorological data obtained from TCEQ (processed using regulatory options). The regulatory option was found to predict higher concentration estimates compared to the BETA option. However, the comparison exhibited minor difference in concentration levels ranging between 2 to 4 percent. Potential reason for the low difference could be that the BETA options are more impactful for studies involving tall stacks (*53*).

Table 23 summarizes the relative difference (expressed as a percentage) in average concentration levels between nighttime and daytime periods. The relative difference expresses how much the concentration estimates are higher in nighttime periods compared to daytime periods for the same traffic activity, and source characterization. The relative difference varies significantly for different land use types, zone of influence, and time period designation (e.g., in El Paso, concentration levels are 110 percent higher during nighttime periods compared to daytime periods for urban land use conditions with time period defined by the TxDOT specification handbook).

The relative difference in average concentration levels between nighttime and daytime periods are found to increase with distance from roadway edge. This is because of the very low concentration values obtained at distances greater than 250 m as shown in Figure 41. Due to the peaking tendency of pollutants emitted from roadway sources and epidemiological evidence of adverse health effects in the near-road zone of influence (*8*), relative difference in the highest concentration levels obtained closer to roadways is assessed. Table 24 lists the relative difference (expressed as a percentage) in the highest concentration levels between daytime and nighttime periods in the near-road zone of influence (between 0–15 m). Similar trends observed with relative difference in average concentration levels between nighttime and daytime periods (Table 23) is observed in Table 24. A higher relative difference is observed for rural land use conditions with time periods defined by the TxDOT specification handbook. The difference in concentration estimates between case study regions (i.e., El Paso, Dallas, and Houston) is due to their different meteorological conditions.

Table 23. Relative Difference in Average Pollutant Concentrations between Nighttime and Daytime Periods.

Relative Difference* in Average Concentration Levels (Expressed as a Percent)				
S: TxDOT specification handbook, P: Construction contractor's information				
El Paso				
Distance from roadway	0–15 m	15–250 m	250–750 m	750–1500 m
Urban – S	110%	176%	269%	267%
Rural – S	151%	254%	370%	367%
Urban – P	81%	119%	166%	164%
Rural – P	109%	167%	226%	228%
Dallas				
	0–15 m	15–250 m	250–750 m	750–1500 m
Urban – S	88%	172%	326%	366%
Rural – S	109%	237%	496%	589%
Urban – P	67%	117%	189%	197%
Rural – P	80%	154%	275%	296%
Houston				
	0–15 m	15–250 m	250–750 m	750–1500 m
Urban – S	106%	174%	302%	333%
Rural – S	159%	300%	495%	536%
Urban – P	80%	121%	183%	191%
Rural – P	118%	194%	274%	281%

* Relative difference is expressed as (Nighttime Concentration – Daytime Concentration)/Daytime Concentration.

Table 24. Relative Difference in Highest Pollutant Concentrations between Nighttime and Daytime Periods within 0 to 15 m from Roadway Edge.

Relative Difference* in Highest Concentration Levels (Expressed as a Percent) Within a Near-Road Distance of 0–15 m			
S: TxDOT specification handbook, P: Construction contractor's information			
	El Paso	**Dallas**	**Houston**
Urban–S	138%	78%	125%
Rural–S	181%	93%	165%
Urban–P	104%	54%	94%
Rural–P	133%	62%	121%

* Relative difference is expressed as (Nighttime Concentration – Daytime Concentration)/Daytime Concentration.

To investigate the variation of pollutant concentrations during a day, pollutant concentrations are estimated at an hourly averaging period for El Paso. The research team executed this run under the assumption of a unit emissions rate for each hour of the day, and not a combination of zero and unit emissions rate for different time periods as performed for the daytime and nighttime scenarios. Hourly concentrations are further classified by seasons and are shown in Figure 42.[3] The trends shown in Figure 42 correspond to a declining rate in the concentration levels with distance from roadway, and with higher levels of vertical flux causing lower concentration estimates during daytime periods.

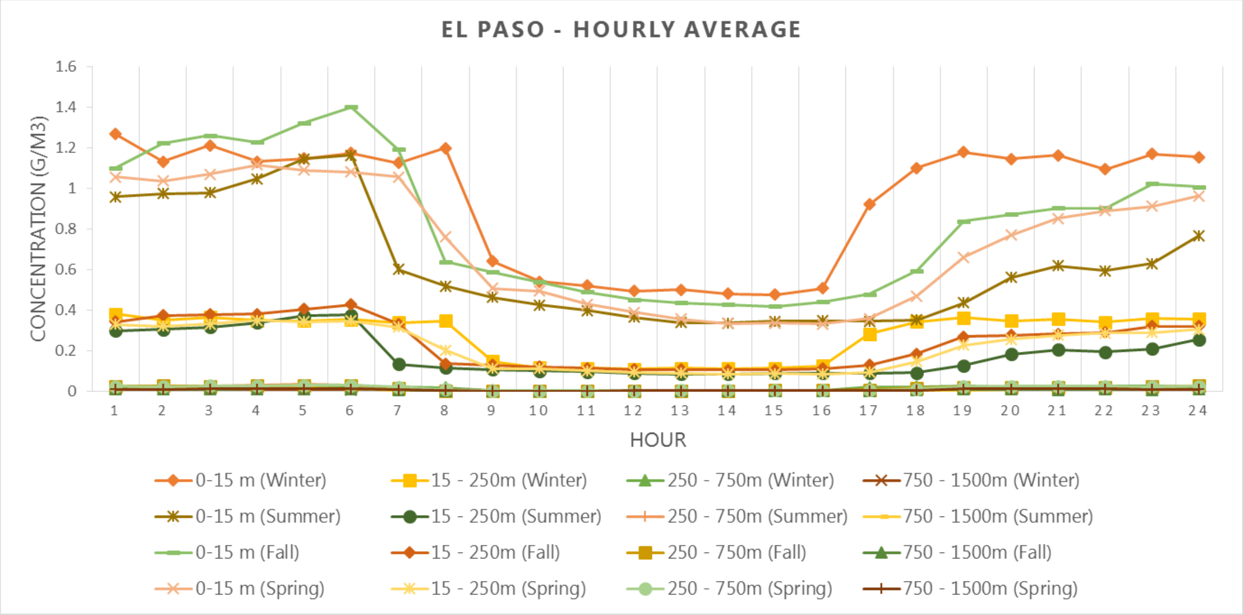


Figure 42. Pollutant Concentrations at an Hourly Averaging Period Varied by Season for El Paso.

Among the different meteorological parameters, atmospheric stability, which is responsible for mixing and dilution, is found to have a significant impact on pollutant concentrations between different time periods. Hence, the variation of atmospheric stability is studied in detail. Atmospheric stability affects the dispersion of vehicle emissions downwind of the highway and is governed by heat and momentum forces in the environment. AERMOD provides for a continuous measure of atmospheric stability based on an energy balance in the planetary boundary layer. The energy balance is represented by the sensible heat flux, which depends on net radiation and surface characteristics such as available surface moisture. Atmospheric stability in AERMOD is represented as a function of the Monin-Obukhov length [L(m)] (*86*).

The atmospheric stability is obtained from the surface and upper air data processed by AERMET. Unstable atmospheric conditions refer to convective conditions when the atmosphere

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[3] The higher concentration values in Figure 42 are because of the lower averaging period of an hour compared to Figure 41, which is based on an annual averaging period.

is not stable leading to increased dispersion and lower pollutant concentration estimates. Stable atmospheric conditions, typically observed during nighttime periods, have low atmospheric transport and dispersion leading to higher pollutant concentration estimates and neutral conditions are in middle between stable and unstable conditions.

Figure 43 shows the hourly distribution of atmospheric stability conditions for all seasons specific to El Paso. Comparing Figure 42 with Figure 43, the variation of concentration estimates closely follows the variation in atmospheric stability conditions. Concentration levels are lower between hours 8 to 17, coinciding with the unstable atmospheric conditions. Concentration levels are higher between hours 1 to 8 and 17 to 24 due to the presence of predominantly stable conditions and limited neutral conditions. The magnitude of concentration levels are higher during winter and fall seasons compared to summer and spring seasons. This is because of the higher prevalence of stable atmospheric conditions (less sunlight time compared to summer and spring) leading to reduced levels of mixing and pollutant dispersion during fall and winter season. Considering seasonal atmospheric conditions, concentration estimates are found to be higher for winter and fall nighttime periods, followed by summer and spring nighttime periods, winter and fall daytime periods, and summer and spring daytime periods.

Combining all estimates from Table 23, on average for any urban area, annual average pollutant concentrations dispersed during nighttime conditions are higher by 100 to 120 percent compared to daytime periods. This relative difference increases to 150 to 200 percent for rural land use conditions. This finding is consistent with other near-road studies examining the difference between daytime and nighttime air pollutant impact.

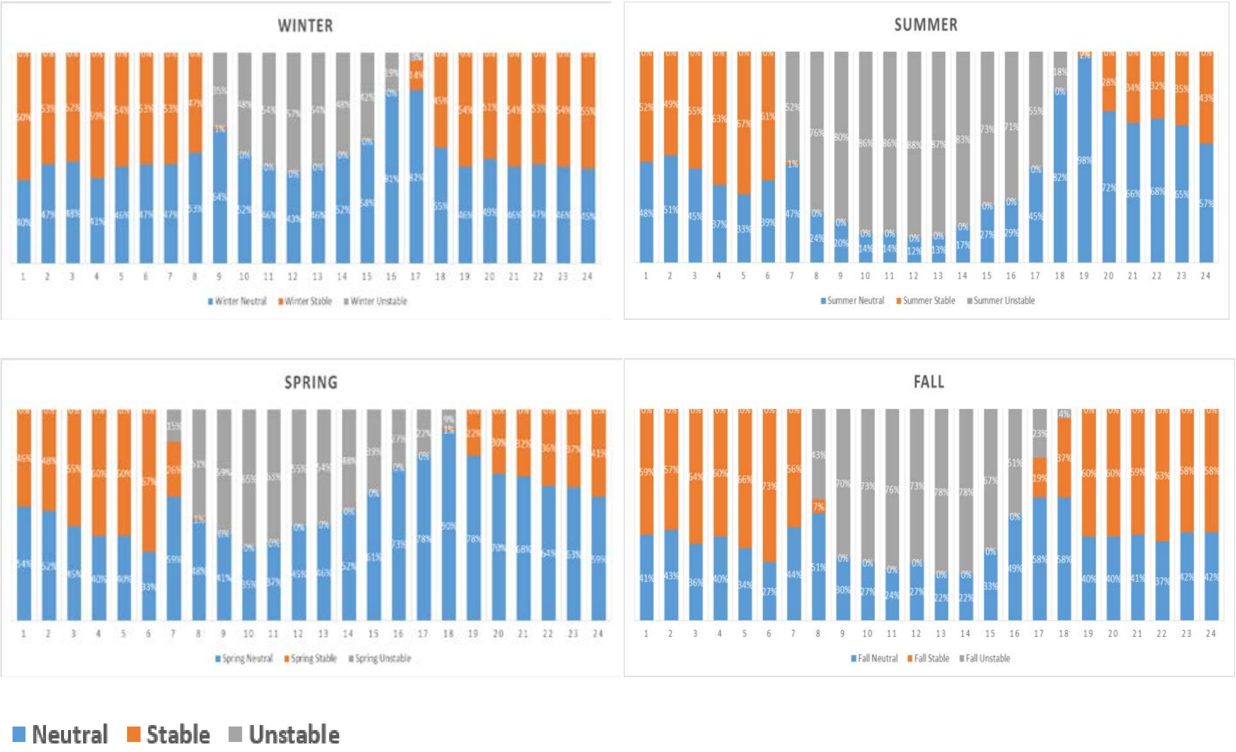

Figure 43. Distribution of Atmospheric Stability Conditions for El Paso.

Ultrafine particle (UFP) concentrations at night were reported by Zhu et al. (*87*), who conducted measurements upwind (300 m) and downwind (500 m) of a freeway from hours 22:30 to 04:00. Although traffic volumes were much lower at night (about 25 percent of peak) particle number concentrations were about 80 percent of the daytime peak concentrations along a major freeway in Los Angeles. Hu et al. (*88*) measured air pollutant concentrations along the I-10 freeway in west Los Angeles, 1–2 hours before sunrise in the winter and summer months using an electric vehicle mobile platform equipped with fast-response instruments. Although traffic volumes during the pre-sunrise hours were lower than during the day, the UFP concentrations were significantly higher in the pre-sunrise period due to strong atmospheric stability, low wind speeds, low temperatures, and high humidity values. In conclusion, the study found the combination of sufficient traffic flow with meteorological conditions during pre-sunrise hours to result in elevated concentrations for UFP, NO_x, and polycyclic aromatic hydrocarbons during pre-sunrise hours.

SUMMARY

Key findings from the series of sensitivity analyses are performed to evaluate the impact of meteorological conditions on pollutant concentrations between daytime and nighttime time periods include the following:

- Peaking effects in pollutant concentrations are observed near-road and concentrations decline with distance from roadway edge. The rate of decline is dependent on meteorological conditions and varies by season.
- Concentrations are higher for rural areas when compared to urban land use conditions due to the retention of heat by urban materials that increase the vertical motion of air, leading to increased pollutant dispersion in urban conditions.
- Concentrations are higher during nighttime compared to daytime (when emissions levels from the source are held equal) because of the stable atmospheric conditions, lower mixing heights, and lower wind speeds leading to higher concentrations of pollutants at the near-ground level during nighttime periods.
- Considering all combinations of input parameters, concentration estimates are found to be higher for the rural nighttime period, followed by the urban nighttime, rural daytime, and urban daytime periods.
- Higher relative difference in concentrations between daytime and nighttime periods are observed in far-road areas (i.e., farther than 250 m from the roadway) because of extremely low values when the concentrations fall back to background levels.
- On average, for any urban area, annual average pollutant concentrations dispersed during nighttime conditions are higher by 100 to 120 percent compared to daytime periods. This relative difference increases to 150 to 200 percent for rural land use conditions.

When construction activities are shifted from daytime to the nighttime period, pollutant concentration levels will be higher for the same traffic activities. However, as highlighted in other chapters of this report, traffic congestion and overall traffic volumes will be lower during nighttime compared to the same project undertaken during the daytime. This, in turn, will reduce the fuel consumption, vehicle emissions, and the net pollutant concentrations associated with nighttime versus daytime projects. The relative difference in pollutant concentrations obtained from shifting construction activities to nighttime from daytime periods should be assessed based on a combination of meteorological and traffic conditions.

Researchers acknowledge the limitations of the results, as they are based on hypothetical case study settings evaluating the impact of meteorological conditions with no change in traffic activities. However, a review of the literature shows the conclusions and findings of this task, for the difference in dispersion patterns between daytime and nighttime periods, and land use, are consistent with other studies.

CHAPTER 7. DEVELOPMENT OF A DECISION-SUPPORT FRAMEWORK

INTRODUCTION

Based on the findings of activities conducted in this project, the research team developed a decision-support framework to provide a simple, flexible framework that can help formalize the process of making decisions on nighttime construction, and acknowledged that air quality is not the primary motivating factor, but incorporate air quality-related findings so that they can be used in the decision-making process if needed. The framework provides different levels of insight for users based on the findings from the project. The first level provides general guidance and a list of resources for users to consult. This is followed by a screening checklist that can be used to evaluate factors that may affect nighttime construction. Finally, a quantitative calculator module is provided that can estimate the emissions impacts for a lane closure under nighttime and daytime construction scenarios.

OVERVIEW OF DECISION-SUPPORT TOOL

The tool was developed in the form of a standalone Microsoft® Excel workbook with an accompanying user guide (submitted as separate project deliverable). The tool contains three modules as described in the following.

General Information and Guidance

The General Information and Guidance section provides a brief compilation of information related to nighttime construction practices compiled as part of this research project. It includes the following sections:

- Introduction.
- Definition of nighttime construction in the context of this research project.
- Advantages and disadvantages of nighttime construction (with a link to a detailed table developed as part of earlier study tasks).
- Findings from a survey of TxDOT practice (with a link to a detailed table of construction and maintenance activities ranked in terms of suitability for nighttime construction).
- List of additional resources discussing research and practical guidance on nighttime construction activities, as well as general guidance and best practices related to work zones.

Screening Checklist

This checklist and scoring system is designed to provide an indication of the potential benefits of nighttime construction for a planned activity, based on user inputs and priorities assigned to a set of 10 criteria. The criteria were identified by the research team based on findings from the literature review and interviews, and cover the following elements:

- Noise impacts.
- Light impacts.
- Safety impacts.
- Congestion levels.
- Lane closures.
- Cost impacts.
- Access to worksite.
- Work quality.
- Air quality.
- Project-specific factors.

Each of the above criteria is associated with a question that can be answered qualitatively as a “yes” or “no” by the user. For some questions, a yes response would indicate that nighttime construction may be feasible or beneficial in terms of the specific criterion. In in other cases, a no response would indicate the same. The user is also required to provide an estimate of relative importance (expressed as a percentage weight) for each of the criteria. The user can enter “0” or “NA” to eliminate criteria from the final scoring, and the total weights assigned to the criteria of relevance must add up to a 100 percent. The checklist then generates a score as the weighted sum of the individual scores, with each response where nighttime construction is feasible or advantageous receiving a score of 1. Thus, the total weighted score is also expressed on a 0–1 scale, with a higher score indicating that there are more factors (or important/higher weight factors) that support the case for nighttime construction.

Quantitative Measures for Emissions and Traffic

The quantitative calculator module is designed to be a supplement to the screening checklist, by providing an estimate of emissions and traffic impacts for nighttime and daytime construction scenarios. The calculations are based on a simplified, sketch-level analysis, developed in a manner consistent with the case study analyses conducted as part of the study. Lane closures are used to represent the presence of a construction/maintenance activity from a traffic and emissions modeling perspective. Simplified calculation methodologies consistent with the case study approach are then used to compute the differences in emissions impact between the baseline (i.e., no lane closure), nighttime lane closure, and daytime lane closure scenarios. The estimated emissions from light plants required for nighttime construction is also included in the results.

The user is required to enter or select the following inputs to perform calculations:

- Area type (select from urban, small urban, or rural).
- Roadway type (select from interstate, freeway, principal arterial, minor arterial, major collector, minor collector, local).
- Total number of lanes in direction of lane closure.
- Number of lanes to be closed.
- Annual average daily traffic (AADT; in direction of lane closure).
- Affected roadway length.
- Duration of planned construction activity.

In addition, the user can also specify optional inputs of percentage trucks in traffic, posted speed limit (i.e., work zone speed), and the number of light plants. Once the user has entered the required information, a set of summary tables is generated, reporting the following parameters for baseline, daytime lane closure, and nighttime lane closure scenarios:

- The change in emissions (daily and for the total construction period) of CO, NO_x, VOCs, and PM_{10} between the nighttime scenario and the baseline, and the daytime scenario and the baseline.
- The change in emissions (daily and for the total construction period) attributable to nighttime lane closure instead of daytime lane closure (i.e., the net difference between the differences reported previously).
- Average speed, total delays, and average delays per vehicle.

SUMMARY

The state-of-the-practice review conducted in the preliminary stages of the project indicated that air quality is most likely not a primary factor driving a decision to move a planned construction activity to the nighttime from the daytime. At the same time, the findings from the case studies can help to quantify the potential air quality impacts, and these improved quantifications could be taken into consideration where needed. Thus, the decision-support framework includes a qualitative module aimed at scoring all relevant factors for decision-support, with the added ability to produce a quantitative, sketch-level estimate of overall emissions impacts. The decision-support tool is not meant to completely replace engineering judgment or existing processes for making decisions on nighttime construction. Rather, it aims to provide practitioners with relevant information and considerations in a systematic manner for potential consideration as part of their decision-making process.

CHAPTER 8. FINDINGS AND CONCLUSIONS

This research project studied the emissions and air quality impacts of shifting work zone and construction activities to the nighttime. The project involved the following main elements:

- State-of-the-practice review.
- Case study analyses, including assessment of construction emissions impacts, traffic emissions impacts, and impacts of meteorological conditions.
- Development of a decision-support framework to evaluate air quality impacts in relation to other factors relevant to making a decision to pursue nighttime construction.

The key findings from this research project are as follows:

- The decision to pursue nighttime construction, in Texas and elsewhere, is generally driven by the need to reduce disruptions to traffic flow and high levels of congestion that may be experienced if work is performed during the daytime. Nighttime work is most often pursued in congested corridors in urban areas.
- Nighttime construction has several potential advantages and disadvantages, in terms of congestion, safety, environmental impacts, and construction-related factors. In general, however, studies have indicated that nighttime work can be performed in many situations without adverse impacts.
- In Texas, there is no formal statewide process for pursuing nighttime construction. The decision to pursue nighttime construction is generally made during the design phase, by the area engineer in charge. Factors that were cited as influencing the decision to pursue nighttime construction included traffic impacts, lane closure requirements, project schedule (accelerated versus normal), location (commercial or residential), material availability, worker safety, TxDOT inspection staff availability, weather, and noise.
- The case study findings indicated that the differences in construction emissions between daytime and nighttime conditions are primarily due to the use of diesel-powered lighting equipment during nighttime construction.
- The case study analyses of traffic emissions impacts suggest that nighttime work zones could potentially result in lower total emissions than daytime work zones, though the impact depends on the pollutant of interest and prevailing daytime and nighttime traffic conditions.
- From a pollutant dispersion perspective, the assessment of the impact of metrological conditions on indicated that for the same amount of emissions (i.e., if traffic volumes were held equal between daytime and nighttime) higher pollutant concentration levels are expected overnight. However, given that traffic congestion and overall traffic volumes

are generally substantially lower in the nighttime period, the findings do not imply a net increase in pollutant concentrations in the region due to nighttime construction.
- Based on the case study and state-of-the-practice findings, a flexible decision-support tool was developed to allow for the qualitative assessment of factors relevant to nighttime construction, along with a sketch-level quantitative estimate of the emissions impacts of nighttime construction.

In conclusion, the findings from this study provided a systematic assessment of the emissions impacts of nighttime construction. Overall, the findings indicate the potential for emissions reduction (primarily from traffic emissions) when construction activities are moved to the nighttime in congested areas. Since air quality is not necessarily a primary consideration in the decision to pursue nighttime construction, these findings were presented in the broader context of a decision-support framework.

During the course of this project, the research team identified several areas of future research that can build on the project findings and advance better understanding of the air quality and other impacts of nighttime construction. Potential areas of future research are as follows:

- The use of real-world travel time and traffic data obtained from GPS, cellphone, or similar sources to study actual traffic behavior around worksites in the nighttime and daytime. These data sources (from commercial firms such as INRIX or through sources such as the National Performance Management Research Data Set) can provide data that is representative of real behavior, for a large sample of vehicles, in a cost-effective manner.
- Conducting further studies to characterize the activity of non-road equipment. The study revealed a lack of activity data from non-road equipment and about operations on the construction site, and limited field observations were conducted for data collection. More comprehensive studies of site operations can provide better and detailed information, on activity patterns, seasonal variations, and differences between nighttime and daytime operations. These findings can all serve to improve assessment of construction emissions impacts.
- Advancing research in the area of traffic modeling and simulation tailored for emissions and energy analysis. This study relied on the use of traffic simulation models that are generally used to assess mobility and traffic flow parameters. The current practices in traffic modeling do not necessarily account for important factors required for accurate emissions analysis, such as only modeling peak hours and lack of control for total VMT traveling across the modeled network. Better convergence of traffic and emissions modeling processes can help advance emissions estimation of work zones and nighttime construction and other air quality applications.
- The dispersion modeling analysis conducted as part of this study was a generic sensitivity analysis that provided an apples-to-apples comparison of pollutant dispersion under

nighttime and daytime conditions. There is the potential to apply these findings to real-world locations with local data to check the generalizability of the results.

- The decision-support framework developed provided a quantitative assessment of only emissions and traffic parameters, with a more qualitative approach providing flexibility to assess other factors. While a qualitative framework provides more flexibility, there is the potential for individual regions or areas (such as a TxDOT district) to develop a more quantitative framework based on local needs and considerations. Such a framework could cover the entire decision-making process, from allocating weights using MCDM techniques to developing quantitative performance measures using local data.
- In addition to investigating air quality issues, a similar study could be performed to understand noise impacts between daytime and nighttime construction scenarios. Differences in terms of the receiver experience (i.e., noise experienced by receivers) are expected, given lower background levels at night.
- Finally, from an occupational exposure perspective, there is the need to understand the differences between daytime and nighttime construction in terms of worker health, taking into account factors such as emissions exposure and fatigue levels.

APPENDIX A. SUPPLEMENTARY DETAILS ON TXDOT SURVEY OF PRACTICE

INTERVIEW DETAILS

Table 25 shows the list of TxDOT staff interviewed and interview dates.

Table 25. TxDOT Staff Interviewed and Interview Dates.

District	Office	Date
AUS	Director of Construction	June 5, 2015
	Director of Transportation Planning & Development	June 25, 2015
DAL	Director of Construction	June 5, 2015
	Director of Transportation Planning & Development	June 22, 2015
	Area Engineer	June 30, 2015
FTW	Director of Construction	June 2, 2015
	Director of Transportation Planning & Development	June 4, 2015
SAT	Director of Construction	June 10, 2015
	Director of Transportation Planning & Development	June 2, 2015
HOU	Director of Construction	June 8, 2015
	Director of District Design	June 23, 2015
ELP	District Construction Engineer	July 1, 2015
	Area Engineer	July 3, 2015
	Area Engineer	July 13, 2015

INTERVIEW QUESTIONNAIRE

TTI is conducting a study for TxDOT to characterize and quantify the benefits of shifting construction activities to nighttime. The information you provide will be used to develop a decision-support framework to help TxDOT evaluate the impacts (including air quality impacts) of nighttime construction on a systematic basis. All TxDOT districts will benefit from this framework, especially those districts in nonattainment[4] and near-nonattainment areas.

This survey developed a comprehensive assessment of the TxDOT state-of-the-practice for the decision-making process for nighttime construction. Please respond to the following questions in a detailed and factual manner. There may be more than one applicable response, so please provide all responses that apply.

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[4] A nonattainment area is an area considered to have air quality worse than the National Ambient Air Quality Standards as defined in the Clean Air Act Amendments of 1970 (P.L. 91-604, Sec. 109).

1) Has there been any nighttime construction in your area (or district) in the past 5 years? Have you dealt with nighttime construction (decision making, preparations, oversight, traffic control, etc.)? If yes, in what roles?

2) Please identify candidate sites where nighttime construction is planned between June 2015–January 2016 along with the area office contact information.

3) At what point in the project design process is the decision for nighttime construction made? Does project size or type (small versus large, or construction versus maintenance projects) influence the decision?

4) Which offices provide input for deciding to perform nighttime construction? Which office makes the final decision on nighttime construction? How much flexibility in terms of when, where, and what operations is allowed for nighttime construction? What role grants this flexibility? When is flexibility withheld?

5) Are there entities outside of TxDOT with a role in this process (e.g., contractors, local/city officials, public)? How do these external stakeholders provide input into this?

6) Is there a formal or informal (i.e., developed in-house) process, flowchart, or checklist that is used by the district to help in the nighttime construction decision-making process? If yes, please share examples of this documentation with us via email or TxDOT Dropbox.

7) How far in advance of the activity is the decision made to conduct a nighttime operation?

8) What factors influence the nighttime construction decision? List and rank the factors from most important to least important. How are these factors used in the decision-making process? Are air quality or other environmental factors (e.g., noise) considered in the decision-making process for nighttime construction? If yes, please provide a recent example of a project in which these factors were considered.

9) For projects in which more than one traffic control option appears to meet the project objectives for nighttime construction, NCHRP recommends performing cost-effectiveness analysis. Is that the practice at your office? If not, how are decisions made concerning traffic control options?

10) What are the major impediments to performing nighttime construction? What public feedback has your office received about nighttime construction?

11) What are the differences in operation between daytime and nighttime work (e.g., cost, equipment, personnel, production)?

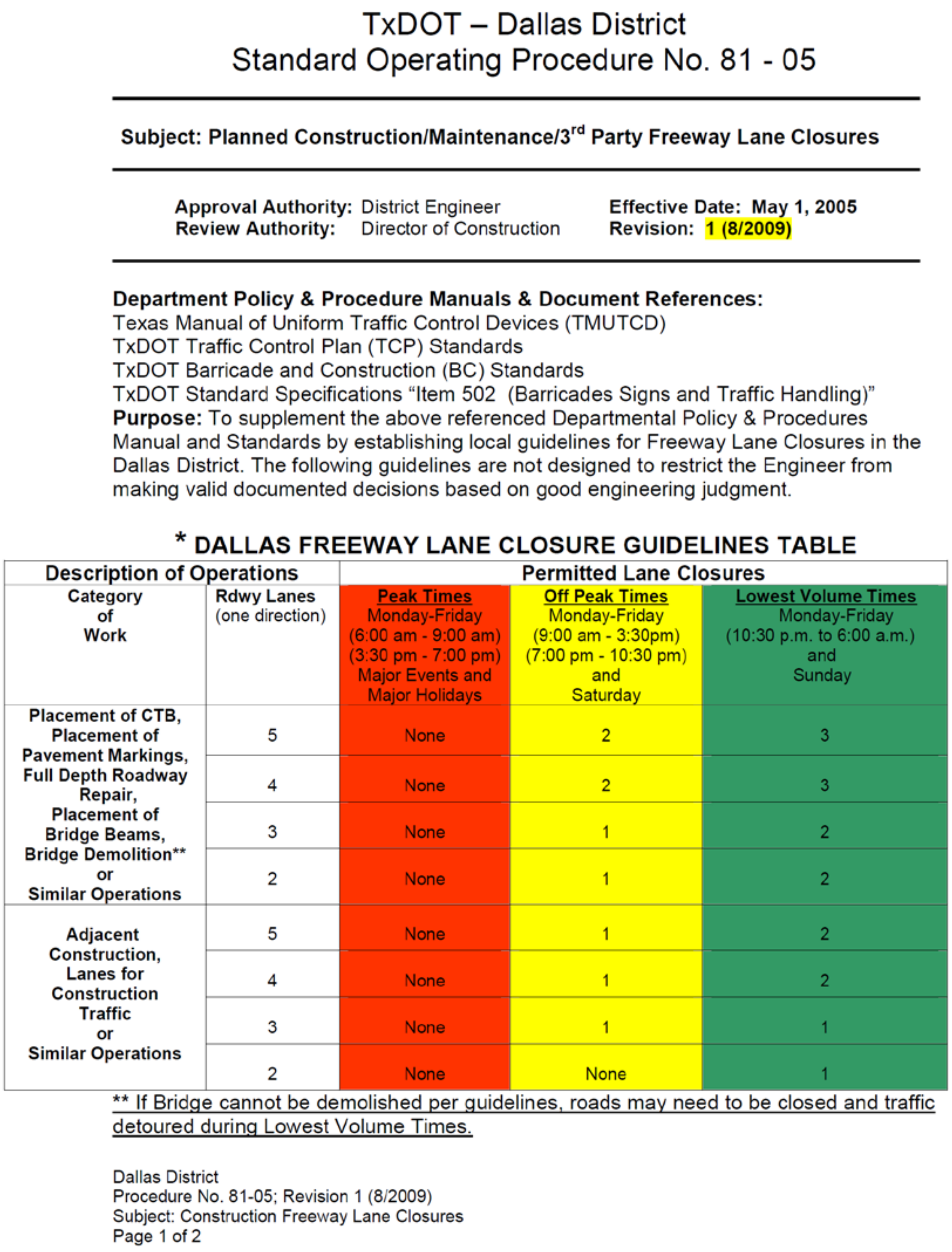
12) Please review Table 26. Which activities are best suited for nighttime work and why? Which activities are least suited for nighttime work and why? Please rank the listed activities as High, Medium, and Low based on suitability for nighttime operations.

Table 26. Suitability Ranking for Nighttime Operations (H=Highly Suitable; M=Moderately Suitable; and L=Least Suitable).

Rank	Construction Activity	Explanation for Given Rank	Rank	Maintenance Activity	Explanation for Given Rank
	Earthwork: excavation/embankment/backfill			Reworking shoulders	
	Subgrade			Maintenance of Earthwork/Embankment	
	Subbase and base course			Drainage structures maintenance & rehabilitation	
	Bituminous surfaces and pavements			Sidewalks repair & maintenance	
	Concrete sawing			Milling and removal	
	Bridge construction			Repair of concrete pavement	
	Shoulders: bituminous and Portland cement concrete			Resurfacing	
	Highway signing			Bridge decks rehab. and maintenance	
	Pavement marking: striping & markers			Pot hole filling	
	Electrical wiring and cables			Waterproofing/sealing	
	Culverts and sewers			Crack filling	
	Drainage structures			Sweeping and cleanup	
	Electrical poles/lighting/traffic signals			Surface treatment	
	Guardrail and fences				
	Erosion control: riprap/ditch lining				
	Landscaping: seeding/mulch/sodding/planting				
	Concrete pavement and sidewalks				
	Work traffic control				

APPENDIX B. DOCUMENTATION OF TXDOT PROCEDURES

DALLAS DISTRICT STANDARD OPERATING PROCEDURES



TxDOT – Dallas District
Standard Operating Procedure No. 81 - 05

Subject: Planned Construction/Maintenance/3rd Party Freeway Lane Closures

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Approval Authority: District Engineer **Effective Date: May 1, 2005**
Review Authority: Director of Construction **Revision: 1 (8/2009)**

Department Policy & Procedure Manuals & Document References:
Texas Manual of Uniform Traffic Control Devices (TMUTCD)
TxDOT Traffic Control Plan (TCP) Standards
TxDOT Barricade and Construction (BC) Standards
TxDOT Standard Specifications "Item 502 (Barricades Signs and Traffic Handling)"
Purpose: To supplement the above referenced Departmental Policy & Procedures Manual and Standards by establishing local guidelines for Freeway Lane Closures in the Dallas District. The following guidelines are not designed to restrict the Engineer from making valid documented decisions based on good engineering judgment.

*** DALLAS FREEWAY LANE CLOSURE GUIDELINES TABLE**

Description of Operations		**Permitted Lane Closures**		
Category of Work	**Rdwy Lanes** (one direction)	**Peak Times** Monday-Friday (6:00 am - 9:00 am) (3:30 pm - 7:00 pm) Major Events and Major Holidays	**Off Peak Times** Monday-Friday (9:00 am - 3:30pm) (7:00 pm - 10:30 pm) and Saturday	**Lowest Volume Times** Monday-Friday (10:30 p.m. to 6:00 a.m.) and Sunday
Placement of CTB, Placement of Pavement Markings, Full Depth Roadway Repair, Placement of Bridge Beams, Bridge Demolition or Similar Operations**	5	None	2	3
	4	None	2	3
	3	None	1	2
	2	None	1	2
Adjacent Construction, Lanes for Construction Traffic or Similar Operations	5	None	1	2
	4	None	1	2
	3	None	1	1
	2	None	None	1

** If Bridge cannot be demolished per guidelines, roads may need to be closed and traffic detoured during Lowest Volume Times.

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*** The Table above is only to be used when traffic counts do not exceed 2000 Vehicles per Lane per Hour. (The capacity of all remaining open lanes must not exceed 2000 Vehicles per Lane per Hour). When traffic counts do or will exceed 2000 Vehicles per Lane per Hour, Director of Construction, Assistant District Engineer or District Engineer approval will be required for lane closures.**

Additional General Guidelines:

1. The safety of workers and the traveling public must be the first consideration when determining closures.
2. Lane closures must be coordinated with adjacent projects. First closure submitted will generally have priority.
3. If reasonable mobility can be maintained, or exceptional circumstances exist, additional lanes may be closed during Off Peak Times or Lowest Times with written permission of the District Director of Construction. Off Peak Times may be started earlier or be extended later if reasonable mobility can be maintained.
4. If at any time backups become unreasonable, (>20 min.), modifications to alleviate the congestion should be taken immediately. Contingency plan of how this will occur should be in place and approved by the District Director of Construction.
5. The Engineer or their representative should meet with Contractor prior to roadway and lane closures to ensure sufficient equipment, materials, devices and manpower will be used. Contingency plans should also be discussed.
6. Inclement weather should be considered when determining closures.
7. The PIO should be informed by 3:15 p.m. on the previous day of all road closures or major lane closures that will affect mobility so they can inform the public, emergency services, schools, etc. as needed.
8. Notify the traveling public by placing Changeable Message Signs a minimum of seven calendar days in advance of the actual closure. Where available, utilize the Dynamic Message Signs maintained by the Freeway Management Section.
9. Use off duty uniformed Peace Officers as directed by the Engineer.
10. **Any freeway closed for construction purposes must have written approval from the District Director of Construction, Assistant District Engineer or District Engineer.**
11. Any complete roadway closure will require a Traffic Control Plan to be submitted by the Contractor and approved by the Engineer. Availability of frontage roads, ramp locations and detour distance should be considered. Planned freeway closures should only be allowed during Lowest Volume Times.
12. Procedures in SOP No. 9-04(Dallas District Lane Closure System (Daltrac) should be followed.

Duration/Update:

This Standard Operating Procedure will remain in effect until revised or rescinded. Recommendations to modify or clarify this document should be submitted in writing to the Review Authority.

William L Hale

8/13/09
Approval Date

William L. Hale, P.E.
District Engineer

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CONSIDERATIONS FOR A TCP NIGHTTIME/WEEKEND CONSTRUCTION ACTIVITIES IN THE SAN ANTONIO DISTRICT

Nighttime construction activity introduces unique and significant challenges that must be proactively addressed to create safe work zone environments. Below is guidance and associated recommendations for each category listed below. This will assist designers and maintenance supervisors in their efforts to improve safety performance.

Construction/Maintenance-Roadway Construction			
Classification	Type of Projects	If Nighttime work is justified (work not behind barrier) Additional Measures that should be included in plans	If Nighttime work is justified (work not behind barrier) Additional Measures that shall be included in plans
Metro -Bexar County	-Mill, Seal, Overlays -Work approved on a Case by case basis	1. Take Additional lanes a. If one lane is available to through traffic 2. Full closures a. Detour available (not longer than # miles) b. One-way direction frontage roads c. Outside major city limits d. Low commercial driveway density 3. Speed reduction via Minute Order 4. Pilot cars 5. Temporary barrier (water filled) 6. Rumble strips (normally rqd) 7. Temp Lighting 8. WZ Intrusion system 9. Law enforcement 10. No Friday or Sat Closures 11. Longer PM hours 12. More PCMS 13. Traffic calming devices 14. RPM in lieu of Traffic buttons 15. STOP/SLOW LEDs 16. Run Q-DAT http://crossroads/org/trf/q-dat.htm 17. Additional Measures*	Include in Gen Notes 1. Full TY 3 Reflective Gear 2. @ Flagging stations: Hard Hat Halo's 3. TY III 500 ft spacing 4. Mandatory Night Work Meeting a. Pickup procedure
Urban -New Braunfels	-Mill, Seal, Overlays -Work approved on a Case by case basis		
Rural -Kerr, Kendall, Guadalupe, Comal, Wilson, Atascosa, Uvalde, Medina, Frio, Bandera	None		

Maintenance Activities			
Type of Work	Type of Projects	If Nighttime work is justified (work not behind barrier) additional Measures that should be included in plans	If Nighttime work is justified (work not behind barrier) additional Measures that shall be included in plans
1. Asphalt Work a. Edging b. Pot Hole Repair c. Seal Coat d. Base Repairs e. Mill/Inlays f. Overlays g. Level-ups h. Crack Seal ***2. Sign Work*** a. Small Sign Repair b. Large Sign Repair c. Delineation ***3. Signal Work*** a. Signal Head Work b. Signal Box Work ***4.*** **ITS (Transguide)** a. CCTV & Sensors b. Cabinet work ***5. R.O.W. Work*** a. Herbicide b. Brush Control c. Litter/Debris d. Rail/Cable Barrier e. Survey f. Street Sweeping g. Ditch Work h. Mowing/Hand Trimming i. Graffiti Removal j. Removal of Illegal Signs/Encroachments	ALL	1. Take Additional lanes 2. Full closures 3. Speed reduction via Minute Order 4. Pilot cars 5. Temporary barrier (water filled) 6. Rumble strips (normally rqd) 7. Temp Lighting 8. WZ Intrusion system 9. Law enforcement 10. No Friday or Sat Closures 11. Longer PM hours 12. More PCMS 13. Traffic calming devices 14. RPM in lieu of Traffic buttons 15. STOP/SLOW LEDs 16. Run Q-DAT 17. http://crossroads/org/trf/q-dat.htm 18. Full TY 3 Reflective Gear 19. @ Flagging stations: Hard Hat Halo's 20. TY III 500 ft spacing 21. Mandatory Night Work Meeting 22. Additional Measures*	

k. Miscellaneous Concrete Repair (rip rap, etc.) l. Cable Barrier/Guard Rail Repair m. Mailboxes ***6. General*** a. ***Flagging*** b. ***Placing traffic control devices*** c. ***Placing temporary work zone markings/markers***			

APPENDIX C. CANDIDATE CASE STUDY PROJECTS

List of All Projects That Involve Nighttime Construction as Provided by Area Engineers and Other TxDOT Staff.

District	Project No.	Begin Date/ Proceed Date*	Project Complete (08/17/15)	Project Type	Project Scope	Area Type	Road Classification	Cooperation from Contractor
SA	052106135	01/02/2015	19%	Maintenance	Resurface roadway	Urban	IH 410	Possible
	025304148	01/31/15*	0%	Maintenance	Resurface roadway	Urban	SS 537	N/A
	084901047	10/5/2015	0%	Construction	Install/upgrade safety barrier	Urban	FM 471	Yes
	052104274	07/31/2015*	0%	Construction	Construct int direct connection ramp	Urban	IH 410	N/A
	007208120	1/2/2012	85%	Construction	Construct new roadway lanes	Urban	IH 10	Possible
HOU	027114228, 213	11/20/2012	62%,34%	Construction	Construct int direct connection ramp	Urban	IH 610	N/A
	017711150	9/15/2015	0%	Maintenance	Repair bridge	Urban	IH 69	Yes
	027114217	6/20/2011	93%	Construction	Construct interchange	Urban	IH610	Possible
	050003042, 44	12/17/2012	46%,28%	Construction	Widen roadway	Urban	IH 45	No
	050003462, 042	6/17/2011	76%	Construction	Widen roadway	Urban	IH 46	N/A
	02712105	4/17/2014	30%	Construction	Widen roadway	Urban	US 59	N/A
	02712097	9/23/2014	22%	Construction	Widen roadway	Urban	IH 69	N/A
FTW	106805009	10/1/2013	90%	Construction	Construct interchange	Rural	IH 30	N/A
	00803103	10/27/2014*	0%	Construction	Widen bridge	Rural	IH 20	N/A
ELP	212104093	4/15/2015	25%	Construction	Construct interchange	Urban	IH 10	N/A
DAL	TBO/Horseshoe			Construction		Urban		No
	035304098	9/10/2015	15%	Maintenance	Repair roadway	Urban	SS 348	Yes
AUS	001609033	6/1/2015	7%	Construction	Construct overpass/underpass	Urban	LP 82	Possible
	026505071	3/2/2015	26%	Construction	Construct overpass/underpas	Urban	SH 71	Possible

Note: * Refers to “Notice to Proceed Date” and may not necessarily reflect that construction has started; TBO refers to projects whose numbers are yet “To Be Obtained” as they were not available at the time.

More details about the project can be found at http://apps.dot.state.tx.us/apps-cq/project_tracker/.

APPENDIX D. DATA COLLECTION FORMS FOR RECORDING EQUIPMENT ACTIVITY

EQUIPMENT W/ ENG HOURS

Date: **Project:** **Contractor:**

Contractor Equipment ID	Equipment Type	Engine Model Year	Fuel Type	Engine HP	Possible DT Use (Y/N)	Vehicle Identification Number (VIN), if applicable	Engine Hours Start of Night	Engine Hours End of Night

VEHICLES W/ MILEAGE

Date: **Project:** **Contractor:**

Contractor Vehicle ID	Vehicle Type	Model Year	Fuel Type	Gross Vehicle Weight	Vehicle Identification Number (VIN)	Mileage Start of Night	Mileage End of Night

APPENDIX E. USE OF TEXN MODEL TO ESTIMATE EMISSIONS

STEP 1: TEXN MODEL SETUP

This step consists of identifying the input parameters and their values for estimating EFs from the TexN model. Table 27 lists the key input parameters and their values used to run TexN in this project. A description of these items follows the table.

Table 27. Input Data Parameters for TexN Model.

Parameter	Parameter Values
TexN Model Version	1.7.1 (TCEQ)
Analysis Year	2016
Time Periods	Summer Season
Met Data	Typical Year (Default)
Altitude	Low (Default)
Fuels	Latest available county-level fuel data
Controls Programs	TXLED, Temperature Corrections
Pollutants	NO_x, SO_2, VOC, CO, PM_{10}, $PM_{2.5}$
Counties	Fort Worth (DFW): Tarrant Temple (TEM): Bell Houston (HGB): Harris El Paso (ELP): El Paso San Antonio (SAN): Bexar
Source types- Major Classification	Construction and Mining Equipment

Analysis Year—It is proposed that the current time period is selected for the analysis (analysis year 2016). This served as a conservative estimate, due to anticipated reductions in emissions from future year fleets based on fleet turnover and more stringent emissions standards.

County Selection—The construction activity sites the research team visited are in the Houston District and Fort Worth District. Since TexN is capable of modeling at the county level, Harris and Tarrant are identified as the representative counties for estimating emission factors. Other nonattainment areas such as El Paso and near nonattainment counties such as San Antonio were modeled so that the emission factor is weighted with these areas and can be used in these areas to estimate emissions impacts.

Equipment Type—The TexN model provides separate equipment population and activity profiles for various different application sectors. The primary equipment categories modeled include recreational vehicles (ATVs, off-highway motorcycles), logging, agricultural, construction/mining, industrial/commercial (e.g., warehouse forklifts), lawn and garden (commercial and residential), recreational marine engines, airport ground support equipment, and railway maintenance. Appendix F shows the source classification codes for assigning the data collected in the field.

The construction/mining category is identified as the major equipment category for estimating the emission factors for this project. DCE is one of the major emitters of NO_x emissions in urban areas (*89*). In TexN, DCE is further divided into two sectors, those that have significant earthwork and surfacing requirements, and those that do not. Highway construction activities such as state highway and bridge work, and city/county roads are included under the earthwork project category. This project uses the TexN default values for the equipment fuel mix corresponding to each Texas region's equipment population, which are based on local specific conditions (*90*).

Meteorology and Fuel Supply Parameters—TexN contains local specific meteorological, fuel supply, and control program information for all regions of Texas. These values are used in this analysis as listed in Table 28 and Table 29.

Table 28. Fuel Properties from TexN Model.

Region	CNG/LPG Sulfur	Diesel Sulfur %	Gas Sulfur %	Marine Diesel Sulfur %	Oxygen Weight %	RVP	Season
DFW	0.003	0.000565	0.00309	0.0056	3.3757	7.25	Summer
HGB	0.003	0.000512	0.00280	0.0056	3.4189	7.09	Summer
SAN	0.003	0.000464	0.00347	0.0056	3.3366	7.56	Summer
ELP	0.003	0.000545	0.00148	0.0056	3.4092	6.83	Summer
TEMPLE	0.003	0.000597	0.00339	0.0056	3.3980	7.51	Summer

Table 29. Meteorological Data (TexN Model).

Region	Season	Minimum Temperature (ºF)	Maximum Temperature (ºF)	Average Temperature (ºF)	Relative Humidity (%)
DFW	Summer	73.6	94.4	83.9	60.3
HGB	Summer	73.2	92.8	82.3	74.4
SAN	Summer	74.2	93.6	82.7	68.8
ELP	Summer	71.7	94.4	83.3	37.4
TEMPLE	Summer	71.9	95.0	83.3	63.2

STEP 2: RUNNING TEXN MODEL

This step consists of running the TexN model with the input parameters identified in Step 1. TexN model is pre-populated with population and activity data for different equipment types derived from equipment sales database, with activity estimates provided by industry experts for different counties in Texas (*90*).

Outputs of TexN are in the form of total emissions disaggregated by equipment type, pollutant, emission process, horse power (hp), and load factor. Equipment population and activity levels (in terms of hours of equipment usage in a year) disaggregated by hp, load factor, and equipment type are also provided in the TexN outputs.

STEP 3: ESTIMATING TOTAL EMISSIONS, POPULATION, AND ACTIVITY LEVELS

The total emissions, population, and activity outputs from Step 2 are processes to extract the information corresponding to each equipment type, hp, and pollutant. TexN estimates emissions for different processes such as exhaust, crankcase, hot-soak, running-loss, or spillage. Depending on the pollutant, the emissions information for each process can be aggregated to generate a combined number for each pollutant, hp, and equipment type.

Table 30 shows the results of this step for diesel-fueled lighting equipment (SCC 2270006005). TexN does not estimate VOC emissions. The research team used the EPA recommended methodology to estimated VOC emissions.[5]

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[5] VOC emissions are estimated by multiplying THC emissions by a factor of 1.053. https://www3.epa.gov/otaq/models/nonrdmdl/nonrdmdl2010/420r10015.pdf.

Table 30. TexN Model Output Emissions for Diesel Lighting Equipment.

Engine Horsepower	Population	THC-Exhaust (tons)	NOx-Exhaust (tons)	Fuel Consumption (gal/season)	Activity (hr)	Load Factor
6	1,604.49	0.25	1.51	17,761.50	135,623.00	15.05
11	1,602.05	0.40	2.39	28,107.40	135,417.00	15.05
16	1,234.82	0.43	2.84	35,075.90	104,376.00	15.05
25	1,944.34	1.05	7.00	86,500.30	164,349.00	15.05
40	3,218.28	1.81	16.34	224,510.00	272,032.00	15.05
50	439.56	0.33	3.02	41,497.50	37,154.60	15.05
75	1,621.86	1.85	15.49	203,250.00	137,091.00	21.50
100	1,973.86	3.22	24.05	356,202.00	166,845.00	21.50
175	673.73	1.28	12.52	171,767.00	56,948.60	21.50
300	374.58	1.15	11.56	167,493.00	31,662.40	21.50
600	194.56	0.90	10.56	153,269.00	16,445.80	21.50

STEP 4: CALCULATING EFS

The EFs for each engine power category of diesel lighting equipment are calculated by dividing the total emissions numbers (Table 31) by the total activity of the same category (Equation E-1). The default population estimates from TexN were converted to population mix for each hp bin and then averaged over all regions modeled to estimate the average population mix provided below. The EFs shown for each region are calculated using Equation E-1, and the average EF for NO_x and VOC shown below is an average for all regions:

$$\boldsymbol{EFs_{pollutant.hp} = \frac{Total\ Emissions(\frac{grams}{year})}{Activity\left(\frac{hr}{year}\right)}} \qquad \textbf{(Eq. E-1)}$$

Table 31. Emissions Factors Estimated for Light Plants.

Horse Power (HP)	Avg Pop Mix	NO$_x$ (g/hr)					Avg. NO$_x$ (g/hr)	VOC (g/hr)					Avg. VOC (g/hr)
		DFW	HGB	TEM	SAN	ELP		DFW	HGB	TEM	SAN	ELP	
6	11%	10.6	10.1	10.5	10.3	11.6	10.6	1.8	1.8	1.8	1.8	1.8	1.8
11	11%	16.8	16.0	16.7	16.4	18.4	16.8	2.8	2.8	2.8	2.8	2.8	2.8
16	8%	25.8	24.7	25.7	25.2	28.3	25.9	3.9	3.9	3.9	3.9	3.9	3.9
25	13%	40.5	38.6	40.2	39.4	44.5	40.6	6.1	6.1	6.1	6.1	6.1	6.1
40	22%	57.1	54.5	56.7	55.6	62.8	57.4	6.3	6.3	6.3	6.3	6.3	6.3
50	3%	77.3	73.7	76.7	75.3	85.0	77.6	8.6	8.6	8.6	8.6	8.6	8.6
75	11%	107.8	102.5	106.9	104.8	119.1	108.2	12.9	12.9	12.9	12.9	12.9	12.9
100	13%	137.5	130.7	136.4	133.7	151.9	138.0	18.4	18.4	18.4	18.4	18.4	18.4
175	5%	210.9	199.5	209.0	204.4	234.7	211.7	21.5	21.5	21.5	21.5	21.5	21.5
300	3%	351.3	331.3	348.0	339.9	392.8	352.7	34.8	34.8	34.8	34.8	34.8	34.8
600	1%	617.4	582.3	611.6	597.4	690.2	619.8	52.4	52.4	52.4	52.4	52.4	52.4

STEP 5: GENERATE COMPOSITE EFS AND AVERAGE ACTIVITY RATE

Researchers converted the EFs corresponding to different hp categories obtained from Step 4 into a composite EF corresponding to each pollutant. The EF from Step 4 is provided for different hp for light plants. In Step 5, research team needed to calculate one average EF that could be used entire state. From the data collected and conversation with contractors, the hp of light plants used at construction site fell in the range of 11–20. EFs for all pollutants of interest were extracted from the data for light plants with hp 11 and 16 with corresponding population percentages (model default) as Table 32 shows. Normalized population (equals to 1.0) percentage for the light plants with hp 11 and 16 were weighted to the EF to estimate a single composite factor for each pollutant as Table 32 shows. This composite EF based on the region-specific default population distribution of the equipment type and hp in the modeled regions is estimated in accordance with Equation E-2:

$$\boldsymbol{CompositeEFs_{pollutant}} = \textstyle\sum_{\boldsymbol{pollutant}}(\boldsymbol{EF_{equipment,hp}} \times \boldsymbol{population\ Mix_{equipment}.\ hp})$$

(Eq. E-2)

Table 32. Composite Emissions Factor Estimation for Light Plant Equipment.

Pollutant	Horse Power (HP)	Normalized Pop Mix (%)	Emissions Factors (g/hr)					Avg EF (g/hr)
			DFW	HGB	TEM	SAN	ELP	
NO_x	11	56%	16.8	16.0	16.7	16.4	18.4	16.8
	16	44%	25.8	24.7	25.7	25.2	28.3	25.9
VOC	11	56%	2.8	2.8	2.8	2.8	2.8	2.8
	16	44%	3.9	3.9	3.9	3.9	3.9	3.9
PM_{10}	11	56%	2.0	2.0	2.0	2.0	2.0	2.0
	16	44%	2.5	2.5	2.5	2.5	2.5	2.5
CO	11	56%	16.4	16.4	16.4	16.4	16.4	16.4
	16	44%	16.3	16.3	16.3	16.3	16.3	16.3

APPENDIX F. TRAFFIC SIMULATION DETAILS AND RESULTS

SIMULATION NETWORKS

The network was coded by defining links and connectors with appropriate roadway geometry and lane configurations, vehicle input points, routing decisions, and all traffic control elements.

Figure 44 shows the simulation network for Case Study 1 (I-35). It covers an approximately 14-mi section of the freeway and frontage road system in the northbound direction. At this location, the freeway has both two- and three-lane segments. The 0.6-mi work zone occurs within the two-lane segment and involves closure of the right lane.

Figure 45 shows the simulation network for Case Study 2 (I-10). It includes an approximately 8-mi section of the freeway in both directions and contains connected major roadways. At this location, the freeway has both three- and four-lane segments. The 0.9-mi work zone occurs in the three-lane segment and involves the closure of a single lane.

Figure 46 shows the simulation network for Case Study 3 (W. Paisano Drive). It covers an approximately 2.9-mi section of the arterial in both directions. W. Paisano Drive has two lanes in each direction. The 0.35-mi work zone is located on the eastbound approach to the signalized intersection with Executive Center Boulevard.

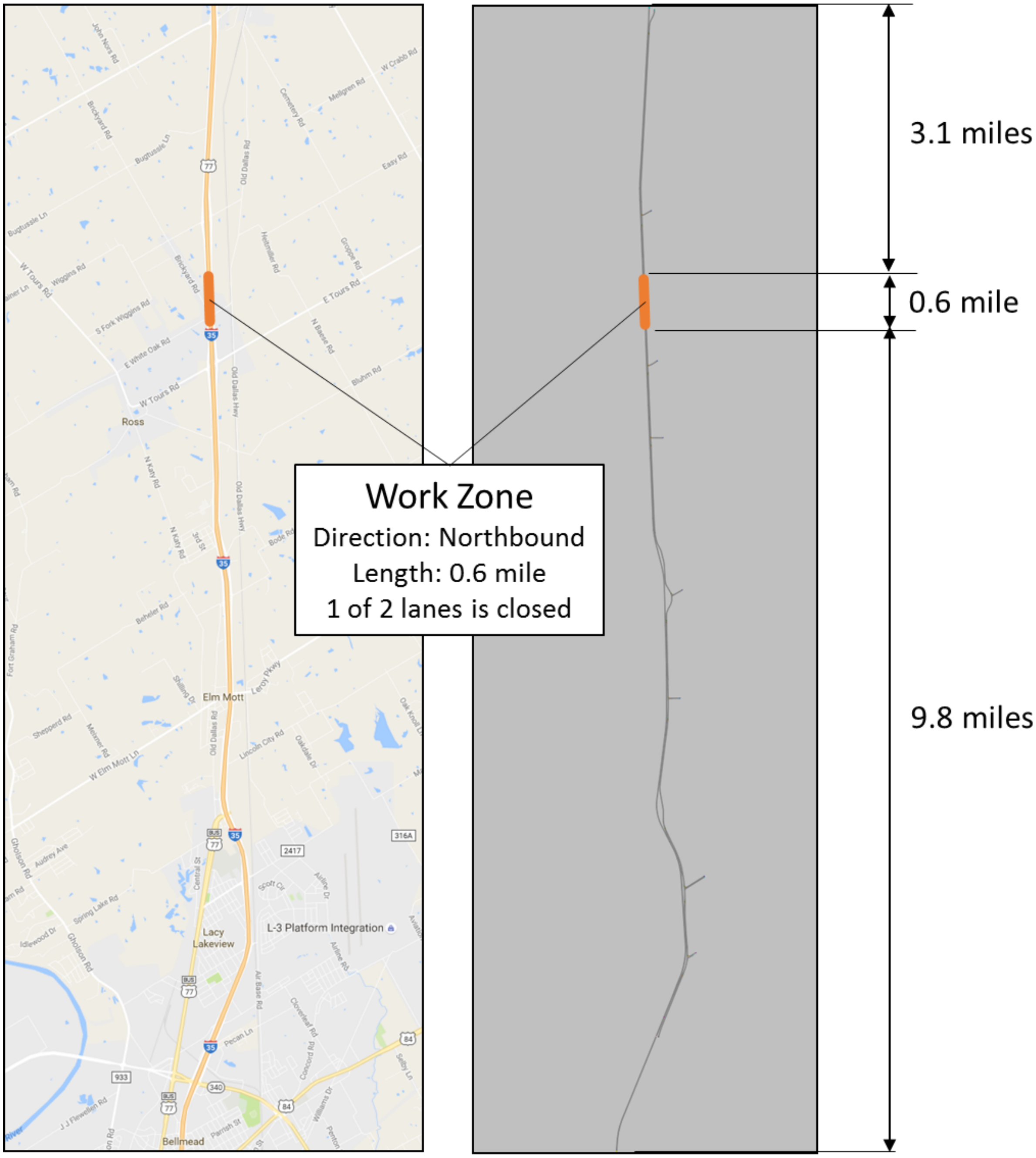
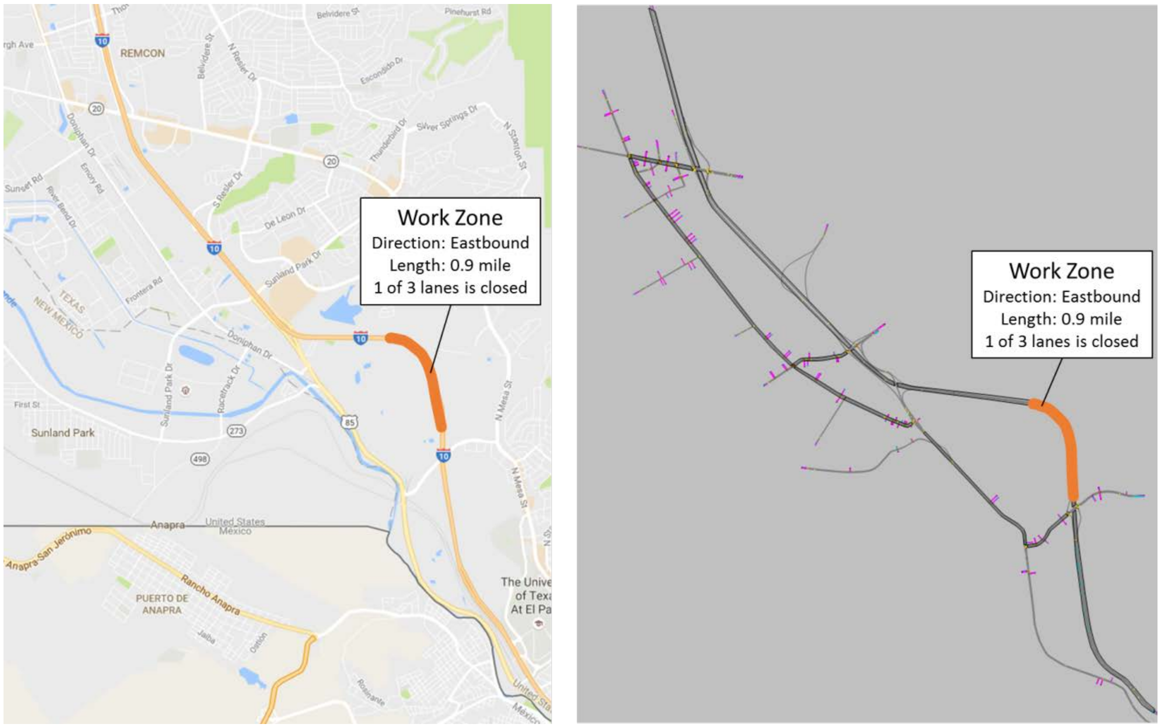


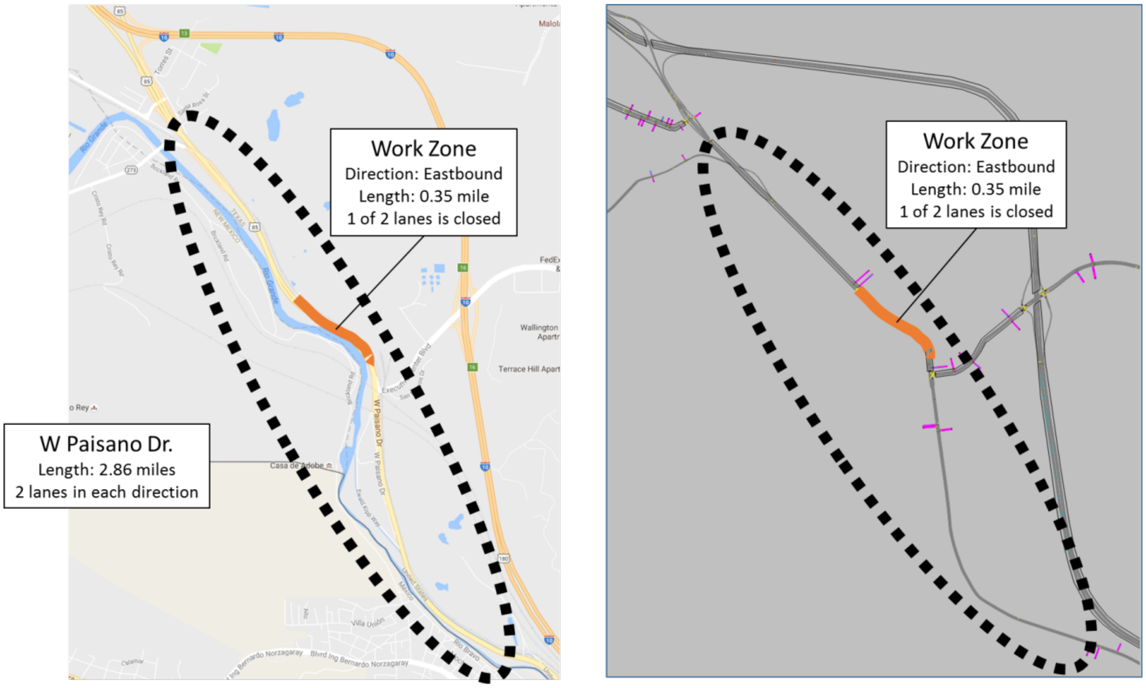
Figure 44. I-35 Simulation Test Bed.



Work Zone
Direction: Eastbound
Length: 0.9 mile
1 of 3 lanes is closed

Work Zone
Direction: Eastbound
Length: 0.9 mile
1 of 3 lanes is closed

Figure 45. I-10 Simulation Test Bed.



Work Zone
Direction: Eastbound
Length: 0.35 mile
1 of 2 lanes is closed

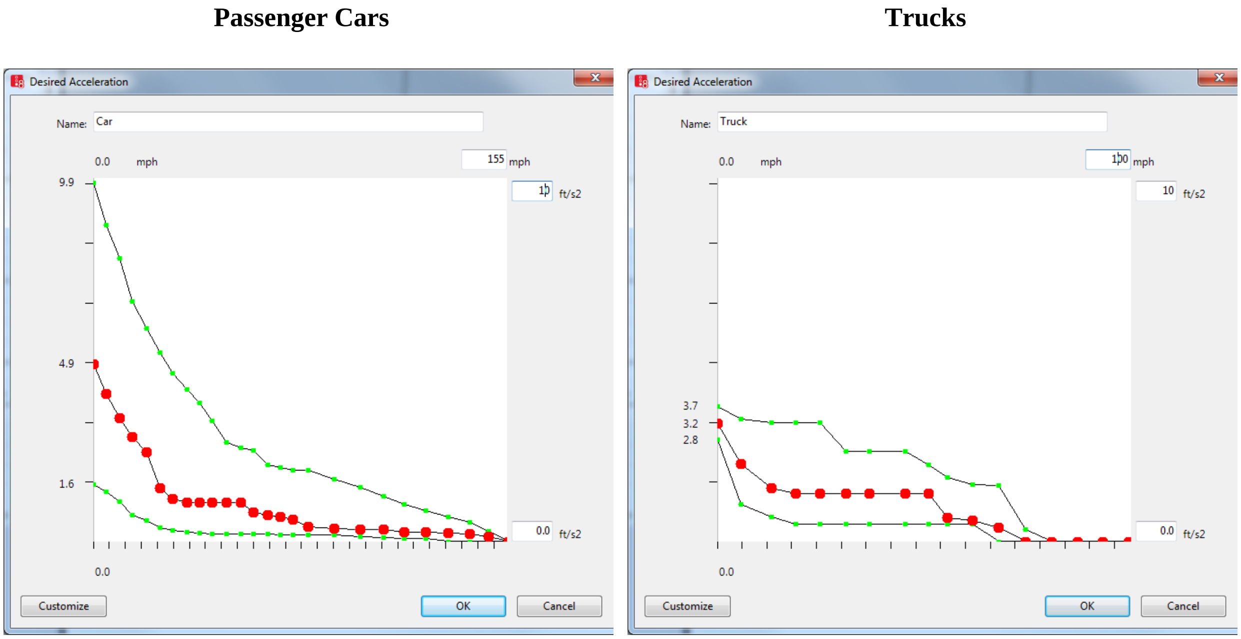
W Paisano Dr.
Length: 2.86 miles
2 lanes in each direction

Work Zone
Direction: Eastbound
Length: 0.35 mile
1 of 2 lanes is closed

Figure 46. W. Paisano Drive Simulation Test Bed.

Vehicle Types

Two vehicle types, passenger cars and heavy-duty trucks, were defined with attributes that are typical to Texas vehicles and drivers. Figure 47 shows an example of model parameters that were adjusted to represent realistic driving behaviors; in this case, acceleration functions were derived from data collected in a recent TxDOT study (*91*). These fine-scale model behaviors are important because they can affect both traffic behavior and emissions.


Passenger Cars

Trucks

Desired Acceleration

Name: Car

Name: Truck

Figure 47. Texas-Specific Desired Acceleration Functions.

The output of the microsimulation model was configured to produce the data required to:

- Estimate the emission impacts of work zones using the EPA's MOVES version 2014a emissions model.
- Assess mobility performance measures such as travel times, delays, and queue lengths.

Traffic Volumes

Traffic volumes were defined to represent a typical weekday at the case study site, using hourly volume data. For the case study site on I-35, six-month historical volumes collected by a Wavetronix radar sensor located in north Waco were analyzed, and hourly average volumes were determined for each day of the week. Volumes from Wednesday 6 a.m. to 7 p.m. were used for the simulation of daytime construction scenarios, and volumes from Wednesday 7 p.m. to Thursday 6 a.m. were used for nighttime construction scenarios (Figure 48).

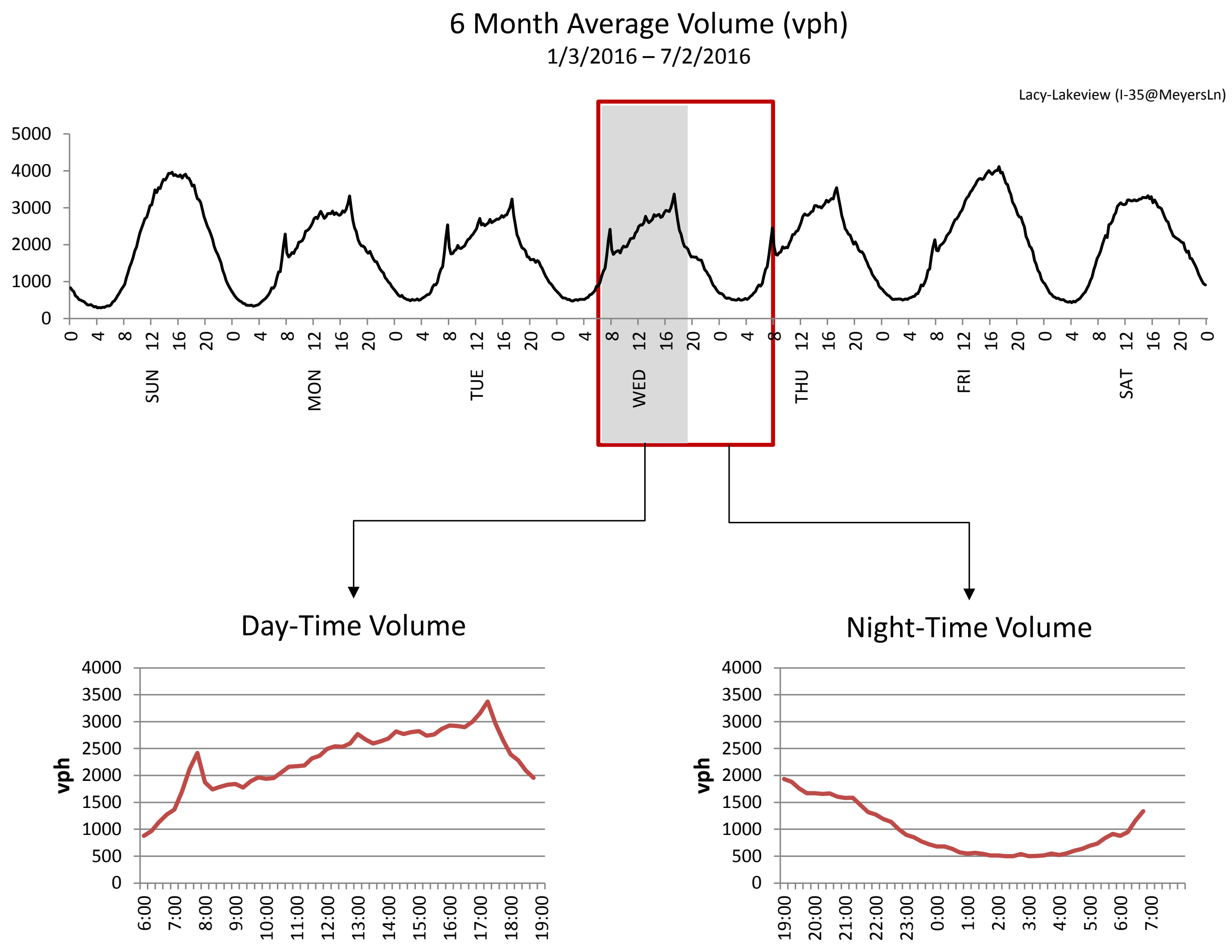


Figure 48. Traffic Volume Input for the Case Study Site on I-35.

For the case study sites in El Paso, typical weekday traffic volumes were extracted from a regional dynamic traffic assignment (DTA) mesoscopic model. The TTI research team used the model to determine the travel demand matrix for microsimulation runs and to extract the network layout and characteristics of the study area from the broader El Paso network. To achieve this, a mesoscopic-to-microscopic tool developed by TTI was used to transfer link geometry, paths, speeds, and traffic volumes to a microlevel software platform (VISSIM). All paths captured from the DTA model were transformed to time-dependent static routes and vehicle flows to represent current traffic conditions in the study area.

MODEL CALIBRATION

The traffic simulation model was calibrated to ensure that it accurately replicated field conditions. Field data collected at a nighttime work zone on I-35 in north Waco were used for model calibration (Figure 49).

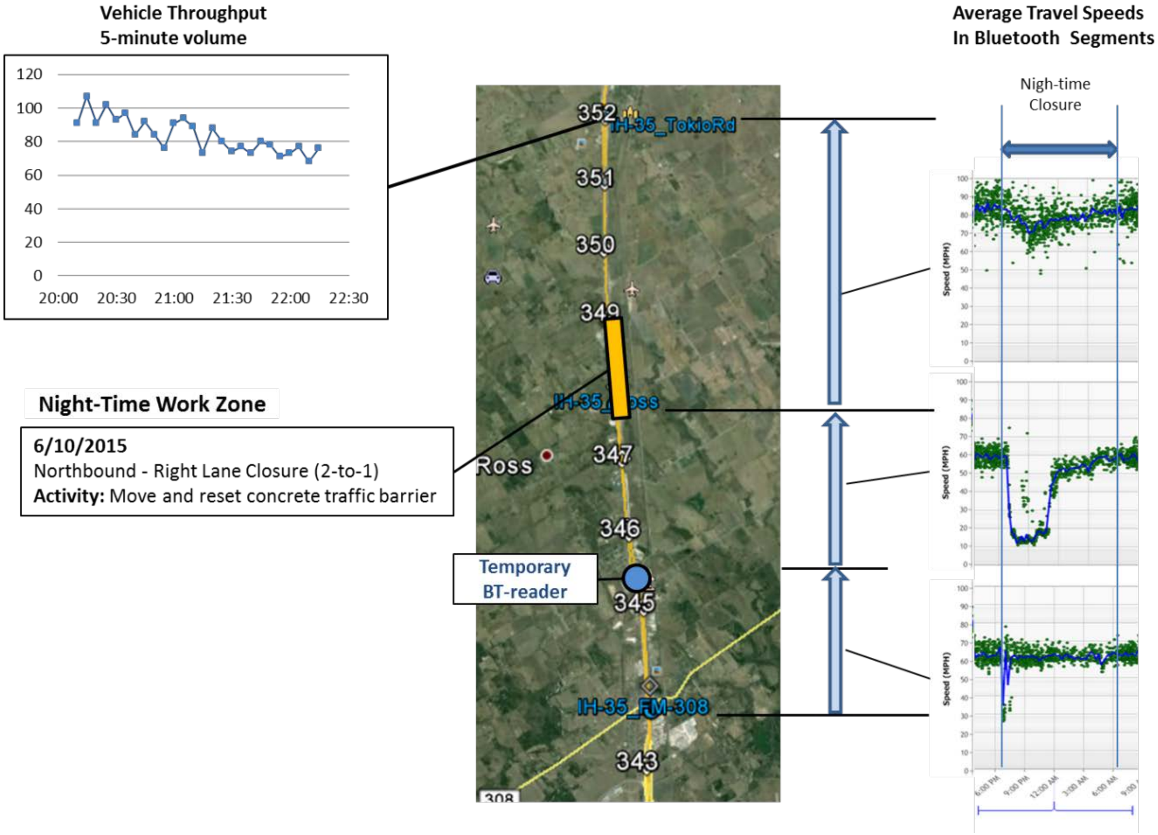


Figure 49. Nighttime Work Zone for Model Calibration.

During the calibration process, car-following and lane-changing parameters were adjusted and fine-tuned to minimize the difference between measured and modeled vehicle throughput and queues, as illustrated in Figure 50. Figure 51 shows the calibrated parameter set.

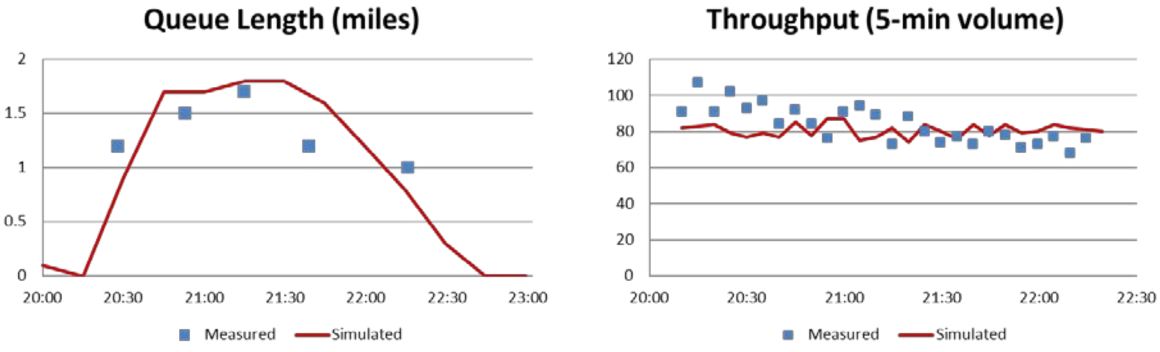
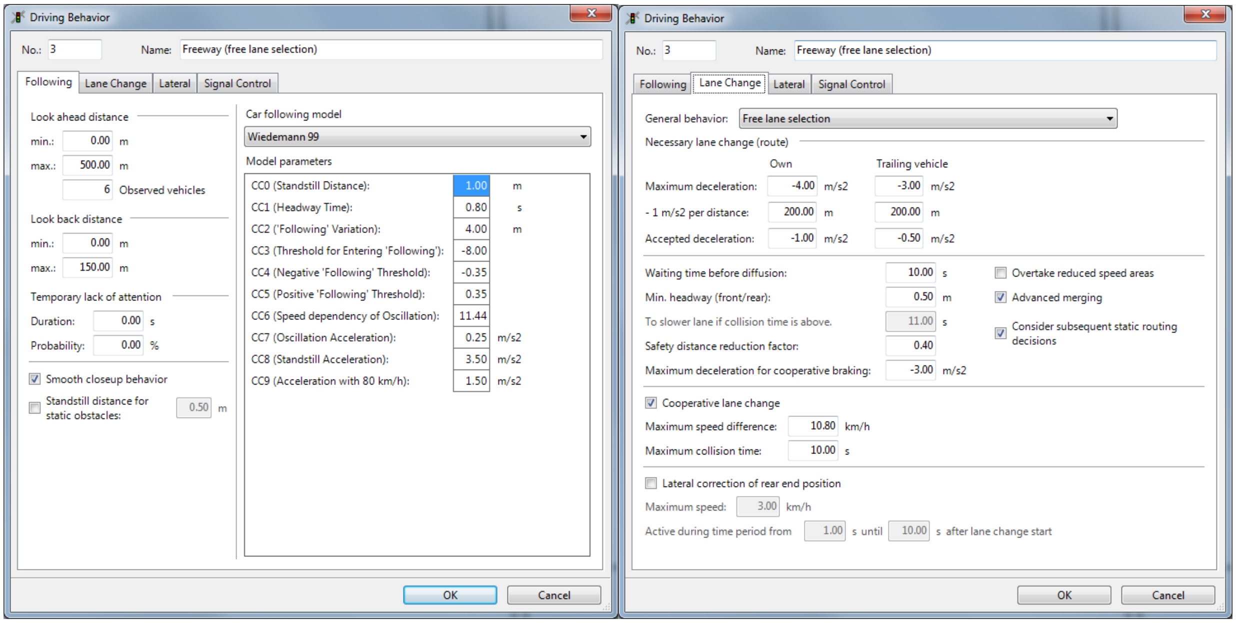


Figure 50. Simulated and Measured Queues and Throughput Using the Calibrated Model.



No.: 3 Name: Freeway (free lane selection)

Look ahead distance
min.: 0.00 m
max.: 500.00 m
6 Observed vehicles

Look back distance
min.: 0.00 m
max.: 150.00 m

Temporary lack of attention
Duration: 0.00 s
Probability: 0.00 %

☑ Smooth closeup behavior
☐ Standstill distance for static obstacles: 0.50 m

Car following model: Wiedemann 99

Model parameters

CC0 (Standstill Distance):	1.00	m
CC1 (Headway Time):	0.80	s
CC2 ('Following' Variation):	4.00	m
CC3 (Threshold for Entering 'Following'):	-8.00	
CC4 (Negative 'Following' Threshold):	-0.35	
CC5 (Positive 'Following' Threshold):	0.35	
CC6 (Speed dependency of Oscillation):	11.44	
CC7 (Oscillation Acceleration):	0.25	m/s2
CC8 (Standstill Acceleration):	3.50	m/s2
CC9 (Acceleration with 80 km/h):	1.50	m/s2

No.: 3 Name: Freeway (free lane selection)

General behavior: Free lane selection

Necessary lane change (route)

	Own		Trailing vehicle	
Maximum deceleration:	-4.00	m/s2	-3.00	m/s2
- 1 m/s2 per distance:	200.00	m	200.00	m
Accepted deceleration:	-1.00	m/s2	-0.50	m/s2

Waiting time before diffusion: 10.00 s
Min. headway (front/rear): 0.50 m
To slower lane if collision time is above. 11.00 s
Safety distance reduction factor: 0.40
Maximum deceleration for cooperative braking: -3.00 m/s2

☐ Overtake reduced speed areas
☑ Advanced merging
☑ Consider subsequent static routing decisions

☑ Cooperative lane change
Maximum speed difference: 10.80 km/h
Maximum collision time: 10.00 s

☐ Lateral correction of rear end position
Maximum speed: 3.00 km/h
Active during time period from 1.00 s until 10.00 s after lane change start

Figure 51. Calibrated Driver Behavior Parameter Set.

SIMULATION SCENARIOS

A simulation scenario matrix was created to guide analysis of selected nighttime and daytime work zones. Nighttime construction and maintenance activities on freeways typically start between 7 p.m. and 9 p.m. and finish by 6 a.m. or 7 a.m. It was assumed that daytime construction can be performed at any time between 6 a.m. and 7 p.m. For consistency, the same nighttime and daytime construction periods were assumed for the arterials. Table 33 shows the simulation scenarios for the three case study sites. The table defines the combinations of lane closure times and durations for different roadway types (freeways and arterial) and work zone lane closure configurations (no lane closure, one of two lanes closed, one of three lanes closed). The different lane closure times also result in different traffic volumes and truck percentages.

Table 33. Simulation Scenario Matrix.

Case Study Sites	Daytime Work Zone Scenarios	Nighttime Work Zone Scenarios
I-35 NB, Waco	1 of 2 lanes closed	1 of 2 lanes closed
	06:00–17:00	19:00–06:00 20:00–07:00 21:00–07:00
I-10 EB, El Paso	1 of 3 lanes closed	1 of 3 lanes closed
	06:00–19:00	19:00–06:00
W. Paisano Drive EB, El Paso	1 of 2 lanes closed	1 of 2 lanes closed
	06:00–19:00	19:00–06:00

SIMULATION RUNS AND RESULTS

The scenario matrix guided all simulation runs for both daytime and nighttime scenarios. For each scenario, 10 replicates were simulated using different random number seeds to account for the stochastic nature of the model.

Mobility performance measures, such as travel time, delay, and queue length, were determined by post-processing the model output. In addition, link segment results (e.g., density, average speed, and volume) and vehicle records/trajectory data (i.e., location, speed, and acceleration/deceleration of each simulated vehicle at each time step) were analyzed. These data were used as input for the emission analysis process.

APPENDIX G. TRAFFIC EMISSIONS MODELING PROCESS

CALCULATING LINK-BY-LINK TRAFFIC ACTIVITY

Outputs from the microscopic traffic model were provided in the form of the instantaneous speed and location of all vehicles (either cars or trucks) moving through the simulated work zones during each second of a simulation. Each case study was used to simulate one daytime work zone scenario and one or more nighttime work zone scenarios per the simulation matrix in Appendix F. Additionally, 10 replicate simulations were performed for each case study scenario.

For each case study scenario, vehicle data from each replicate simulation were used to calculate mean hourly vehicle speeds and VMT on each link of the simulated network. Speed and VMT were calculated for both cars and trucks. Each case study scenario simulation generated between 1–20 million rows of data. Custom code written for SAS/STAT® software was used to aggregate the data into hourly, link-by-link volumes, and speeds per the following equations:

$$\boldsymbol{VMT_{link,hour}} = \frac{\sum_{i=0}^{n} \boldsymbol{speed_i\ (mph)}}{\boldsymbol{3600\ (seconds/hour)}} \qquad \text{(Eq. G-1)}$$

$$\boldsymbol{Average\ Speed_{link,hour}} = \frac{\sum_{i=0}^{n} \boldsymbol{speed_i\ (mph)}}{\boldsymbol{n}} \qquad \text{(Eq. G-2)}$$

Where:

> $\mathrm{VMT}_{\mathrm{link,hour}}$ is average hourly VMT for each link of the modeled case study scenario (either composite heavy-duty or composite light-duty vehicle types).
>
> Average $\mathrm{speed}_{\mathrm{link,hour}}$ is hourly average speeds for each link of the modeled case study scenario (either heavy-duty or light-duty vehicle types).
>
> $\mathrm{speed}_{\mathrm{i}}$ is the instantaneous speed of observation i for each link of the modeled case study scenario during each hour (either heavy-duty or light-duty vehicle types).
>
> n is the number of observations for each link of the modeled case study scenario during each hour (either heavy-duty or light-duty vehicle types).

This process was repeated for each of the 10 case study scenario replicates. Finally, mean hourly speed and VMT for each link were calculated, yielding data describing the mean response of traffic (hourly VMT and hourly average speed) for light-duty and heavy-duty vehicles for each link of each case study scenario.

MOVES EMISSIONS RATES

The TTI research team used El Paso–specific emission rates to estimate total emissions for each case study scenario, irrespective of its location within Texas. Specifically, emission rates were daily average tail pipe emissions representative of winter El Paso conditions. The analysis year was 2016. The use of fixed El Paso emissions rates ensured maximum comparability of results across the case studies. The use of daily average rather than hourly rates (i.e., based on temperature) helped isolate the effects of changes in traffic activity on emissions impacts.

MOVES was used to calculate El Paso–specific emission rates for all MOVES vehicle types and for each pollutant of interest (THC, CO, NO_x, CO_2, VOC, $PM_{2.5}$, and PM_{10}). Table 34 illustrates the full range of MOVES vehicle types. The resulting emission rates describe rates per mile for each pollutant based on MOVES vehicle type, average speed, and link type (i.e., interstate or arterial links). Emission rates for each pollutant were calculated at the following speeds: 2.5, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, and 75 mph. A full description of MOVES inputs and methods used for generating the emission rates can be found in a 2014 report by TTI (*92*).

Table 34. Vehicle Types in MOVES.

Vehicle Type ID	MOVES Vehicle Type Description
11	Motorcycle
21	Passenger Car
31	Passenger Truck
32	Light Commercial Truck
41	Intercity Bus
42	Transit Bus
43	School Bus
51	Refuse Truck
52	Single Unit Short-Haul Truck
53	Single Unit Long-Haul Truck
54	Motor Home
61	Combination Short-Haul Truck
62	Combination Long-Haul Truck

Composite Emissions Rates for Light-Duty and Heavy-Duty Vehicle Categories

For tractability, the microsimulations used only two vehicle types (cars or light-duty vehicles; and trucks or heavy-duty vehicles) to represent the broader range of vehicle types present on real-world road networks. An objective of this project was to estimate the changes in absolute total emissions arising from nighttime versus daytime work zones. To improve the realism of emission rates, the TTI research team developed composite emission rates for two representative vehicle categories: composite light-duty vehicles (CLD) and composite heavy-duty vehicles (CHD). These compound emission rates correspond to the cars and trucks simulated in the traffic model.

Table 35 illustrates the distribution of vehicle types on arterial and interstate links (representative of El Paso County). Using the data in Table 35, the TTI research team defined CLD vehicles as passenger cars (MOVES Type 21), passenger trucks (MOVES Type 31), and light commercial trucks (MOVES Type 32). Together, these vehicle types (highlighted green) comprised approximately 90 percent of all vehicles and 99 percent of light-duty vehicles using either arterial or interstate links. All CLD vehicles were assumed to use gasoline fuel. Similarly, CHD vehicles were assumed to comprise long-haul combination trucks (MOVES Type 62) and short-haul combination trucks (MOVES Type 61). Together, CHD vehicle types represented approximately 7 percent of all vehicles and 99 percent of heavy-duty vehicles on interstate or arterial links (highlighted yellow). All CHD vehicles were assumed to use diesel fuel.

Table 35. Distribution of MOVES Vehicle Types in El Paso County, Texas.

MOVES Vehicle Type	MOVES Vehicle ID	Interstate Highway	Arterial
Motorcycle	11	0.0008	0.0008
Passenger Car	21	0.7671	0.7649
Passenger Truck	31	0.1178	0.1455
Light Commercial Truck (Gasoline)	32	0.0380	0.0470
Light Commercial Truck (Diesel)	32	0.0009	0.0022
Intercity Bus	41	0.0003	0.0007
Transit Bus	42	0.0010	0.0024
School Bus	43	0.0003	0.0003
Refuse Truck	51	0.0009	0.0010
Single Unit Short-Haul Truck	52	0	0
Single Unit Long-Haul Truck	53	0	0
Motor Home	54	0	0
Combination Short-Haul Truck	61	0.0239	0.0109
Combination Long-Haul Truck	62	0.0465	0.0212

Composite speed-specific emission rates (i.e., for CHD and CLD categories) were calculated using the following equation:

$$\boldsymbol{CER_{speed,link}} = \sum_{\boldsymbol{MVT}} \boldsymbol{ER_{MVT,speed,link}} \times \boldsymbol{P_{MVT}} \qquad \text{(Eq. G-3)}$$

Where:

$CER_{speed,link}$ is the composite emission rate (either CHD or CLD vehicle types).

ER_{MVT} is the emission rate corresponding to a MOVES vehicle type at a specified speed and for a specified link type.

P_{MVT} is the proportion of the specified MOVES vehicle type making up the composite vehicle type.

Figure 52 through Figure 58 illustrate the speed-specific CLD and CHD emissions rates for each pollutant on interstate links. Figure 59 through Figure 65 illustrate the speed-specific CLD and CHD emissions rates for each pollutant on arterial links.

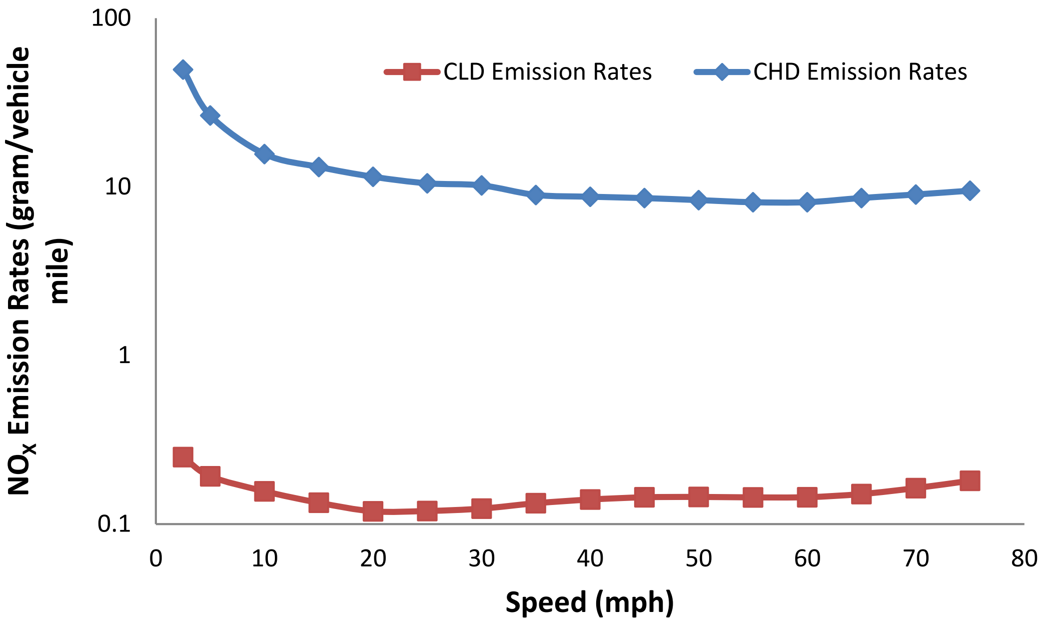


Figure 52. NO$_X$ Emissions Rates vs. Speeds on Interstate Links.

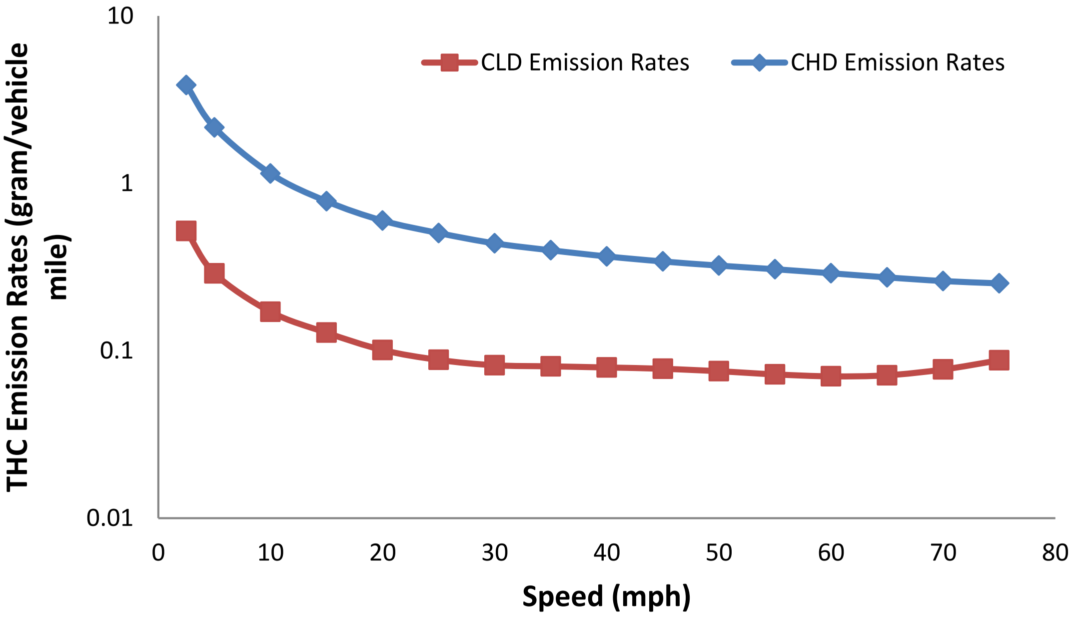


Figure 53. THC Emissions Rates vs. Speed on Interstate Links.

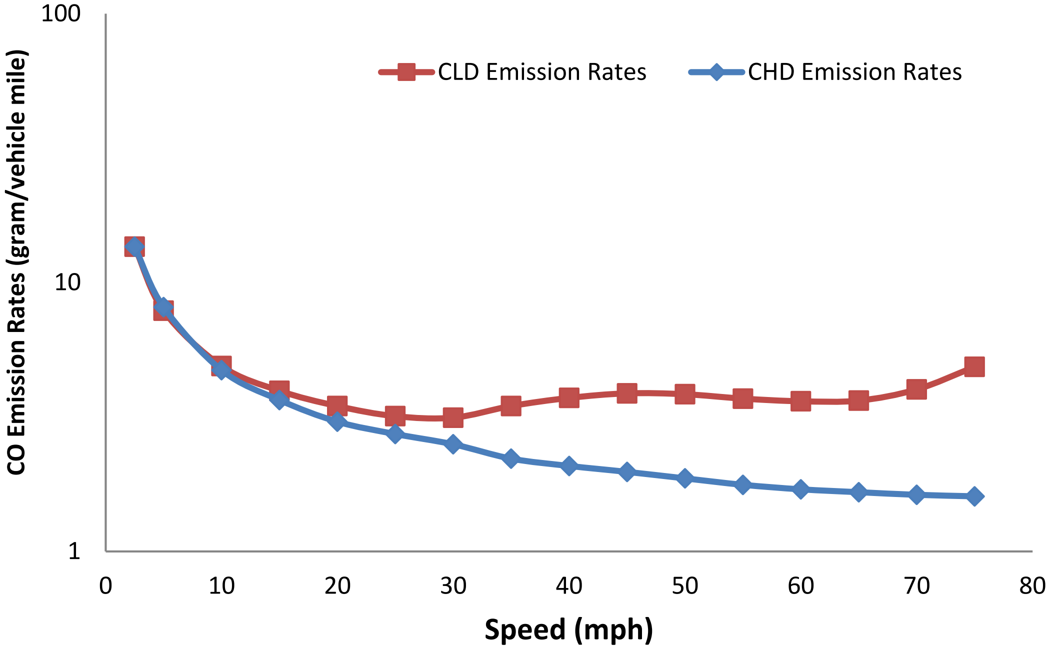


Figure 54. CO Emissions Rates vs. Speed on Interstate Links.

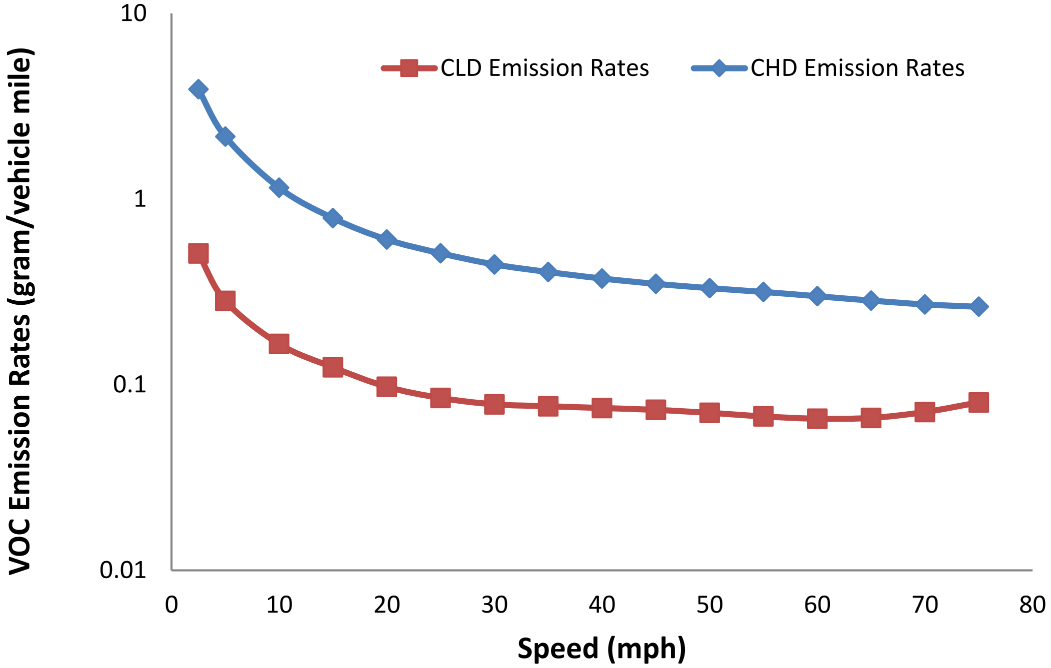


Figure 55. VOC Emissions Rates vs. Speed on Interstate Links.

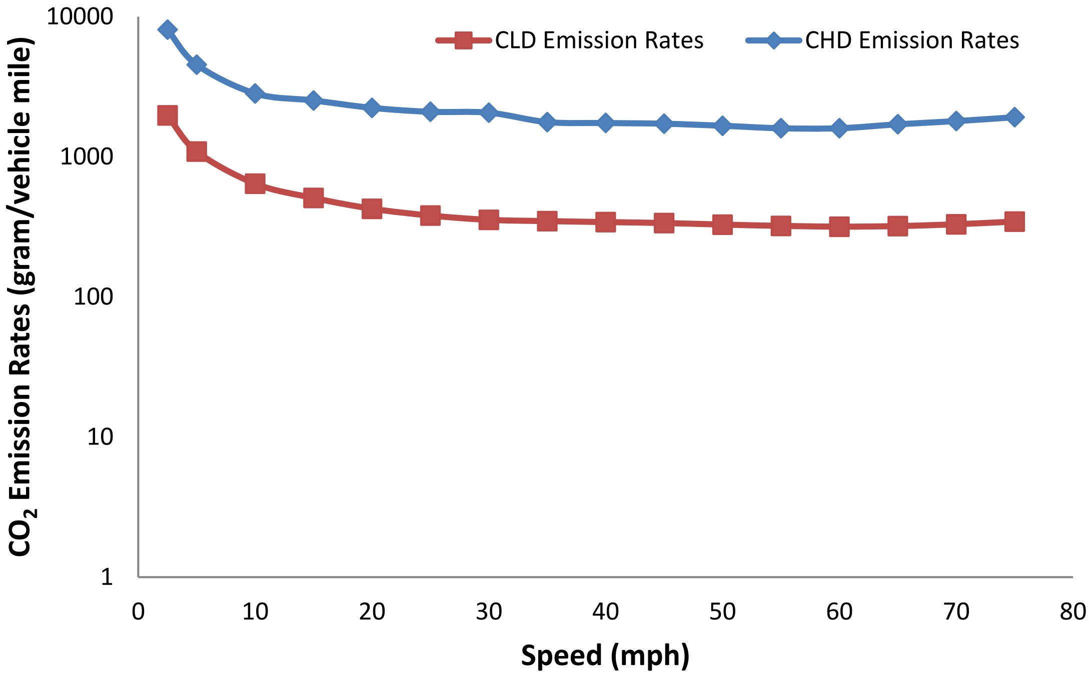


Figure 56. CO_2 Emissions Rates vs. Speed on Interstate Links.

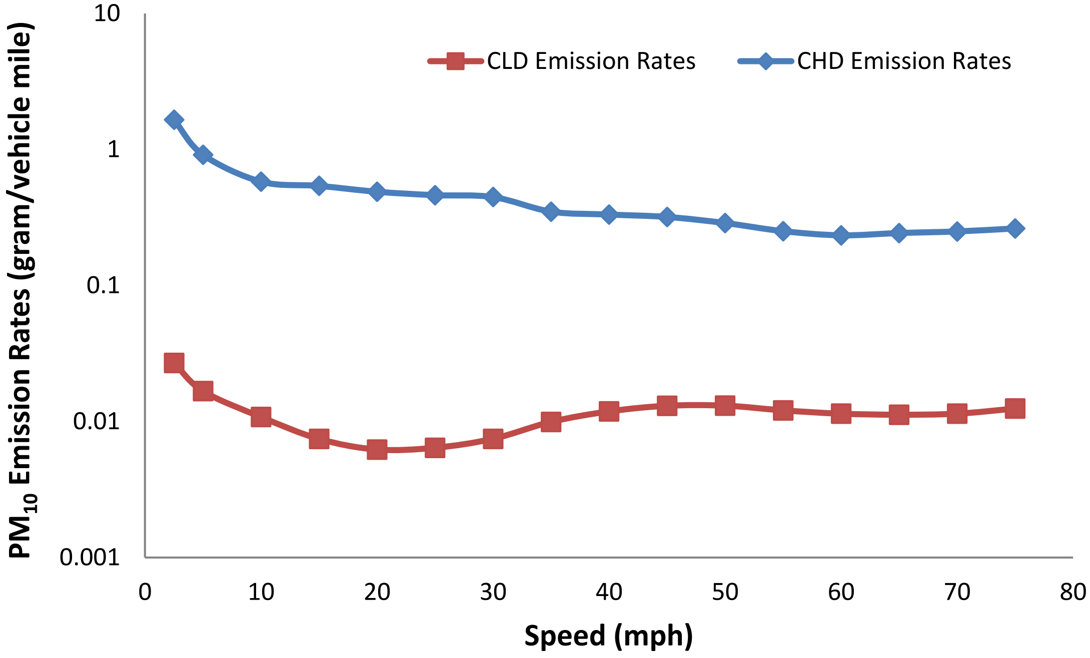


Figure 57. PM_{10} Emissions Rates vs. Speed on Interstate Links.

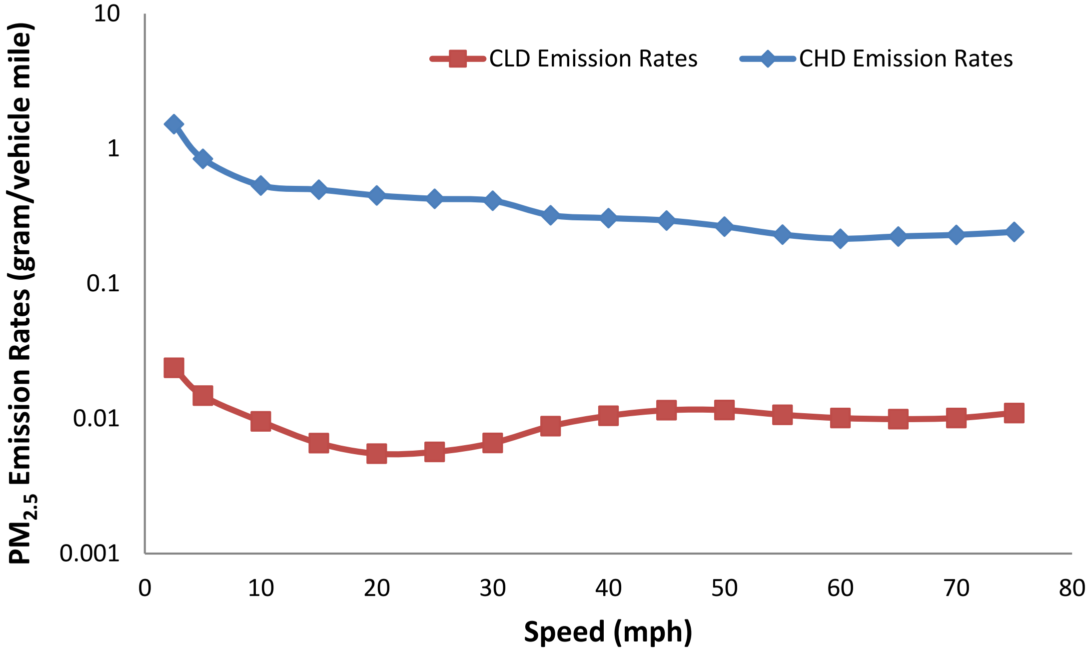


Figure 58. $PM_{2.5}$ Emissions Rates vs. Speed on Interstate Links.

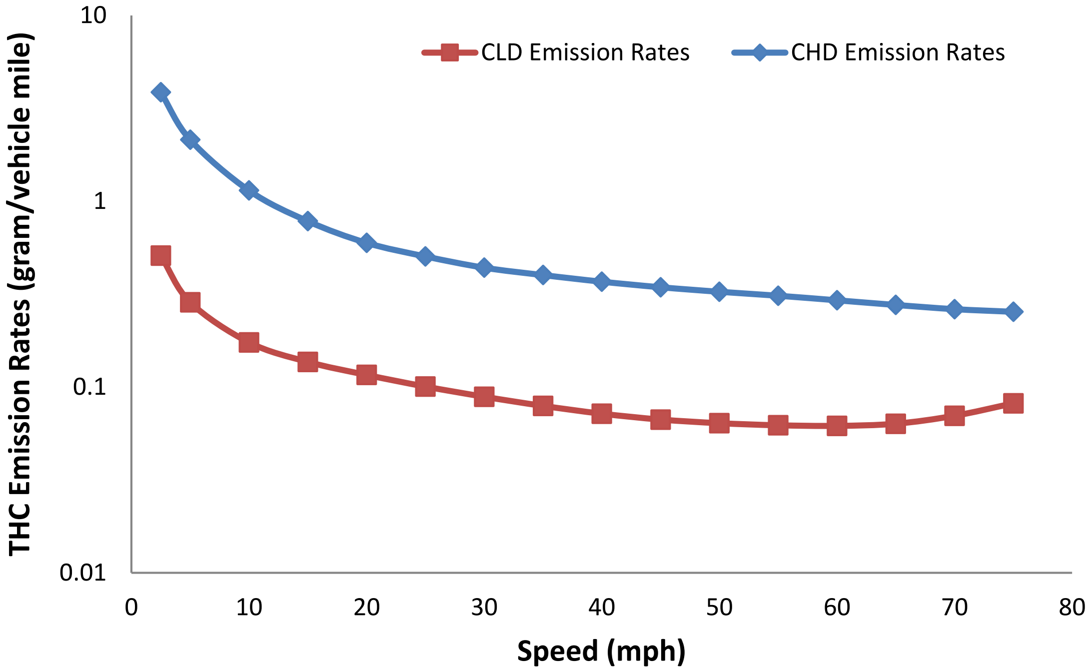


Figure 59. THC Emissions Rates vs. Speed on Arterial Links.

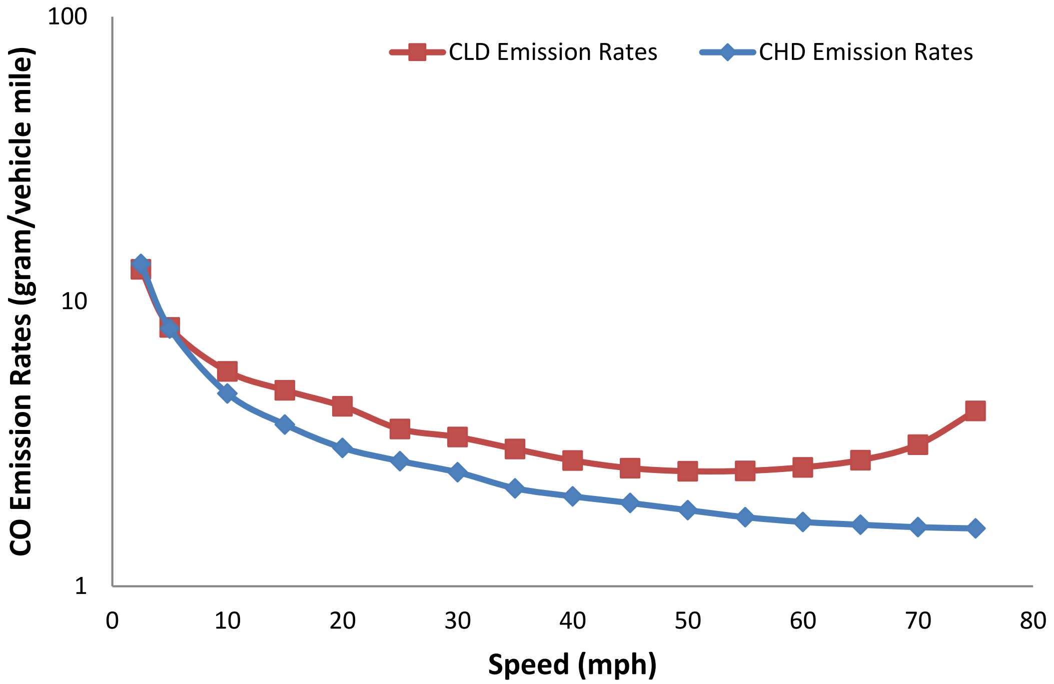


Figure 60. CO Emissions Rates vs. Speed on Arterial Links.

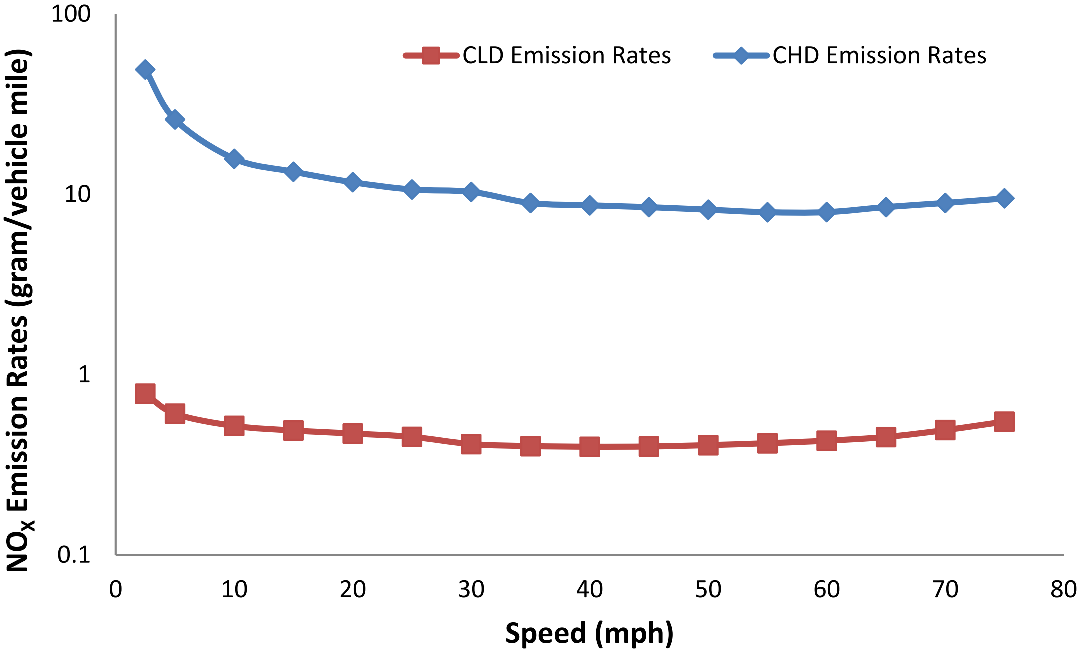


Figure 61. NO_X Emissions Rates vs. Speed on Arterial Links.

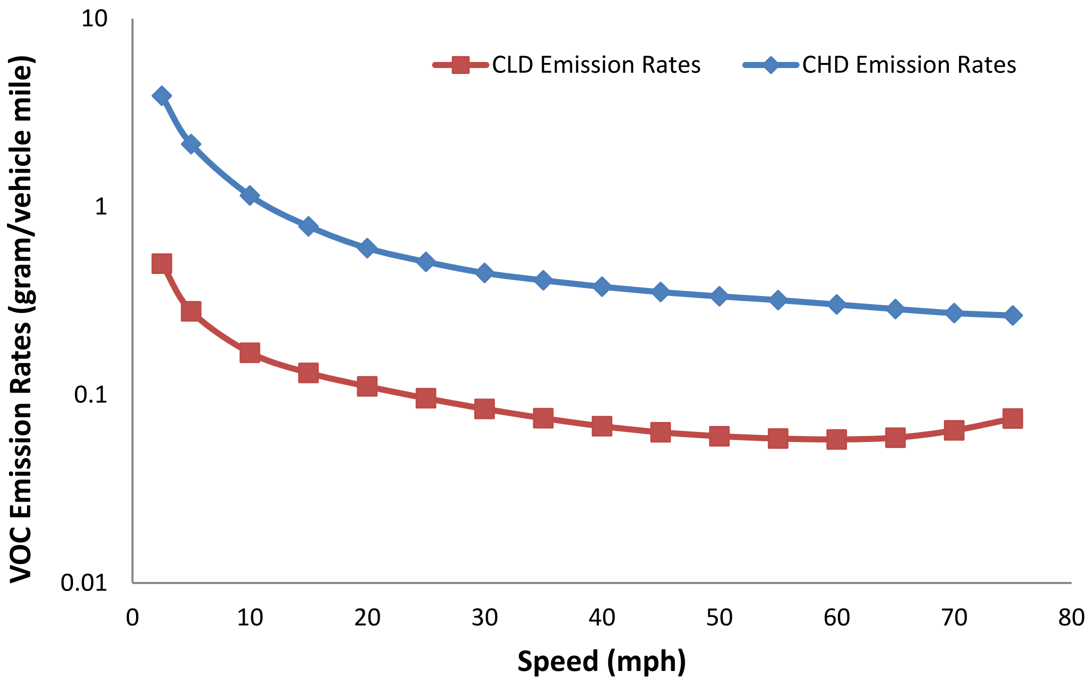


Figure 62. VOC Emissions Rates vs. Speed on Arterial Links.

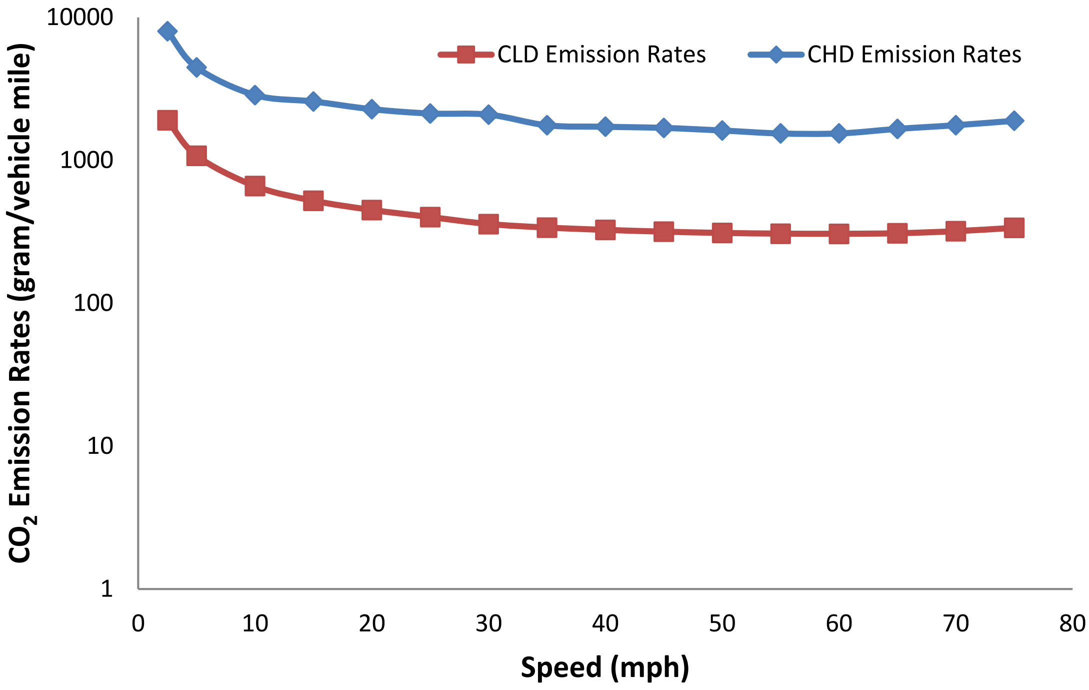


Figure 63. CO_2 Emissions Rates vs. Speed on Arterial Links.

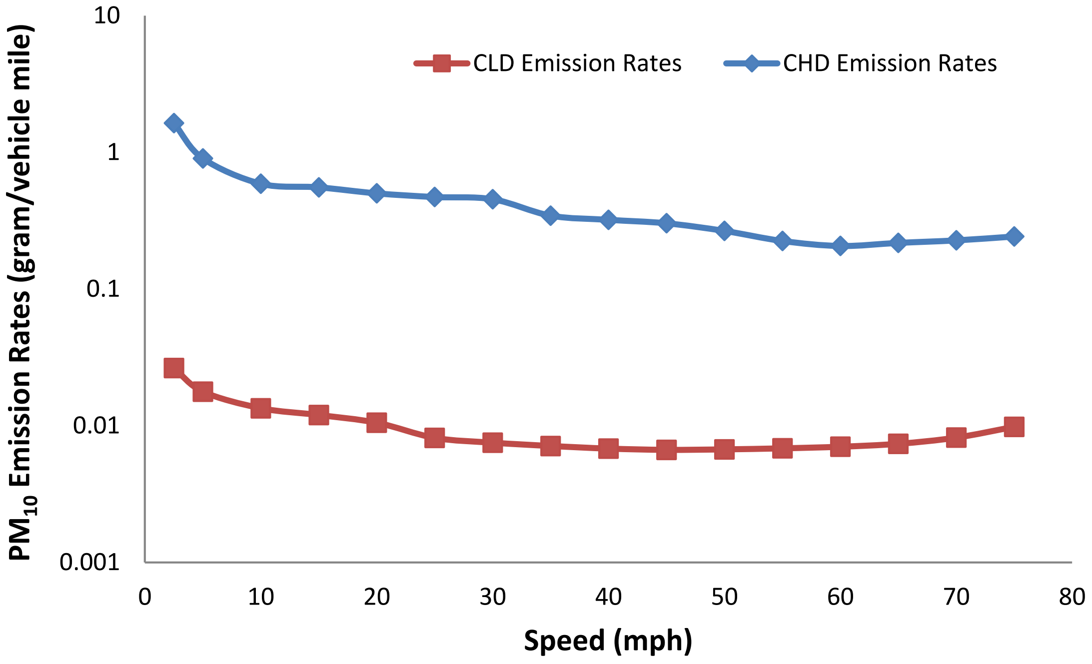


Figure 64. PM_{10} Emissions Rates vs. Speed on Arterial Links.

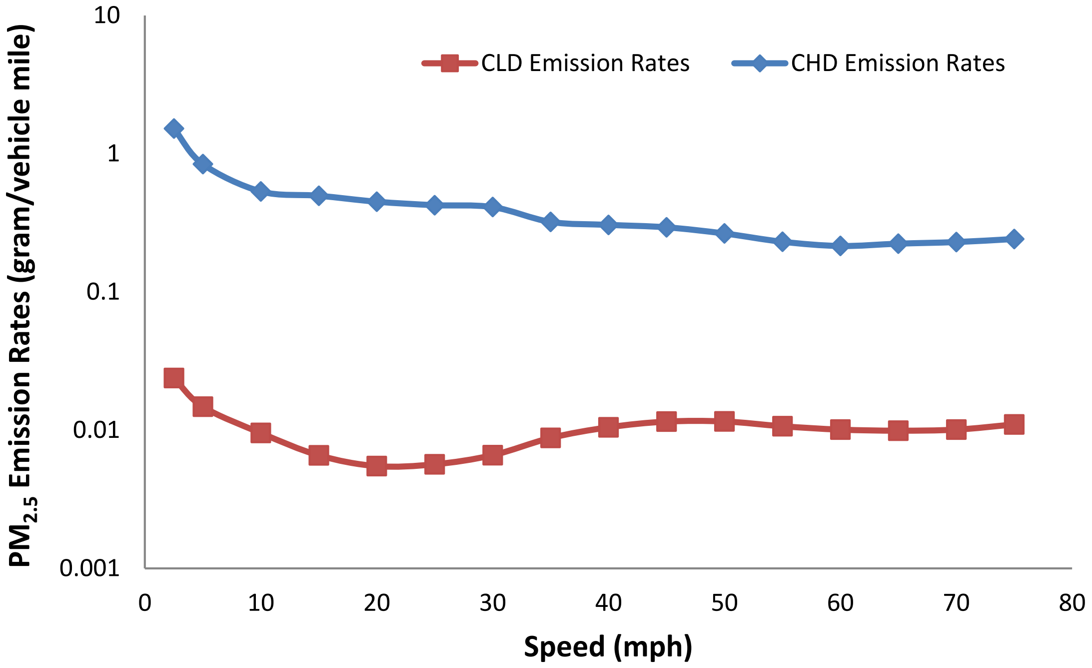


Figure 65. $PM_{2.5}$ Emissions Rates vs. Speed on Arterial Links.

Calculating Link-by-Link Emissions

The preceding sections described methods to (a) calculate hourly estimates of speeds and VMT for trucks and cars on each link in a case study scenario, and (b) calculate speed- and link-specific composite emission rates for representative light-duty and heavy-duty vehicle types (CLD and CHD, respectively).

The outputs from each of these steps were used to calculate hourly total emissions for each link in each case study scenario:

$$\mathbf{TE_{link,\ hour} = VMT_{trucks,\ hour} \cdot ER_{CHD,\ speed,\ link} + VMT_{cars,\ hour} \cdot ER_{CLD,\ speed,\ link}} \qquad \text{(Eq. G-4)}$$

Where:

$TE_{link,\ hour}$ is the total emissions for a specified hour of the day and for a specified link type (interstate or arterial).

$VMT_{trucks,\ hour}$ is the miles of truck activity on the link during the specified hour.

$ER_{CHD,\ speed,\ link}$ is the emission rate (grams per mile) of CHD vehicle types, traveling at a specified average speed.

$VMT_{cars,\ hour}$ is the miles of car activity on the link during the specified hour.

$ER_{CLD,\ speed,\ link}$ is the emission rate (grams per mile) of CLD vehicle types, traveling at a specified average speed on a specified link type.

$ER_{CLD,\ speed}$ and $ER_{CHD,\ speed}$ represent the emissions rates at a given speed and were estimated using a lookup table containing the previously calculated composite emissions rates. Here, the subscript *speed* is the average speed of vehicles using the link during the hour specified in Equation G-4. Because CLD and CHD emissions rates were calculated for 16 discrete average speeds between 2.5 and 75 mph, interpolation was used to estimate emissions rates at intermediate speeds (Equations G-5 and G-6):

$$\boldsymbol{EF_{Interp} = EF_{LowSpeed} - FAC_{Interp} \times (EF_{LowSpeed} - EF_{HighSpeed})} \qquad \text{(Eq. G-5)}$$

Where:

$EF_{LowSpeed}$ = emission factor (EF) corresponding to the speed below the link speed.

$EF_{LowSpeed}$ = EF corresponding to the speed below the link speed.

EF_{Interp} = EF corresponding to the actual link speed.

$$\boldsymbol{FAC_{Interp} = \left(\frac{1}{Speed_{link}} - \frac{1}{Speed_{low}}\right) / \left(\frac{1}{Speed_{high}} - \frac{1}{Speed_{low}}\right)} \qquad \text{(Eq. G-6)}$$

APPENDIX H. CASE STUDY EMISSIONS IMPACTS

CASE STUDY 1—EMISSIONS IMPACTS OF LIGHT-DUTY AND HEAVY-DUTY VEHICLES

Table 36. Summary of Light-Duty Vehicle Emissions Generated during Daytime versus Nighttime Work Zone Scenarios for Case Study 1.

			Speed (mph)	**VMT**	**Emissions (kg)**						
					THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
Daytime	6 AM–7 PM	Total		236,343	26.21	1115.71	125.43	2.54	2.87	24.65	104,315.61
		Hourly Average	35.57	21,486	2.38	101.43	11.40	0.23	0.26	2.24	9483.24
		Ave. Rate (g/VMT)*			0.11	4.72	0.53	0.01	0.01	0.10	441.37
Nighttime	7 PM–6 AM	Total		97,724	8.90	448.60	52.78	1.04	1.17	8.22	35,633.61
		Hourly Average	59.08	8884	0.81	40.78	4.80	0.09	0.11	0.75	3239.42
		Ave. Rate (g/VMT)*			0.09	4.59	0.54	0.01	0.01	0.08	364.64
	8 PM–7 AM	Total		90,984	7.86	417.35	49.64	0.97	1.10	7.22	31,541.92
		Hourly Average	67.37	8271	0.71	37.94	4.51	0.09	0.10	0.66	2867.45
		Ave. Rate (g/VMT)*			0.09	4.59	0.55	0.01	0.01	0.08	346.67
	9 PM–7 AM	Total		76,681	6.54	353.92	42.17	0.82	0.93	5.99	26,209.50
		Hourly Average	71.58	7668	0.65	35.39	4.22	0.08	0.09	0.60	2620.95
		Ave. Rate (g/VMT)*			0.09	4.62	0.55	0.01	0.01	0.08	341.80

* Average rate is the average emissions rate for the entire period.

Table 37. Summary of Heavy-Duty Vehicle Emissions Generated during Daytime versus Nighttime Work Zone Scenarios for Case Study 1.

			Speed (mph)	**VMT**	**Emissions (kg)**						
					THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
Daytime	6 AM–7 PM	Total		50,693	30.40	141.89	606.35	17.72	19.26	30.83	114,976.25
		Hourly Average	33.29	4608	2.76	12.90	55.12	1.61	1.75	2.80	10,452.39
		Ave. Rate (g/VMT)*			0.60	2.80	11.96	0.35	0.38	0.61	2268.09
Nighttime	7 PM–6 AM	Total		42,433	14.18	80.17	417.01	11.28	12.26	14.57	82,730.60
		Hourly Average	58.72	3858	1.29	7.29	37.91	1.03	1.11	1.32	7520.96
		Ave. Rate (g/VMT)*			0.33	1.89	9.83	0.27	0.29	0.34	1949.68
	8 PM–7 AM	Total		39,431	10.93	66.62	371.18	9.72	10.57	11.30	74,450.18
		Hourly Average	67.28	3585	0.99	6.06	33.74	0.88	0.96	1.03	6768.20
		Ave. Rate (g/VMT)*			0.28	1.69	9.41	0.25	0.27	0.29	1888.13
	9 PM–7 AM	Total		32,998	8.61	53.78	307.98	7.93	8.62	8.92	61,953.26
		Hourly Average	71.69	3300	0.86	5.38	30.80	0.79	0.86	0.89	6195.33
		Ave. Rate (g/VMT)*			0.26	1.63	9.33	0.24	0.26	0.27	1877.50

* Average rate is the average emissions rate for the entire period.

CASE STUDY 2— EMISSIONS IMPACTS OF LIGHT-DUTY AND HEAVY-DUTY VEHICLES

Table 38. Summary of Light-Duty Vehicle Emissions Generated during Daytime versus Nighttime Work Zone Scenarios for Case Study 2.

			Speed (mph)	VMT	Emissions (kg)						
					THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
Daytime	6 AM–7 PM	Total		220,176	34.17	1096.70	108.86	2.27	2.57	32.94	134,923.80
		Hourly Average	11.21	16,937	2.63	84.36	8.37	0.17	0.20	2.53	10,378.75
		Ave. Rate (g/VMT)*			0.16	4.98	0.49	0.01	0.01	0.15	612.80
Nighttime	7 PM–6 AM	Total		84,606	6.22	248.93	36.62	0.57	0.64	5.87	28,637.85
		Hourly Average	52.27	7691	0.57	22.63	3.33	0.05	0.06	0.53	2603.44
		Ave. Rate (g/VMT)*			0.07	2.94	0.43	0.01	0.01	0.07	338.48

* Average rate is the average emissions rate for the entire period.

Table 39. Summary of Heavy-Duty Vehicle Emissions Generated during Daytime versus Nighttime Work Zone Scenarios for Case Study 2.

			Speed (mph)	VMT	Emissions (kg)						
					THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
Daytime	6 AM–7 PM	Total		35,006	38.55	158.87	549.12	17.79	19.34	38.79	98,984.01
		Hourly Average	10.72	2693	2.97	12.22	42.24	1.37	1.49	2.98	7614.15
		Ave. Rate (g/VMT)*			1.10	4.54	15.69	0.51	0.55	1.11	2827.61
Nighttime	7 PM–6 AM	Total		11,029	3.92	21.24	94.65	2.57	2.79	4.01	18,321.55
		Hourly Average	51.78	1003	0.36	1.93	8.60	0.23	0.25	0.36	1665.60
		Ave. Rate (g/VMT)*			0.35	1.93	8.58	0.23	0.25	0.36	1661.18

* Average rate is the average emissions rate for the entire period.

CASE STUDY 3— EMISSIONS IMPACTS OF LIGHT-DUTY- AND HEAVY-DUTY VEHICLES

Table 40. Summary of Light-Duty Vehicle Emissions Generated during Daytime versus Nighttime Work Zone Scenarios for Case Study 3.

			Speed (mph)	VMT	Emissions (kg)						
					THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
Daytime	6 AM–7 PM	Total		24,541	1.64	64.23	9.93	0.15	0.17	1.55	7755.93
		Hourly Average	46.16	1888	0.13	4.94	0.76	0.01	0.01	0.12	596.61
		Ave. Rate (g/VMT)*			0.07	2.62	0.40	0.01	0.01	0.06	316.04
Nighttime	7 PM–6 AM	Total		5664	0.37	14.50	2.30	0.03	0.04	0.35	1765.87
		Hourly Average	49.05	515	0.03	1.32	0.21	0.00	0.00	0.03	160.53
		Ave. Rate (g/VMT)*			0.06	2.56	0.41	0.01	0.01	0.06	311.75

* Average rate is the average emissions rate for the entire period.

Table 41. Summary of Heavy-Duty Vehicle Emissions Generated during Daytime versus Nighttime Work Zone Scenarios for Case Study 3.

			Speed (mph)	VMT	Emissions (kg)						
					THC	CO	NO_X	$PM_{2.5}$	PM_{10}	VOC	CO_2
Daytime	6 AM–7 PM	Total		1688	0.59	3.32	14.34	0.46	0.50	0.60	2831.42
		Hourly Average	43.96	130	0.05	0.26	1.10	0.04	0.04	0.05	217.80
		Ave. Rate (g/VMT)*			0.35	1.97	8.50	0.27	0.29	0.36	1677.35
Nighttime	7 PM–6 AM	Total		440	0.15	0.84	3.67	0.11	0.12	0.15	724.44
		Hourly Average	47.13	40	0.01	0.08	0.33	0.01	0.01	0.01	65.86
		Ave. Rate (g/VMT)*			0.34	1.90	8.34	0.26	0.28	0.34	1644.86

* Average rate is the average emissions rate for the entire period.

APPENDIX I. SENSITIVITY ANALYSIS METHODOLOGY

CASE STUDY SETUP

This task evaluated the impact of meteorological conditions on pollutant concentrations, a sensitivity analysis is performed on a simplified representation of a roadway segment to isolate the impact of complicated roadway geometry and emission rates. The case study setup for this task consists of a hypothetical roadway line source with generic assumptions made for emissions rates and source parameters. Figure 66 displays the source and receptor setup for the task. AERMOD is a Gaussian-based dispersion model capable of predicting the dispersion patterns of any primary non-reactive pollutant with no chemical transformation. Accordingly, the dispersion patterns predicted by AERMOD apply to any primary non-reactive pollutant (such as CO, primary $PM_{2.5}$ and PM_{10}, and primary NO_x).

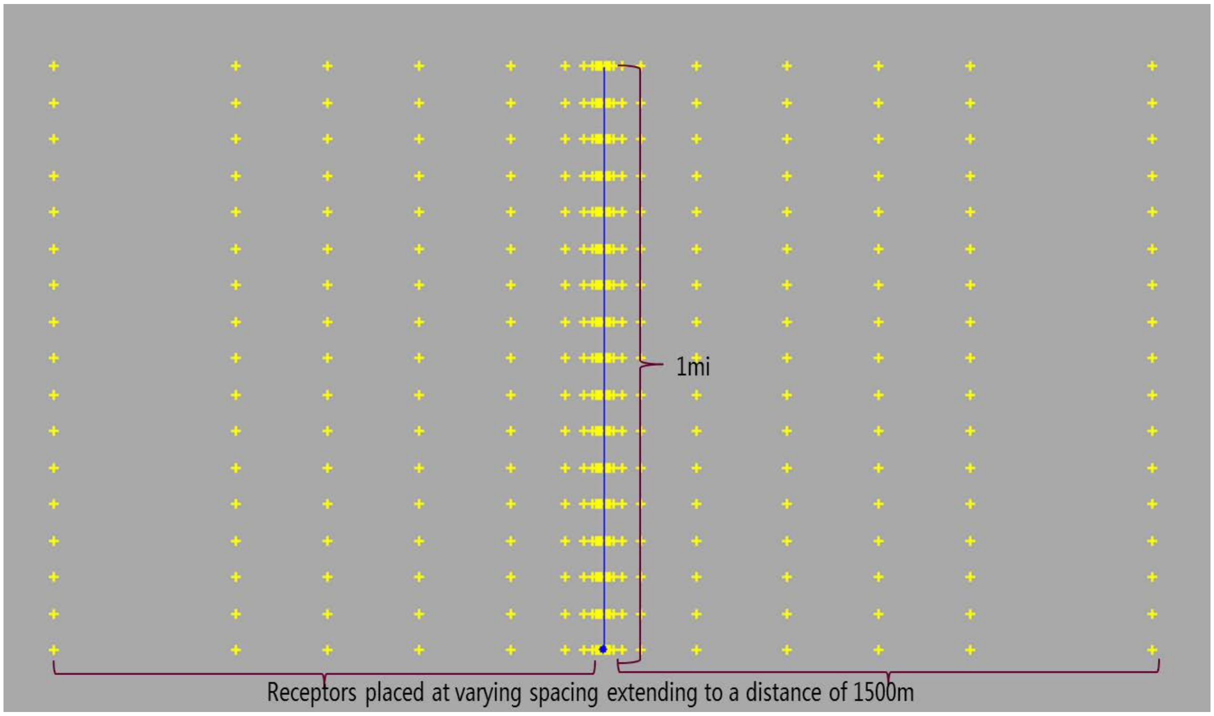


Figure 66. Source and Receptor Characterization.

The emissions source consists of a two-lane, at-grade highway segment extending to a length of 1 mi and a width of 24 ft. Inputs of highway configuration data (except for emissions rates) are defined according to the EPA project-level hot-spot analysis. The highway segment is characterized using AERMOD area source with a source elevation of 0 m, a release height of 1.3 m, and an initial vertical dispersion parameter of 1.2 m. A unit emissions rate is used for all modeling runs. Receptors are placed along the roadway from start of the roadway at 0 m and end of the roadway at 1600 m at a spacing of 100 m. At each of these locations along the roadway, receptors are placed at 6.15 m, 8.65 m, 13.65 m, 18.65 m, 28.65 m, 53.65 m, 103.65 m, 253.65 m, 503.65 m, 753.65 m, 1003.65 m, and 1503.65 m. Table 42 lists the input data parameters used for AERMOD model runs. BREEZE AERMOD, a proprietary software developed by Trinity Consultants, is used to help with the source and receptor coding. For a majority of the model runs, the meteorological data are obtained from TCEQ in an AERMOD compatible format. For limited number of model runs (to assess the impact of AERMET non-default options for meteorological data processing), raw meteorological data are processed using AERMOD preprocessors (AERMET, AERMINUTE and AERSURFACE) as described previously.

Table 42. Input Parameters for AERMOD Modeling.

Input	Description
Averaging period	Annual.
Pollutant	Primary non-reactive pollutant.
Modeling options	CONC: Specifies that concentration values will be calculated. FLAT: Specifies that the terrain is flat.
Emission Rate	A unit emission rate is used.
Dispersion Parameter	Initial vertical dispersion to account for effects of vehicle-induced turbulence. A default value of 1.2 m is used. Release Height is the height at which wind effectively begins to affect the plume. A default value of 1.3 m is used. Urban/rural representativeness of a case study site to account for the effect of urban heat island effect, a term used to describe urban areas that are hotter than nearby rural areas, especially at night, mainly as a result of heat retention by urban materials. Both land use types are evaluated in the sensitivity analysis.
Source dimensions	AREA sources are used.
Receptor placement	Receptors are placed at an average human breathing height of 1.8 m. Receptors locations are placed at varying spacing along the highway segment at distances of 100, 200, 300, 400, 500, 600, 700, and 800 m. At each of these locations along the roadway, receptors are placed at 6.15, 8.65, 13.65, 18.65, 28.65, 53.65, 103.65, 253.65, 503.65, 753.65, 1003.65, and 1503.65 m.
Meteorological data	Meteorological data for all urban areas were obtained from TCEQ in AERMET format. One set of raw meteorological data for El Paso was processed using AERMET beta options (LOWWIND3, ADJ_U*) to check the sensitivity of the model results under low wind conditions.

KEY INPUT PARAMETERS FOR SENSITIVITY ANALYSIS

The impact of meteorological conditions on pollutant concentrations between daytime and nighttime time periods are assessed for different input parameter settings as listed in Table 43.

Table 43. Key Input Parameters Assessed for Sensitivity Analysis.

Parameters Evaluated	Values
1. Case Study Location	• Dallas • Houston • El Paso
2. Zone of Influence	• Near-road (0–250 m) from roadway edge • Far-road (> 250 m)
3. Time Period of Construction	• TxDOT Specification Handbook • Practical time period information from contractors
4. Land Use	• Rural • Urban
5. Averaging Period	• Annual • Hourly (evaluated only for El Paso)
6. AERMET	• Regulatory default option • BETA option for LOWWINDS

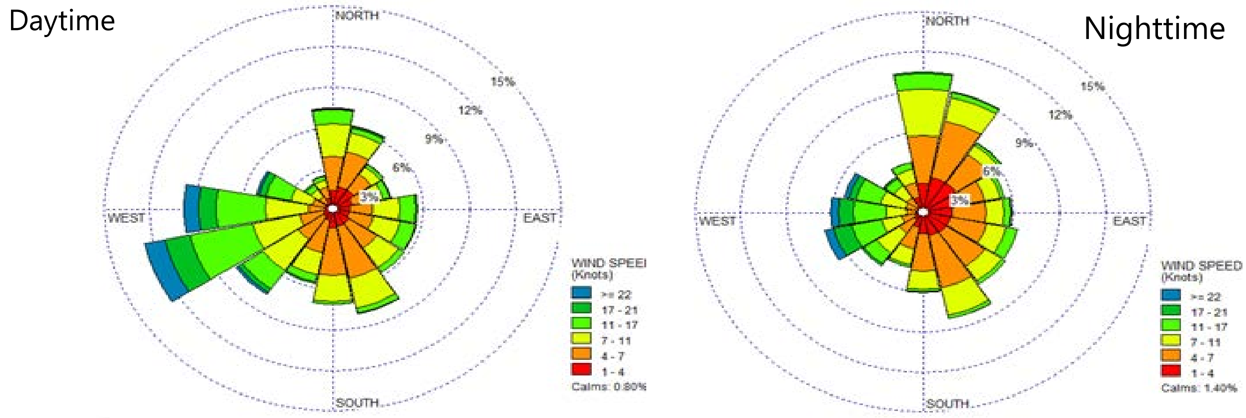
The following section provides a description about key input parameters and their parameter values considered for sensitivity analysis.

Case Study Location

As it is difficult to generalize the meteorological conditions between different case study sites, sensitivity analyses were performed based on local parameters for three major areas in Texas, namely Dallas, Houston, and El Paso. Processed meteorological data for all the case study regions were obtained from the TCEQ database (*93*). Figure 67 shows the prevailing wind rose diagram for daytime and nighttime periods (on an annual averaging basis) for the case study regions. The predominant wind direction is the same for both daytime and nighttime periods for Dallas and Houston. However, for El Paso, the predominant wind direction changes drastically from blowing from south-west (daytime period) to north-east (nighttime period).

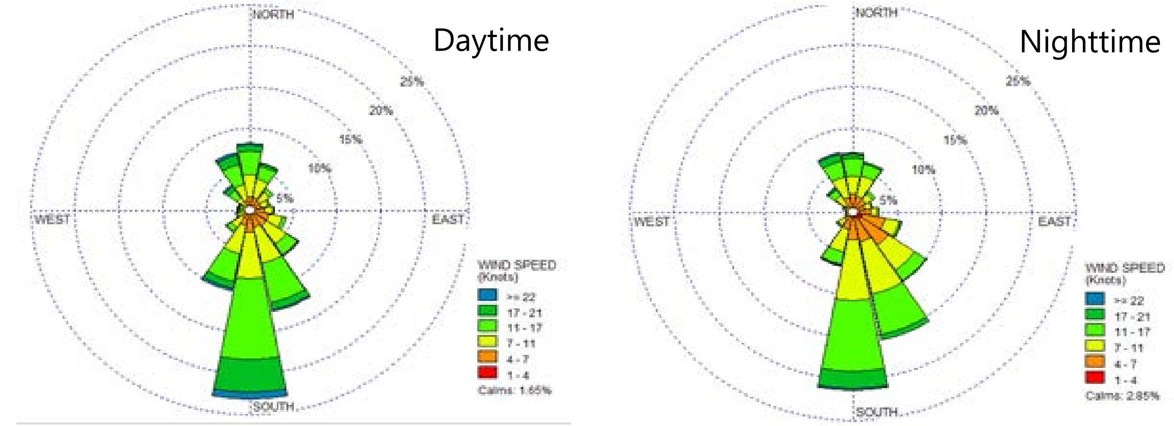
El Paso

Surface Station: El Paso Airport, Upper Air Station: Santa Teresa



Dallas

Surface Station: Dallas/Ft Worth Airport Upper Air Station: Ft Worth



Houston

Surface Station: Lufkin Angelina, Upper Air Station: Shreveport Regional Airport

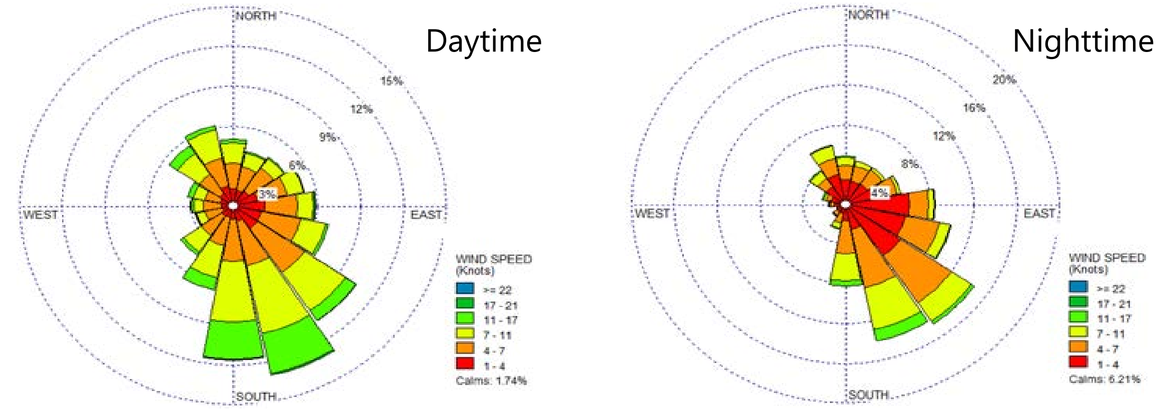


Figure 67. Wind Rose Diagrams for Case Study Regions.

Zone of Influence

Roadside monitoring and modeling studies (*94*, *85*) in literature have exhibited that vehicular pollutants decay to background levels within a few hundred meters from the edge of the roadway and the decay rate varies from one pollutant to another. The pollutant decay rate is dependent on factors related to pollutant properties (settling and deposition), existence of sound walls, level of roadway (at-grade freeways, elevated, or filled), canopy vegetation, and classification of atmospheric stability condition. Accordingly, near-road exposures have recently been documented to cause an array of health effects (such as asthma, reduced lung function, adverse birth outcomes, and pulmonary mortality), especially on population groups living or working in close proximity to near-roadways (*95*, *96*). To evaluate the impact of meteorological condition by distance from the roadway edge, a sensitivity analysis is performed for receptors placed at 6 m and extending to 1500 m from the roadway edge.

Time Period of Daytime and Nighttime Construction

Time periods during which construction activities are performed during daytime and nighttime periods are obtained from two sources, namely (a) the TxDOT Standard Specification Handbook and (b) input obtained from construction contractors performing the activities. According to the TxDOT Standard Specification Book (*97*), "nighttime work is defined as work performed from 30 minutes after sunset to 30 minutes before sunrise." Accordingly, the daytime and nighttime construction periods are calculated according to the seasonal sunrise and sunset times in Texas as listed in Table 44. Table 45 lists the daytime and nighttime construction periods based on the construction contractors' information.

Table 44. Daytime and Nighttime Construction Time Period According to TxDOT Specification Handbook.

Season	Sunrise/Sunset	Daytime Construction Period	Nighttime Construction Period
Winter (Dec., Jan., Feb.)	Sunrise 7:30 a.m., Sunset 5:30 p.m.	7 a.m.–6 p.m.	6 p.m.–7 a.m.
Spring (Mar., Apr., May)	Sunrise 7 a.m., Sunset 8 p.m.	6:30 a.m.–8:30 p.m.	8:30 p.m.–6:30 a.m.
Summer (June, July, Aug.)	Sunrise 6:30 a.m., Sunset 8:30 p.m.	6 a.m.–9 p.m.	9 p.m.–6 a.m.
Fall (Sep., Oct., Nov.)	Sunrise 7:30 a.m., Sunset 7 p.m.	7 a.m.–7:30 p.m.	7:30 p.m.–7 a.m.

Table 45. Daytime and Nighttime Construction Time Period According to Construction Contractors.

Season	Practical Daytime Construction Period	Practical Nighttime Construction Period
Winter (Dec., Jan., Feb.)	6 a.m.–9 p.m.	9 p.m.–6 a.m.
Spring (Mar., Apr., May)	6 a.m.–9 p.m.	9 p.m.–6 a.m.
Summer (June, July, Aug.)	6 a.m.–9 p.m.	9 p.m.–6 a.m.
Fall (Sep., Oct., Nov.)	6 a.m.–9 p.m.	9 p.m.–6 a.m.

Land Use

The urban/rural land use representativeness of a case study site is found to have an impact on the dispersed pollutant concentrations. Urban areas are generally hotter than nearby rural areas, especially at night, mainly because of heat retention by urban materials. Because of this heat retention, the vertical motion of the air is increased through convection, leading to increased dispersion of pollutants (*98*). This phenomenon is referred to as the urban heat island effect (Figure 68). AERMOD accounts for urban dispersion effects through the use of an urban dispersion option for indicating the effect of urban heat island effect and uses urban area population as a surrogate for the degree of urban heat island effect occurring in a specific area. The purpose of evaluating this key parameter is to assess the impact of land use on relative difference in concentration estimates between daytime and nighttime periods, given the same traffic characteristics and site configuration.

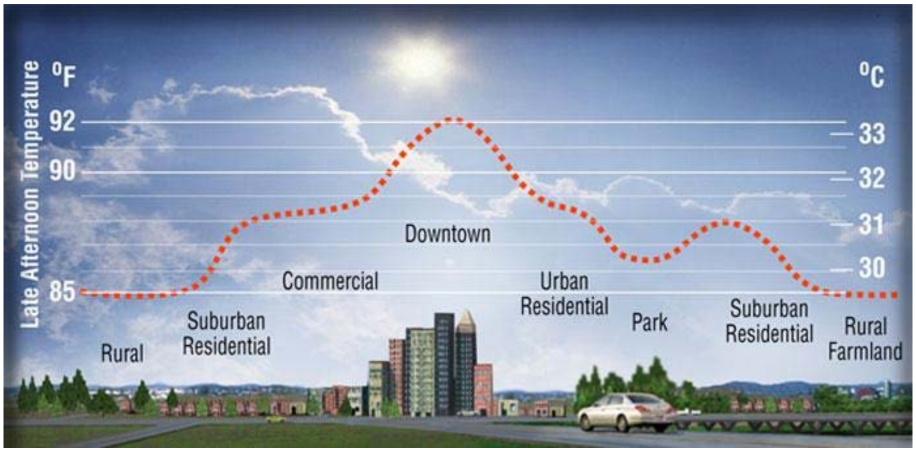


Figure 68. Heat Island Effect (*98*).

Averaging Period

Sensitivity analysis is performed for annual averaging periods for all case study regions. To evaluate the variation of pollutant concentration with atmospheric stability over a day, pollutant concentrations are estimated at an hourly averaging period for El Paso.

AERMET Meteorological Data Processing

EPA noted, in 2007, issues with high concentrations due to treatment of light winds in AERMOD. AERMOD currently exaggerates the nighttime concentration estimates due to the way it handles low winds (low wind speeds <1 m/s) (*99*). These low wind conditions typically occur during nighttime periods. To overcome the issue of over prediction, EPA, in 2012, developed non-default BETA options for meteorological data processing in AERMET to improve AERMOD performance under low wind conditions (*99*). The non-default BETA options were included in AERMOD Version 12345 to address the issues within the model in over prediction under low wind speed and stable conditions. This included the LOWWIND1 and LOWWIND2 BETA options on the MODELOPT keyword in AERMOD and the ADJ_U* option included in Stage 3 of the AERMET meteorological processor. The LOWWIND3 BETA option was included in the AERMOD with Version 15181. The LOWWIND3 BETA option is a combination of LOWWIND1 and LOWWIND2 BETA options (*100*). The LOWWIND1 option increases the minimum value of sigma-v from the default of 0.2 to 0.5 m/s, and also eliminates the horizontal meander algorithm. The LOWWIND2 option increases the minimum value of sigma-v from 0.2 to 0.3 m/s and retains the horizontal meander algorithm with an upper limit of 0.95. The LOWIND3 option increases the minimum value of sigma-v from 0.2 to 0.3 m/s and replicates the centerline concentration accounting for horizontal meander, but uses an effective sigma-y and eliminates upwind dispersion. The ADJ_U* option adjusts the surface friction velocity (U*) to improve the performance of the model in dealing with low wind speed and stable conditions (*101*). These non-default options are not approved for regulatory purposes but can be used for research purposes with the approval of appropriate reviewing authority. Meteorological data will be processed using these non-default options (developed to address the issue of model over prediction under low wind conditions) to assess their impact on pollutant concentrations between different time periods.

PERFORMING AIR DISPERSION MODELING AND OBTAINING RESULTS

The AERMOD air dispersion model data files (control files and meteorological data files) are prepared for the key input parameters identified previously. The AERMOD model requires emissions factors to be specified for all hours of the day and does not allow the user to run the model for specific time periods. To overcome this issue, the AERMOD model is set to run for the daytime and nighttime time periods as follows:

- Daytime model runs: emission rates are assigned a value of 1 for the daytime period hours and are given a value of 0 for nighttime period hours.
- Nighttime model runs: emission rates are assigned a value of 0 for the daytime period hours and are given a value of 1 for nighttime period hours.

Whenever a given hour is specified a value of 0, AERMOD does not compute concentration estimates for that hour. For example, in a daytime model run AERMOD concentration estimates are based only on emissions occurring during a daytime period and a nighttime model run AERMOD concentration estimates are based only on nighttime period emissions. Sensitivity of all key input parameters identified previously are tested with these two sets of daytime and nighttime model runs. The resulting pollutant concentrations obtained are normalized by the corresponding time periods. The following section describes the results of the dispersion modeling process in detail.

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