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16. Abstract

The passage of the 1990 Clean Air Act Amendments (CAAA) has resulted in several urban areas in Texas being designated non-attainment areas. While the non-attainment areas are acting to improve air quality, several near non-attainment areas need to act to maintain their air quality at current levels to avoid being designated a non-attainment area. These areas are reviewing several transportation-related strategies to reduce emissions and prevent further degradation of air quality. One option already being implemented is the observation of ozone action days that encourage citizens to seek alternative modes of travel such as transit and car pool/van pool on days conducive to the formation of high ozone levels. Alternative highway construction practices may also offer air quality benefits, especially on ozone action days.

Reconstruction and rehabilitation activities requiring lane closures on high-volume roadways result in traffic congestion and delays. The traffic congestion caused by construction activities and the materials and equipment used in construction may aggravate the air quality problem in non-attainment areas, especially during hot summer months when atmospheric conditions lead to the formation of high ozone levels. There is a need to determine the impact of highway construction on air quality and to determine alternative construction practices designed to minimize the detrimental effects on ambient air quality.

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AIR QUALITY IMPACTS
OF
HIGHWAY CONSTRUCTION AND SCHEDULING

by

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Research Report 1745-S
Research Study Number 0-1745
Research Study Title: Air Quality Impacts of Highway Construction and Scheduling

Sponsored by the
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TEXAS TRANSPORTATION INSTITUTE
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IMPLEMENTATION STATEMENT

In addition to the state's four urban areas currently designated as non-attainment areas, there is one maintenance area and four near non-attainment areas. A large proportion of the state's population resides within these nine urban areas. The contribution that mobile source emissions make to urban air quality is a significant concern. This project will provide information to the Texas Department of Transportation on the impacts of highway construction on corridor and regional mobile source emissions inventories. The project will also provide information on the additional construction costs incurred by highway contractors who are required to participate in ozone alert programs. This information will allow the Department to make more informed policy decisions on whether or not to include highway construction projects in ozone alert programs.

DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented hererin. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. It is not intended for construction, bidding, or permit purposes. George B. Dresser, Ph.D., was the Principal Investigator for the project.

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SUMMARY

The passage of the 1990 Clean Air Act Amendments (CAAA) has resulted in several urban areas in Texas being designated non-attainment areas. While the non-attainment areas are acting to improve air quality, several near non-attainment areas need to act to maintain their air quality at current levels to avoid being designated a non-attainment area. These areas are reviewing several transportation-related strategies to reduce emissions and prevent further degradation of air quality. One option already being implemented is the observation of ozone action days that encourage citizens to seek alternative modes of travel such as transit and car pool/van pool on days conducive to the formation of high ozone levels. Alternative highway construction practices may also offer air quality benefits, especially on ozone action days.

Reconstruction and rehabilitation activities requiring lane closures on high-volume roadways result in traffic congestion and delays. The traffic congestion caused by construction activities and the materials and equipment used in construction may aggravate the air quality problem in non-attainment areas, especially during hot summer months when atmospheric conditions lead to the formation of high ozone levels. There is a need to determine the impact of highway construction on air quality and to determine alternative construction practices designed to minimize the detrimental effects on ambient air quality.

INTRODUCTION

BACKGROUND

The passage of the 1990 CAAA resulted in several urban areas in Texas being designated "non-attainment areas." A non-attainment area is any area, usually designated by county, which does not meet the EPA's National Ambient Air Quality Standards (NAAQS) for one of six pollutants. The six criteria pollutants are ozone (O_3), carbon monoxide (CO), particulate matter (PM), sulfur oxide (SOx), nitrogen oxide (NOx), and lead. The pollutants of most concern to transportation are O_3, PM, and CO.

The current non-attainment designations are based on standards adopted in 1990 and three years of pollutant concentration data from ambient air monitors throughout the state. Those areas that did not meet the standards for one or more of the pollutants were designated non-attainment. A non-attainment designation results in the need to demonstrate conformity prior to any construction of "new capacity" (there are additional constraints on increases in single occupancy vehicle capacity) and consequently severely limits transportation construction projects. In 1997, the EPA adopted new standards that are more stringent. New designations will be made in 1999 or 2000, based on 3 years of data under the new standards.

The four current non-attainment areas in Texas (Houston, Dallas - Fort Worth, El Paso, and Beaumont - Port Arthur) are acting to improve air quality. Several other areas that are currently in attainment need to act to maintain their air quality and avoid being designated non-attainment (San Antonio, Austin, Corpus Christi, Longview, Tyler, and Victoria). These areas are reviewing various strategies to reduce emissions. One such measure is the designation of "ozone action days" when citizens are encouraged to seek alternative modes of travel. Ozone action days, as well as other air quality alerts, are especially important in areas of the state that are near "non-attainment." Alternative highway construction practices may also offer air quality benefits, especially on ozone action days.

Ozone Monitoring Programs

The agency responsible for predicting and issuing alerts for high ozone days is the Texas Natural Resource Conservation Commission (TNRCC). TNRCC uses forecast weather data from models run at National Weather Service (NWS) headquarters in Washington, D.C. to make decisions on predictions. When forecast information is received, it is compared to a set of criteria that includes temperature, wind direction, wind speed, and sky conditions. In 1995, TNRCC attained a 72 percent accuracy rate for forecast ozone concentrations that were above target levels set for each area participating in the ozone alert program. TNRCC issues forecast alerts by 2:00 p.m. to the NWS and to each area's local air quality coalition. The NWS broadcasts the alerts across its weather wire. Local air quality coalitions notify the news media, local government, businesses, and industries. Table 1 shows the number of ozone alert days issued and recorded ozone violations in 1994 and 1995 for selected Texas areas and Tulsa, Oklahoma.

TABLE 1
OZONE ALERT DAYS AND RECORDED VIOLATIONS

Area	1994			1995		
	Alert Days Issued	Recorded Violation	Violations with No Alert Days Issued	Alert Days Issued	Recorded Violations	Violations with No Alert Days Issued
Austin	15	0	0	29	0	0
Dallas-Fort Worth	28	12	2	25	26	3
Houston-Galveston	N/A	391	391	331	63	81
San Antonio	15	0	0	30	0	0
Tulsa, OK	4	0	0	10	0	0

[1]Houston-Galveston Ozone Watch Program initiated August 16, 1995

Highway Construction

Highway construction/rehabilitation is an essential activity. Construction projects increase mobility through increased capacity of existing facilities and provide critical transportation linkages. The side effects of highway construction include increased motorist delays both from the freeway and from traffic diversion onto alternate arterial streets. Other side effects include the use of some VOC emitting construction materials such as solvents, certain types of asphalt, and paints. These effects contribute to some of the air quality problems cities are experiencing today. Although the same construction projects in these cities are anticipated to ease the air quality problem in the long term, they are nonetheless contributing to the problem in the short term.

Temporary lane closures on construction projects provide access to work areas and to protect workers and motorists from possible conflict. These lane closures also create traffic congestion through queues and motorist diversion onto parallel arterial facilities. The traffic congestion resulting from the temporary lane closures increases mobile source emissions. The increase in mobile source emissions from lane closures contributes to regional air quality problems.

Some construction materials used contain organic compounds that produce HC emissions. The HC emissions from these materials also contribute to regional air quality problems.

Emissions controls are not placed on construction machinery. The CAAA prohibits any controls on equipment used for highway construction. The high visibility of these machines to the motorist public, however, creates a perception that they are large contributors to regional air quality problems.

Ozone Day Provisions

Local air quality coalitions have recently focused on the impacts of highway construction projects during ozone action days. Because of the high visibility of these projects, states are placing controls on contractors to mitigate activities during ozone alert days to provide an example to the public. Public groups and citizens react negatively to attempts by local and state governments to get the public to modify their travel behavior during ozone action days when no action is taken by the government to modify its own behavior.

Local air quality coalitions see the benefits of mitigating construction activity on ozone action days as threefold. First, traffic congestion associated with temporary lane closures can be reduced or eliminated. By reducing excessive queuing and the associated mobile source emissions increases from these queues, there are some savings to the regional air quality. Second, reducing or eliminating the use of high VOC emitting construction materials on construction sites will yield some incremental benefit on the regional air quality. Finally, these limitations also fit the public's desire of requiring government to lead by example on ozone action days. The Texas and Oklahoma DOTs are beginning to include some of these limitations in new highway contracts and are negotiating their inclusion into existing contracts.

The Oklahoma Department of Transportation (OkDOT) negotiated an ozone day provision into a contract in the Tulsa area. The provision discouraged contractors from installing a temporary lane closure in the peak direction during the peak period on the facility under construction/rehabilitation. Although no effects to regional air quality could be established from these ozone provisions, OkDOT officials believe that it was beneficial both in terms of reducing mobile source emissions from the construction project. They also believe it provides an example to the public that changing normal work habits for ozone action days is necessary if an area is to meet the NAAQS and remain in attainment.

In Texas, San Antonio became the first area to include provisions for ozone action days in its highway construction contracts. TxDOT began to develop a set of ozone provisions for use throughout the state in highway contracts where District Engineers felt they were applicable. However, the draft provisions were later recalled after discussions between TxDOT and AGC members throughout the state. The final recommendation by TxDOT was that each District develop its own ozone provision for each specific project and include the provisions in the general notes on the particular set of plans for that project. San Antonio remains the only Texas metropolitan area to include ozone provisions in contracts. Their current provisions are shown below:

> THE TEXAS NATURAL RESOURCE CONSERVATION COMMISSION (TNRCC) IS MONITORING WEATHER CONDITIONS ON A DAILY BASIS IN THE SAN ANTONIO AREA TO FORECAST THE PROBABILITY OF OZONE FORMATION. IN THE EVENT WEATHER CONDITIONS INDICATE THAT EXCESSIVE OZONE MAY OCCUR, THE NATIONAL WEATHER SERVICE WORKING WITH THE TNRCC WILL ISSUE AN AIR STAGNATION AND OZONE ACTION DAY FOR THE FOLLOWING DAY. TNRCC ESTIMATES THAT APPROXIMATELY 25 OZONE ACTION DAYS MIGHT BE ISSUED DURING THE OZONE SEASON (APRIL THRU OCTOBER). THE OZONE READINGS TAKEN DURING THESE DAYS ARE VERY CRITICAL TO FUTURE CONSTRUCTION FUNDS FOR THE SAN ANTONIO AREA; THEREFORE, ANY CONSTRUCTION OPERATIONS THAT ADVERSELY AFFECT THE READINGS NEED TO BE REDUCED.
>
> ON OZONE ACTION DAYS, TEMPORARY LANE CLOSURES THAT HAVE THE POTENTIAL OF CREATING/INCREASING TRAFFIC CONGESTION, AS DETERMINED BY THE ENGINEER, WILL NOT BE ALLOWED BETWEEN THE HOURS OF 6:00 AM AND 7:00 PM. IN ADDITION, DUE TO THE HIGH PERCENTAGE OF VOLATILES, CUTBACK ASPHALTS (MC OR RC ASPHALT) FOR SURFACE TREATMENT, PRIME OR TACK COATS, ETC. WILL NOT BE ALLOWED BETWEEN APRIL 1ST AND OCTOBER 31ST. DURING THE OZONE SEASON, HMCL AND/OR LRA WILL NOT BE ALLOWED UNTIL AFTER 12 NOON. ON THESE DAYS, THE CONTRACTOR SHOULD ALSO AVOID THE USE OF SMALL GASOLINE ENGINES. THE STATE WILL NOTIFY THE CONTRACTOR BY 4:00 PM THE DAY BEFORE THE OZONE ACTION DAY TO INFORM THEM OF THE LANE CLOSURE AND ASPHALT RESTRICTIONS FOR THE FOLLOWING DAY AND TO REQUEST THEIR ASSISTANCE IN REDUCING ANY OTHER OPERATIONS THAT MAY CONTRIBUTE TO AN INCREASE IN THE OZONE READINGS. IF THESE RESTRICTIONS AFFECT THE CRITICAL ITEMS OF WORK PREVIOUSLY SCHEDULED BY THE CONTRACTOR, A WORKING DAY WILL NOT BE CHARGED. TIME CHARGES ON OZONE ACTION DAYS WILL BE AS DETERMINED BY THE ENGINEER FOR EACH ACTION DAY.

TxDOT's Houston District office believes that contractual ozone provisions are not a reasonable strategy for their area due to the high number of ozone watches issued each ozone season. If such provisions were used, construction projects would fall significantly behind schedule, with devastating effects on the region's construction labor market and highway improvement program.

The benefits of the ozone provisions claimed by OkDOT were also echoed by TxDOT officials in San Antonio. They believed their efforts in the ozone provisions helped maintain the air quality in San Antonio during high ozone days. Additionally, they believed public relations were strengthened from the high visibility of the state's efforts to help reduce ozone formation in the area.

The ozone provisions in San Antonio are an example of a successful reconciliation of potentially conflicting agendas between the state and the contractors. Though these provisions place strains on the contractor in completing the project on schedule and in keeping crews working, the contractors recognize that these efforts must be taken to ensure that San Antonio remains in attainment. They are aware that critical federal funding for highway construction projects may be lost due to restrictions placed upon areas that become or are currently classified as non-attainment for one or more of the EPA monitored pollutants.

PROJECT OBJECTIVES

The primary objective of this research is to gain an understanding of the contribution to regional emissions of highway construction projects and of the additional costs incurred if highway construction projects are required to participate in ozone alert programs. This research will also provide information for TxDOT to use in developing ozone alert policy and programs.

- Assess the construction related air quality impacts due to traffic congestion, operation of construction equipment, and use of construction materials.
- Evaluate the economic and environmental benefits of construction abatement, especially on ozone action days.
- Identify alternative construction practices and activities to minimize negative impacts on air quality.
- Evaluate the emissions reduction benefits and costs of alternative construction scheduling, including lengthening contract time, construction during non-summer months, night construction, etc.

This study does not explore the relationship between increased mobile source emissions associated with construction projects and observed regional ozone concentrations. Previous work conducted by TTI (TTI Research Project 0-1279), examined the application of EPA's Urban Airshed Model (UAM) to Texas's urban areas and concluded that the UAM is not sensitive to small changes in the regional mobile source emissions inventory. Indeed, the ability of the UAM to correctly predict ozone concentrations is limited, even with extensive, costly, and specialized inventories of emissions and meteorology. It is not possible, given the current scientific understanding of the conditions that lead to ozone exceedances, to associate small regional changes in mobile source emissions (e.g., those associated with a construction project) with predicted ozone concentrations.

This project allows the department to quantify the impact of construction related emissions on corridor and regional mobile source emissions inventories and to quantify the additional construction costs incurred by participating in ozone alert programs. This information allows TxDOT to make a more informed policy decision on whether or not to include restrictions on highway construction projects as an integral part of ozone alert programs.

LITERATURE REVIEW

The literature reviewed for this research falls into five general areas:

- voluntary ozone mitigation measures;
- contracting issues - contractor risk and contractor fees;
- construction cost estimation;
- benefit-cost models; and
- construction project scheduling.

VOLUNTARY OZONE MITIGATION MEASURES

Ground-level ozone is the most widespread air quality problem in the U.S. Episodic, Voluntary Ozone Control (EVOC) programs provide information to the public, so people can take voluntary actions to reduce air pollution. Most programs involve forecasting high ozone days and alerting a network of private firms, government agencies, and the media. Voluntary actions to reduce air pollution include delaying grounds maintenance and reducing auto trips. On ozone action days, employers may provide van pooling and free trips may be offered on transit (Farrell, 1995: 1,2,5,6).

Meteorological teams determine when to initiate ozone action days. Although most teams are accurate at predicting high-ozone days, ozone action days are declared "according to a liberal standard" (Farrell, 1995: 3-5). Since a high-ozone condition may last one day or one week, businesses can have substantial difficulty in adjusting to voluntary pollution mitigation measures.

Tulsa has the oldest EVOC program in the nation, called Ozone Alert. It includes a network of 360 firms and government offices. The local transit operator provides free service on Ozone Alert days, and the media readily convey information about the program (Farrell, 1995: 8-9).

The San Francisco Bay area has a well-established EVOC program. "Spare the Air" includes 635 firms. It is administered by the Bay Area Air Quality Management District. Local transit operators provide free advertising space for program information, and the media have cooperated in reporting on the program (Farrell, 1995: 10-11).

Construction impacts air quality in three areas: on-road mobile emissions from workers' vehicles, off-road mobile emissions from construction equipment, and PM-10 emissions from earthwork. The South Coast Air Quality Management District (SCAQMD) in the Los Angeles area has proposed a voluntary program that includes suspending construction equipment operations during second stage smog alerts. However, the degree to which this strategy reduces emissions has not been quantified and compliance is entirely voluntary (SCAQMD, ND: 11-7, 11-14).

CONTRACTING ISSUES

Risk is a central issue in contracting. Contractors are businesses that provide customers products and services within the context of a contractual relationship (Marshall, 1969: 531). The purpose of a contract is to explicitly distribute risks to parties by assigning acceptable responsibilities. In other words, contracting involves assuming a degree of risk (Ashley and Workman, 1986: 5,13).

Risk stems from the uncertainties of the world. Risk for contractors involves exposure to possible economic gains or losses (Stukhart, 1984: 35). Contractors assume risks involving cost variability, contract structure, and utility for money (Marshall, 1969: 531,532). Their risk is "the variation in the utility value of contractor fee[s]" (Ashley and Workman, 1986:16).

The contractor fee is composed of three elements: the service fee, the actuarial fee, and the incentive fee. The service fee is for work performed by the contractor. The actuarial fee provides compensation for the risk assumed by the contractor. The incentive fee provides a reward for superior results. It may also provide a penalty for less than targeted performance (Marshall, 1969: 533). The contract type establishes a method for determining the amount of the contractor fee. There are two basic types of contracts—fixed-price and cost-reimbursable. Each type has a number of slight variations.

The fixed-price arrangement is ideal only when the drawings and specifications are complete before the contract is signed. A well-defined project may use a lump-sum fixed-price arrangement. Under this type of agreement, one price covers all work to be completed under the contract.

One variation is the unit price method that establishes fixed per unit prices the owner will pay the contractor (Ashley and Mathews, 1986:10-11). The quantity of items is not specified, but an estimate is provided. The contractor assumes all of the risk with the lump sum method and assumes the risk for price variation with the unit price method. One method to reduce the contractor's risk of cost increases is to use the fixed-price with escalation agreement. In these agreements, increases in certain allowable costs can be passed to the owner. Another method to reduce the contractor's risk is to have a series of fixed-price contracts on the same project (Arditi and Khisty, 1994:7-8).

Unforeseen conditions frequently result in contractual disputes with fixed-price contracts, and these contracts require a high degree of project definition. Cost-reimbursable contracts allow the contractor to be reimbursed for actual expenses plus a contractor fee. These contracts can be agreed upon before project design is complete, and they offer more flexibility for cost changes (Arditi and Khisty, 1994: 8-9).

The variations of cost-reimbursable contracts include cost-plus-percent-fee, cost-plus-fixed-fee, target price, and convertible. The cost-plus-percent-fee agreement provides reimbursement for construction costs and includes a fee based on a percentage of final costs.

Cost-plus-fixed-fee provides reimbursement plus a fixed contractor fee. The target price agreement reimburses the contractor for costs and includes a fee based on a profit formula. A convertible agreement begins as cost-reimbursable and converts to a fixed-fee after the project is sufficiently defined (Ashley and Mathews, 1986: 12-14).

Any of these contract types may involve incentive or disincentive provisions. Incentives are tools for bringing the contractor's goals in line with the owner's (Arditi and Khisty, 1994: 5). Incentives create a win-win outcome, rewarding the contractor for achieving performance goals and benefitting the owner by achieving those goals (Ashley and Workman 1986: 21).

The owner's goals focus on completing a project on time, on budget, and on quality. The contractor seeks to make a reasonable profit, reduce risk, enhance long-term relationships with owners, capture greater market share, and satisfy survival and growth needs. Naturally, not all goals are in harmony. A balance of goals must be achieved through contract negotiation. Incentives focus on one or more goals of each party in an understandable and a manageable way to improve performance (Stukhart, 1984: 34).

Bonus/Penalty or Incentive/Disincentive (I/D) provisions of contracts apply to the goals of scheduling and budgeting. These provisions can offer bonuses for completing work under budget or ahead of schedule and impose penalties for being over budget or behind schedule. For example, I/D contracts are often used to expedite projects. These contracts provide a bonus to contractors for every day the project is completed ahead of schedule (up to a maximum) and a penalty for every day the project is late. Liquidated damages are not incentives. A liquidated damages clause requires the contractors to repay costs incurred by the owner for construction delays. Courts hold liquidated damages clauses to be unenforceable if used to penalize contractors to obtain performance (Stukhart, 1984: 37-38).

The FHWA first defined I/D contract provisions in a Federal Register notice in 1984, according to Arditi and Khisty (1994:17), by stating "[t]he I/D concept is a predetermined method of scheduling payments that compensates the contractor a certain amount of money for each day the work is completed ahead of schedule and makes a deduction for each day the contractor overruns the completion date." I/D provisions are appropriate for well-defined highway projects in where road user savings would be large (fewer accidents, less delay, etc.) and high traffic volumes could not be easily diverted. Typically, bonuses represent up to 5% of the total project cost. While I/D projects are completed in less time (reducing congestion, delay, and user inconvenience), they usually have higher costs (Gendell, 1987: 77-78). More than 93% of I/D projects by the Illinois Department of Transportation were completed on time or ahead of schedule. I/D projects in Illinois opened to motorists, on average, 18% earlier than non-I/D projects (Arditi and Khisty, 1994:92).

Texas uses an I/D method called "A+B bidding." Contractors bid projects in two areas: cost and number of working days. The number of days multiplied by the bonus/liquidated damages rate, is added to the cost bid to determine a contractor's total bid. Projects are awarded to the lowest bidder based on total bids. I/D provisions in the project contract award bonuses for completion in less than the number of bid days and charge liquidated damages for projects completed beyond the number of bid days. McFarland (1987: 2, 51-52) recommends A+B bidding be used in awarding all construction contracts. He proposes using liquidated damages clauses in all construction contracts and bonuses for only the most critical projects.

For example, the Metropolitan Transit Authority of Harris County and the then-Texas State Department of Highways and Public Transportation used I/D contracting and A+B bidding on construction of a transitway in an existing freeway median in the early 1980s (Christiansen, 1987: 69-70). The number of working days was multiplied by $5,000 per day and added to the cost bid to produce total bids. The $5,000 figure was derived by estimating the daily administrative, engineering, inspection, and operation costs of the transitway. Phase

1B was awarded to the low bidder. A $5,000 bonus per day (up to 90 days) would be paid for early completion and an equal amount incurred for late completion. The contractor bid 360 days and completed the project in 269 days. Therefore, the contractor received the maximum bonus of $450,000. Although A+B bidding was successfully used on this project, Christiansen (1987:75) states the use of this practice is under debate, and he does not recommend its use.

Although incentives can serve to reduce owners' risks associated with uncertain completion dates or costs, incentives and risks for contractors do not go hand-in-hand. Incentives are based solely on performance. They stem only from those factors within the contractor's control, and they do not come from risk assumption (Ashley and Workman, 1986:14-16,23). Bradley and McCuiston (1972:25) state the importance of relating incentives to contractor actions, as "[r]ewards for performance must be based upon deterministic relationships between the contractor's efforts and the resulting outcome."

An increase in risk for the contractor corresponds to an increase in the actuarial component of the contractor's fee. Contractors are risk adverse. The amount of the actuarial fee is determined by the perception of risk, the controllability of risk, the individual's preference for risk, and the potential return from assuming risk (Ashley and Workman, 1986:14). In contracts, risk should be allocated based on potential return, controllability of risk, and the ability of parties to protect themselves against risk. Risk allocation has strong implications in contract execution because "[d]espite efforts of owners to develop a 'team' approach at the start of a contract, adversary relationships generally develop, and the intensity of this adversary relationship is heightened by imposition of excessive risks" (Stukhart, 1984: 35).

CONSTRUCTION COST ESTIMATION

Contractors often aggregate cost estimates for bidding purposes using references, such as *General Construction Estimating Standards* (Richardson Engineering Services, Inc., 1986). These guides provide specific data about average materials requirements, labor-hour requirements, labor costs, and materials costs for individual specification items. The estimates are provided for individual project items according to the Construction Specifications Institute format. This format includes 16 broad divisions that are standard in the construction industry.

While these estimates are precise and perfectly suited for project-specific cost estimates, they do not provide any categorical project cost data. The use of average cost data for categories of construction projects will likely result in inaccuracy. Construction projects each have unique materials and labor requirements, so a "typical" construction project can be viewed only from the perspectives of comparables or individual definition.

BENEFIT-COST MODELS

When cost estimates are generated from either cost estimation schedules or historical data, they can be inputs to benefit-cost models. These econometric models usually relate predicted present values of total project benefits and costs. They can be used to compare alternative proposed capital improvements.

Rollins, Memmott, and Buffington (1981) analyzed the suitability of using urban development models for examining the relationship between roadway improvements and urban development factors. Urban development models are often used to forecast regional growth or evaluate policy alternatives (Rollins, Memmott, and Buffington, 1981: iii). These models fall into three category types: research models, Lowrey descriptive models, and EMPIRIC models.

Lowrey descriptive models relate residential, employment, and shopping factors to population and employment growth. Examples include projective land use models and disaggregate residential allocation models. EMPIRIC models use a system of simultaneous regression equations to forecast the effects of alternative policies on regional growth based on population, land use, and employment data (Rollins, Memmott, and Buffington, 1981: 46 - 50). Rollins, Memmott, and Buffington (1981) conclude that urban development models should be applied only to land use patterns analysis on a regional level, and that "... no attempt should be made to adapt any urban development model to the analysis of land use changes and roadway improvements in specific-locations within urban regions" (Rollins, Memmott, and Buffington, 1981: 54 - 56).

Memmott and Buffington (1981) discussed factors affecting average daily traffic volume forecast by the Highway Economic Evaluation Model (HEEM). This model was created to estimate potential highway user benefits and costs associated with proposed highway improvements using factors such as highway capacity and categories of land development. The authors conclude error exists in some projections: for instance, population and land use projections are generally inaccurate, and they propose changes in the model to improve accuracy (Memmott and Buffington, 1981: ii - v).

In another report, Memmott and Buffington (1982) evaluated the feasibility of using HEEM to evaluate High Occupancy Vehicle (HOV) projects. They discuss model deficiencies and recommend changes to improve applicability. The proposed changes would allow HEEM users to perform more robust economic evaluations of proposed HOV facilities (Memmott and Buffington, 1982: ii - vi).

Chui, Memmott, and Buffington (1983: ii - iv) applied regression models to explain capacity improvements on land use. They used two regression models. The first related land use (by percentage of area) to time using the factors of capacity improvements, median treatments, traffic, highway type, and city. The second model related average daily traffic to time, using the same factors plus stage of development. The models produced mixed results and indicated land use is affected differently by various types of improvements. In a similar study, Buffington, Chui, and Memmott (1985: i) used a regression analysis of historic land uses to examine the impact of staged freeway construction.

After questions surfaced about the assumptions and limitations in HEEM, Memmott and Buffington (1983: ii - iii) developed a report documenting the improvements incorporated in the revised model HEEM-II. Improvements included the ability to evaluate 29 additional highway types and updated costs associated with vehicle operations, accidents, and maintenance.

Estimated construction and right-of-way costs are inputs in HEEM and HEEM-II (Memmott and Buffington, 1983: 24 - 27). In HEEM-II, the benefits (in terms of delay savings, operating cost savings, accident cost savings, and maintenance savings) are compared to the costs. Construction and right-of-way costs are discounted to obtain the present value of capital costs. The present value of the sum of the benefits is divided by the present value of the sum of the costs, and an internal rate of return is calculated. The benefit-cost ratio produced by HEEM-II is based on the assumption of total construction cost for the proposed facility under evaluation. It is input into the model and must be known before running the model.

In 1993, McFarland, Memmott, and Chui authored a study discussing the MicroBENCOST model. This highway benefit-cost model was similar to the HEEM models. Again, the construction costs are taken as given inputs into the model. McFarland, et al (1993) also produced a user's manual to MicroBENCOST.

Capital costs are used as inputs into these models that can assist decision-makers. The costs, specifications, and schedules of each project are unique. Contractors use industry averages to create estimates of project costs for many purposes, including resource allocation and bidding. Another major activity of contractors is project planning and the creation of project schedules.

CONSTRUCTION PROJECT SCHEDULING

Contractors utilize a variety of methods, spreadsheets, and software applications to plan and schedule construction projects. One of the most widely applied is the Critical Path Method (CPM). Whatever method is used, a contractor must determine the tasks that must be performed, the duration of each task, and the sequence of the tasks. Then, using a tool (such as CPM), critical activities and an optimal scheduling plan are developed within temporal, budgetary, and quality targets. Critical activities are defined as those that would increase project completion time if task completion time is increased (Levy, Thompson, and Wiest, 1963: 98).

CPM defines a number of target times. The early start time is the earliest time a task can begin, and the early finish is the earliest possible completion time for a task. The late start time represents the latest time a task can begin without delaying the project. The late finish is the latest time a task can end without delaying the project. The amount of time a task can be delayed beyond the early start time without delaying to the project is called slack (Levy, Thompson, and Wiest: 1963: 100-104). Tasks along the critical path have no free slack, as they cannot be delayed without delaying the project's scheduled completion. Projects are often represented in network diagrams to show the sequence and duration of tasks, the critical path, early start and finish, late start and finish, and slack.

The important point in project scheduling is that not all tasks are equal. One task could be delayed for a certain period without affecting the overall project, while another critical task could not be delayed one day without delaying the entire project. Each task has different time and resource requirements, different durations, and different preceding tasks. Further, multiple tasks occur simultaneously. A considerable level of complexity is involved in scheduling and planning any construction project. Not only is each project unique, but each day on the construction site involves a unique set of tasks.

CONSTRUCTION IMPACT EVALUATION TOOLS

Due to the aging road network, rehabilitation work is being conducted in many parts of the U.S. Roadway rehabilitation and reconstruction projects pose special types of scheduling challenges because the activities are usually performed with traffic in adjacent lanes, thus impacting the traffic flow and resulting in additional motorist and environmental costs.

Past efforts to estimate the impacts of reconstruction activities on traffic flow, road user costs, and emissions have produced various estimation tools. These tools include the findings of various research efforts that studied the impacts of roadway construction activities prior to the development of these tools. Each is discussed separately below.

QUEWZ-92

Research has been conducted in several areas to study the impacts of traffic, user cost, safety, and emissions from highway reconstruction activities. The traffic flow and user cost impact findings from these studies led to the development of QUEWZ-92, a microcomputer-based tool for evaluating freeway lane closures.

QUEWZ-92 compares traffic flows through a freeway segment with and without a work zone lane closure and estimates the changes in traffic flow characteristics and road user costs resulting from the lane closure. Model analysis can be applied to freeway facilities or multilane divided highways with as many as six lanes in each direction and the model can analyze work zones with any number of lanes closed in one or both directions. QUEWZ-92 cannot generate emissions information resulting from lane closures.

QUEWZ-92 generates road user costs and lane closure schedules. The road user cost option analyzes a user-specified lane closure configuration and schedule of work activities and generates estimates of traffic volumes, capacities, speeds, queue lengths, and additional road user costs for each hour affected by the lane closure. A diversion algorithm can be used with this option to estimate the volume of traffic that might divert from the freeway in response to work zone related delays. The diversion algorithm is based on observations of urban freeway work zones in Texas. It was observed that, on average, the maximum queue engulfed 5 ramps, and the maximum delay was 20 minutes before motorists began to divert from the freeway.

The lane closure schedule option summarizes the hours of the day when a given number of lanes can be closed without causing excessive queuing (user specified). QUEWZ-92 considers each hour as a possible starting hour for the lane closure and determines the number of consecutive hours the lanes could remain closed without causing excessive queuing.

The speed and queue estimation methods of the model are based on the Highway Capacity Manual; the work zone capacities are based on observations at freeway work zones in Texas.

QUEWZ-EE

The Center for Transportation Research conducted a study to develop a model, QUEWZ-EE, to estimate mobile source emissions (HC, CO, NOx) and energy consumption impacts of work zones. This model is based on QUEWZ-85, an earlier version of QUEWZ-92, which does not consider traffic diversion due to excessive queuing. The work zone capacities used are based on a limited number of studies, and the model does not include the effects of lane configurations, type, and intensity of work activity as in QUEWZ-92.

The emissions in the work zone are estimated in QUEWZ-EE based on the time spent by each vehicle in each operating mode (acceleration, deceleration, cruise, and idle/queue).

The modal emissions rates are obtained after applying modal correction factors to the emissions rates obtained from the MOBILE model. The correction factors were derived using limited sets of emissions data from Surveillance Driving Sequence (SDS) and driving cycle tests. This approach closely resembles the approach employed in the MICRO2 and CALINE4 models. The modal emissions rates for heavy vehicles were obtained using the same correction factors as for passenger vehicles.

The idle emissions rates used in QUEWZ-EE are based on the idle emissions rates generated by the MOBILE4.1 model. The deceleration mode emissions rates were assumed to be 1.5 times the idle emissions rates based on the findings from a CARB study.

CARHOP

CARHOP was developed at the Institute of Transportation Studies, University of California, Irvine. The CARHOP environment provides a method for testing various transportation system management alternatives related to the reconstruction of freeways and arterials in an existing transportation network. This system is based on an integration of the CORFLO and the TRANSYT-7F traffic simulation models. CORFLO is used for traffic assignment and simulation in the freeway/arterial network and TRANSYT-7F is used for signal timing optimization. CARHOP also includes a post-processor module to generate comparative statistics from the output generated by the CORFLO simulation model.

CARHOP allows the analyst to create reconstruction zones, modify their characteristics, and then evaluate the performance of the network subject to the alteration of the surrounding arterial network characteristics and signal timings. The impacts of different driver characteristics and vehicle occupancies may also be studied within this modeling environment. Traffic diversion can be modeled using the assignment model in CORFLO, or the user may specify a diversion route to by-pass the work zone.

It should be noted that, unlike QUEWZ, CARHOP can be used to evaluate impacts of both arterial and freeway reconstruction activities.

Since the development of this model, the FHWA has released new versions of CORFLO. There is no documented effort to upgrade CARHOP to interface with recent releases of the base models. Although this model was developed mainly to evaluate various TSM strategies for highway rehabilitation management, it can be used for emissions estimation since CORFLO can generate information on mobile source emissions. However, it should be noted that the emissions generated by CORFLO are not based on the EPA-approved MOBILE model.

Apart from non-standard emissions rates, another drawback of CARHOP is the application of simulation models. Like all network-based simulation models, the development, calibration, and implementation of a CORFLO model for a roadway network consisting of freeways and arterials is very complex. No validation efforts were reported for CARHOP. CARHOP represents an application of traditional traffic simulation models used to study work zone related traffic problems.

WORK ZONE ANALYSIS TOOL FOR ARTERIAL

Work Zone Analysis Tool for Arterial (WZATA) was developed for the analysis and evaluation of a system consisting of a lane closure between two signalized intersections. While considerable effort has been expended to study the impact of freeway work zones, this is the only reported study directed mainly at the evaluation of the impacts of arterial work zones.

WZATA is a microcomputer-based microscopic simulation tool that simulates traffic between two signalized intersections consisting of a work zone lane closure. This tool is capable of simulating several different lane closure configurations and different merge and diverge scenarios for the work zone. The simulation is based on car-following logic. Traffic merging and diverging before and after the work zone is explicitly considered. Vehicle progression is also simulated. WZATA computes vehicle delay both between intersections and at the downstream intersection.

One of the main drawbacks of WZATA is that it does not have any emissions estimation capabilities. It can simulate only one unidirectional link consisting of two intersections and the work zone. An entire arterial cannot be simulated. Heavy vehicles are not simulated. Uniform arrivals and lane usage are assumed in the model. Normal merging and lane changing outside the work zone area is not simulated. Merging and diverging behavior is not based on the traditional gap acceptance logic, but follows a program generated or a user-specified pattern. Non-platoon flows are assumed to have no delays between the intersections. Over-saturated conditions and queues are not considered in the model.

WZATA represents a first attempt at developing a tool to evaluate the impact of arterial lane closures, and more work is required as is evident from the above discussion of its drawbacks. There is no discussion of any effort to validate this model in the literature.

These construction evaluation tools are summarized in Table 2.

TABLE 2
CONSTRUCTION IMPACT EVALUATION MODELS

Model	Evaluates Diversion	Evaluates Emissions	Freeway	Arterial
QUEWZ-92	X		X	
QUEWZ-EE		X	X	
CARHOP	X	X	X	X
WZATA				X

QUEWZ, CARHOP, and WZATA are the tools developed for estimating work zone impacts. Among these tools, the highest level of research effort went into the development of the QUEWZ model.

From Table 2 it is clear that only CARHOP is capable of evaluating both arterial and freeway construction impacts. However, since CARHOP is a simulation-based tool, it is very complex and not easy to use for the practicing engineer. QUEWZ-EE is a simpler tool than CARHOP and is capable of evaluating the emissions impact of highway construction activities. Consequently, the QUEWZ-92 with the energy and emissions module from the QUEWZ-EE appended model was selected. (QUEWZ-EE is based on an earlier version of QUEWZ that does not include the findings of recent research in this area. Thus, the incorporation of the emissions module in QUEWZ-EE into the new QUEWZ-92 model is required.)

SUMMARY OF USER'S MANUAL ADDITIONS

QUEWZ-92 is an enhanced version of QUEWZ-85. QUEWZ-EE added an emissions calculation capability to QUEWZ-85 using MOBILE4.1 emissions rates. An objective of this project is to update the emissions rates in the QUEWZ-EE module to the latest version of MOBILE (MOBILE5a), and the linkage of the updated QUEWZ-EE emissions module to QUEWZ-92. The updating of the QUEWZ model (QUEWZ-98) included the following:

- Update the emissions module of QUEWZ-EE from MOBILE4.1 to the latest version of Mobile (Mobile5a).
- Integrate the updated emissions module into the QUEWZ-92 model.
- Test and demonstrate the updated software.
- Update User's Manual for the QUEWZ model. (Provided as a separate research report.)
- Prepare updated model software for delivery to TxDOT.

This section summarizes the updated QUEWZ model (QUEWZ-98), including the revisions to the QUEWZ-EE module and its integration into the QUEWZ-92 model. The reader is referred to the revised user's manual for a detailed description and operating instructions.

QUEWZ-98

As described above, the original QUEWZ model estimated vehicle operating and time delay costs, reported as a total cost. The original QUEWZ included two configurations of work zone lane closures. These are (1) one or more lane closures in one direction with the opposite direction unaffected, and (2) all lanes in one direction are closed and two-lane two-way traffic is maintained on the lanes normally traveling in the other direction. The model can accommodate up to six lanes in each direction. (Seshadri et al. 1993)

QUEWZ-EE

The original QUEWZ program was modified by Seshadri and Harrison (1993) to include operating costs and emissions. Operating costs were disaggregated to separate fuel and oil from total operating costs. Additional emissions are calculated by comparing predicted free-flow emissions with emissions associated with various work zone configurations and reporting the differences. (Seshadri et al. 1993)

QUEWZ-EE uses a two-step process to predict emissions. The first step characterizes traffic at the work zone location, because traffic behavior varies with location. For example, if the location is normally free flowing traffic, vehicle speed and flow are the critical variables. Intersection related emissions, on the other hand, may require traffic signal phasing data, queue lengths, delay times, or capacity. The second step is the estimation of the emissions source, meaning emissions rates. These rates are provided by EPA's MOBILE models (originally MOBILE4.1, updated by this project to MOBILE5a).

Ideally, the dispersion of emissions would also be modeled, including factors such as roadway width, wind speed, wind direction, source height, and mixing height, as well as calibration of the dispersion model using site specific data. At this time there is no dispersion model associated with QUEWZ-EE.

QUEWZ-EE is an enhancement of the original QUEWZ model. The only additional input required for the enhanced version are idle emissions rates (hot stabilized) for the three key pollutants (HC, CO, and NOx) for passenger cars and trucks for the scenario (i.e., MOBILE5a setup parameters) being examined. Hourly and total daily emissions are reported, in addition to the parameters reported by the original QUEWZ model.

QUEWZ-98 incorporates the QUEWZ-EE enhancements in the updated version of QUEWZ (QUEWZ-92), as well as updating the QUEWZ-EE emissions rates.

The MOBILE5a setup in Table 3 was used to generate the default emissions rates for QUEWZ-98. These parameters represent San Antonio in the summer of 1998. The RVP is 8.2, the diurnal temperature range is 73.3 to 94.0, and the operating mode is 100% hot stabilized. The VMT mix shown is 92% cars (LDGV) and 8% heavy-duty diesel trucks (HDDV). Note that QUEWZ-98 considers only these two vehicle types. The actual percent of trucks is input by the user.

TABLE 3
DEFAULT MOBILE5a EMISSIONS SETUP

```
1       PROMPT
MOBILE5a BASE Run for QUEWZ98
1       TAMFLG
1       SPDFLG
3       VMFLAG  - Input single Vmt mix
1       MYMRFG
1       NEWFLG
1       IMFLAG
1       ALHFLG
1       ATPFLG
1       RLFLAG
2       LOCFLG  - User input: one LAP record
2       TEMFLG  - Don't calculate exhaust temp.
3       OUTFMT
4       PRTFLG
1       IDLFLG
3       NMHFLG  - VOC
2       HCFLAG  - print HC components
.920.000.000.000.000.000.080.000   VMT mix
           73.3 94.0  8.2  8.2 90                                LAP
1 98  2.5 86.0  0.0  0.0  0.0                                    Scenario
```

The resulting default emissions rates are shown in the following three tables.

TABLE 4
HC EMISSIONS RATES (GRAMS PER MILE)

Speed	LDGV	HDDV
2.5	13.9570	5.05655
3	11.0127	4.92534
4	7.76775	4.67615
5	6.05221	4.44346
6	5.00501	4.22608
7	4.30455	4.02286
8	3.90805	3.83279
9	3.60453	3.65492
10	3.35589	3.48837
11	3.14719	3.33234
12	2.96845	3.18609
13	2.81274	3.04894
14	2.67510	2.92026
15	2.55190	2.79948
16	2.44039	2.68606
17	2.33849	2.57950
18	2.24457	2.47934
19	2.15737	2.38518
20	2.07756	2.29661
21	2.01315	2.21328
22	1.95409	2.13485
23	1.89967	2.06101
24	1.84932	1.99147
25	1.80255	1.92598
26	1.75895	1.86428
27	1.71817	1.80614
28	1.67992	1.75136
29	1.64394	1.69974
30	1.61002	1.65109
31	1.57797	1.60524
32	1.54762	1.56204
33	1.51882	1.52134
34	1.49144	1.48301
35	1.46537	1.44692
36	1.44051	1.41294
37	1.41677	1.38098
38	1.39406	1.35093
39	1.37231	1.32270
40	1.35144	1.29620
41	1.33140	1.27134
42	1.31212	1.24806
43	1.29356	1.22629
44	1.27566	1.20596
45	1.25837	1.18701
46	1.24166	1.16938
47	1.22547	1.15303
48	1.20999	1.13791
49	1.20546	1.12398
50	1.20119	1.11119
51	1.19717	1.09952
52	1.19337	1.08893
53	1.18978	1.07939
54	1.18638	1.07087
55	1.18316	1.06336
56	1.20903	1.05683
57	1.23505	1.05126
58	1.26122	1.04665
59	1.28752	1.04297
60	1.31395	1.04022
61	1.34050	1.03839
62	1.36716	1.03748
63	1.39392	1.03748
64	1.42079	1.03839
65	1.44774	1.04022

TABLE 5
CO EMISSIONS RATES (GRAMS PER MILE)

Speed	LDGV	HDDV
2.5	87.40553	37.83645
3	74.03694	36.29847
4	57.16034	33.45314
5	46.93938	30.88701
6	40.09179	28.56967
7	35.19143	26.47433
8	31.51654	24.57736
9	28.66209	22.85788
10	26.38314	21.29741
11	24.52289	19.87963
12	22.97634	18.59003
13	21.67056	17.41576
14	20.55335	16 34539
15	19.58640	15.36874
16	18.74096	14.47678
17	17.99505	13.66142
18	17.33162	12.91547
19	16.73728	12.23249
20	16.06641	11.60674
21	15.32849	11.03305
22	14.65632	10.50683
23	14.04125	10.02393
24	13.47610	9.58065
25	12.95492	9.17365
26	12.47272	8.79995
27	12.02529	8.45684
28	11.60905	8.14192
29	11.22093	7.85300
30	10.85831	7.58813
31	10.51891	7.34556
32	10.20072	7.12369
33	9.90198	6.92111
34	9.62115	6.73654
35	9.35684	6.56883
36	9.10780	6.41697
37	8.87291	6.28004
38	8.65116	6.15722
39	8.44162	6.04781
40	8.24344	5.95116
41	8.05583	5.86672
42	7.87805	5.79402
43	7.70943	5.73264
44	7.54928	5.68224
45	7.39699	5.64255
46	7.25191	5.61334
47	7.11343	5.59445
48	6.98089	5.58579
49	6.98089	5.58730
50	6.98089	5.59899
51	6.98089	5.62092
52	6.98089	5.65322
53	6.98089	5.69607
54	6.98089	5.74969
55	6.98089	5.81439
56	7.95058	5.89053
57	8.92028	5.97854
58	9.88997	6.07891
59	10.8596	6.19223
60	11.8293	6.31916
61	12.7990	6.46043
62	13.7687	6.61689
63	14.7384	6.78949
64	15.7081	6.97928
65	16.67780	7.18744

Table 6
NOx EMISSIONS RATES (GRAMS PER MILE)

Speed	LDGV	HDDV
2.5	1.89956	21.24983
3	1.78027	20.78645
4	1.63086	19.91098
5	1.54094	19.09949
6	1.48081	18.34710
7	1.43775	17.64940
8	1.40538	17.00235
9	1.38016	16.40230
10	1.35996	15.84591
11	1.34344	15.33015
12	1.32967	14.85225
13	1.31805	14.40970
14	1.30810	14.00020
15	1.29952	13.62166
16	1.29203	13.27220
17	1.28546	12.95007
18	1.27965	12.65372
19	1.27448	12.38172
20	1.27605	12.13279
21	1.28395	11.90575
22	1.29115	11.69956
23	1.29776	11.51328
24	1.30385	11.34607
25	1.30948	11.19718
26	1.31470	11.06594
27	1.31956	10.95177
28	1.32410	10.85419
29	1.32835	10.77277
30	1.33234	10.70715
31	1.33610	10.65705
32	1.33964	10.62226
33	1.34300	10.60262
34	1.34619	10.59807
35	1.34922	10.60856
36	1.35211	10.63416
37	1.35487	10.67497
38	1.35752	10.73116
39	1.36007	10.80297
40	1.36254	10.89073
41	1.36492	10.99479
42	1.36723	11.11562
43	1.36949	11.25375
44	1.37170	11.40979
45	1.37387	11.58442
46	1.37601	11.77845
47	1.37813	11.99274
48	1.38023	12.22828
49	1.43042	12.48617
50	1.48060	12.76761
51	1.53078	13.07395
52	1.58096	13.40666
53	1.63115	13.76737
54	1.68133	14.15788
55	1.73151	14.58016
56	1.78170	15.03636
57	1.83188	15.52888
58	1.88206	16.06032
59	1.93225	16.63355
60	1.98243	17.25171
61	2.03261	17.91828
62	2.08279	18.63705
63	2.13298	19.41220
64	2.18316	20.24831
65	2.23334	21.15046

The default idle emissions are calculated by converting the idle emissions rate from grams per mile to grams per hour (i.e., multiplying the emissions rate at 2.5 mph by 2.5 miles per hour). The default idle emissions (in grams per hour) are:

HC Car 34.9 (g/hr)
HC Truck 12.6 (g/hr)
CO Car 218.5 (g/hr)
CO Truck 94.6 (g/hr)
NOx Car 4.7 (g/hr)
NOx Truck 53.1 (g/hr)

If the user provides idle emissions, six scale factors are calculated and applied to the three emissions rate tables above. Default cruise emissions rates are calculated as the ratio of the input rate (if any) over the default rate for each vehicle type (i.e., cars or trucks) and for each pollutant type (i.e., HC, CO, NOx). If the user inputs a complete set of emissions factors then the scaling is omitted and the idle emissions are only converted to grams per hour as described above. Cruise emissions rates are also converted from grams per mile to grams per hour for each speed.

The original QUEWZ-EE routine provided estimates of acceleration and deceleration emissions separate from cruise and idle emissions. This procedure was found to be incorrect. No research is currently available that can provide a basis for such an approximation. (An NCHRP study is nearing completion that may provide such a basis. This is discussed below.) Consequently, for QUEWZ-98, the deceleration emission rates are set to the idle emissions rates and the acceleration emissions rates are set to the cruise emissions rates.

In general, all emissions calculations in QUEWZ-98 are as follows:

$$E_p = T_{m\,c}\, R_{p\,m\,c\,s}\, V_c$$

where,

E = emissions in grams

T = time in seconds for vehicle type and operating mode

R = emissions rate in grams/second

V = vehicles

Subscripts

P = emissions type (HC, CO, or NOx)

M = operating mode (cruse, deceleration, queue, or acceleration)

C = vehicle type (car or truck)

S = speed

The T_{mc} and V_c values are found in the original QUEWZ-92 procedure. The emissions rates are new to QUEWZ-98. The emissions rates used by QUEWZ-98 are either based on the default emissions rates (derived from Mobile5a) scaled by the six default idle emissions rates, or are based on the user's input emissions rates. To develop a complete set of emissions rates there are three emissions types, two vehicle types, and 64 speeds that are input. The speeds are 2.5 and 3 to 65 mph in one-mph increments. (Note that there are 384 input emissions values in a complete set of rates.)

VEHICLE ACTIVITY MEASURES

TTI and others have performed extensive analyses of the vehicle delay associated with major construction projects. Much of this work is reported in a series of reports published as a part of Project 0-1108, Traffic Pattern Assessment and Road User Delay Costs Resulting from Roadway Construction Options. Consequently, new data collection to characterize vehicle delay was not necessary. Instead, data were extracted from several recently completed studies on vehicle delay associated with major construction projects and summarized for use in this study. The additional on-road vehicle emissions associated with this delay are estimated using the enhanced QUEWZ model described earlier. Specifically, this task provides the following:

- Apply the enhanced QUEWZ model to estimate emissions impacts.

- Estimate the vehicle delay and additional emissions associated with typical freeway projects as represented by the Project 0-1108 San Antonio data. Delay is in vehicle hours; emissions are in grams of HC, CO, and NOx.

- Characterize delay and emissions estimates by type of construction activities based on the data available from Project 0-1108.

As described in the previous chapter, the QUEWZ-92 model was enhanced by adding the idle emissions rates for HC, CO, and NOx for passenger cars and trucks. No other modifications to the model were made. The new model was named QUEWZ-98. The resulting QUEWZ-98 software requires the following input data:

- Maximum Length of Queue (as Basis for Estimating Diversion);
- Lane Closure Configuration;
- Length of Lane Closure;
- Work Zone Capacity;

- Work Zone Closure Schedule;
- Work Zone Activity Schedule; and
- Directional Hourly Volumes.

The QUEWZ-98 software provides the following outputs:

- Input Data Echo;
- Road User Costs Associated with the Closure;
- Work Zone Approach Speed;
- Work Zone Speed;
- Queue Length by Hour;
- Volume of Traffic Diverting from Freeway;
- Base Emissions (without closure);
- Work Zone Emissions (because of closure); and
- Excess Emissions (because of closure).

SAN ANTONIO DATA

As noted above, the data for this task were previously collected as part of Project 0-1108. Details of the collection and various uses of these data in the development of the original QUEWZ model (QUEWZ-92) are contained in the reports associated with Project 0-1108. The summary of the San Antonio data provided here is excerpted from Research Report 1108-6, Natural Diversion at Temporary Work Zone Lane Closures on Urban Freeways in Texas.

The data collection for the field study portion of Project 0-1108 consisted of measurements of travel time, queue length, and traffic volume near the lane closure. Travel time data were collected using the floating-car technique, where the measurement vehicle travels at the speed of an average vehicle in the traffic stream. Traffic queue data were collected during the travel time runs using an in-vehicle distance measuring instrument that records instantaneous speed, time, and cumulative distance from the start of the run to selected locations (landmarks) along the route. The beginning of the queue was defined as the location where the instantaneous speed became lower than 30 mph. Traffic volume data were collected continuously using an automatic traffic recording station operated by TxDOT 3 to 4 miles upstream of the work zone close to the beginning of the study section. (Ullman 1992:4)

Researchers observed four separate lane closures. Table 1 summarizes the characteristics of each observation. The four closures were all located along the I-410 North Loop in San Antonio, Texas. These lane closures were performed as part of a seal-coat operation in both directions of travel. Crews closed two of the three main lanes at each site. (Ullman 1995:5) Note that Table 6-2 of the 1994 Highway Capacity Manual estimates a work zone capacity of 1,050 vehicles per hour (vph) for a (3,1) closure where the activity was pavement repair, resurfacing, or asphalt removal.

Table 7 also shows the range of demand volumes recorded throughout the day at each location, along with the range of work zone capacities expected at the site, and the estimated excess demand at each location. Excess demand is defined as the difference between the normal demand volumes and expected work zone capacities. This excess demand must either queue upstream of the lane closure or divert to another route. Based on these estimates, normal traffic demand at the four sites was from 2,000 to 5,000 vph higher than the expected capacity of the work zones. The relationship between normal demand and work zone capacity is expressed as a ratio is also shown in Table 7. Normal demand at the four sites was two to four times the work zone capacity. (Ullman 1992:4)

TABLE 7
SUMMARY OF SAN ANTONIO STUDY SITES

Site	Direction	Normal Volume at Work Zone (vph)	Expected Work Zone Capacity (vph)	Excess Demand (vph)	Volume to Work Zone Capacity Ratio
1	WB	4,150 - 4,900	1,600	2,550 - 3,300	2.6 - 3.1
2	WB	3,750 - 4,500	1,600	2,150 - 2,900	2.3 - 2.8
3	EB	5,300 - 6,450	1,600	3,700 - 4,850	3.3 - 4.0
4	EB	3,300 - 4,000	1,600	1,700 - 2,400	2.1 - 2.5

CONSTRUCTION DELAY ESTIMATES

Similar to previous versions of QUEWZ, the QUEWZ-98 model does not provide the delay due to work zone lane closures. However, the average queue length during each hour affected by the work zone is provided in the Road User Cost Option output. The number of vehicles in the queue can be estimated using the following equation:

$$Q_t = \frac{L_t * N}{l}$$

where,

L_t = length of queue, in feet;

Q_t = number of vehicles in queue at time t;

N = number of open lanes upstream of the site; and

l = average length of vehicle (assumed

The delay is then estimated by:

$$D = \sum Q_t * t$$

where,

D = delay in vehicle hours; and

t = time increment, in hours.

Table 8 provides a summary of the QUEWZ Delay Inputs for each of the four San Antonio sites.

TABLE 8
QUEWZ-98 DELAY INPUTS FOR SAN ANTONIO FREEWAY DATA

Site	Maximum Length of Queue (mi)	Length of Closure (mi)	Normal Volume at Work Zone (vph)	Measured Work Zone Volume (vph)	Duration of Work Zone Activity (hrs)
1	2.3	2.5	4,150 - 4,900	1412	6
2	1.3	2.7	3,750 - 4,500	1340	7
3	1.6	2.2	5,300 - 6,450	1399	7
4	1.6	2.6	3,300 - 4,000	1400	8

Based on field measurements, the average work zone volume was determined for each site for the duration of the work activity. This process was necessary since the QUEWZ software permits entry of only one work zone volume for entire duration of work activity. The QUEWZ software assumes that the work zone throughput is the capacity for determining the queue length and diversion. The data was entered and the queue length was determined by QUEWZ for each hour of activity. The queue lengths were then used to manually calculate the associated delay for each site. Table 9 is a summary of the range of queue lengths and delays.

TABLE 9
QUEWZ-98 DELAY FOR SAN ANTONIO FREEWAY DATA

Site	Hourly Queue Length (mi)	QUEWZ Delay (veh-hrs)
1	0 - 2.3	4,798
2	0 - 1.3	2,696
3	0 - 1.6	3,658
4	0 - 1.6	4,192

The QUEWZ models overestimate queue lengths, because of the "toggle switch" effect of the diversion algorithm. The QUEWZ model simulates *no* diversion when the queue length is less than the maximum. When the maximum queue length is reached, then *all* arriving vehicles in excess of the work zone capacity are diverted. The QUEWZ delay includes only the delay experienced by those vehicles that remain on the freeway. Any other delays experienced by vehicles that divert from the freeway are not included in this total. Also, flow through the work zone is affected by merging, diverging, weaving, grades, alignment and other factors, that are not included as variables in the capacity estimation equations used by QUEWZ. Therefore, the emissions associated with these activities are not included in the estimates produced by QUEWZ.

CONSTRUCTION EMISSIONS ESTIMATES

Sample site data from the QUEWZ-92 package was used as input to the QUEWZ-98 model, and excess emissions from the output results were compared to manual calculations. The results were consistent. Next, field data from the San Antonio sites were used as inputs to the model. In addition to the previous inputs for delay, the emissions rates in Table 10 were also entered.

TABLE 10
QUEWZ-98 EMISSIONS RATE INPUTS
FOR SAN ANTONIO FREEWAY DATA

Pollutant	Vehicle Type	
	Car	Truck
HC (g/hr)	34.9	12.6
CO (g/hr)	218.5	94.6
NOx (g/hr)	4.7	53.1

The QUEWZ-98 model was run and the output results were again compared to manual calculations. The results were consistent and a summary of the results is provided in Table 11.

TABLE 11
QUEWZ-98 EMISSIONS OUTPUTS FOR SAN ANTONIO FREEWAY DATA

Pollutant at Each Site	Normal Emissions (g)	Work Zone Emissions (g)	Excess Emissions (g)	Ratio of Excess to Normal Emissions.
HC Site1	49.2	189.0	139.8	3.8
HC Site2	64.8	160.9	96.1	2.5
HC Site 3	44.7	152.4	107.7	3.4
HC Site 4	88.4	201.3	112.9	2.3
CO Site 1	280.8	1199.9	919.1	4.3
CO Site2	356.7	983.2	626.4	2.8
CO Site 3	254.6	969.5	714.9	3.8
CO Site 4	513.7	1287.6	773.9	2.5
NOx Site1	93.0	87.9	-5.1	0.95
NOx Site2	117.5	104.9	-12.6	0.89
NOx Site 3	80.3	78.4	-2.0	0.98
NOx Site 4	149.7	131.0	-18.7	0.88

The ratio of excess emissions to normal emissions for HC and CO is consistent with the corresponding volume to work zone capacity ratio. However, the NOx excess-to-normal emissions ratio differs because vehicles produce less NOx at lower speeds, such as time spent in the queue.

Arterials have flow characteristics that are distinctly different from freeway flow characteristics. Arterials were also considered as candidate facilities in this study. However, the QUEWZ models were developed for analysis of freeway work zones, and do not have the capability to analyze the impacts of work zones on arterials. Therefore, the QUEWZ-98 model could not be applied to arterials.

SUMMARY

QUEWZ-98 was used to estimate the excess emissions expected as a result of a queue forming at four short-term work zone lane closure sites in San Antonio, Texas. Excess HC emissions exceeded normal emissions by 2.3-3.8 times. Excess CO emissions exceeded normal emissions by 2.5-4.3 times. The NOx emissions were reduced slightly, resulting in an excess-to-normal emissions ratio of 0.89-0.98.

MATERIAL AND EQUIPMENT EMISSIONS

A critical aspect of this project is to develop an understanding of the emissions associated with construction-related materials and equipment. This will be part of the basis for estimating the overall impact of construction activities on countywide emissions. Construction materials-related emissions rates are drawn from the Environmental Protection Agency (EPA) series AP-42 documents. Similarly, emissions rates associated with construction equipment are extracted from EPA AP-42 series documents. Each type of emissions is discussed separately.

EMISSIONS ASSOCIATED WITH PAINTING

Application of painted highway markings, painting of exterior structure surfaces, and painting of signs are all applications of surface coatings. Volatile organic compounds (VOC) emissions originate from paint vehicles, thinners, or solvents. Almost all emissions from surface coatings occur during application. Emissions factors for various types of surface coating applications are as shown in Table 12. (EPA, 1985a: 4.2-1)

TABLE 12
SURFACE COATING EMISSIONS

Coating type	Emissions in kg/Mg	Emissions in lb/ton
Paint	560	1,120
Varnish and Shellac	500	1,000
Lacquer	770	1,540
Enamel	420	840
Primer (zinc chromate)	660	1,320

In 1997, TxDOT used about 1,194,000 gallons of paint throughout the state (Seelig, 1998). The typical density of air-dried enamel paint is 7.6 pounds per gallon (EPA, 1985a: 4.2.2.1-4). As shown above, paints typically emit 1,120 lbs. of VOC per ton of paint. An estimate of annual emissions from paint application was made by multiplying the annual volume of paint used statewide by EPA's suggested typical density of paint. This was then multiplied by a pounds to tons unit conversion factor, and then by EPA's suggested quantity of VOC emissions per ton of paint. Annual, statewide VOC emissions from application of paints at highway construction sites are estimated to be slightly over five million pounds (5,081,664).

EMISSIONS ASSOCIATED WITH ASPHALT APPLICATION

Emissions from asphalt application are almost exclusively VOC. Asphalt types are emulsified asphalt, asphalt cement, and cutback asphalt. The only significant emissions originate from cutback asphalt, which is composed of asphalt cement and diluents. Diluents vary from 25% to 45% by volume. There are three types of cutback asphalt: rapid cure (RC), medium cure (MC), and slow cure (SC). Cure depends on the type of diluent used. SC cutback asphalt contains heavy residual oils, MC cutback asphalt contains kerosene-type solvents, and RC cutback asphalt contains gasoline-type solvents. Evaporation of diluents, from time of application, occurs as shown in Table 13. (EPA, 1985a: 4.5-1 - 4.5-3)

TABLE 13
ACCRUED EVAPORATION OF DILUENTS

	Next Day	Next Month	Four Months
RC	75%	90%	95%
MC	20%	50%	70%
SC	No data, but greatly less		~25%

There are three steps used to calculate emissions associated with asphalt application when the mass of cutback asphalt is known:

A. Solve simultaneous equations for volume of diluent

where,

X = volume of diluent

Y = volume of asphalt cement

Density of diluent: SC = 0.9 kg/l MC = 0.8 kg/l RC = 0.7 kg/l

Density of asphalt cement = 1.1 kg/l

1. Total Mass of Cutback = (X)(Density of diluent) + (Y)(Density of asphalt cement)
2. X = (% Diluent)(X+Y)

B. Solve for mass of diluent

Mass of diluent = (X)(Density of diluent)

C. Solve for emissions

Emissions = (% Accrued Evaporation)(Mass of diluent)

TxDOT used 27,947,608 liters (7,383,000 gallons) of cutback asphalt at highway construction sites, statewide, in 1997 (Seelig, 1998). If the exact value for the percent of diluent in the volume of cutback asphalt is unknown, EPA (1985a: 4.5-1 - 4.5-3) recommends using a value of 35%.

Assuming the diluent is 35% of the cutback asphalt's volume, construction crews applied 9,781,663 liters of diluent in Texas during 1997. The density of medium cure cutback asphalt diluents is 0.8 kg/l, and accrued evaporation of diluents is 70% of mass. To determine mass of diluent in the cutback asphalt, density is multiplied by volume. The product of diluent mass and percent of accrued evaporation equals mass of material emissions. Therefore, TxDOT construction sites produced approximately twelve million pounds of VOC last year, statewide (12,076,206 pounds or 5,477,731 kg).

EMISSIONS ASSOCIATED WITH ON-ROAD CONSTRUCTION EQUIPMENT AND OFF-ROAD MOBILE SOURCE EQUIPMENT

Emissions rates associated with on-road construction equipment are given by EPA (EPA 1991:A4-A9). Emissions rates are provided by model year and emissions type for light-duty trucks, heavy-duty gasoline-fueled vehicles, and heavy-duty diesel-fueled vehicles. The range of these rates for selected pollutants is shown in Table 14, without model year distinction.

TABLE 14
SUMMARY OF ON-ROAD CONSTRUCTION EQUIPMENT EMISSIONS RATES

Vehicle	CO	NOx
LDT	10 - 39 gpm	3.0 - 1.2 gpm
HDGV	14.4 - 40.0 g/pbhp-hr	5.0 - 10.7 g/pbhp-hr
HDDV	15.5 - 40.0 g/pbhp-hr	5.0 - 10.7 g/pbhp-hr

Emissions rates are provided by equipment type by hour of operation for each pollutant by EPA (EPA 1985b:II-7-1 - II-7-2). The rates for the various categories of vehicle are shown in Table 15. All rates are for diesel powered equipment.

TABLE 15
SUMMARY OF OFF-ROAD CONSTRUCTION EQUIPMENT EMISSIONS RATES

Equipment Category	CO	NOx
Track tractor	157.0	570.7
Wheeled tractor	1,622.8	575.8
Scraper	568.2	1,740.7
Motor grader	68.5	324.4

Emissions are estimated by generating the product of the brake-specific emissions factor, time of usage, rated power, and load factor. Approximate annual operating hours of the heavy construction vehicle types (EPA, 1985b: II-7-1 - II-7-2) are shown in Table 16.

TABLE 16
CONSTRUCTION VEHICLE ANNUAL OPERATING HOURS

Category	**Hours / Year**
Tracklaying tractors	1050
Tracklaying shovel loaders	1100
Motor graders	830
Scrapers	2000
Off-highway trucks	4000
Off-highway trucks and wheeled dozers	2000
Wheeled loaders	1140
Wheeled tractors	740
Rollers	740
Miscellaneous	1000

EMISSIONS ASSOCIATED WITH STATIONARY EQUIPMENT

EPA provides brake-specific emissions factors for gasoline and diesel industrial engines. Emissions are estimated, as with off-road mobile source equipment, by determining the product of the brake-specific emissions factor, time of usage, rated power, and load factor. Emissions factors for gasoline and diesel engines (EPA, 1985a: 3.3-1, 3.3-2) are shown in Table 17.

TABLE 17
STATIONARY ENGINE EMISSIONS RATES

Pollutant	Gasoline	Diesel
Carbon monoxide (g/hphr)	199	3.03
Exhaust hydrocarbons (g/hphr)	6.68	1.12
Evaporative hydrocarbons (g/hr)	62	—
Crankcase hydrocarbons (g/hr)	38.3	—
Nitrogen oxides (g/hphr)	5.16	14
Aldehydes (g/hphr)	0.22	0.21
Sulfur oxides (g/hphr)	0.268	0.931
Particulate (g/hphr)	0.321	1

Large bore diesel and dual fuel engines have at least 560 cubic inch displacement per cylinder. Construction crews use these engines for drilling, hoisting, operating pumps, or generating power. Emissions for these large engines (EPA, 1985a: 3.4-1, 3.4-2) are shown in Table 18.

TABLE 18
LARGE ENGINE EMISSIONS RATES

Pollutant	Diesel	Duel Fuel
Particulate (g/hphr)	1.10	n/a
Nitrogen oxides (g/hphr)	11.00	8.00
Carbon monoxide (g/hphr)	2.90	2.70
Methane VOC (g/hphr)	0.03	2.10
Nonmethane VOC (g/hphr)	0.29	0.70
Sulfur dioxide (g/hphr)	1.30	0.32

SUMMARY OF CASE STUDIES

The collection of construction site activity data is part of this study. These activity data along with the emissions data discussed previously are used to estimate additional vehicle emissions and the direct construction related emissions associated with major construction activities. The case study portion of this research is documented in detail in a separate research report that includes a summary of construction equipment inventory data, construction equipment activity measures (hours of use), and construction materials in use that contribute to organic emissions. It also includes estimates of construction-related emissions by category (on-road, off-road, stationary equipment, materials, etc.), and an overall characterization of activity and emissions associated with major construction project activities. The reader is referred to the separate report for additional detail. An overview of the construction site case studies is provided here.

SITE SELECTION CRITERIA

Data were collected during late summer and early fall of 1997 at five sites in the Dallas/Fort Worth area. Sites were selected based on location within the metropolitan area, level or construction activity, variety of construction activities, cooperation from the prime contractor, and deployment on the site.

All five sites were in Dallas and Tarrant counties. These counties are among the most urbanized counties in Texas and contain the majority of the urban freeway miles in the region. These counties include the majority of major reconstruction sites in the area. In Dallas County, two urban freeway sites (NCS-1 and NCE S-2) were selected along US 75 (North Central Expressway). In Tarrant County, three sites were selected, I-35W/I-30 interchange, I-820 interchange, and a section of FM 156.

The study sites involved four heavy highway construction projects and a maintenance project. The heavy construction sites use more and larger construction equipment at a higher level of activity. The maintenance project provided an example of the activities associated with routine maintenance activities. A variety of activities was observed at each of the study sites. This variety of activity provided the research team with samples of activity for similar construction tasks, as well as a basis for comparison. The activities observed ranged from elevated slab placement to demolition of existing pavements and soil compaction.

ACTIVITY MEASURES AND OBSERVATIONS

Construction equipment and associated activity was observed and recorded at each of the five sites. Equipment was initially classified into three categories—field trucks, materials trucks, and construction equipment. Equipment activity was measured and recorded through four activity measures for each piece of construction equipment observed. These are engine hours of use, starts, throttling frequency, and refueling. The engine hours of use are the primary determinants in the estimation of emissions from construction equipment. The number of engine starts provides an indication of cold or hot starts and their associated increased emissions. Engine throttling in terms of frequency and duration give some indication of the load placed on an engine. Engine throttling was defined as the visible emissions from the equipment's exhaust pipe. Finally, the frequency and duration of refueling was observed to develop a better estimate of evaporative emissions at the construction site.

As noted above, construction equipment activity was divided into three categories for purposes of emissions estimation (i.e., field trucks, materials trucks, and construction equipment proper). Each is defined and discussed below.

FIELD TRUCKS

Field trucks are light-duty diesel, gasoline, or low emissions (e.g., natural gas) pickup trucks used by the contractor or TxDOT on the construction site. Data collection included engine on/off times (as a basis for estimating the number of cold-and hot-starts and the total engine run time), vehicle model year, model type, initial odometer reading, and fuel type.

Table 19 shows the distribution of field trucks by their fuel source. Contractors use conventionally fueled field trucks with a majority of those being diesel-fueled. TxDOT vehicles however, were observed to be a mix of conventional gasoline-fueled field trucks and clean- or dual-fueled trucks (presumably the result of government agency mandates and clean air goals).

TABLE 19
FUEL SOURCE DISTRIBUTION FOR FIELD TRUCKS

Fuel Source	Contractor	TxDOT
Diesel	24	0
Gasoline	17	10
Clean/Dual	1	9

FIELD TRUCK EMISSIONS

Emissions estimates from field trucks were calculated using assumptions and data collected from the sites. For purposes of estimating the emissions of field trucks, idle time was assumed to be 80%, running time was assumed to be 20%, and the average speed was assumed to be 15 mph. Running and idle emissions were calculated as follows:

*Total Emissions = Idle Emissions Rate * (Total Running Time * Percent of Time Idle) + Running Emissions Rate * [Avg Speed * (Total Running Time * Percent Time Running)/60]*

where,

Idle Emissions Rate = MOBILE emissions rate for LDGT or LDDT at idle

Running Emissions Rate = MOBILE emissions rate for LDGT or LDDT at average speed

Avg Speed = Average speed of the vehicle (15 mph)

Total Running Time = Total truck running time observed at the site

Percent of Time Idle = Percent of time spent idling (20%)

Percent Time Running = Percent of time spent traveling from location to location (80%)

Emissions rates were derived using EPA's MOBILE5a emissions factor model. The idle rate was calculated by using guidance supplied by EPA. This guidance states that the idle emissions rate may be calculated as the emissions factor at 2.5 miles per hour multiplied by a factor of 2.5 to yield an idling emissions rate of grams per hour. MOBILE cannot model clean or dual-fueled vehicles. Consequently, clean- or dual-fueled field trucks were treated as gasoline-fueled vehicles (overestimating field truck emissions slightly).

MATERIALS TRUCKS

Another category of construction activity is the activities of materials trucks delivering or removing materials from the construction site. The research team observed nine distinct activities ranging from the delivery of concrete, asphalt, and lime to the removal of excavated material and asphalt demolition. A materials truck was considered "on-site" from the time it first came into view at the location of activity until it left that location. Of the nine activities observed, only a third had total on-site durations greater than 12 hours. The majority of activities recorded had on-site duration between two and four hours.

The average on-site time for materials trucks ranged from 0.03 hours to a high of 0.58 hours. This high value was recorded during the placement of concrete on an elevated section. These trucks were typically queued prior to delivery of their load at the concrete pump. Trucks were either cleaned on-site, extending their time on-site, or cleaned at an off-site location prior to returning to the concrete batch plant for another load. The average on-site time was 12 minutes.

MATERIALS TRUCKS EMISSIONS

The emissions estimates were calculated as the product of the total on-site time and the idling emissions rate for heavy-duty diesel vehicles (HDDV). The highest emissions producing sites were NCE S-1, I-35W/I-30, and FM 156, in decreasing order. The latter two sites only recorded one activity each and had similar results to the combined three activities observed at the NCE S-1 study site. This implies that the activity at I-35W/I-30 and FM 156 was either more intense in nature or required the trucks to be on-site longer.

Overall, materials trucks emissions are much less than emissions for the field trucks. The contribution of materials trucks emissions to the total site's emissions is small. The effects of materials trucks in transit to and from the construction site are not included in this analysis. Off-site emissions from materials trucks are captured through vehicle-miles traveled at average speeds, and idling emissions at a location away from the construction site (batch plant, etc.).

CONSTRUCTION EQUIPMENT

The majority of equipment is diesel-fueled. Those that are not diesel-fueled are light-duty gasoline-fueled equipment. This equipment is classified as "Misc" according to AP-42. It includes small portable gasoline-fueled equipment such as generators < 50 Hp, compressors, and light plants, as well as other light-duty equipment.

Gasoline-fueled equipment hours of use ranged from 10% to 65% of the diesel-fueled equipment hours of use. This proportion decreases as the diesel-fueled equipment hours of use increases. The location with the highest gasoline-fueled hours of use was observed at the I-35W/I-30 study site. This was due to the high use of light-duty equipment such as small portable generators and portable light plants used for the pre–dawn placement of concrete. No gasoline-fueled equipment was observed at the FM 156 study site.

CONSTRUCTION EQUIPMENT EMISSIONS

Emissions for construction equipment was estimated as the product of engine hours of use and the associated AP-42 emissions rate by fuel source for CO, exhaust HC, and NOx. No consideration was given to the available horsepower or power loading of construction equipment. Instead, the analysis assumes the engine is under a full load and is therefore producing the highest emissions.

Construction equipment produces primarily CO, followed by NOx and HC respectively. The highest CO production was observed at the I-35W/I-30 study site because of the amount of gasoline-fueled light-duty equipment. Gasoline-fueled equipment produces more CO emissions than diesel-fueled equipment. The FM 156 study site produced the second highest total from the use of equipment in the "Rollers" and "Off-highway Truck" classes.

TOTAL EMISSIONS

Emissions from each vehicle category (field trucks, materials trucks, and construction equipment) were summed to generate estimates of the total emissions at each of the construction sites during the observation day. Table 20 shows this summary.

TABLE 20
SUMMARY OF HIGHWAY CONSTRUCTION CASE STUDY SITE EMISSIONS PRODUCTION BY SITE AND SOURCE

		Emissions (kg)			Emissions (tons)		
Site	**Source**	**CO**	**HC**	**NOx**	**CO**	**HC**	**NOx**
NCE S-1	Field Trucks	5.846	0.936	0.904	0.006	0.001	0.001
	Material Trucks	1.674	0.224	0.908	0.002	0.000	0.001
	Const. Equipment	141.507	13.212	109.678	0.156	0.015	0.121
	TOTAL	**149.027**	**14.372**	**111.490**	**0.164**	**0.016**	**0.123**
NCE S-2	Field Trucks	5.872	0.958	0.956	0.006	0.001	0.001
	Material Trucks	0.347	0.046	0.188	0.000	0.000	0.000
	Const. Equipment	167.417	9.859	54.313	0.184	0.011	0.060
	TOTAL	**173.636**	**10.863**	**55.457**	**0.190**	**0.012**	**0.061**
I-35W/I-30	Field Trucks	18.477	1.785	0.939	0.020	0.002	0.001
	Material Trucks	1.435	0.192	0.778	0.002	0.000	0.001
	Const. Equipment	237.839	10.303	44.937	0.262	0.011	0.049
	TOTAL	**257.751**	**12.280**	**46.654**	**0.284**	**0.013**	**0.051**
I-820 NE	Field Trucks	16.972	1.582	0.756	0.019	0.002	0.001
	Material Trucks	0.596	0.080	0.323	0.001	0.000	0.000
	Const. Equipment	176.761	9.607	52.362	0.194	0.011	0.058
	TOTAL	**194.329**	**11.269**	**53.441**	**0.214**	**0.013**	**0.059**
FM 156	Field Trucks	1.037	0.099	0.052	0.001	0.000	0.000
	Material Trucks	1.113	0.149	0.604	0.001	0.000	0.001
	Const. Equipment	18.536	3.057	46.765	0.020	0.003	0.051
	TOTAL	**20.686**	**3.305**	**47.421**	**0.022**	**0.003**	**0.000**
GRAND TOTAL		**795.429**	**52.089**	**314.463**	**0.874**	**0.057**	**0.294**

The relative contribution of field trucks, materials trucks, and construction equipment to highway construction site total emissions is summarized in Table 21.

TABLE 21
HIGHWAY CONSTRUCTION PROJECT EMISSIONS SOURCES

	Percent Contribution		
Pollutant	**Field Trucks**	**Material Trucks**	**Construction Equipment**
CO	5 - 10	1 / 5 [1]	90 - 95
HC	10 - 15	1 / 5 [1]	85 - 90
NOx	1 - 2	1	95 - 99

Note: [1] Large construction projects / small construction projects

For each of the three primary pollutants, emissions from construction equipment represent 90% to 95% of CO emissions, 85% to 90% of HC emissions, and 95% to 99% of NOx emissions. Emissions from field trucks represented 5% to 10% of the CO production, 10% to 15% for HC emissions, and 1% to 2% of the NOx emissions production. The emissions generated from materialS trucks contributed 1% percent at large construction sites to CO and HC emissions, 5% at small construction sites for CO and HC emissions, and 1% of NOx emissions regardless of construction site size.

In general, as a site progresses from earthwork to more structural concrete or pavement work, NOx emissions decrease and CO emissions increase. No relationship was found for HC emissions. Total emissions increase as a site progresses though its construction schedule to a stage where activity begins to diminish and the total daily emissions diminishes. Structural work causes the highest emissions when major milestones are met, such as the placement of a large section of concrete (probably due to a corresponding increase in equipment activity). Total emissions for each of the three primary pollutants was less than one ton. At a regional scale, this is a very small amount. For example, HC emissions from all five study sites are estimated to be only 0.1 ton and NOx emissions are less than 0.3 tons.

Several general conclusions can be made from the analysis of case study data relating to a highway construction and emissions. These are:

1. NOx emissions decrease and CO emissions increase as a site progresses from earthwork to structural work, such as concrete or pavement. No correlation with HC was found.

2. Total site emissions appear to increase as a site progresses through its construction schedule to a stage where activity diminishes and the total daily emissions decreases. Evidence from similar study sites in different phases of construction provided support for this conclusion.

3. Structural work appears to result in higher emissions when major milestones are being met. The increase in emissions might be due to increases in construction activity for one or more critical tasks to meet such milestones. For example, a large-scale effort to place concrete on an elevated section requires the intensive use of a range of equipment.

4. The total emissions for each of the three primary pollutants were less than one ton. This is a very small amount compared to the hundreds of tons in regional emissions inventories. (This is discussed in more detail in the next section.)

COUNTYWIDE EMISSIONS

Construction-related emissions must be examined in the context of the emissions inventory for the entire study area. Countywide emissions were estimated based on 1997 VMT estimates developed by TTI for this project. The countywide emissions estimate includes estimates of construction-related emissions as a fraction of total corridor mobile source emissions using urban travel demand models. The diversion of traffic to alternative routes because of reduced capacity on the primary route is considered. Construction-related emissions as a fraction of countywide mobile source emissions and total emissions are also estimated. (Total emissions consist of on-road mobile, off-road mobile, point, stationary, and biogenic emissions.)

OZONE MEASUREMENTS

As discussed below, ozone action days are an important consideration in any assessment of the air quality impacts of construction activities. Table 22 shows when the five study sites were observed, temperature ranges for that particular day, and ozone measurements made for the region on that day. Additionally, the table indicates whether ozone action days were called the day prior to, the day of, or the day after the observation day.

TABLE 22
REGIONAL METEOROLOGICAL INFORMATION

County	Site	Study Date	Temperature (°F)		Ozone (PPM)	Ozone Action Day		
			High	Low		Prior	On	Next
Dallas	NCE S-1	July 29, 1997	101	80	139	Y	Y	N
	NCE S-2	August 1, 1997	93	73	115	N	Y	Y
Tarrant	I-35W/I-30	August 15, 1997	97	78	54	N	N	N
	I-820 NE	August 18, 1997	95	77	70	N	N	N
	FM 156	October 22, 1997	64	49	36	N	N	N

MOBILE SOURCE INVENTORY COMPARISON

Further analysis was performed to determine the contribution of highway construction project emissions to the urban mobile source emissions inventory. The analysis required two emissions estimates, the 1997 daily on-road mobile source, and the 1997 estimated daily non-road construction emissions.

Estimates of the 1997 daily on-road mobile source emissions were developed from estimates of vehicle-miles traveled for Dallas and Tarrant counties. The VMT estimates were calculated using Federal Highway Performance Monitoring System (HPMS) data by functional class. The estimated daily VMT for 1997 is 63.0 million for Dallas County and 40.8 million for Tarrant County.

On-road mobile source emissions are estimated as a function of VMT and speed-specific emissions rates (derived from MOBILE) by roadway functional class. Table 23 shows the total emissions in tons for each of the three primary pollutants by county.

TABLE 23
1997 DAILY ON-ROAD MOBILE SOURCE INVENTORY

County	Tons of Emissions		
	CO	**VOC**	**NOx**
Dallas	788	160	108
Tarrant	474	96	65
TOTAL	1,262	256	173

Daily non-road construction emissions were estimated from estimates of daily construction activity during summer months for each county (provided by Fort Worth and Dallas TxDOT District personnel), and case study field data collected and processed for this purpose.

Average daily construction projects for the two-county area were estimated to be 41 major and 75 minor. Major activity is represented by the four large sites observed in this study. The small maintenance project observed is representative of minor construction activity. Emissions production was averaged from each of the study sites observed in this report and applied to the average construction activity estimates supplied above. Countywide estimates of construction emissions are shown in Table 24.

TABLE 24
1997 ESTIMATED DAILY NON-ROAD CONSTRUCTION EMISSIONS

County	Emissions (tons)		
	CO	**VOC**	**NOx**
Dallas	7.8	0.6	4.2
Tarrant	3.1	0.3	2.8
TOTAL	**10.9**	**0.9**	**7.0**

On-road and construction emissions are compared by county in Table 25. Construction emissions contribute 0.9% of the total mobile CO inventory, 0.5% of the total mobile VOC inventory, and 2.7% of the total mobile NOx inventory.

TABLE 25
MOBILE SOURCE CONTRIBUTIONS

	Pollutants					
	CO		**VOC**		**NOx**	
County	**On-Road**	**Construction**	**On-Road**	**Construction**	**On-Road**	**Construction**
Dallas	99.0 %	1.0 %	99.5 %	0.5 %	97.4 %	2.6 %
Tarrant	99.4 %	0.6 %	99.6 %	0.4 %	97.1 %	2.9 %
TOTAL	**99.1 %**	**0.9 %**	**99.5 %**	**0.5 %**	**97.3 %**	**2.7 %**

COST OF ALTERNATIVE PRACTICES

One important objective of this project is to identify the cost to contractors (and ultimately to TxDOT) of alternative construction practices to mitigate air quality impacts. That is, attempt to quantify the additional construction costs incurred by contractor participation in ozone alert programs, including:

- Scheduling changes (changes in the scheduling of specific construction activities to avoid ozone alert days);

- Contract performance period changes (changes in the performance period of the construction due to the delay of certain construction activities to avoid ozone alert days);

- Non-summer construction (performance of air quality sensitive construction activities during less ozone sensitive seasons, i.e., non-summer); and

- Night time construction (performing specific construction activities at night rather than during the day to avoid ozone and traffic intensive conditions)

Note that these alternate construction practices consist of two types. Scheduling changes and performance period changes as defined above are in response to specific incidents. Consequently, they are inherently uncertain and carry a high degree of risk for contractors. Non-summer construction and nighttime construction, on the other hand, are categorical and seek to avoid high ozone periods altogether. These alternative practices are entirely predictable once implemented and carry no additional uncertainty for the contractor, though they may carry additional costs.

Similarly, construction projects can be separated into broad categories. These are new right-of-way preparation (grading, drainage, sub-base, and base), surface work (application of asphalt, HMAC, concrete, etc.), major structures (elevated structures, over passes, bridges, and depressed structures), and restoration (revegetation, landscaping, etc.). Of these four general categories of construction, project surface work is the most common, followed by less frequent major structure projects. Right-of-way preparation applies only to totally new roadways and consequently is relatively rare. (In addition, new roadway construction is by definition not disruptive of existing traffic, since there is no existing traffic.) Restoration projects (revegetation, landscaping, etc.) are typically modest in scope and duration, and therefore have only minimal impact on traffic flow and air quality.

The four alternative practice categories, along with the four construction project categories form the framework for the analysis and recommendations discussed below.

Ideally, the research team would like to summarize and evaluate the additional costs identified as a fraction of total construction costs and delay in completion for all four alternative construction practices. However, as discussed below, this is not feasible for all categories of construction projects. The first two categories are difficult because they are highly project specific. The second two categories are more categorical and generic cost estimates are feasible.

The review of current practice is summarized below, along with our interviews with various contractors. Finally, a recommendation is presented and discussed.

REVIEW OF CURRENT PRACTICE

Following the initial literature review, the research team conducted a nationwide survey of current practice relating to construction activities and air quality. Participants were selected based on discussions with the National Association of Regional Councils (NARC) in Washington D.C. The results of this survey are summarized below.

Tulsa, Oklahoma

Tulsa has the oldest episodic voluntary ozone control (EVOC) program in the nation. It includes 360 firms and government offices. The local transit operator provides free service on ozone action days and the media provide information about the program. Tulsa has "shut down" construction for air quality problems on several occasions. These shut downs include construction equipment (more for public relations than actual emissions reduction), as well as certain paving operations (such as asphalt application). Contractors have been reimbursed for equipment costs and contract completion times have been extended. However, these stoppages, so far, are technically voluntary (that is, they are not contractual). Awareness of the public relations aspects of air quality alert days is especially high (e.g., all OkDOT mowing is stopped on alert days). Specific contract language is pending for up to six days of air quality related work stoppage, with contract cost provisions for any days over six. Provisions are based on an estimate of the overhead costs incurred (in the case of Tulsa, 10% of the cost of the contract divided by the duration).

Southern California

The South Coast Air Quality Management District (SCAQ) is primarily concerned with Ozone, CO, and especially Pm10. Programs include prohibition of open burning (a.k.a. agricultural burning) and general construction site dust control (a.k.a. "Rule 403"). The California Environmental Quality Act (CEQA) requires mitigation of construction air quality impacts on a project specific basis (but for the duration of the project, not linked to specific air quality incidents). Mitigation provisions may require incident-specific stoppages. No compensation is provided for these stoppages. CEQA mitigation is the primary means of controlling construction related air quality impacts. SCAQ's primary interest is in dust control that is accomplished through a "Rule 403" mitigation plan (part of the CEQA mitigation for construction). Regulation 7 stage 2 smog alert program may be analogous, but has not been activated for 10 years. Rule 403.1 (high winds) for Coachella Valley may also be analogous.

Northern California

The San Francisco Bay area has a well-established EVOC program involving 635 firms. The program is administered by the Bay Area Air Quality Management District. Local transit operators provide free advertising for the program and the media provides coverage of the program. In the Sacramento Air Quality District (SAQD) the local "Spare the Air" program is voluntary. The emphasis is on avoiding ozone excedences on ozone alert days (as opposed to the San Joaquin program that responds to excedences). There are no construction restrictions in SAQD, nor in the San Francisco Bay Area.

Indianapolis, Indiana

Lake and Porter County (NW Indiana) are planning a resurfacing project this summer. Delay and air quality issues are included, but in the form of coordination between cognizant authorities. There are no contractor delay/interruption provisions at this time.

Atlanta, Georgia

Atlanta is in non-attainment for ozone. Atlanta's ozone alert program is relatively new and was suspended during the Olympics. Atlanta also had a non-conforming TIP for summer 1996 and is unable to add new highway capacity. Consequently, they receive no EPA credit for episodic control measures that are not mandatory. Voluntary ozone reduction plans (VORPs) are being developed. Ozone information is provided as health advisories but with "credits" for business programs. Since most controls involve the public and mandatory controls are highly unpopular, Atlanta's revitalized ozone program is voluntary. They have no controls on construction since the program is voluntary and construction is limited (i.e., no new capacity).

CONTRACTOR INTERVIEWS

Another important source of information on the potential impacts of air quality regulations and ozone alert delays on construction costs is the construction contractors themselves. Consequently, extensive interviews were held with a wide range of construction contractors under the auspices of their industry organization (Associated General Contractors), as well as individually. A selection of statewide contractors was interviewed at their monthly air quality committee meeting in Austin (March 1997). San Antonio area contractors were interviewed at a special meeting called for this purpose in conjunction with their monthly meeting in San Antonio (July 1997). This format provided access to a wide range of contractors in a setting conducive to frank and open discussion of construction air quality. Additional individual interviews were also conducted. These meetings are summarized below.

AGC - Austin Air Quality Committee Meeting

The Committee noted that summer is the ideal construction season because of the dry weather and long days. These factors affect both cost and quality of the construction. Ozone action days incur a variety of costs. In addition to the obvious variable costs (primarily labor) associated with actual operations, these include the ethical/human relations issue of diminished income for workers, relatively intangible costs associated with the disruption, and the fixed costs such as equipment rental or depreciation. The uncertainty imposed on the industry also incurs costs, such as reduced profits, lower corporate viability, and a less stable industry, but these are difficult to measure. (Uncertainty has two cost components. The first and most obvious is the cost of the actual work stoppage. The second and more subtle is the cost of the uncertainty itself, meaning the cost associated with being prepared or anticipating the uncertain event. Both of these elements will affect contractor margins, as opposed to documented overhead and direct costs.)

There is also a corporation size factor in that larger firms are more likely to have multiple jobs within a given geographic area that can absorb the labor force displaced by the work stoppage caused by an ozone alert day. Where sub-contractors have different specialties the impacts of ozone related work stoppage is likely to be greater on those whose areas of practice are less flexible, such as utility contractors who require greater lead time to prepare a site (e.g., location of underground utility of lines, etc.).

The Committee expressed severe skepticism regarding the validity of the level of pollution attributed to construction equipment and activities. Monitoring locations was seen as particularly prone to producing biased and unrepresentative estimates of air quality.

In addition, there were serious concerns relating to the release of any information which could be used by competitors. In other words, even the most basic statistics (e.g., fuel consumed) was seen as proprietary in that it could reveal a cost estimating strategy or bidding strategy.

Another concern expressed involved the assumption that there was no additional cost associated with air quality delays just because there were no overt air quality delay cost estimates used in the cost estimate calculations.

AGC - San Antonio Area Meeting

For this meeting, the project team explored these issues further with a wide range of San Antonio area contractors. In addition, three hypothetical scenarios were discussed.

- Scenario 1: Up to six days of air quality related work stoppage, with contract cost provisions for any days over six. Those provisions are based on an estimate of the overhead costs incurred (overhead cost of the contract divided by the duration).

- Scenario 2: Contract cost provisions for any days of air quality related work stoppage, based on an estimate of the overhead costs incurred (overhead cost of the contract divided by the duration).

- Scenario 3: Air quality is more sensitive to certain construction activities than others. This is recognized in the San Antonio District's contract provisions. Can the cost formula shown above be refined to better reflect the specific activities being delayed? Lane closures and surfacing activities are especially critical. Possible categories include:

    - New Right of Way (initial preparation of right of way, i.e., grading, drainage, sub-base, and base). The concern is primarily lane closures and traffic delays that increase emissions. This category relates primarily to new construction. Consequently, it is relatively rare.

    - Surface (asphalt, HMAC, etc.) The concern is lane closures and traffic delay, as well as the surfacing materials emissions. This category includes resurfacing. This is the most common category of transportation related construction. Projects range from short duration and modest intensity to extended duration and intensive activity.

    - Major Structures (elevated structures, depressed structures, etc.) The concern is primarily lane closures and traffic delays that increase emissions. This category of construction may be more frequent in some areas than others, but is extensive and intensive whenever it does occur.

- Restoration (revegetation, landscaping, etc.) The concern is lane closures and traffic delay, as well as the surfacing materials emissions. The impacts of this category are minimal. Project duration is short and the level of activity is not intense.

The group noted that construction costs are highly context and situation specific. Additionally, overhead rates vary between large and small contractors. Consequently, they felt that any generalized cost formula would likely be unfair or inaccurate a substantial part of the time. Specific data is highly revealing and, consequently, is considered proprietary. There was a general dissatisfaction with the first two scenarios. The estimate of overhead (even if adjusted to reflect current Texas conditions) was seen as too imprecise (i.e., too aggregate).

The impact of any ozone related work stoppage or delay would vary with the type of project as well as with the phase of construction for a particular project (perhaps even day-to-day within a particular phase). That is, it would be too much in some cases and too little in others. While this would perhaps average out for TxDOT, it was seen as potentially biased towards the larger contractors. (The re-allocation of resources is always problematic. However, larger contractors are more likely than small ones to have other jobs to re-allocate resources to, as well as having more total jobs over which to average out differences in the cost of ozone related work stoppages or delays.)

The third scenario was seen as better, but still problematic. Two alternatives were suggested to address the cost of ozone alert related work stoppages. These are:

- Include ozone alert days as a separate bid item. Treating ozone alert days as a separate bid item allows the various sub-contractors to calculate their own costs for their particular situation, as well as allowing them to assess the level of risk they are willing to assume. In effect, each sub-contractor would bid the cost of an extra day or days (the bid working days component or "B" in "A+B bidding"). This could lead to larger, less risk sensitive companies under bidding these items. Consequently, this option was not seen as addressing the potential for bias against smaller companies, though it clearly does correct for the differences between specialties and spreads (diffuses) the risk exposure for general contractors. This was also recognized as requiring additional administrative effort for all parties.

- Establish a force account to cover ozone alert related delays. Funds for ozone alert days would be allocated separately from the bidding process and would be based on specific actual documented costs of those delays. This would treat ozone alert stoppages and delays more like weather days. This option would also remove the ozone alert costs from the bidding and estimation process.

A third option, treating ozone alert delays as a separate change order, was discussed briefly and rejected as being too difficult to administer. It was also observed that there is not adequate funding for identified highway construction needs. Any delay in construction adds to the cost of that construction, as well as delaying the availability of the improvement being constructed. There was concern that not all the costs of the air quality issue were being considered. In particular, the group felt that the benefit of having the improvement available for use on schedule was not being included in the assessment of the cost of construction related air quality impacts. Concerns were also expressed over the need to use all available funds for actual construction (as opposed to paying for work not done or work delayed, as would be the case with ozone alert delays)

The concern over bias was raised repeatedly, primarily in the context of company size and ability to assume risk and uncertainty, but also in terms of the type of company (e.g., utility versus general contractor) and public versus private projects. The issue here involves potential bias towards larger contractors (because they have more resources and are more likely to have a range of projects to reallocate resources released due to air quality related work stoppages, they may be willing to accept greater uncertainty). At the sub-contractor level there is potential bias due to the nature of the specialties (e.g., utility contractors are much less flexible than paving contractors due to the need to locate buried utility lines). The group observed that similar restrictions are not being proposed for commercial or private construction, rather only public projects appear to be subject to ozone alert delays.

Another theme that surfaced throughout these discussions was the extreme lack of credibility of the entire ozone alert process. In particular, the explanation of the risks of ozone is not adequately conveyed to the public. Additionally, private or commercial entities are only asked to voluntarily limit certain of their activities (whereas contractors for highway projects, which may in fact contribute to reducing air quality problems, are being asked to curtail their activities by contract).

The results of our analysis of construction cost differentials of alternative construction practices are summarized in Table 26 by construction category.

TABLE 26
CONSTRUCTION COST DIFFERENTIALS OF ALTERNATIVE PRACTICES BY CONSTRUCTION CATEGORY

<table>
<tr><th rowspan="2">Alternative Practice</th><th colspan="4">Construction Category</th></tr>
<tr><th>New ROW</th><th>Surface</th><th>Major Structure</th><th>Restoration</th></tr>
<tr><td>Schedule Changes</td><td rowspan="4">New Construction Only</td><td colspan="2" rowspan="2">Overhead cost of contract divided by Duration of contract multiplied by Ozone Alert Days</td><td rowspan="4">Minimal Impact</td></tr>
<tr><td>Performance Period Changes</td></tr>
<tr><td>Non-summer Construction</td><td colspan="2">30% to 40% increase</td></tr>
<tr><td>Night Construction</td><td colspan="2">40% to 60% increase</td></tr>
</table>

Construction Categories:

- New Right of Way (initial preparation of right of way, i.e., grading, drainage, sub-base, and base).
- Surface (asphalt, HMAC, etc.)
- Major Structures (elevated structures, depressed structures, etc.)
- Restoration (revegetation, landscaping, etc.)

Alternative Practices:

Incident specific practices:

- Schedule Changes (changes in the scheduling of specified construction activities to avoid ozone alert days).
- Performance Period Changes (changes in the performance period of the construction due to the delay of certain construction activities to avoid ozone alert days).

Categorical practices:

- Non-summer Construction (performance of air quality sensitive construction activities during less ozone sensitive seasons, i.e., non-summer).
- Night Construction (performing specified construction activities at night rather than during the day to avoid ozone and traffic intensive conditions).

SUMMARY AND RECOMMENDATIONS

SUMMARY

NAAQS for ozone, set by the EEPA, specifies that the daily, one-hour maximum ozone concentration for urban areas and counties shall not exceed 125 parts per billion more than one day per year, averaged over a three-year period. Areas that violate this standard become designated as non-attainment. As the number of violations in an area increases, so does the non-attainment designation (marginal, moderate, serious, severe, extreme) of that area. Texas currently has four ozone non-attainment areas ranging from moderate (Dallas-Fort Worth) to severe (Houston-Galveston). These areas and several others in Texas are aggressively implementing measures to reduce emissions in order to achieve the ozone NAAQS. One strategy being used in several areas is an ozone alert/watch program that informs and encourages the public to modify their travel behavior, reduce the use of small engine equipment, and delay the use of emissions contributing materials.

Highway construction/rehabilitation is an essential activity. Construction projects improve mobility through increased capacity on existing facilities and provide critical transportation linkages. The side effects during construction activities are increased motorist delays both from the freeway and from traffic diversion onto alternate arterial streets and the use of some VOC emitting construction materials such as solvents, certain types of asphalt, and paints. These side effects contribute to some of the air quality problems cities are experiencing today. Although the same construction projects in these cities are anticipated to ease the air quality problem in the long term, they are nonetheless contributing to the problem in the short term.

Temporary lane closures are used on construction projects to provide access to work areas and to protect workers and motorists from possible conflict. These lane closures create traffic congestion through queues and motorist diversion onto parallel arterial facilities. The traffic congestion resulting from the temporary lane closures increases the quantity of mobile source emissions generated per mile upstream from and through the lane closure. The increase in mobile source emissions from these lane closures contributes to the regional air quality.

Reconstruction and rehabilitation activities requiring lane closures on high-volume roadways result in traffic congestion and delays. The traffic congestion caused by construction activities and the materials and equipment used in construction may aggravate the air quality problem in non-attainment areas, especially during hot summer months when atmospheric conditions lead to the formation of high ozone levels. There is a need to determine the impact of highway construction activities on air quality and to develop alternative construction practices designed to minimize the detrimental effects on ambient air quality.

RECOMMENDATIONS

In the incentive/disincentive (I/D) method called "A+B bidding," contractors bid projects in two areas: cost and number of working days. The number of days multiplied by the bonus/liquidated damages rate, plus the cost bid represents a contractor's total bid. Projects are awarded to the lowest bidder based on total bids. Incentive/disincentive provisions in the project contract may award bonuses for completion in less than the number of bid days and charge liquidated damages for projects completed beyond the number of bid days.

McFarland (1987: 2, 51-52) recommends "A+B bidding" be used in the awarding of all construction contracts, with liquidated damages clauses in all contracts and bonuses only for the most critical projects. (This recommendation has not been adopted in Texas.) Although incentives can help reduce TxDOT's risks associated with uncertain completion dates or costs, incentives and risks for contractors do not go hand-in-hand. Incentives are based solely on performance. They stem from only those factors within the contractor's control, and they do not come from risk assumption (Ashley and Workman, 1986:14-16,23). Bradley and McCuiston (1972:25) state the importance of relating incentives to contractor actions, noting that rewards for performance should be based upon deterministic relationships between the contractor's efforts and the outcome.

Air quality related work stoppages are contrary to this framework (i.e., the general I/D logic and structure). I/D provisions, however creatively applied, will not reduce the risk and uncertainty associated with air quality work stoppages. (Note that the deliberate displacement of certain construction projects from summer to non-summer or from daytime to nighttime is consistent with I/D logic.)

Categorical Alternative Construction Practices

If construction projects are rescheduled either from summer to non-summer or from daytime to nighttime, projects will generally take longer and cost more.

In non-summer construction, weather delays and shorter workdays are the primary factors in the cost differential. Weather delays involve temperature and rain. Some processes cannot be performed below certain temperatures or during precipitation (e.g., concrete pours and some asphalt applications) causing project delays. The shorter workday is also a factor. Construction sites typically operate 10-12 hours per day during the summer, as opposed to only 8-9 during the winter. The impact of these factors is a 30% to 40% cost differential, along with a commensurate increase in project duration.

In nighttime construction, the issues are primarily related to the shorter work period. Nighttime schedules are typically 10:00 PM to 6:00 AM. Allowing for the deployment and retrieval of barriers, lights, and other equipment, this leaves a radically shortened workday (approximately 6 hours, as opposed to the daytime 8 to 12). Delays are also more common since the delivery of materials may be more difficult at night and other disruptions (e.g., equipment failures) are not as easily overcome since most support facilities are not operating at night. Certain activities cannot be done at night at all, causing additional delay beyond what would be experienced during daytime construction (e.g., beam delivery and placement). Safety is also an issue. Note that there is generally not a labor cost differential for nighttime work in Texas. The impact of these factors is 40% to 60% cost differential, along with a commensurate increase in project duration.

The impact of these changes may vary from project to project, but can be generally expected to be as follows:

- Non-summer construction: approximately 30% to 40% additional cost (due to the additional time required) and 30% to 40% longer project duration (due to the shorter workday).

- Night construction: approximately 40% to 60% additional cost (due to the additional time required) and approximately 40% to 60% longer project duration (due to the additional time required to set up and dismantle night construction equipment e.g., lights, barriers, etc.).

Incident Specific Alternative Construction Practices

If mandatory air quality incident related work stoppage clauses (ozone alerts) are inserted in construction contracts, the following is recommended:

- Given the absence of mandatory air quality work stoppage programs in the country, and consequently the lack of data on the cost impacts of air quality related work stoppages, researchers recommend that the overhead calculation described above (overhead cost of the contract divided by the duration) be used for planning purposes and initial implementation.

- Researchers further recommend an assessment of the administrative impacts of establishing a "force account" similar to what is used to compensate for work stoppage due to weather.

- If the force account strategy proves unacceptable or unworkable, researchers recommend that the administrative impacts of including air quality related work stoppages as bid items be more fully explored (especially in regard to the impact of such procedures on current bidding practices).

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