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16. Abstract

This report summarizes findings on the cost and schedule impacts anticipated from a proposed rule on construction equipment operating restrictions as a revision to the State Implementation Plan (SIP) by the Texas Natural Resource Conservation Commission (TNRCC). These restrictions have been proposed for the Houston-Galveston (HG) and Dallas-Fort Worth (DFW) ozone non-attainment areas. The proposed rule establishes a restriction on the use of heavy-duty diesel construction equipment morning hours (6:00 AM to 10:00 Am for the DFW area and 6:00 Am to noon for the HG area) starting in April 2005. Heavy-duty diesel construction equipment includes off-road equipment rated above 50 horsepower.

The research team surveyed contractors and Texas Department of Transportation (TxDOT) personnel to determine potential cost and schedule impacts on TxDOT sponsored construction projects in the ozone non-attanment areas. Results from the survey indicate, that on average, the overall cost impact could be 16 percent and the schedule impact could be 14 percent during the imposed restriction period.

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# POTENTIAL COST AND SCHEDULE IMPACT OF TEXAS NATURAL RESOURCE CONSERVATION COMMISSION'S PROPOSED RULE RESTRICTING CONSTRUCTION EQUIPMENT

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# DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Transportation Institute (TTI) 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. The project director was Wayne Young, and Jason Crawford, PE (TX # 83241), was the Research Supervisor.

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# CHAPTER I INTRODUCTION

This report summarizes findings on the cost and schedule impacts anticipated from a proposed rule on construction equipment operating restrictions as a revision to the State Implementation Plan (SIP) by the Texas Natural Resource Conservation Commission (TNRCC). Specifically, this report focuses on the cost and schedule impacts on TxDOT projects. The proposed rule establishes a restriction on the use of heavy-duty diesel construction equipment in the Houston-Galveston (HG) and in the Dallas-Fort Worth (DFW) ozone non-attainment areas starting in April 2005. The restriction applies during Daylight Savings Time (first Sunday in April to the last Sunday in October) for the HG area and from June 1 and October 31 for the four core counties of the DFW area. Heavy-duty diesel construction has been defined as construction equipment rated above 50 horsepower (hp). Exemptions to the proposed rule include use of equipment for emergency operations and use of equipment necessary to support wet concrete operations. The rule also provides for an exemption if an alternative plan is submitted assuring equivalent emission reductions.

To forecast the potential cost and schedule impacts due to the proposed rules, the research team developed a survey and distributed to TxDOT area engineers and to construction contractors who perform a majority of the TxDOT construction in the HG and the DFW areas. The survey was based on possible future alternative daily work schedules that contractors could adopt to effectively comply with the new restrictions and five distinct project types that exemplify typical TxDOT highway construction projects.

## TNRCC RESTRICTIONS

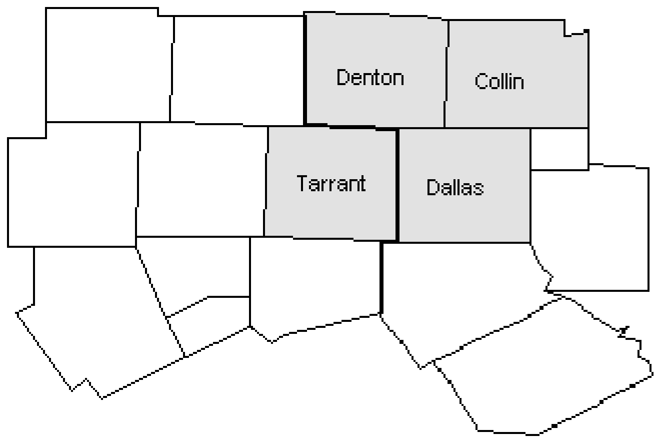
The TNRCC rules have been proposed to reduce the ozone levels in the HG and DFW non-attainment areas. Ozone is a colorless gas that is found in two layers of the atmosphere, high level and ground level. Ground level ozone can be very harmful, causing breathing problems. Ground level ozone is formed through chemical reactions between oxygen, volatile organic compounds (VOC), and nitrogen oxides (NOx) in the presence of sunlight. VOCs come mainly from automobile exhausts and NOxs from industry, power plants, and construction equipment (Effects of Ozone..., 2000).

TNRCC Chapter 114 – Control of Air Pollution from Motor Vehicles report explains the mechanism by which ozone is formed:

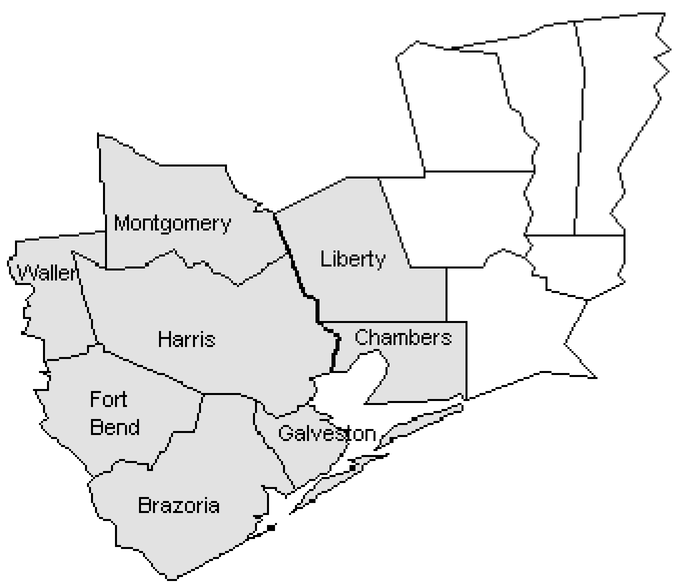
"Ozone is formed through chemical reactions between natural and man-made emissions of VOC and NOx in the presence of sunlight. Higher ozone levels occur most frequently on hot summer afternoons. The critical time for the mixing of NOx and VOC is early in the day. By delaying the hours of operation for construction equipment and delaying the release of NOx emissions until after noon during Daylight Savings Time in the HG nonattainment area, the NOx emissions will not mix in the atmosphere with other ozone-forming compounds until after the critical mixing time has passed. Therefore, production of ozone will be stalled until later in the day when optimum ozone formation conditions no longer exist, ultimately reducing the peak level of ozone produced" (Chapter 114 – Control of Air …, 1999).

In order to reduce the production of ground level ozone, TNRCC has suggested a restriction on the use of construction equipment (non-road, heavy-duty diesel equipment rated at 50 hp and greater) during morning hours. The effective hours of the rule are 6:00 a.m. to 12:00 p.m. for the HG area. The HG non-attainment area includes eight counties, as shown in Figure 1. They are: Brazoria, Fort Bend, Galveston, Harris, Montgomery, and Waller counties in the Houston District and Chambers and Liberty counties in the Beaumont District (Chapter 114 – Control of Air …, 1999). The requirements of the rule restrict equipment operations in the DFW ozone non-attainment area from 6:00 a.m. to 10:00 a.m. This non-attainment area includes Denton, Collin, and Dallas counties in the Dallas District and Tarrant County in Fort Worth District, as depicted in Figure 1 (Chapter 114 – Control of Air …, 1999).

The equipment to which the rule applies includes all non-road, heavy-duty diesel machinery classified as "construction equipment" rated over 50 hp, regardless of how it is being used. The rule also covers construction equipment such as bulldozers used in sanitary landfills, non-road cranes used in demolition, and rubber tire loaders used in manufacturing operations.




Dallas Fort Worth Ozone Non-Attainment Areas




Houston-Galveston Ozone Non-Attainment Areas

**Figure 1. Maps of Non-Attainment Areas.**

(Chapter 114 – Control of Air …, 1999). The TNRCC considers construction equipment as

> "…pavers, paving equipment, plate compactors, rollers, scrapers, surfacing equipment, signal boards/light plants, trenchers, bore/drill rigs, excavators, concrete/industrial saws, cement and mortar mixers, cranes, graders, off-highway trucks, crushing/processing equipment, rough terrain forklifts, rubber tire loaders, rubber tire tractors/dozers, tractors/loaders/backhoes, crawler tractors/dozers, skid steer loaders, off-highway tractors, and dumpsters/tenders." The TNRCC also includes other equipment in its definition. (Chapter 114 – Control of Air …, 1999).

The proposed rule contains some exemptions that include construction equipment used exclusively for emergency operations to protect public health and the environment and equipment used for mixing, transporting, pouring, or processing wet concrete. Also, there is an exemption if the operators submit an emissions reduction plan that is approved by the executive director of the TNRCC by May 31, 2002, and a plan that the EPA approves by May 31, 2003 (Chapter 114 – Control of Air …, 1999).

The proposed restrictions could have a significant impact on the time window available for construction operations. Construction operations are currently impacted by other factors, including traffic in the metropolitan areas, weather, and amount of natural light hours.

## CURRENT CONSTRUCTION PRACTICES

Methods and practices for the heavy construction industry are laden with the use of diesel equipment. The industry relies on the use of heavy equipment as a necessary means to be productive in the large-scale nature of highway construction. Diesel equipment rated above 50 hp can be found in almost all operations associated with the construction, rehabilitation, and repair of the State's roadway system. Additionally, tasks that are labor-intensive require the use of heavy equipment to support their operations. Equipment used to support labor is typically planned or sequenced; however, heavy equipment is also necessary at unplanned or critical times.

TxDOT conducts large amount of highway construction in the summer months during extended hours of daylight and under favorable temperature and weather conditions. Daily highway construction operations typically begin at dawn, around 6:00 a.m. to 8:00 a.m., and continue throughout the day until the late afternoon. The length of daily operations vary depending on many factors, including the phase of the project, weather conditions, and the amount of daylight available, but normally last for approximately 10 to 12 hours.

Night work is not unfamiliar to TxDOT and its construction contractors. Portions of projects, especially those projects centered in the metropolitan areas, are often conducted at night. Concreting operations are frequently conducted at night or at pre-dawn hours due to the restrictions imposed when placing concrete in high temperatures. However, TxDOT personnel in the HG and DFW areas indicated that the amount of work conducted at night is a small fraction of that conducted overall. The HG area seemingly conducts more night work than the DFW area; however, a recent large project in the DFW area was accomplished primarily at night.

The amount of time that is allotted to a contractor is established for each individual project. Most contracts allocate a given amount of working days to a contractor to finish the project. The definition of a "working day" can be found in the *TxDOT Standard Specifications* (1995) but is often tailored for each project:

> "A working day is defined as a calendar day, not including Saturdays, Sundays, or legal holidays authorized in the list prepared by the Department for contract purposes, in which weather or other conditions not under the control of the Contractor will permit the performance of the critical activity or activities of work underway for a continuous period of not less than 7 hours between 7 a.m. and 6 p.m. For every Saturday or legal holiday except the following holidays: January 1st, the last Monday in May, July 4th, the first Monday in September, the fourth Thursday in November and December 25th…"

Overall, there is not a fixed or stereotypical type of work schedule that can be stated, though most work is conducted during daylight hours. Work hours depend upon the unique characteristics of the project. Usually the typical material suppliers, such as asphalt concrete plants, are operational during daytime. Typically, suppliers charge premiums if they are required to provide material services in the evening or at night.

## TRAFFIC RESTRICTIONS

Due to the heavy volume of traffic in the metropolitan areas, work performed on most major roadways in both the DFW and HG areas is restricted to specific times. Project plans usually contain wording that details the specific restriction applicable to the project. A typical example of a restriction would be: "The existing number of lanes open to traffic shall not be reduced. Exception will be made only during off-peak hours as shown on plans." Off-peak hours in the HG area are normally construed as being between 9:00 a.m. and 3:00 p.m. This time period effectively limits the daytime work that requires lane closures to Monday through Friday 9:00 a.m. through 3:00 p.m. and Saturdays, if allowed. In the Dallas-Fort Worth area, normally lanes cannot be closed during the hours of 7:00 - 9:00 a.m. and from 4:00 - 7:00 in the late afternoon. TxDOT projects in the DFW area typically distinguish between outbound and inbound traffic flows when specifying these restrictions.

## OBJECTIVES

This research effort is focused on meeting the following objectives as they pertain to the HG and DFW areas:

- determine the potential cost and schedule impacts to highway construction operations for TxDOT projects in the HG and DFW areas based on the implementation of alternative daily work schedules;
- identify key elements that affect cost and project duration due to the implementation of construction equipment restrictions as proposed by the TNRCC;
- determine the potential cost and schedule impacts by project type as a result of equipment usage restrictions;
- identify alternative daily construction work schedules that the contractors may implement for projects performed in the non-attainment areas as a consequence of the proposed rule; and

- generate base data as a function of project type, metropolitan area, and alternative work schedules.

This project could also assist TxDOT with the following issues pertaining to the proposed restrictions:

- understanding of potential new work schedules that the contractors may adopt to comply with the regulations and
- assist in future cost estimating and work planning.

# CHAPTER II  LITERATURE SEARCH

The implementation of the TNRCC's proposed rule on the restrictions for the use of heavy off-road diesel construction equipment in highway construction operations would force the construction contractors to find alternative daily construction schedules that comply with the restrictions.  These could impact the construction duration and cost.  The analysis of these potential impacts on the construction schedules and costs is the focus of this research.

Applying alternative schedules can affect various construction-related factors that, in turn, can have significant impacts on the costs and schedule components of a project.  This literature search focuses on the identification of research and empirical data related to alternative construction schedules and their impact on construction costs and duration.  Alternative schedules are those that differ from the normal daily construction schedules.  Information regarding nighttime construction operations was found during review of the existing literature; however, little information exists on other alternative construction schedules.  The main reason for this lack of information is the uniqueness of TNRCC's implementation plan and its possible repercussions.   Hinze and Carlisle (1990) conducted the most comprehensive research on the impacts of nighttime operations on highway construction projects.

The various articles and reports reviewed conclude that the average estimated project cost increase is approximately 10 percent for nighttime construction operations (Hinze and Carlisle, 1990; Elraham and Perry, 1998).  This cost increase is due to daily cost impacts and project schedule changes.  The literature focuses on various factors that affect nighttime construction costs.  These factors affect one or more of the elements that compose a construction budget (field labor, materials, equipment, field indirect, and home office costs).  The factors that have been determined to impact night work should also have varying impacts on other work schedules and therefore have been included as part of the research.

The primary factors identified are as follows:

- labor wage rates
- lighting (construction illumination)
- productivity
- traffic control
- materials and equipment availability
- safety and accidents
- quality
- noise
- worker morale

## LABOR WAGE RATES

One of the major elements that comprise a project's budget is direct field labor cost. Labor cost is determined primarily by the labor quantity required and the labor wage rates. The labor requirement is based on the quantity of work to be completed, on the complexity of the work, and on the workers' expertise. The labor wage rate depends primarily on the workers' craft and expertise based on the local wage standards.

Typically, night work schedules require premium wages. This premium accounts for the non-standard work hours and for any overtime. Hinze and Carlisle (1990) concluded that the expected direct field labor cost increment for night work is approximately 18 percent as a result of the higher labor premiums and/or due to lower productivity. Lower productivity is a consequence of adjusting to new work conditions and to the other night-related disadvantages, such as limited visibility. Another reason for lower productivity is that night shifts tend to be shorter, but the workers are still paid a full day's work (Hinze and Carlisle, 1990).

Hinze and Carlisle (1990) found that direct field labor cost is a major part of a project's budget, and thus labor cost impacts are responsible for the major part of a project's total cost increment. They added that, “Most of the added costs were attributed to the premium wages paid for shift work”. (Hinze and Carlisle, 1990)

Night construction also directly affects the contractors’ staff as premiums may be paid for overtime or night work. These cost impacts can also extend to the owners’ personnel. Hinze and Carlisle (1990) found that agency costs due to overtime could rise 16 percent as a result of night work.

## CONSTRUCTION ILLUMINATION

One of the most important factors that differentiates nighttime work from daytime is the need for site illumination. During day operations, natural light is the source of illumination. For night work, artificial illumination has to replace natural light. Since daytime work normally does not require artificial light, any illumination related cost is additional. According to Hinze and Carlisle (1990) in a comprehensive evaluation of the important variables in nighttime construction, project lighting cost increased by an average of 63 percent compared to current practices. Nonetheless, illumination costs are not a major part of a construction budget, as indicated by one contractor in the evaluation performed by Hinze and Carlisle (1990).

Construction illumination is an essential and an important factor for nighttime work. Lighting affects many aspects of nighttime construction, such as safety, productivity, and quality (Hinze and Carlisle, 1990; Elraham and Perry, 1998). The lack of proper illumination is a primary cause of construction-related accidents, both from drivers and within the site itself. Nonetheless, the use of site illumination has to be considered cautiously because it can create negative side effects in the form of glares and shadows. Lighting can create problems for drivers as they go from an area of low visibility to one of high illumination, and their sight can not adjust in time, therefore increasing the possibilities of accidents (Elraham and Perry, 1998; Hinze and Carlisle, 1990). Lighting serves in nighttime operations as a safety and traffic control method (Hinze and Carlisle, 1990), thus reducing the probability of accidents. Construction accidents can have significant negative cost and schedule impacts on construction projects.

The proper and careful use of construction illumination is essential in residential areas because of potential nuisances to the neighbors. It is important to take into account local ordinances regulating construction lighting, such as those pertaining to construction in residential areas; "excessive glare can be … annoying to nearby residents" (Elraham and Perry, 1998). This problem can cause an additional cost in the form of limited lighting or light barriers.

Lighting also has a major impact on construction schedules. Improper illumination reduces productivity and slows operations. The lack of visibility can force a greater degree of care in the operations and a slower work rate, potentially resulting in increased project duration.

## PRODUCTIVITY

Productivity is dependent on a series of factors, such as communication, material and equipment availability, visibility, quality requirements, rework, worker morale, and others (Elraham and Perry, 1998). Similarly, productivity has a direct impact on projects' cost and duration. The lower the productivity, the longer a project will take and/or the greater the resources needed. Low productivity rates also affect indirect costs due to extended project duration.

Communication is a vital part of construction projects. The large numbers of parties involved in a construction project require a high level of communication (Hinze and Carlisle, 1990). The client, the contractor, the engineer, the suppliers, and the field personnel all have to maintain constant communication.

Night work causes problems in productivity because not all of the involved parties involved work at night (Ellis and Kumar, 1993). If TxDOT cannot achieve the necessary coordination at the required time, the project may have to be delayed until authorization to proceed is obtained. Inspection is a clear example of the potential problems (Hinze and Carlisle, 1990). In some cases, inspectors may not work at night; therefore, until approval is obtained during the next day, a certain task may have to be stopped or delayed. In cases where inspectors do work at night, communication with the base office has to be arranged because incompatibilities between the construction and the office schedules may exist.

Along with the allocation of experienced personnel with sufficient authority to make on-site decisions and maintaining certain key personnel available during the night shifts, good planning can mitigate these inconveniences (Hinze and Carlisle, 1990). All of these actions can increase costs, though their proper implementation may reduce potentially more serious problems.

## TRAFFIC CONTROL

Traffic control is an essential element in highway construction projects and is especially important for nighttime work. Consequently, night construction operations are typically more dangerous than daytime operations, not only as a result of the lack of visibility but also as a result of the higher degree of drivers that are inattentive and under the influence of drugs or alcohol (Shephard and Cottrell, 1986; Elharam and Perry, 1998). Alternatively, the reduced traffic volume can result in safer conditions (Hinze and Carlisle, 1990). To reduce the probabilities of drivers' accidents, a good traffic control system must be implemented since traffic control and road accidents are intimately related (Hinze and Carlisle, 1990). Traffic control not only protects the drivers, but also protects the construction workers from the drivers (Shephard and Cottrell, 1986).

The requirements for selecting the type of devices used for traffic control depend on the time of day they are used (nighttime devices must be illuminated or reflectorized), traffic volume, local regulations, and the type of work to be performed (Hinze and Carlisle, 1990). There are many traffic control methods, such as barriers, lanterns, flashing signals, flags, and reflectorized cones. The effectiveness of the various methods varies according to the type of lane closure implemented.

A major traffic control method is lane closures (Elraham and Perry, 1998). During daytime operations, depending on the location of the construction site, partial or total lane closure may be allowed. Due to traffic volume and congestion in major metropolitan areas, lane closures may be forbidden during certain hours. Because extreme traffic conditions exist in certain cities, TxDOT often shifts highway construction to nighttime hours. Partial nighttime lane closures can create serious potential safety problems for drivers and workers. Night driving can reduce a driver's ability to distinguish a partial closure, and total lane closures are often required (Elraham and Perry, 1998).

According to Hinze and Carlisle (1990), traffic control costs increase by 28 percent on average for nighttime construction, though this percentage can vary significantly depending on the requirements of the local authorities and individual contractor procedures. One respondent to the Hinze and Carlisle (1990) survey stated that traffic control requirements for nighttime construction are essentially the same as for daytime operations. Traffic control does not affect only project cost but can also affect the project schedule because additional time is required to set up and take down the traffic control elements. Because nighttime work can potentially require a greater degree of control devices, the time required is also greater, taking away from productive time.

## MATERIALS AND EQUIPMENT AVAILABILITY

Material delivery may become a problem for nighttime work. If materials are available at night, the delivery may be less of a problem, compared to daytime delivery, as a result of less traffic interruptions and delays (Hinze and Carlisle, 1990). Nonetheless, not all suppliers continue operations at night. Some materials can be ordered during the daytime and stored for use at night, but this option depends on site layout (Hinze and Carlisle, 1990). Storage areas in highway construction operations are usually small and therefore, large quantities of material cannot be stockpiled.

If the suppliers are required to work at night to meet a shift in demand, a premium may have to be paid for the alterations to their business hours which could raise material prices (Elraham and Perry, 1998). This factor becomes especially important for materials that can not be stored, such as concrete or asphalt concrete. Batch plants usually charge a premium for opening the plant at night. This additional cost may be waived if the contractor owns a batch plant. For all materials that can be stored, careful planning is essential due to the limited storage areas. Hinze and Carlisle (1990) identified a potential material cost increment of 5 percent for projects conducted during night.

TxDOT may encounter similar problem with equipment availability. Equipment repair shops' hours typically do not extend into the night, and a piece of equipment that breaks down or requires maintenance during nighttime operations may not be repaired until the next day. This delay can result in lost time (Elraham and Perry, 1998). As with batch plants, premiums may have to be paid for repair shops to stay open at night. An alternative solution is to keep permanent equipment repair personnel on the site with sufficient stock of spare parts or to maintain standby equipment for the key pieces of equipment in case one or more become inoperable. But the alternative still requires additional project funds.

Highway construction operations rely on heavy equipment, and the breakdown of such equipment can cause serious delays that can impact the project's duration. Delays can result in increased project costs. It is very difficult to estimate additional costs due to equipment-related problems because it is a function of the type of equipment that is damaged and the time lost on the project.

## SAFETY AND ACCIDENTS

The rate of accidents at night is less than during daytime due to the lower traffic volumes, but the severity of the accidents tends to be greater (Elraham and Perry, 1998). Safety is intimately related to proper visibility for night work and, also to construction illumination (Hinze and Carlisle, 1990). Many of the accidents in the construction site occur as a result of improper illumination, especially on the perimeter of the immediate construction zone where visibility is limited. The change in the degree of illumination can cause workers to experience temporary blindness as they adjust to the changes in light and, that can lead to higher occurrences of accidents.

Another aspect of construction safety for highway construction operations is related to motor-vehicle accidents. Nighttime drivers tend to drive faster, be under the influence of alcohol or drugs, and experience drowsiness, all of which increase the probabilities of having an accident (Shephard and Cottrell, 1986).

Improper illumination can cause the driver to avoid seeing the upcoming construction site or experience blindness if the transition from a dark to a well-illuminated area is not adequate. To minimize potential accidents, adequate traffic control must be implemented. The traffic control technique used must incorporate sufficient and acceptable lighting.

It is very difficult to quantify the impact of safety in the construction costs and schedule, although it is most likely an influencing variable. Shephard and Cottrell (1986) have listed liability as one of the factors that should be considered when contemplating night operations. The research by Hinze and Carlisle (1990) indicated that safety was the second most important factor when deciding whether to implement nighttime work. The consequences of site accidents can be significant to a project both in cost and in time. Fines related to accidents can make a significant difference in the project's profit and contractor's reputation. The best approach to mitigate accidents and improve safety is to take necessary precautions, though this approach may increase the construction cost. These precautions can include proper illumination, a traffic control plan, and a good public information campaign.

## QUALITY

Quality is a primary factor during the execution of a job. Work that does not meet quality standards may have to be replaced, resulting in lost time and increased cost. Quality depends directly on visibility and therefore, for night work, on illumination (Hinze and Carlisle, 1990). Other factors that affect quality are the workers level of fatigue and morale (Elraham and Perry, 1998). Workers that are tired or distracted will not pay as much attention to quality as those who are rested and are able to concentrate on the job. Similarly, if a worker is unmotivated, he/she will not strive to achieve high quality standards. Quality was considered as one of the most important factors considered during the decision making process of night work implementation (Hinze and Carlisle, 1990).

Conversely, night work can provide certain positive factors that affect the quality, such as lack of traffic interference and moderate temperatures (Hinze and Carlisle, 1990). Reduced traffic allows for work with less interruption, which could improve quality (Elraham and Perry, 1998). The moderate temperatures at night may allow for better conditions for certain types of work, such as concrete placement.

Insufficient information is available to determine if quality is reduced during nighttime work, though there is a recognized potential for reduced quality (Hinze and Carlisle, 1990). Quality-related problems can have potential cost and schedule-associated problems, though it is difficult to evaluate the impact.

## NOISE

One effect of construction operations is the high noise level. Various operations and activities produce noise levels for which special protection is necessary. Noise level can be a serious problem in sites near residential or commercial areas, especially during nighttime. Hinze and Carlisle (1990) found that noise is the third most important factor when arriving at the decision of implementing nighttime construction. Ellis and Kumar (1993) also identified noise as a major factor affecting nighttime work implementation.

Many jurisdictions have special restrictions regarding noise levels in certain areas and at certain times (Elraham and Perry, 1998; Hinze and Carlisle, 1990). Noise abatement becomes a necessity for this type of work, and it can result in a considerable cost, depending on the requirements. There are several methods to reduce noise around construction sites, including sound barriers, improved engine blocks, mufflers, and others (Hinze and Carlisle, 1990). The method adopted will depend on the cost of differing alternatives and on local noise ordinances. If the restrictions are too strict, night work may not be a feasible option or workers will have to perform certain operations during daytime.

Schexnayder (1999) analyzed a night project in downtown Boston (Central Artery/Tunnel Project) that placed special noise reduction requirements on the contractor. These special requirements included a noise control plan, a noise monitoring plan, qualifications for an acoustical engineer, shop drawings for the noise mitigation structures, and construction compliance reports. To satisfy these requirements the contractors included the following elements into their mitigation program: computer tracking and a report system to ensure compliance of requirements; distinctive sign and construction barrier system for cars and people; community liaisons; 24-hour monitoring center for surveillance of traffic and construction; a 24-hour telephone line for complaints; and a proactive noise control program.

If the noise level is found to be considerable, there may be negative public opinion causing problems to the development of the project. Shephard and Cottrell (1986) identify noise as one of the main disadvantages of nighttime construction.

The costs related to noise mitigation and control depend on the type of project, the location of the project, and the local regulations. An effective public information process can reduce the negative impact from noise-related problems (Elraham and Perry, 1998). A good preliminary study of possible noise mitigation techniques and methods tends to reduce noise-related costs.

**WORKER MORALE**

Worker morale is related to the mental well being of the workers. The condition of the workers has a direct impact on productivity and quality of the final product (Elraham and Perry, 1998). Nighttime work may cause sleep deprivation, fatigue, alterations in the biological clock (circadian rhythm), and social and domestic adjustment problems, all of which result in low morale. Shephard and Cottrell (1986) identify low worker morale as a disadvantage of night work, leading to difficulty in hiring personnel despite pay incentives. Hinze and Carlisle (1990) indicate that night work may lead to high turnover rates.

Nighttime work may cause disruptions in family routines, leading to preoccupied workers. Also, nighttime work alters the circadian rhythm, which can cause serious physical and mental problems. Another possible outcome is that workers may work at another location during the day instead of taking rest (Shephard and Cottrell, 1986). This pattern results in sleep deprivation and tired workers, increased the probability of accidents, lower productivity of work, and reduced quality (Elrahman and Perry, 1998).

Nonetheless, Hinze and Carlisle (1990) identified that for most contractors, worker morale was not a problem. They alleged that high premiums, time off, shorter projects, motivation, and implementing regular night work shifts improved worker morale, mitigating its possible negative impacts.

The cost and schedule impacts caused by poor worker morale cannot be easily identified, but some of its potential effects can be identified. As mentioned, these effects include lower productivity and quality, unsafe conditions, high turnover rates, and difficulty in recruiting new people. All of these factors can have significant potential cost and schedule impacts. A high turnover rate increases cost because of the extra training required, lost time, and lower productivity. Problems in recruitment may force wage raises to increase attractiveness within the industry. Low productivity and quality have direct impacts on cost and schedule, and unsafe conditions have all the cost impacts previously described.

# CHAPTER III  RESEARCH METHODOLOGY

## METHODOLOGY APPROACH

To determine the cost and schedule impacts due to the proposed rule by TNRCC, the research team considered various approaches.  The selected research method was designed to provide significant and meaningful findings while also taking into account the many unknowns associated with such a unique proposed change and the limited time available to conduct this research project.  Important factors in determining an appropriate method of study include the meaningfulness of the data, the amount of time available, and the correlation to forecasted changes to the construction industry.

### Existing Cost Estimating Tools

One option available to the research team was to utilize past methods and data derived from previous work or cost-estimating tools and handbooks.  Confidence in the cost and schedule impacts could be increased if they were derived from proven models or tools.  As discussed in the literature review, minimal past research and practical experience is available that compares the proposed new restrictions on the use of heavy diesel equipment.  Standard cost-estimating manuals do not reflect anticipated shifts in the work schedule caused by the restricted use of heavy equipment.  Also, the tendency of contractors to shift work schedules in response to the proposed restrictions is unknown. Therefore, the cost and schedule impacts can not be determined using previous cost-estimating tools, software, or models.

### Systems View

A gross estimate of cost and schedule impacts can be prepared by assuming that a contractor's work schedule will be shortened in direct proportion to the amount of work hours lost during the restriction period.  For instance, in the DFW area the restriction period will reduce the workday by three to four hours.  One can then predict that since the workday is shortened by

30 to 40 percent (assuming a ten-hour work day), the schedule will be impacted in direct proportion, and the cost will be impacted by some factor of this change.  This method gives a quick conservative estimate of the impact due to the proposed change but does not take advantage of contractors' and area engineers' experience and expertise in gauging the response of the construction work force to the proposed rule.  Thus, the research team used a more comprehensive approach.

**Historical TxDOT Project Cost Data**

One promising approach was to utilize the vast line item cost database maintained by TxDOT.  This database contains project line item "Average Low Bid Unit Price" for both TxDOT districts and statewide.  The line items follow the divisions outlined in TxDOT's Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges (Standard Specifications) as shown in Table 1.

**Table 1.  Divisions of TxDOT's Standard Specifications.**

| |
|---|
| DIVISION I, Earthwork |
| DIVISION II, Sub-base and Base Courses |
| DIVISION III, Surface Courses or Pavement |
| DIVISION IV, Structures |
| DIVISION V, Incidental Construction |
| DIVISION VI, Lighting and Signing |
| DIVISION VII, Maintenance |

This database could be used to generate unit costs for various major components of TxDOT projects.  These components could consist of linear foot of continuous reinforcement concrete pavement, for example.  Collective unit costs for various project components would be gathered for projects conducted during normal workdays and projects conducted at times that complied with the proposed restriction periods.  Though historic cost data on TxDOT projects could provide actual information to forecast future impacts, this approach did have insurmountable drawbacks.  The drawbacks included:

- Average low bid unit prices are not indicative of actual installation costs.
- Many unascertainable factors impact the derivation of the unit price for an item.
- It is difficult to identify projects and/or extract portions of projects that can be used for comparison between standard conditions and those conditions expected in the future in response to the proposed rule.
- Line item costs do not separate labor, material, equipment, and overhead cost that can be attributed to the specific factors impacted by the proposed rule.

TxDOT usually compensates contractors for work performed based on bid unit prices for line items that fall within the various divisions of the Standard Specifications. However, it is common knowledge between a majority of TxDOT area engineers and contractors that these unit prices are not indicative of the cost of in-place work. Projects can be front loaded, allowing the contractor to receive more funding at the onset of a project to assist with project cash flow. Additionally, there are many factors that impact the bid unit price such as the current price of materials, the level of congestion at the site, the size of the project, and the volume of work for the contractor.

Applying the data to predict future impacts due to the proposed rule is also problematical. Unit prices from TxDOT projects cannot be directly associated with the work schedules utilized. Though it may be possible to distinguish a few projects that were conducted at night and compare them to similar projects conducted during the day, the impact of the proposed rule on the amount of night work is not known. Finally, when analyzing differences in cost between candidate projects, it would be difficult to attribute those differences to factors associated with the type of work schedule, especially since the line item costs are not broken down into any cost elements.

**Survey Approach**

In light of the concerns with the previous approaches the research team had to develop a method that did not solely rely on past or historical data. This fact especially valid since the researchers have not encountered similar restrictions of such magnitude enacted within the construction industry. Not only is there a lack of historical data to determine cost and schedule impacts, the responses of the contractors regarding the implementation of new work schedules to the proposed rule are unknown. Therefore, the research team decided that further research was necessary to determine how contractors would respond to the proposed restrictions and, consequently, how the change in operations would impact current schedules and cost.

The available sources that could shed light on the changes in construction practices and work schedules of TxDOT projects are the construction contractors who perform the work and the TxDOT personnel that let and oversee such work. Therefore, conducting interviews and gathering survey data from these parties could reflect forecasted changes in the construction industry as it pertains to TxDOT, increase the meaningfulness of the data, and make beneficial use of the limited amount of time available for this project.

## SURVEY DEVELOPMENT

### Funding and Work Categories

The initial step in developing the survey was to determine how to categorize the construction work that represents the projects within TxDOT. Survey and interview data collected from contractors and TxDOT area engineers must be correlated to an overall impact on TxDOT. For example, a potential increase in material delivery charges must be correlated to the total cost of work anticipated for TxDOT to fully appreciate the impact due to material delivery. Though TxDOT projects are normally categorized by funding source, each project also maintains a primary project classification. This classification is used to denote the overall type of work. Table 2 shows classifications used by TxDOT to designate the type of work.

**Table 2. TxDOT Project Classifications.**

| | |
|---|---|
| Convert Non-Freeway to Freeway | Miscellaneous Construction |
| Widen Freeway | Safety Rest Areas |
| Widen Non-Freeway | Traffic Signal |
| New Location Freeway | Hazard Elimination and Safety |
| New Location Non-Freeway | Corridor Traffic Management |
| Interchange (New or Reconstructed) | Grade Crossing Protection |
| Bridge Replacement | Traffic Protection Devices |
| Bridge Widening or Rehabilitation | Landscape and Scenic Enhancement |
| Remove Hazardous Paint | Junkyard Control |
| Seal Coat | Utility Adjustment |
| Overlay | Outdoor Advertisement |
| Restoration | Ferry Boat |
| Rehabilitation of Existing Road | Tunnel Construction |
| Upgrade to Standard Freeway | Railroad Relocation |
| Upgrade to Standard Non-Freeway | |

Such an extensive list makes it infeasible to arrive at an overall cost and schedule impact to TxDOT from the cost and schedule impacts of each individual classification. However, it was evident that a majority of the funding and work conducted by TxDOT fell into a relatively defined scope of work. A majority of the funding and work was focused into major highway and bridge construction and reconstruction. Therefore, an effort was made to focus on these types of projects in the developed surveys. Five major project types were selected from the appropriate classifications to form the basis for the developed survey. These project types are shown in Table 3 and further discussed in the following section.

**Table 3. Project Types and Percent Distribution of Funds in Each Project Type.**

| PROJECT TYPES | PROJECT CATEGORIES | % OF FUNDS HG | % OF FUNDS DFW |
|---|---|---|---|
| Freeway Reconstruction and Widening | Convert non-freeway to freeway<br>Widen freeway<br>Portion: Bridge widening or rehabilitation<br>Upgrade to standard freeway | 34.0 | 23.0 |
| Non-Freeway Reconstruction and Widening | Widen non-freeway<br>Portion: Bridge widening or rehabilitation<br>Upgrade to standard non-freeway | 20.2 | 23.9 |
| New Construction | New location freeway<br>New location non-freeway<br>Interchange (new or reconstructed) | 10.3 | 21.0 |
| Bridge Replacement | Bridge replacement | 4.3 | 6.1 |
| Rehabilitation and Overlay | Seal coat<br>Overlay<br>Restoration<br>Rehabilitation of existing road<br>Miscellaneous construction | 25.8 | 23.0 |
| Other:<br>Safety / Traffic Control Environmental Others | Safety rest areas<br>Traffic signal<br>Hazard elimination and safety<br>Corridor traffic management<br>Grade crossing protection<br>Traffic protection devices<br>Landscape and scenic enhancement<br>Junkyard control<br>Utility adjustment<br>Outdoor advertisement<br>Ferry boat<br>Tunnel construction<br>Railroad relocation<br>Remove Hazardous Paint | 5.4 | 3.0 |
| Total | | 100.0 | 100.0 |

The percentages of funds are based on data provided by TxDOT in the form of project costs for years 1997, 1998, 1999 and 2000. The numbers are based on the funds allocated to the Houston and Beaumont districts for the HG area and Dallas and Fort Worth districts for the DFW area.

The five project types used for the impact evaluation are freeway reconstruction and widening, non-freeway reconstruction and widening, new construction, bridge replacement, and rehabilitation and overlay. They represent 94.6 percent of the total funding allocated by TxDOT for highway construction projects in the HG area and 97 percent in the DFW area. For the purpose of analysis, the research team considered only these project types and the funding for these project types was assumed to be 100 percent.

## Important Factors Affecting Cost and Schedule

Based on feedback from TxDOT area engineers, construction contractors, and the literature search, factors affecting an urban highway construction project cost and schedule include labor wage rates, traffic control, construction lighting, insurance, workers' compensation, and rework. It was also identified that an analysis of impact on the individual constituents of the project cost was needed.

## Cost Elements

As previously discussed, it was important to be able to correlate the impacts of the proposed rule on the various aspects of TxDOT construction projects to the overall cost and schedule impact. Since the survey heavily relied on the input from construction contractors, the research team felt it was beneficial to identify key cost elements that were easily identifiable by contractors. The cost elements of direct field labor, material, equipment, field indirect, and home office are common components of cost estimates for the construction contractor. Therefore, these cost elements were utilized in the survey to apportion the cost from each aspect and to form the main framework for generating feedback.

## Work Schedule Alternatives

To better anticipate the effects of the proposed rule, attempts were made to forecast the reaction of the construction contractor in terms of daily construction operations. Initial discussions were held with top members of the TxDOT construction offices and with construction contractors to better understand the options available to the contractor in order to execute the project and comply with the proposed restrictions on the use of heavy off-road diesel equipment. In short, construction relies heavily on the use of diesel equipment for the daily operations. Very little, if any, work can be conducted without the use of equipment that is targeted by the restrictions. After careful consideration and deliberation, the research team developed work schedule alternatives that best represented future potential response.

The work schedule alternatives (WSA) are daily work schedules that a contractor could implement to comply with the proposed restrictions. Overall cost and schedule impacts varies according to the WSA selected by contractors. Therefore, four potential alternatives were designed to accommodate most types of work performed in the impacted areas and to confirm to the traffic restriction policies implemented by TxDOT. These alternatives were defined based on their potential to allow continuous work and considered the time of the day that would provide for a full day's work. They also supported the belief that only very minor portions of construction projects could be conducted without the use of heavy equipment. The defined alternatives included:

A. delayed, continuous operations (shifting schedule to avoid the restricted period);
B. partially delayed, continuous operations (re-sequencing the work schedule to minimize equipment use during restricted periods);
C. delayed non-continuous operations (work alternative to be followed for the projects that have to stop operations during rush hours) – applicable to the HG area;
D. shortened continuous operations (work alternative to be followed for the projects that have to stop operations during high volume traffic periods) - applicable to the DFW area; and
E. continuous nighttime operations (changing the shifts from a day schedule to a night schedule).

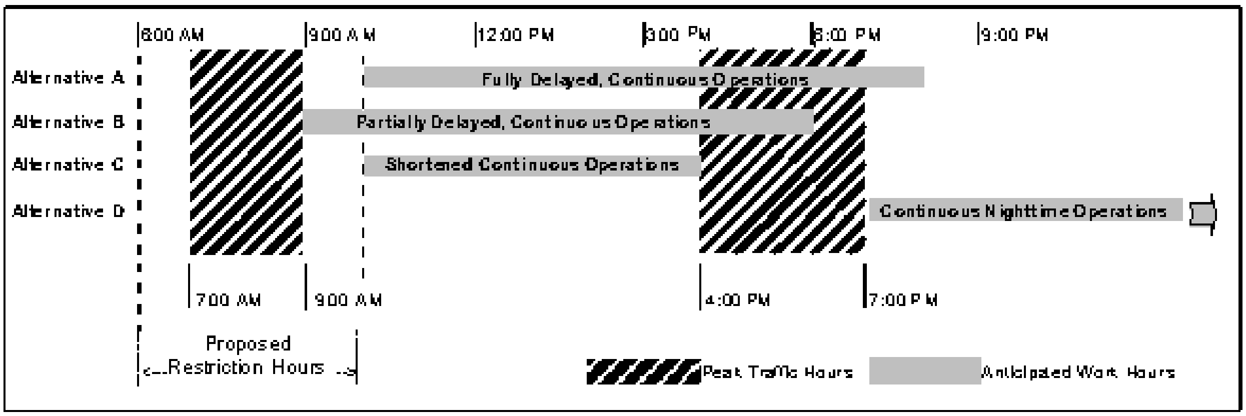
Fully Delayed Continuous Operations (Alternative A)

The first anticipated revised work schedule would be to simply delay daily operations until after the restriction period. Therefore, as shown in Figure 2, all construction operations could be shifted to coincide with the end of the restriction period, noon for the HG area and 10:00 a.m. for the DFW area. For the purposes of this project it was assumed that the workday consists of 10 hours, thereby shifting the end of the workday to 10:00 p.m. and 8:00 p.m. for the HG area and DFW areas, respectively. It is also assumed that minor preparation for construction work will occur prior to the start of the restricted period as long as it complies with the restriction requirements. This WSA is compatible with those projects that do not have to stop operations due to traffic restriction policies.

Partially Delayed, Continuous Operations (Alternative B)

The second anticipated revised work schedule is to estimate the portion of daily operations that can be executed without the need of heavy diesel equipment. Therefore, it is anticipated that some of the work conducted by contractors can be initiated two hours prior to the start of the restricted period; work will then continue for the remainder of the day until completing a regular 10-hour work day (Figure 2). Thus, all construction operations will be shifted to 10:00 a.m. for the HG area and 8:00 a.m. for the DFW area. The end of the workday would consequently be shifted to 8:00 p.m. and 6:00 p.m. for the HG and DFW areas, respectively. This WSA is also compatible with those projects that do not require lane closures.

Work Schedule Alternatives (DFW Area):




Work Schedule Alternatives (HG):

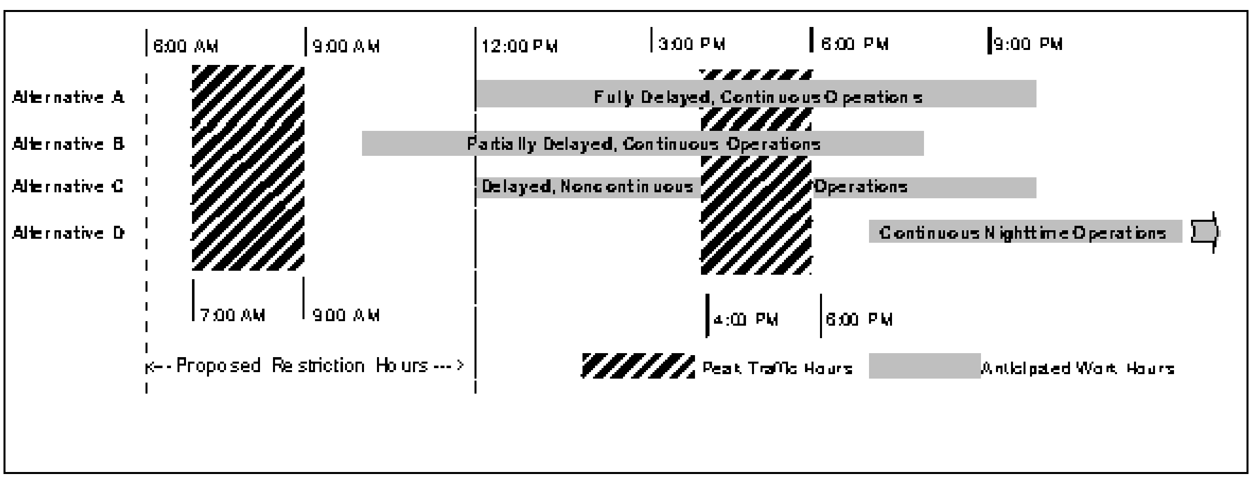



**Figure 2. Work Schedule Alternatives for DFW and HG Areas.**

Delayed, Non-Continuous Operations (Alternative C : HG)

The proposed rule has the greatest anticipated impact for construction that will directly impact traffic and require lane closures. For this type of projects in the HG area, TxDOT personnel mentioned that all lanes must be available during the afternoon rush hour starting at 3:00 p.m. The additional restriction placed by the proposed rule delays the onset of operations to late morning, therefore preventing continuous operations because of TxDOT traffic restriction policies (Figure 2). Thus, there may be times when the only option for a contractor is to split the operations for the day: work from the end of the restriction period, at noon, halt activities for approximately two hours in the late afternoon to coincide with traffic restrictions, and then continue operations afterward. It is assumed that the contractor workday will still consist of 10 hours; however, very little or no work will be conducted during a two-hour time period when traffic restrictions are imposed.

Shortened Continuous Operations (Alternative C : DFW)

For the DFW area, restricted lane closures in the afternoon are less stringent than those required for the HG area. Therefore, it is anticipated that contractors would not consider splitting the workday, but instead shorten the workday during the periods of construction that would interfere with traffic restriction policies. This potential work schedule is shown in Figure 2 and was included in the survey submitted to contractors in the DFW area.

Continuous, Nighttime Operations (Alternative D)

Contractors may find it more effective or necessary to conduct construction operations totally at night. Continuous operations at night may be the only viable alternative for construction that directly interferes with traffic or during periods of excessive heat (Figure 2).

## Standard TxDOT Project Types

The proposed restrictions on heavy equipment operations may have varying impacts on cost and schedule depending on the unique characteristics associated with each TxDOT project. Projects differ in many aspects, including physical attributes (such as the number and type of bridge overpasses), amount of traffic, frequency of lane closures, the type and use of heavy equipment, construction methods, and materials. To best capture the potential effects of the proposed restrictions on varying types of work, five representative project types were developed. These project types were categorized based on existing TxDOT project classifications discussed earlier and include:

- freeway reconstruction and widening
- non-freeway reconstruction and widening
- new construction
- bridge replacement
- rehabilitation and overlay

Because overlay work is a function of traffic volume, separate rural and urban cases were prepared for the rehabilitation and overlay project type.

**Representative Project Types**

The survey delineated each representative project type to provide all survey respondents the same basic project scope when attempting to petition the impact of the proposed rule. The research team and TxDOT representatives developed the following representative project types and their corresponding definitions and characteristicsfrom a variety of existing TxDOT projects. These project types represent a majority of the construction projects conducted in the HG area.

Freeway Reconstruction and Widening

This category was defined as freeway reconstruction projects that exceed $20 million. These projects involved heavy traffic (100,000 vehicles/day) and consisted of typical continuous reinforced concrete pavement. This type of project was defined as being 2 to 4 miles in length, with a threespan overpass every threefourths of a mile.

Non-Freeway Reconstruction and Widening

This category was defined as non-freeway reconstruction project that range from $10 - $20 million. These projects involved moderate traffic volumes (15,000 - 20,000 vehicles/day) and consisted of typical continuous reinforced concrete pavement. This type of project was defined as converting a two-lane road into five lanes with a center left-turn lane. This project type also included one three-span water crossing.

New Construction

This category was defined as new construction projects that range from $10 - $20 million. These projects involved virtually no traffic and consisted of typical continuous reinforced concrete pavement. This type of project was defined as constructing five lanes with a center left-turn lane for approximately 5 to 6 miles. This project type also included one three-span water crossing.

Bridge Replacement

This category was defined as simple bridge replacement project valued at approximately $500,000. These projects involved relatively low traffic volume (1000-1500 vehicles/day) and consisted of concrete I-beam constructed 150-foot 3-span bridge with asphalt tapers. The scope was further defined as having a 45-foot width, two lanes, and two shoulders with a roadway consisting of transitions and minimum embankment widening.

Rehabilitation and Overlay

The final defined project type consisted of rehabilitating and overlaying a typical road with asphaltic concrete. Since traffic varied immensely between urban and rural areas, the project type was broken into sub-project types: traffic with less than 30,000 vehicles/day (rural) and traffic with more than 100,000 vehicles/day (urban). The scope of the project included a five-lane road with a length of five miles. Work included full depth repair with asphalt-stabilized base and a 2 inches asphalt surface overlay.

## Survey Elements

The intention of the survey was to capture the day-to-day cost impacts and the total schedule changes. This information would lead to the total cost impact. To do this, the survey asked the respondents to consider impacts based on the use of the same resources (type and quantity) on the WSA as on normal daytime operations.

In order to determine the total cost and schedule impacts to TxDOT, the survey was covered into four main sections. Each section gathered a specific type of information by means of the survey elements.

The first section attempted to record the impacts on daily cost operations through the impacts on the cost elements. The cost elements were direct field labor, materials, equipment, field indirect, and home office. Additionally, the relative cost allocation to each cost element with regard to the total project cost was requested. The second section focused on the overall project duration impacts. Two elements were included in this section: the project duration and the overall labor productivity. The third section attempted to determine the percent of work that the contractors would perform under each WSA. The fourth section recorded the impacts to the individual cost factors: labor wage rates, traffic control, construction illumination, and safety.

## SURVEY IMPLEMENTATION

The survey questioned all TxDOT area engineers in the HG and DFW areas, as well as on contractors currently performing a significant amount of TxDOT work. The survey form was provided to all respondents and feedback conducted through personal interviews, phone interviews, or completed written forms. The surveys are shown in Appendices A and B for the HG and DFW areas, respectively. The process was performed during August and September 2000.

The respondents were asked to anticipate the impacts on the elements in the survey assuming that upon implementing the new work schedules that comply with the proposed restrictions, the typical resources assigned (number of work crews and equipment, for example) would remain constant compared to those currently used during a normal daytime work schedule. The survey requested estimated impacts on various elements for each project type and, according to each WSA impacts were given as a percentage of the original total. Results gathered for each project type included the overall project cost impact, the overall project duration impact, the anticipated percent of work to be performed under each type of WSA, and the impacts on specific pre-identified factors that may affect cost and schedule. The overall project cost impact was determined through the information compiled on the impacts on the various cost elements (labor, equipment, material, field indirect, and home office costs).

**Conducting the Survey**

Surveys were mailed/faxed to each participant after initial discussion of the purpose and intent of the study. Different approaches were used to contact and collect information from the prospective respondents. The selection of a particular approach was a function of convenience of the respondents. The approaches were as follows:

- Personal interview:

  Members of the research team visited the respondents' offices at pre-arranged times. The survey document was mailed/faxed to the respondents before the visit. The members of the research team explained the survey document and then asked the respondents to quantify their opinions about various categories.

- Telephone interview:

  In this approach, the survey document was faxed to the respondents before the phone interview. Through a telephone conversation, a research team member explained the survey. When the respondent was well versed, the values in the questionnaire were requested. The information was either faxed on a later date or recorded during the interview. Respondents' comments were also documented. This approach was used when it was difficult to set an appointment with the respondent.

- Visit for comments and feedback:

  In some cases, the survey document was faxed to the respondent and later explained through telephone conversations. A followup visit was conducted to gather the respondents' data and comments regarding the implementation of the proposed rule and on the survey.

Personnel interviewed were TxDOT Area Engineers and Construction Directors, and estimators, presidents, and project managers of various general contractors.

After the survey from the HG area was completed, the feedback and comments from respondents were evaluated. It was determined that TxDOT officials are generally not in a position to provide accurate quantified opinions regarding cost impacts on individual constituents of a project, namely direct field labor, material, equipment, field indirect, and home office costs.

Since the proposed control requirement duration for the DFW area was different than that of the HG area, respective changes were made in the survey document for the DFW area. Questions related to breakdown of the project cost were removed from the questionnaire due to the reason stated in above paragraph (see Appendices A and B).

## DATA MANAGEMENT

Once all interviews were conducted, the data were entered into spreadsheets to arrive at the total anticipated cost and schedule impact for the HG and DFW areas. The variables used during the management of the data are indicated by the total daily cost impact, the total project duration impact, and the total compounded cost impact. To arrive at these gross amounts, information was aggregated from the lowest levels of detail, those provided by the respondents in the surveys, to the higher level variables mentioned above.

The total daily cost impact summarizes the expected cost increments to highway construction projects on a day-to-day basis without accounting for the cost changes due to extended project duration. The total project duration indicates the expected changes to the overall project schedule. The total compounded cost impact incorporates these two elements, providing an estimated total cost impact due to day-to-day changes and those produced by the extended schedules (Figure 3).

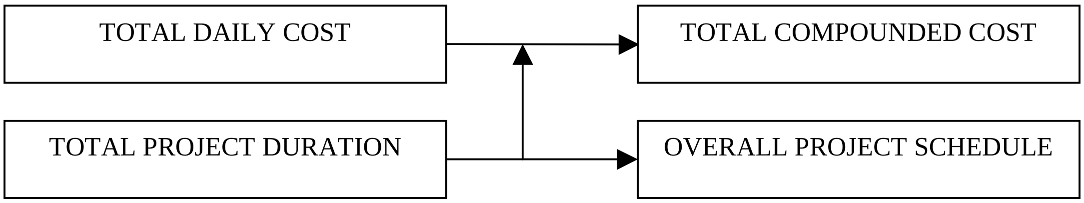



**Figure 3. Cost and Schedule Impact.**

The total daily cost impact was evaluated using the daily cost impacts for each project type (Figure 4). These totals were obtained from the daily cost impacts for each WSA per project type (Figure 5). The individual WSA daily cost impacts were calculated from aggregating the data collected from the surveys regarding individual cost changes for the various cost elements. This procedure was also followed for the evaluation of the total project duration impact and the total compounded cost impact.

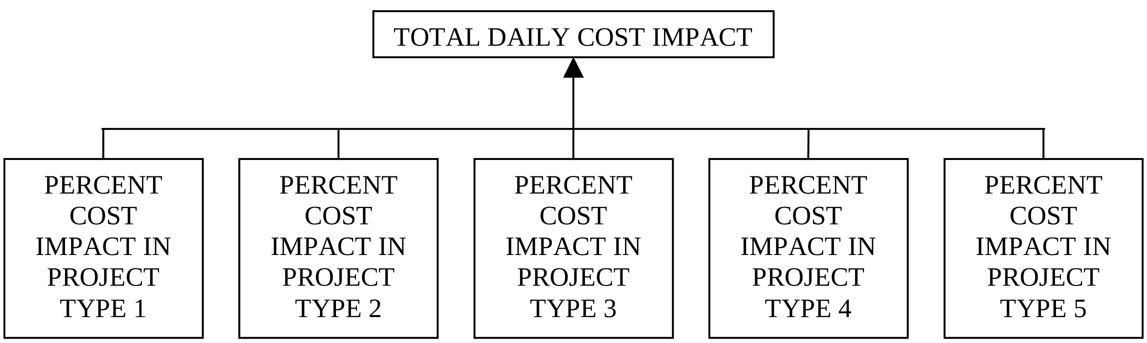



**Figure 4. Total Daily Cost Impact.**

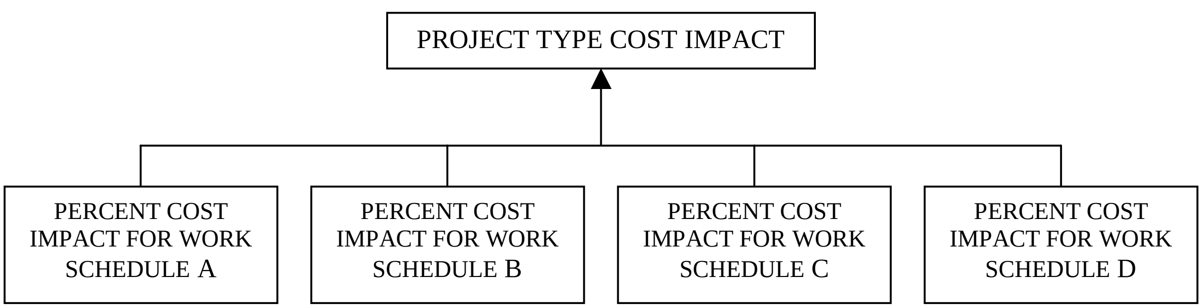



**Figure 5. Cost Impact Per Project Type.**

The survey information was documented as a percent change for the different survey elements. The survey elements were:

- cost elements: direct field labor, materials, equipment, field indirect, and home office;
- cost elements percent weight: the relative cost of each cost element compared to total projects cost;
- schedule elements: project duration and overall labor productivity;
- estimated work to be done under each WSA; and
- individual cost factors.

Respondents provided their input as a range of expected values. Therefore low, high, and average values were calculated for each survey element. As an exception, the cost elements percent weight was supplied as a single value. Throughout the various levels of compilation produced to arrive at the overall cost and schedule impacts (total daily cost impact, total project duration impact, and total compounded cost impact), low, high, and average values were calculated. The evaluation of the low, high, and average values was identical throughout the data management process. (One exception was the average cost element impact, which will be discussed later in this section.)

The total calculation procedure (see Figure 6) will first be discussed for the total daily cost impact. This standard method was consequently used as a basis for the total project duration impact and the total compounded cost impact. Finally, the data management for individual cost factors impact will be discussed at the end of the section.

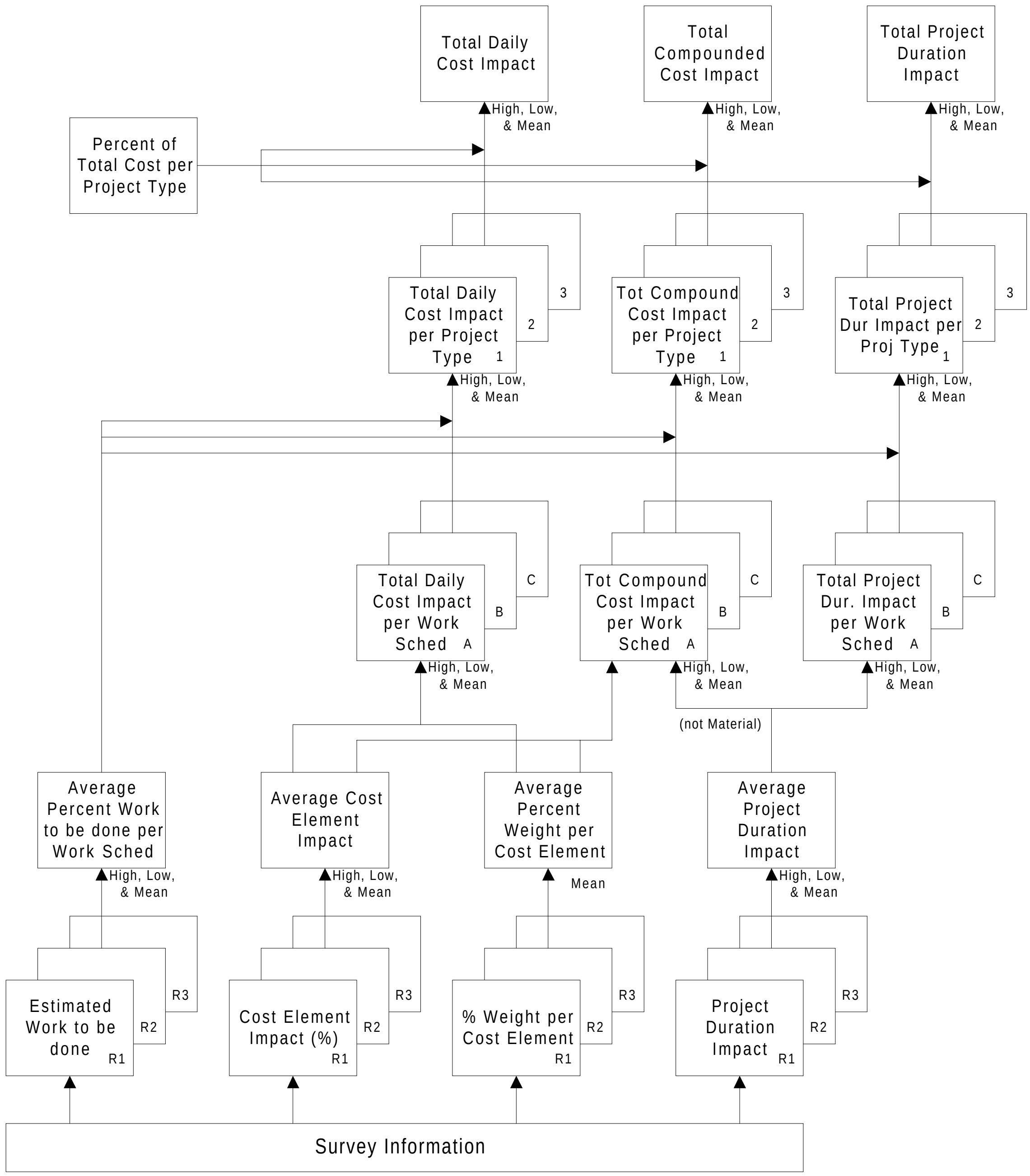
## Total Daily Cost Impact

Survey Elements

The survey elements were provided as ranges with a high and a low value except for the cost elements percent weight. For each range, an average value was calculated. Consequently, for each respondent’s survey element, a high, a low, and an average value was determined.

The Estimated Work to be done under a particular WSA is the expected percent of work that each contractor will perform under each WSA. The average of the different responses determined the average percent work to be done under a WSA.

The respondents also provided a percent cost breakdown for each cost element. These cost element percent weights represent the relative cost allocation for each cost element compared to the total project cost. These data were supplied as single numbers.




Legend:
R1, R2, R3: Respondent information supplied in the surveys
A, B, C: WSAs
1, 2, 3: Project types
High, Low, Mean: High, low, and mean (average) values were calculated for the element

**Figure 6. Calculation Procedure for Overall Cost and Schedule Impact.**

### Average Cost Elements Impact

It was desired to provide TxDOT with both a value and a range to reflect the anticipated impact to the cost and duration of future projects. Therefore, both the average of the respondents' input and the ranges provided were utilized in determining the overall effects. The average cost elements impact represents the average of the impacts given by the various respondents for each cost element. The cost elements' values discussed above served as the basis for calculating the average cost elements impact high, low, and average values. The low value was determined as the minimum value provided by the different respondents. The high value was determined as the maximum value provided by the different respondents. The average value was determined as the mean of the averages calculated from the information provided by the respondents.

The average percent weight per cost element was evaluated as the mean of the individual percent weights for each cost element.

### Work Schedule Alternative Total Daily Cost Impact

The total daily cost impact for a WSA represents the expected total cost change for a project performed under a particular WSA due to daily cost impacts on construction operations. The cost impacts caused by changes to the project duration are not included in this component of the overall cost.

The total daily cost impact per WSA was calculated as a weighted average of the individual average cost element impacts based on the average percent weights per cost element. Each average cost element percent impact was multiplied by its corresponding average percent weight and the totals added to arrive at the WSA total daily cost impact. This calculation was done for the high, low, and average values.

### Project Type Total Daily Cost Impact

The total daily cost impact for a project type represents the estimated total cost change for a particular project type due to day-to-day cost impacts on construction operations. Cost changes due to project duration changes are not included in this component of the overall cost.

The total daily cost impact per project type was calculated using the total daily cost for each WSA for that particular project type and the average percent work to be done under a WSA. The average perrcent work to be done under a WSA indicates the expected relative application of a particular WSA by the construction contractors.

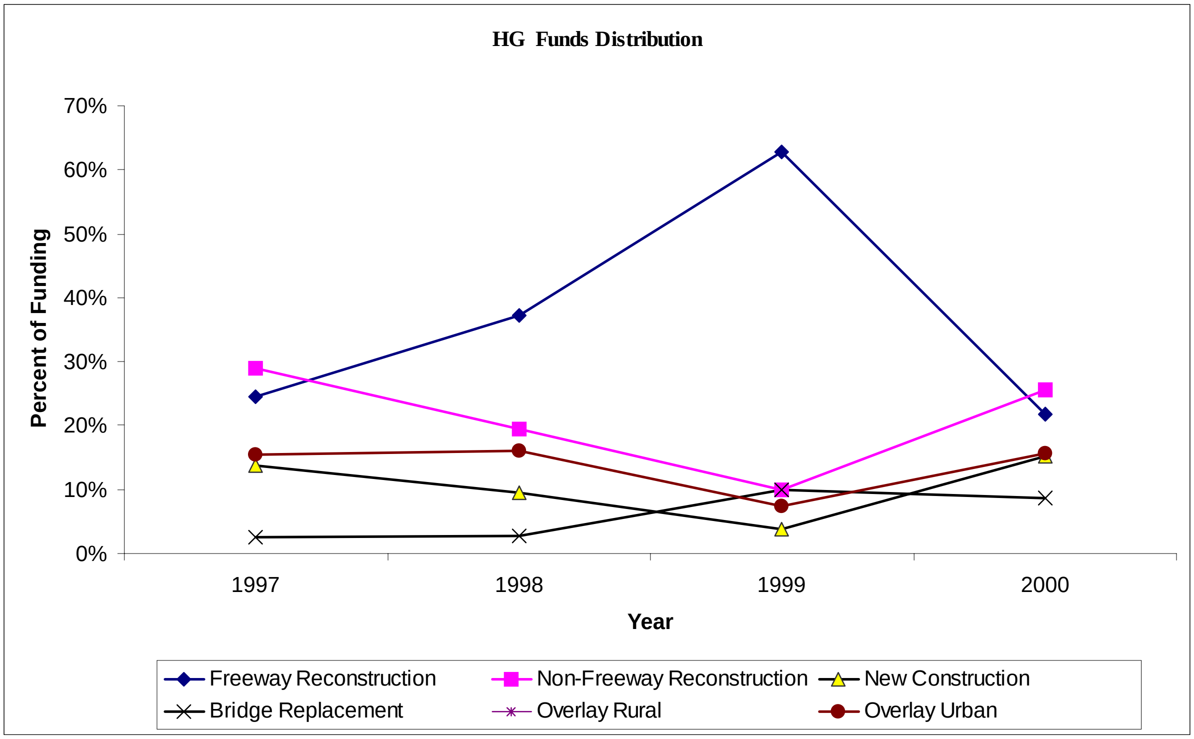
The total daily cost impacts for each WSA, obtained previously, were multiplied by the average percent work for each WSA, and then the totals were added to produce the project type's total daily cost.

Total Daily Cost Impact

The total daily cost impact indicates the estimated cost change for all construction projects within an area (HG and DFW) due to day-to-day cost impacts on the construction operation. It does not incorporate cost changes due to changes in the project duration.

The evaluation used the total daily cost impact for each project type as well as each project type's percent of total cost. The percent of total cost represents the relative funding expended by TxDOT on highway construction projects for each project type with respect to its total funding. These values were calculated using historical data for the HG and DFW areas for 1997, 1998, 1999, and 2000 (see Figure 7).

The total daily cost impact is a weighted average of the individual total daily cost impacts for each project type based on the percent of total costs.



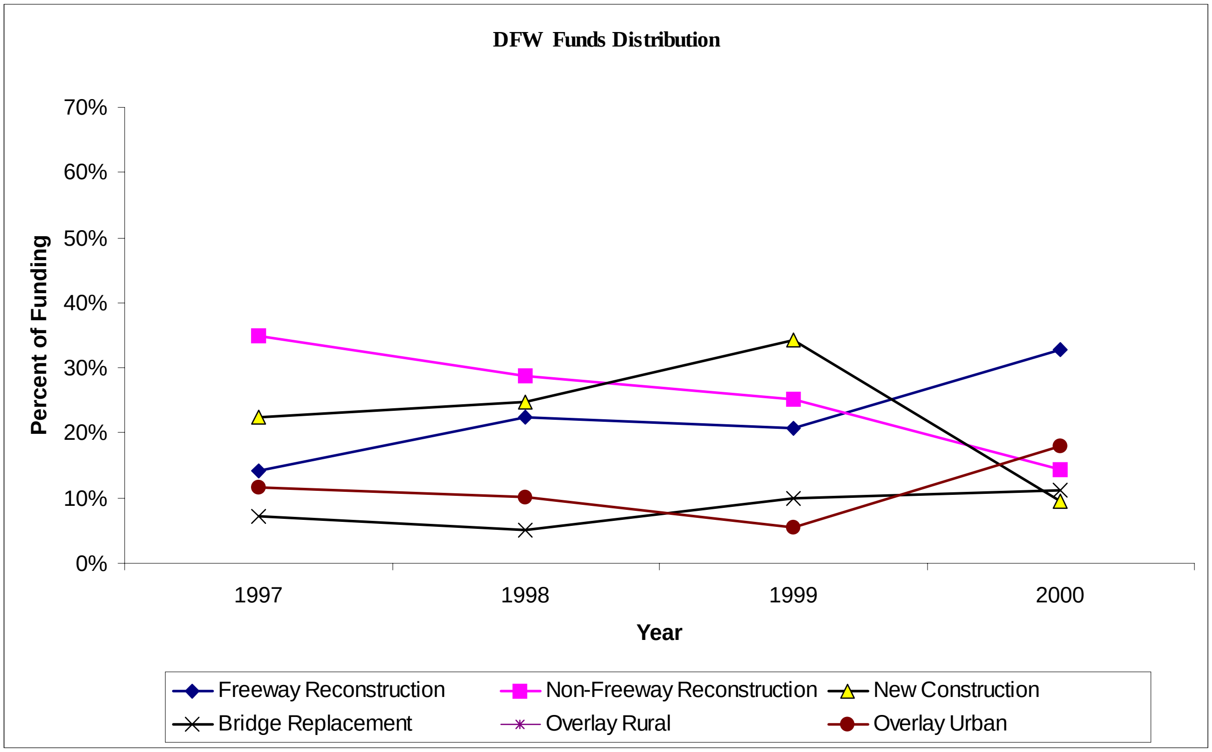




**Figure 7. Trends of Distribution of Funds in HG and DFW Areas.**

## Total Project Duration Impact

The procedure used to calculate the total project duration impact followed the same sequence as the one used to determine the total daily cost impact. The information regarding the estimated overall project duration changes provided by the respondents was used to determine the average project duration impact. High, low, and average values were calculated. This information served as a base for the WSA total project duration impact. The WSA project duration impacts were used to calculate the total project duration impact per project type using the average percent work to be done under each WSA.

The Total Project Duration impact is a weighted average of the individual project types project duration impacts based on the percents of total costs.

## Total Compounded Cost Impact

The procedure followed to calculate the total compounded cost impact was based on the daily cost and the project duration impacts. After calculating the average cost elements impacts for the direct field labor, equipment, field indirect, and home office variables, the average cost element impacts were multiplied by the average project duration impact to determine the average compounded cost element impact (Figure 8). Material costs were not affected by the project duration impact because the total material cost on a project does not depend significantly on the time frame upon which it is expended.

The total compounded cost impact per WSA was calculated as a weighted average of the average compounded cost elements, including the materials average cost element and the average percent weights per cost element. The total compounded cost impact per project type was determined as a weighted average of all the total compounded cost impacts per WSA and the average percent work to be done under each WSA. The total compounded cost impact was calculated as a weighted average of all the project types compounded cost impacts based on the percents of total costs.

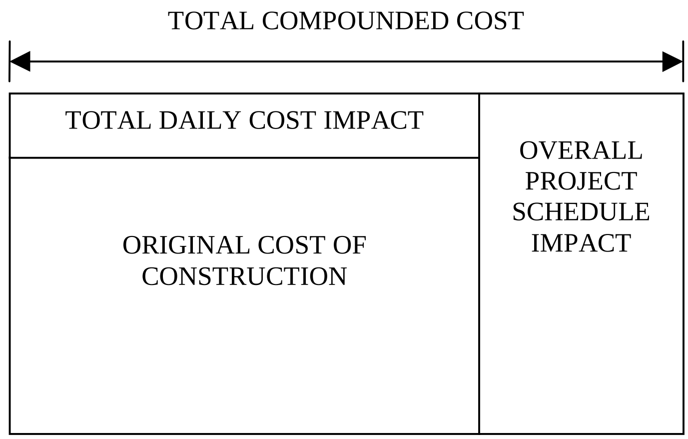



**Figure 8. Calculation of Overall Project Schedule Impact.**

## Individual Cost Factors

The individual cost factors were used primarily for qualitative analysis. Averages of the values provided by the respondents were determined on a WSA basis and then aggregated to a project type level. The information obtained was compared to that produced by the literature search to verify similarities and differences.

# CHAPTER IV RESULTS

## GENERAL

An evaluation of highway construction project costs and schedule impacts due to the implementation of the TNRCC rules was conducted separately for the HG and DFW areas. This analysis included the anticipated daily cost impacts, the overall impact projected for duration of construction projects conducted for TxDOT, and the overall cost impact taking into account the effects of daily and schedule-based impact. Overall results are found in Appendices C and D for the HG, and in Appendices E and F for the DFW area.

The evaluation was conducted using information gathered from leading construction contractors in the HG and DFW areas and was compared to comments provided by TxDOT area engineers and district construction representatives. Separate analyses were conducted to determine the impacts on the construction project cost elements and on the factors associated with these cost elements. This information provides insight to the expected changes in the elements that compose the construction cost and to the specific elements that impacted by the implementation of the proposed rules. Additionally, an analysis of the expected work schedules to be implemented by the contractors to comply with the requirements of the rule was performed. The results of the analysis provide information on potential organizational and schedule changes by TxDOT and the contractors if the rules are implemented.

## HOUSTON-GALVESTON AREA

A total of 11 contractors that perform a majority of the work for TxDOT in the HG area were preliminarily selected for the study, nine of which were subsequently contacted by the research team. Surveys were delivered to each of them, and responses were received from five contractors in the form of interviews, with four of them completing the survey. The survey return rate for the HG area was 44 percent. The volume of work performed by these four contractors is 64 percent of the total funds allocated for highway projects in the HG by TxDOT (based on TxDOT August 2000 data).

Data and comments were obtained from the four respondents for Project Types 1 through 4 (freeway reconstruction and widening, non-freeway reconstruction and widening, new construction, and bridge replacement). One respondent did not provide information for project type 5a (rehabilitation and overlay – rural) because of lack of experience in this type of work. Additionally, for project type 5b (rehabilitation and overlay – urban), two respondents did not provide data, again based on their lack of knowledge for this type of project.

The expected percent changes for the HG area were obtained by extending anticipated daily cost increases over the expected increases in project duration to arrive at an overall total increase in cost. This process was conducted for each of the principal construction project types associated with TxDOT. The evaluation considered the total funds allocated by TxDOT on highway construction projects to determine the percent weight of each of the project types. The relative percent weights of the project types, used to evaluate the total cost and schedule impacts, were calculated using the funds allocated to the five project types included in the analysis. Table 4 presents the relative percent weights of the major construction project types conducted in the HG area for TxDOT.

**Table 4. Relative Percent Weight of Project Types (HG).**

| Project Type | | | | | | Total |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5a/5b | | |
| Freeway | Non-Freeway | New Construction | Bridge Replacement | Rehab & Overlay | | |
| | | | | Rural | Urban | |
| 36.0% | 21.4% | 10.8% | 4.6% | 13.7% | 13.7% | 100% |

All TxDOT area engineers in the HG area were contacted and interviewd. Six personal interviews were carried out and the remaining interviews were performed through telephone conversations. Eight area engineers completed the surveys and comments were received by the research team from each of them. The survey return rate for the HG area TxDOT was 80 percent. Qualitative data were requested from two of the ten area engineers due to time constraints.

The following sections summarize findings gathered from the interviews conducted with construction contractors in the HG area. The findings are summarized in a variety of categories. First, the results are summarized by the representative project types for TxDOT construction. The section continues with the summarized findings of the various cost elements included in each of these projects. Results for separate cost factors are presented, followed by the anticipated cost and schedule changes for various work schedules. Lastly, overall findings for the cost and schedule impact are then summarized.

## Project Types

### Freeway Reconstruction and Widening

The TxDOT work categorized as freeway reconstruction and widening (Project Type 1) encompasses approximately 36 percent of TxDOT project funding for the HG based on funds allocation from 1997 through 2000. Table 5 shows the anticipated cost and schedule increases calculated from the information supplied by construction contractors in the HG area in order to comply with the TNRCC proposed rule. The total anticipated change reflects the overall cost impact that is determined from the anticipated increases in daily costs extended over longer projected project duration.

**Table 5. Anticipated Freeway Reconstruction and Widening Cost and Schedule Impact (HG).**

| **Freeway Reconstruction and Widening** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 9 % | + 4 % | + 17 % |
| Anticipated Change in Duration | + 10 % | + 4 % | + 20 % |
| Total Anticipated Cost Change | + 13 % | + 6 % | + 27 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

To arrive at the overall cost and schedule impacts above, the respondents' feedback regarding implementation of forecasted WSA was employed. Comments from the contractor interviews indicated that the likely WSA would involve continuous operations. The largest impact to this type of project is the inability to close lanes during peak late afternoon/evening traffic periods. Currently, a contractor can work a span of approximately six hours (0900 to 1500) with the ability to close lanes and work within times of reduced traffic. This window would be cut to three hours with the restrictions. Of the four available work schedules presented in the survey, contractors estimated that the majority of work might be performed under continuous night operations due to reduced traffic interference. Survey respondents work schedule preferences are shown in Table 6.

**Table 6. Freeway Reconstruction/Widening WSA (HG).**

| WSA | Forecasted to Employ |
|---|---|
| A – Delayed, Continuous Operations | 31 % |
| B – Partially Delayed, Continuous Operations | 18 % |
| C – Delayed, Non-Continuous Operations | 6 % |
| D – Continuous Nighttime Operations | 45 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Non-Freeway Reconstruction and Widening

The non-freeway reconstruction and widening project type differs from the freeway projects mainly in the traffic volume associated with highway reconstruction efforts and a greater ability to work behind barriers. This project type encompasses approximately 21 percent of TxDOT funds allocated for projects in the HG area from 1997 through 2000. Table 7 shows the anticipated cost and schedule impact for non-freeway reconstruction and widening.

**Table 7. Anticipated Non-Freeway Reconstruction and Widening Cost and Schedule Impact (HG).**

| **Non-Freeway Reconstruction and Widening** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 8 % | + 3 % | + 16 % |
| Anticipated Change in Duration | + 9 % | + 4 % | + 17 % |
| Total Anticipated Cost Change | + 13 % | + 5 % | + 26 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The respondents indicated that they forecast the majority of work to be performed for non-freeway widening under WSA that allowed continuous operations. According to the respondents, this type of project can be phased to avoid most of the traffic encountered during construction. With the reduced traffic volume and less associated interference, contractors anticipate implementing a work schedule that is delayed until noon, the end of the proposed restricted period. Survey results for the WSA are reflected in Table 8.

**Table 8. Non-Freeway Reconstruction/Widening WSA Selection (HG).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 45 % |
| B - Partially Delayed, Continuous Operations | 25 % |
| C - Delayed, Non-Continuous Operations | 5 % |
| D - Continuous Nighttime Operations | 25 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

New Construction

The New Construction projects are characterized such that they are performed with negligible traffic interference. This project type encompasses approximately 11 percent of TxDOT projects for the HG area based on funds allocation for 1997 through 2000. Results for this project type were consistent with the freeway and non-freeway reconstruction and widening and are found in Table 9.

**Table 9. New Construction Cost and Schedule Results (HG).**

| **New Construction** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 7 % | + 2 % | + 14 % |
| Anticipated Change in Duration | + 8 % | + 4 % | + 15 % |
| Total Anticipated Cost Change | + 10 % | + 4 % | + 21 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The survey respondents preferred to implement day schedules for this project type. The reduced traffic interference was the main reason for this selection. Also, to reduce the impacts on the work sequence and methods, the fully delayed alternative (Alternative A) was preferred. Results of the survey indicating the expected allocation of work to the various WSA for this type of project are shown in Table 10.

**Table 10. New Construction WSA Selection (HG).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 60 % |
| B - Partially Delayed, Continuous Operations | 34 % |
| C - Delayed, Non-Continuous Operations | 2 % |
| D - Continuous Nighttime Operations | 4 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Bridge Replacement

Typically, bridge replacement projects are less equipment intensive than other types of projects. Bridge replacement projects are already impacted by many factors, including traffic, confined areas, phased tasks, and elevated work areas. These characteristics, added to temperature conditions for concrete placement, are presently forcing a significant part of work to be conducted at nighttime. This project type accounted for approximately 5 percent of TxDOT projects for the HG area based on funds allocation for 1997 through 2000. The anticipated cost and schedule impacts as calculated from the data supplied through the surveys are shown in Table 11.

**Table 11. Bridge Replacement Cost and Schedule Results (HG).**

| **Bridge Replacement** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 10 % | + 5 % | + 17 % |
| Anticipated Change in Duration | + 12 % | + 4 % | + 19 % |
| Total Anticipated Cost Change | + 16 % | + 7 % | + 28 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The survey respondents indicated that most of the work would be performed under continuous operations for this type of work. Also, the data indicated that contractors would prefer to perform night work instead of restructuring of construction sequences and methods. Results from the survey indicating the percent of work contractors expect to perform under the various WSA are shown in Table 12.

**Table 12. Bridge Replacement WSA Selection (HG).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 51 % |
| B - Partially Delayed, Continuous Operations | 21 % |
| C - Delayed, Non-Continuous Operations | 1 % |
| D - Continuous Nighttime Operations | 26 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Rehabilitation and Overlay (Rural)

Rehabilitation and Overlay projects are highly dependent on traffic volume and therefore have been divided accordingly into rural and urban projects. Rural projects are anticipated to have lower traffic volumes and the urban projects higher volumes. Both types of projects are otherwise very similar and highly equipment intensive. Survey results for the rural rehabilitation and overlay projects encompass approximately 14 percent of TxDOT projects for the HG area (based on funds allocation for 1997 through 2000). Anticipated cost and schedule impact results determined from the information supplied by the contractors are shown in Table 13.

**Table 13. Rehabilitation and Overlay (Rural) Cost and Schedule Results (HG).**

| **Rehabilitation and Overlay (Rural)** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 7 % | + 3 % | + 12 % |
| Anticipated Change in Duration | + 8 % | + 4 % | + 13 % |
| Total Anticipated Cost Change | + 9 % | + 4 % | + 16 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The contractors predicted that the majority of work would be performed under continuous workday schedules, preferable during daytime hours. This type of project, as a result of the lower traffic volumes, would not likely be as affected by traffic and therefore would be able to proceed continuously. Night work was not selected because continuous day work is a viable alternative. Results from the survey indicate that the contractors rated the various WSA as shown in Table 14.

**Table 14. Rehabilitation and Overlay (Rural) WSA Selection (HG).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 77 % |
| B - Partially Delayed, Continuous Operations | 7 % |
| C - Delayed, Non-Continuous Operations | 0 % |
| D - Continuous Nighttime Operations | 17 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Rehabilitation and Overlay (Urban)

The urban rehabilitation and overlay projects differ from the rural rehabilitation and overlay projects in that they are expected to have a higher traffic volume. The survey respondents commented that in the case of urban areas, a significant portion of the work is currently done at nighttime. Approximately 14 percent of TxDOT project funds for the HG area were allocated for this type of work based on TxDOT funding from 1997 through 2000. Anticipated cost and schedule impact results determined from the information gathered from the surveys are shown in Table 15.

**Table 15. Rehabilitation and Overlay (Urban) Cost and Schedule Results (HG).**

| **Rehabilitation and Overlay (Urban)** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 6 % | + 0 % | + 12 % |
| Anticipated Change in Duration | + 9 % | + 0 % | + 18 % |
| Total Anticipated Cost Change | + 9 % | + 0 % | + 18 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The respondents indicated that the most suitable schedule for this type of project consisted of continuous workdays. However traffic becomes a problem in this case and operations would have to stop during high traffic hours, possibly affecting productivity and forcing the contractor to schedule a split shift. Since nighttime operations are minimally impacted by traffic, night work was selected as a schedule to perform a majority of work performed in this type of project as shown in Table 16.

**Table 16. Rehabilitation and Overlay (Urban) WSASelection (HG).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 12.5 % |
| B - Partially Delayed, Continuous Operations | 0 % |
| C - Delayed, Non-Continuous Operations | 12.5 % |
| D - Continuous Nighttime Operations | 75 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

**Cost Elements**

The cost elements used to develop a budget, as previously described, include direct field labor, materials, equipment, field indirect, and home office costs. These elements are affected differently according to the WSA implemented and according to the type of work performed (i.e., the project type). Nonetheless, a general pattern was developed from the survey responses between the various project types for the impacts on the cost elements. Table 17 shows the overall average expected cost increase calculated from the information supplied by the respondents, including the cost of an extended schedule for the cost elements of each project type.

**Table 17. Overall Average Cost Element Impacts per Project Type (HG).**

| Project Type | Anticipated Increase in Cost Elements (%) | | | | |
|---|---|---|---|---|---|
| | Field Labor | Materials | Equipment | Field Indirect | Home Office |
| 1 – Freeway Reconstruction | 27 | 8 | 16 | 22 | 23 |
| 2 – Non-Freeway Reconst. | 23 | 7 | 15 | 20 | 21 |
| 3 – New Construction | 19 | 6 | 14 | 18 | 19 |
| 4 – Bridge Replacement | 28 | 8 | 17 | 24 | 25 |
| 5a – Rural Rehab/Overlay | 22 | 6 | 14 | 18 | 19 |
| 5b – Urban Rehab/Overlay | 19 | 5 | 13 | 17 | 8 |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The values determined from the survey data indicate that direct field labor cost is expected to change the most. The proposed rules may have a serious impact on field labor costs primarily because of the premiums that may have to be implemented as a result of the altered work schedules. The respondents indicated that reduced productivity may be another potential impact. They pointed out that it is difficult to estimate the future wage rates and that the proposed new conditions regarding the work schedules could reduce their capacity to attract workers. Workers may opt to transfer to areas where these restrictions do not apply, work in other industries, or apply to other companies that can offer daytime work schedules. Several respondents noted that this loss of workers could put smaller companies at a disadvantage. The altered work schedules may also have effects on the worker's morale, which, as identified in the literature search, can have potential negative effects on productivity and quality. In addition, labor costs are dependent on project duration and thus will increase proportional to the total project duration. Some respondents mentioned that labor productivity may increase due to lessened interference and distractions during evening and nighttime operations.

The project's indirect costs (field indirect and home office) could also increase based on the additional personnel that will be required to work during the extended hours in the home office and the premiums policy that might be implemented for the field personnel. Additional field indirect costs that are expected to experience changes are construction lighting and traffic control.  The contractor respondents commented that night operations might also require additional supervision and special surveying equipment.  As a consequence of the modified schedules, TxDOT may transfer portions of its non-critical quality control and assurance tasks to the contractors or private testing agencies.  Both the home office and field indirect costs are time dependent and, as such, they will vary according to the project duration.

Results calculated from the survey information indicate that the cost for materials and equipment will not be severely impacted.  Material costs will be affected in the case when certain materials such as asphalt or concrete have to be placed during non-routine hours.  Cost due to extra hours of plant will also affect the material cost.  Start-up plant costs could be required.  In addition, the transportation cost of many supplies could increase as the receiving times will be altered to compensate for limited material stockpile capacity.  A limited number of material suppliers may be required to alter their business hours or remain open for longer hours, which can affect material costs.  In general, material costs are not significantly affected by the proposed schedule alterations.

Equipment costs may be affected by the overall duration impacts and the lower productivity.  When work is conducted at dusk or night, equipment productivity may decrease because of limited visibility.  On the other hand, respondents indicated that the day-to-day costs should not be significantly impacted because they do not foresee the need for additional equipment to comply with the restrictions.  Other potential problems related to the implementation of the proposed rule on construction equipment include equipment maintenance and spare part availability.  Part suppliers and repair shops business hours may not be compatible with the alternative schedules.  This incompatibility may force the contractors to keep standby equipment for critical operations, stock extra spare parts, hire additional personnel dedicated to minor equipment repair work, or negotiate with repair shops to work on damaged equipment at irregular hours.

The contribution of the impacts in the individual cost elements towards the project cost depends on the average relative weight of each cost factor compared to the overall project cost. The average relative weight per cost element indicates the relative allocation of funds towards a cost element from the project cost. The contribution of each cost element on a project level is calculated by multiplying each cost element's respective impact by its average relative weight. Table 18 shows the average relative weights, the average impacts, and the contribution of each cost element towards the project cost impact.

**Table 18. Overall Average Cost Element Impact (HG).**

| | Field Labor | Materials | Equipment | Field Indirect | Home Office | Total |
|---|---|---|---|---|---|---|
| Average Relative Weights (%) | 13 | 61 | 13 | 7 | 6 | 100 |
| Average Impact (%) | 24 | 7 | 15 | 20 | 20 | - |
| Contribution to Total Impact (%) | 3.5 | 4.5 | 2 | 1 | 1 | 12 |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

**Cost Factors**

Changes to a typical construction work schedule can affect the cost and duration of a project as assessed above. Certain factors that lead to these changes were identified in the literature. These factors have varying effects on cost and schedule. Interview and feedback data gathered during the research indicate the expected change in these factors if the TNRCC rule is implemented. The cost factors included as part of this research were:

- labor productivity,
- labor wage rates,
- traffic control,
- construction lighting,
- safety: insurance and worker's compensation, and
- quality: rework.

The overall impacts to these factors resulting from the implementation of the proposed rule, as determined from the information gathered through the surveys, were consistent throughout the various project types. Table 19 displays the estimated daily impacts as a percent of the original value on the cost factors per project type. The impacts on the cost factors per project type account for the estimated work to be performed under each WSA.

The factors that are expected to experience the most significant changes are overall labor productivity, construction lighting, labor wage rates, and safety. Productivity has a significant impact in project cost and duration. The literature did not provide quantitative information regarding productivity impacts, but it did mention the various factors that affect productivity levels such as worker morale, fatigue, and degree of illumination for nighttime construction work.

**Table 19. Average Cost Factors Impacts per Project Type (HG).**

| Cost Factor | Anticipated Increase in Cost Factors per Project Type (%) | | | | | | Average |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5a | 5b | |
| Labor Productivity | - 13 | - 12 | - 10 | - 11 | - 10 | - 9 | - 11 % |
| Labor Wage Rates | 15 | 13 | 11 | 14 | 14 | 6 | + 13 % |
| Traffic Control | 5 | 4 | 1 | 2 | 8 | 4 | + 5 % |
| Construction Lighting | 33 | 25 | 18 | 27 | 32 | 32 | + 29 % |
| Safety | 12 | 11 | 8 | 9 | 11 | 7 | + 10 % |
| Quality | 4 | 3 | 3 | 4 | 5 | 2 | + 4 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

**(Note: for description of project types please refer to figure 3.)**

The literature search indicated an estimated construction lighting increase of 63 percent for projects performed at night. The estimated impact for construction lighting for work conducted only under continuous night time operations averaged 52 percent, a value that is consistent with that found throughout the literature. The respondents commented that currently there is little need for construction lighting since most projects are conducted during daytime. They also indicated that lighting might be disturbing in residential areas, limiting the amount of light that can be used or adding to the complexity of installation.

The estimated labor wage rate impact in the literature was estimated to be 18 percent for nighttime work. The findings of this research indicate a change of 18 percent for the fraction of work anticipated to be conducted under continuous nighttime operations. As previously mentioned, the main impacts on labor costs are due to premiums and overtime that affect the daily construction costs.

The research related safety to insurance and worker's compensation. The safety-based cost issues, such as accidents, were only evaluated qualitatively. The survey respondents commented that increased risk to construction workers during evening and nighttime operations would have adverse effects on worker safety, in part due to sleep deprivation and fatigue. There are also additional safety risks for drivers resulting from night construction operations.

The survey respondents also indicated that night and dusk operations may require additional traffic control. The literature does not conclude that quality will suffer due to night operations. The respondents' data indicate that the expected impact of the different WSAs on quality, identified as rework, is minimal (4 percent).

**Results from TxDOT Personnel**

In addition to the information provided by contractors, TxDOT area engineers in the HG area were interviewed to gain quantitative and qualitative feedback on the proposed rule (see Appendix C). Though contractors manage project costs utilizing the elements as previously evaluated in this report (field labor, materials, equipment, indirect filed, and home office costs), TxDOT manages project cost with unit cost line items. As a result of commonly employing unit costs as a basis for tracking project budgets, TxDOT personnel are not familiar with the cost elements used in this research. The results gathered from TxDOT, therefore, were supplementary to the contractor data.

TxDOT personnel anticipated a total cost impact between 8 percent and 35 percent, with a most likely value of 19 percent, as calculated from information supplied through the surveys.

As shown in Table 20, the expected daily cost impact varies between 1 percent and 26 percent, with an average of 11 percent, and the estimated project duration impact ranges from 5 percent and 35 percent, with an average of 18 percent. The total anticipated change reflects the overall cost impact that is determined from the anticipated increases in daily costs extended over longer projected project duration.

**Table 20. TxDOT Personnel Overall Cost and Schedule Results (HG).**

| **Overall Impact** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 11 % | + 1 % | + 26 % |
| Anticipated Change in Duration | + 18 % | + 5 % | + 35 % |
| Total Anticipated Cost Change | + 19 % | + 8 % | + 35 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Although TxDOT and the contractors align in the percent of work to be done under each WSA as shown in Table 21, the expected duration impact differs significantly, especially in the continuous day schedules. The largest difference between the information provided by TxDOT and by contractors resides in the project duration estimates as shown in Table 22. TxDOT personnel provided more conservative data, expecting project duration to increase by 100 percent more than that estimated by the contractors.

**Table 21. WSA Selection by TxDOT and Area Contractors (HG).**

| **WSA** | **TxDOT** | **Contractors** |
|---|---|---|
| A - Delayed, Continuous Operations | 43 | 42 |
| B - Partially Delayed, Continuous Operations | 15 | 17 |
| C - Delayed, Non-Continuous Operations | 9 | 5 |
| D - Continuous Nighttime Operations | 33 | 36 |
| Total | 100 | 100 |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

**Table 22. HG Average Impacts in Project Duration by TxDOT and Area Contractors.**

| WSA | TxDOT | Contractors |
|---|---|---|
| A - Delayed, Continuous Operations | 17 % | 5 % |
| B - Partially Delayed, Continuous Operations | 20 % | 10 % |
| C - Delayed, Non-Continuous Operations | 20 % | 19 % |
| **D - Continuous Nighttime Operations** | 19 % | 12 % |
| Total | 18 % | 9 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The data evaluated from the information supplied by TxDOT personnel indicates that the largest impact would be on the non-freeway reconstruction and widening project type, with an overall cost increase of 25 percent. Contractor supplied information indicated only an estimated 12 percent increase for this same Project Type as shown in Table 23. Furthermore, while contractors estimated that bridge replacement would experience a larger impact, TxDOT personnel considered that this project type would be the second most affected. freeway reconstruction and widening was ranked third by TxDOT and second by the contractors. New construction, rural rehabilitation and overlay, and urban rehabilitation and overlay were ranked fourth, fifth, and sixth respectively by both TxDOT and the contractors.

**Table 23. Average Cost Impacts for Project Types by TxDOT and Contractors (HG).**

| WSA | TxDOT | Contractors |
|---|---|---|
| 1 – Freeway Reconstruction and widening | 20 % | 13 % |
| 2 – Non-Freeway Reconstruction and widening | 25 % | 12 % |
| 3 – New Construction | 18 % | 10 % |
| 4 – Bridge Replacement | 22 % | 16 % |
| 5a – Rural Rehab/Overlay | 13 % | 9 % |
| 5b – Urban Rehab/Overlay | 13 % | 8 % |
| Total | **19 %** | **12 %** |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

TxDOT personnel indicated that TxDOT may experience internal cost and organizational impacts due to the proposed rules. Currently, TxDOT performs continuous supervision on the various highway construction projects. To retain its current level of oversight, TxDOT may be required to increase the number of inspectors to cover work conducted during irregular hours or increase the use of outside consultants. Additionally, an increased amount of the required supervision responsibility could shift to the contractors.

The alternative schedules may also introduce modified workdays. To cope with these changes, TxDOT may have to restructure its organization and work hours. Key personnel may have to increase their availability after the regular business hours. This restructuring may require additional personnel to fill the new work times or require rotating schedules. These alternatives may result in additional costs to TxDOT. An additional side effect of extended and irregular hours, as commented by TxDOT personnel, include social and domestic issues.

**Overall Cost and Schedule Impacts**

The anticipated cost and schedule impacts in the HG area (see Appendix D) calculated from contractor interviews and survey results are shown in Table 24. The total anticipated change reflects the overall cost impact that is determined from the anticipated increases in daily costs extended over longer projected project duration. Respondents attribute these anticipated cost increases to greater impacts from traffic, lower labor productivity, and other effects from night/evening work hours. Additionally, respondents indicated that the proposed restrictions pose a significant concern for small contractors. Smaller contractors tend to have a limited labor pool and resources, which limits their ability to adjust to irregular work hours. Similarly, many subcontractors may lose some of their flexibility in working for multiple general contractors.

**Table 24. Overall Cost and Schedule Results (HG).**

| **Freeway Reconstruction and Widening** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 8 % | + 3 % | + 15 % |
| Anticipated Change in Duration | + 9 % | + 4 % | + 17 % |
| Total Anticipated Cost Change | + 12 % | + 4 % | + 23 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The WSA used in the research reflect possible daily work schedules that contractors could adopt in order to comply with the proposed TNRCC rule as well as with the existing TxDOT construction restrictions.

The selection of the WSA by HG area contractors varies according to the type of work to be performed. Primary factors used in selecting the WSA are traffic volume and traffic restrictions. Portions of TxDOT projects require contractors to interrupt traffic flow and therefore force the need for lane closures. TxDOT does not authorize lane closures during peak traffic hours. Contractors prefer to implement continuous work schedules (through peak hours) to maintain productive work operations.

Table 25 indicates the preference of the different WSA according to project type and the average selection of each WSA based on the percent weight of each project type.

**Table 25. WSA Preference per Project Type (HG).**

| Work Schedule Alternative (WSA) | Implementation of WSA per Project Type (%) | | | | | | Average % |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5a | 5b | |
| A - Delayed, Continuous Operations | 31 | 45 | 60 | 51 | 76 | 12.5 | 42 |
| B - Partially Delayed, Continuous Operations | 18 | 25 | 34 | 22 | 7 | 0 | 17 |
| C - Delayed, Non-Continuous Operations | 6 | 5 | 2 | 1 | 0 | 12.5 | 5 |
| D - Continuous Nighttime Operations | 45 | 25 | 4 | 26 | 17 | 75 | 36 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Contractors typically employ three main criteria when selecting the anticipated WSA for each Project Type. The primary selection criterion, as previously indicated, is the desire to perform continuous work. Another important factor is whether work can be carried out during daytime. A third criterion is the potential of work methods and sequences to comply with the restrictions. Contractors indicated that they would choose a continuous work schedule rather than having a split shift. Contractors also indicted that the amount of productive work that could be performed behind barriers during the rush hour traffic was limited. Contractors are forced to close traffic lanes, with closure authorized during non-peak traffic hours. Additionally, contractors would try to perform as much as work possible during daytime due to the additional costs and risks involved in night work. Contractors also indicated that the amount of productive work that could be performed without heavy equipment is limited, and would, therefore, implement schedules that allowed them to operate such equipment continuously.

## DALLAS-FORT WORTH AREA

A total of seven contractors that perform work for TxDOT in the DFW area were contacted and surveys were delivered to each of them. Five contractors answered the surveys and were interviewed. One set of data was excluded from the quantitative evaluation because values were more than an order of magnitude higher than the average values. The survey acceptable reply rate for the DFW was 57 percent.

Data was obtained from the four respondents for Project Types 1 through 4 (freeway reconstruction and widening, non-freeway reconstruction and widening, new construction, and bridge replacement). Information was not available from one respondent for Project Type 5a (rehabilitation and overlay – rural) and 5b (rehabilitation and overlay – urban) because of the lack of experience in this type of work. One respondent did not include values for the percent weights for the cost elements and thus averages calculated from the values provided by the other three respondents were used.

The approach taken with the DFW TxDOT personnel differed from the approach used in the HG area. Instead of performing individual interviews with each TxDOT area engineer, common meetings were held with TxDOT engineers in the Dallas and Fort Worth districts that were impacted by the proposed changes. Five area engineers were present in the Dallas District meeting and two in the Fort Worth District meeting. Two additional TxDOT construction personnel were also present in the Fort Worth meeting. The survey was conducted during the two interviews. The respondents discussed the values of the different impacts and achieved a consensus. The data product of this consensus was recorded in the survey. The survey reply rate for the DFW TxDOT area engineers was 100 percent.

As with the HG area analysis, the overall expected impacts in cost and schedule for the DFW area on highway construction projects were calculated from the estimated impacts to the different project types. The relative weight of each project type for the DFW area was determined from information provided by TxDOT regarding funds allocation to highway projects for the years 1997, 1998, 1999, and 2000. Table 26 reflects the relative percent weights for the major construction project types conducted in the DFW area for TxDOT.

**Table 26. Relative Percent Weight of Project Types (DFW).**

| Project Type | | | | | | Total |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5a/5b | | |
| Freeway | Non-Freeway | New Construction | Bridge Replacement | Rehab & Overlay | | |
| | | | | Rural | Urban | |
| 24% | 25% | 22% | 6% | 11.5% | 11.5% | 100% |

**Project Types**

Freeway Reconstruction and Widening

Based on the information gathered from the contractors' interviews, the cost of the Freeway Reconstruction and Widening project was estimated to increase approximately by 16 percent as shown in Table 27. The total anticipated change reflects the overall cost impact that is determined from the anticipated increases in daily cost extended over longer projected project duration. This project type encompasses approximately 24 percent of TxDOT projects for the DFW area based on funds allocation from 1997 to 2000.

**Table 27. Freeway Reconstruction and Widening Cost and Schedule Results (DFW).**

| **Freeway Reconstruction and Widening** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 8 % | + 2 % | + 17 % |
| Anticipated Change in Duration | + 13 % | + 4 % | + 28 % |
| Total Anticipated Cost Change | + 16 % | + 5 % | + 35 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

As shown in Table 28, construction contractors preferred to perform the majority of work under the WSA that allow continuous daytime operations. For projects that require lane closures, night work was selected above reduced daytime work schedules.

**Table 28. Freeway Reconstruction and Widening WSA Selection (DFW).**

| WSA | Forecasted to Employ |
|---|---|
| A – Delayed, Continuous Operations | 33 % |
| B – Partially Delayed, Continuous Operations | 30 % |
| C – Delayed, Shortened Operations | 13 % |
| D – Continuous Nighttime Operations | 25 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Non-Freeway Reconstruction and Widening

Contractors anticipated Non-Freeway Reconstruction and Widening projects to increase overall cost by an average of 16 percent as shown in Table 29. This project type encompasses approximately 25 percent of allocated funding for TxDOT projects in the DFW area.

**Table 29. Non-Freeway Reconstruction and Widening Cost and Schedule Results (DFW)**

| **Non-Freeway Reconstruction and Widening** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 8 % | + 2 % | + 16 % |
| Anticipated Change in Duration | + 13 % | + 6 % | + 28 % |
| Total Anticipated Cost Change | + 16 % | + 5 % | + 33 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

As with freeway reconstruction projects, contractors indicated that they prefer WSA that allow continuous operations during the day. Because this project type is typified by traffic volume and interference, continuous day operations was the preferred alternative as shown in Table 30. As with freeway reconstruction projects, night work is preferred over a shortened daytime operation for project work that requires closures.

**Table 30. Non-Freeway Reconstruction/Widening WSASelection (DFW).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 38 % |
| B - Partially Delayed, Continuous Operations | 26 % |
| C - Delayed, Shortened Operations | 11 % |
| D - Continuous Nighttime Operations | 25 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

New Construction

Values determined from the information supplied through the surveys indicated that the contractors expect an overall cost increase for new construction projects to be between 5 percent and 33 percent, with the most likely cost increase being 15 percent. Anticipated changes in cost and schedule are shown in Table 31. Based on TxDOT funding allocation from 1997 through 2000, this project type accounted for approximately 22 percent of TxDOT projects in the DFW area.

**Table 31. New Construction Cost and Schedule Results (DFW)**

| **New Construction** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 8 % | + 2 % | + 16 % |
| Anticipated Change in Duration | + 13 % | + 5 % | + 27 % |
| Total Anticipated Cost Change | + 15 % | + 5 % | + 33 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The respondents indicated that full continuous day operations were preferred because lane closures are not typically required for new construction. Shortened daytime operations were not an attractive alternative. The data indicate that relatively more work could be accomplished without heavy equipment, and therefore starting before the deadline is a more viable option. The amount of work the contractors would perform under contractors' preferences for the various WSA for new construction is shown in Table 32.

**Table 32. New Construction WSA Selection (DFW).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 40 % |
| B - Partially Delayed, Continuous Operations | 30 % |
| C - Delayed, Shortened Operations | 8 % |
| D - Continuous Nighttime Operations | 23 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Bridge Replacement

The Bridge Replacement projects tend to require less heavy equipment than the other types of projects. As shown in Table 33, contractors estimate the schedule increases to vary between 5 percent and 33 percent, with a most likely value of 17 percent. This project type accounts for approximately 6 percent of the funding allocated by TxDOT to the DFW area.

**Table 33. Bridge Replacement Cost and Schedule Results (DFW).**

| **Bridge Replacement** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 9 % | + 2 % | + 17 % |
| Anticipated Change in Duration | + 12 %5 | + 5 % | + 28 % |
| Total Anticipated Cost Change | + 17 % | + 5 % | + 33 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

For Bridge Replacement projects, contractors expressed that most of the work would be done during daytime operations. However, a considerable amount of work could potentially start before the deadline without the use of heavy equipment. This condition is possible as a result of the smaller number of equipment-related tasks involved. As shown in Table 34, for projects or part of projects where traffic restrictions apply, night schedules were selected over delayed, shortened operations.

**Table 34. Bridge Replacement WSA Selection (DFW).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 39 % |
| B - Partially Delayed, Continuous Operations | 38 % |
| C - Delayed, Shortened Operations | 9 % |
| D - Continuous Nighttime Operations | 15 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Rehabilitation and Overlay (Rural)

Rehabilitation and Overlay projects are highly dependent on traffic volume, and therefore, were divided accordingly into rural and urban projects. Rural rehabilitation and overlay projects were assumed to have low traffic volumes, while urban projects were most likely to be significantly impacted by traffic. Both types of projects are otherwise very similar and highly equipment intensive. The overall cost and schedule impacts for rural projects determined from the data supplied by the contractors are shown in Table 35. This project type accounts for approximately 12 percent of TxDOT projects in the DFW area based on funding allocation for 1997 through 2000.

**Table 35. Rehabilitation and Overlay (Rural) Cost and Schedule Results (DFW).**

| **Rehabilitation and Overlay (Rural)** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 7 % | + 1 % | + 14 % |
| Anticipated Change in Duration | + 15 % | + 5 % | + 27 % |
| Total Anticipated Cost Change | + 13 % | + 3 % | + 26 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

As shown in Table 36, the respondents indicated a preference towards Delayed, Continuous Operations for rural rehabilitation and overlay projects. The relatively small traffic volumes would allow the implementation of this work schedule. The high degree of equipment-intensive operations is not conducive to working within the heavy equipment restriction period proposed by TNRCC. As with the other project types, more work would be done under a night schedule than under a reduced day schedule for rehabilitation and overlay projects.

**Table 36. Rehabilitation and Overlay (Rural) WSA Selection (DFW).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 65 % |
| B - Partially Delayed, Continuous Operations | 18 % |
| C - Delayed, Shortened Operations | 7 % |
| D - Continuous Nighttime Operations | 10 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Rehabilitation and Overlay (Urban)

The urban rehabilitation and overlay projects differ from the rural rehabilitation and overlay projects in that they have a higher traffic volume. As shown in Table 37, the values calculated indicate that respondents estimated a cost increase between 4 percent and 30 percent with a most likely value of 16 percent. This project type accounts for approximately 12 percent of TxDOT projects in the DFW area based on funding allocation from years 1997 through 2000.

**Table 37. Rehabilitation and Overlay (Urban) Cost and Schedule Results (DFW).**

| **Rehabilitation and Overlay (Urban)** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 8 % | + 1 % | + 16 % |
| Anticipated Change in Duration | + 17 % | + 6 % | + 30 % |
| Total Anticipated Cost Change | + 16 % | + 4 % | + 30 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The comparatively higher traffic volume related to urban rehabilitation and overlay projects and the consequent restrictions in lane closures indicate a reduced desire or ability to operate in the daytime. Nonetheless, as seen in Table 38, the majority of work is expected to be performed during the daytime. A considerable part of the work that is impacted by traffic is preferred to be completed under a delayed shortened operations schedule rather than during the night time nighttime operations.

**Table 38. Rehabilitation and Overlay (Urban) WSA Selection (DFW).**

| WSA | Forecasted to Employ |
|---|---|
| A - Delayed, Continuous Operations | 40 % |
| B - Partially Delayed, Continuous Operations | 18 % |
| C - Delayed, Shortened Operations | 15 % |
| D - Continuous Nighttime Operations | 27 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

## Cost Elements

The cost element impacts as provided by the respondents present a consistent pattern for the different WSA and for the different project types. Table 39 indicates the average expected impacts on the cost elements according to the project types as calculated from the information supplied through the contractor surveys.

**Table 39. Overall Average Cost Element Impacts per Project Type (DFW).**

| Project Type | Anticipated Increase in Cost Elements (%) | | | | |
|---|---|---|---|---|---|
| | Field Labor | Materials | Equipment | Field Indirect | Home Office |
| 1 – Freeway Reconst. | 35 | 6 | 24 | 20 | 14 |
| 2 – Non-Freeway Reconst. | 34 | 4 | 24 | 21 | 14 |
| 3 – New Construction | 33 | 6 | 23 | 20 | 14 |
| 4 – Bridge Replacement | 34 | 7 | 26 | 23 | 17 |
| 5a –Rehab/Overlay (Rural) | 35 | 6 | 24 | 21 | 15 |
| 5b –Rehab/Overlay (Urban) | 41 | 7 | 28 | 25 | 17 |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The data from the survey indicate that contractors would expect the direct field labor to experience the largest cost increase, followed by equipment and field indirects. Labor was affected primarily through wage premiums and increased overtime. A potential side effect from the proposed rule on labor is a reduction in labor productivity. Survey respondents commented that the construction labor force might migrate towards other metropolitan areas that would not be bound by the proposed restrictions. Labor productivity might also be affected by the necessity of having to modify the current work schedules and practices.

Contractors in the DFW area anticipated similar impacts to their construction operations, as did contractors in the HG area. Field Indirect costs may increase due to the premium policy that may be implemented for the field personnel. The impacts on labor productivity may affect equipment productivity. Limited visibility during night and dusk hours may also have a negative impact on equipment productivity. Equipment costs may also be impacted by the overall project duration changes.

Home office costs may increase as a result of the addition of personnel to fill the extended hours and/or as a result of paying increased overtime. These costs are further increased by the anticipated lengthening of the project duration. Material costs may be affected by the need for suppliers to adjust delivery schedules to match the altered construction activity. Respondents pointed out that site material storage areas are limited and therefore delivery schedules may have to adjust to the new work schedules.

Table 40 reflects the overall contribution of each cost elements towards the total project cost impact. This contribution is based on the average percent weight of each element.

**Table 40. Overall Average Cost Element Impact (DFW).**

| | Field Labor | Materials | Equipment | Field Indirect | Home Office | Total |
|---|---|---|---|---|---|---|
| Relative Weights | 15 | 51 | 17 | 10 | 7 | 100 |
| Average Impact | 35 | 6 | 24 | 21 | 15 | - |
| Contribution to Total Impact | 5 | 3 | 4 | 2 | 1 | 16 |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Forecasted field labor cost increases contribute the most to the total change as a result of the relatively high anticipated increase for this element. Similarly, equipment cost contributes 17 percent of the total project cost and has an impact of 24 percent; the cost impact due to equipment is forecasted to be 4 percent at the overall project level. Although material cost increases are anticipated to be minimal, the overall cost impact is found to be approximately 3 percent, because material costs account for such a large portion of the overall construction costs.

## Cost Factors

The cost factors included in the DFW survey were the same as those included in the HG survey:

- labor productivity,
- labor wage rates,
- traffic control,
- construction lighting,
- safety: insurance and worker's compensation, and
- quality: rework.

Table 41 shows the anticipated cost increases for the various cost factors by the DFW area contractors as calculated from the data supplied through the surveys. The factors that are expected to be impacted the most by the implementation of the proposed rule are labor productivity, construction lighting, labor wage rates, and traffic control.

**Table 41. Average Cost Factors Impacts per Project Type (DFW).**

| Cost Factor | Anticipated Increase in Cost Factors per Project Type (%) | | | | | | Average (%) |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5a | 5b | |
| Labor Productivity | -18 | -17 | -16 | -16 | -17 | -20 | -17 |
| Labor Wage Rates | 15 | 15 | 15 | 13 | 15 | 19 | 16 |
| Traffic Control | 12 | 12 | 7 | 7 | 13 | 17 | 11 |
| Construction Lighting | 40 | 41 | 38 | 32 | 33 | 45 | 39 |
| Safety | 9 | 9 | 8 | 7 | 8 | 11 | 9 |
| Quality | 8 | 8 | 8 | 6 | 4 | 8 | 7 |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

**(Note: for description of project types please refer to figure 3.)**

The literature indicates an estimated impact of 63 percent for nighttime construction lighting. The findings of this research indicate an increase of 39 percent for the total compounded impact of the projected work schedules and 100 percent in lighting cost for solely nighttime operations. Currently, most projects in the DFW area are performed during daytime hours, and a shift towards night schedules would force full use of construction illumination. Construction lighting costs are part of the field indirect costs. The literature review did not provide quantitative information regarding labor productivity impacts. However, as with the contractors surveyed, the literature did comment on the various factors that affect productivity levels such as worker morale, fatigue, and illumination for nighttime construction work.

With regard to labor wage rates, the literature estimated an impact of approximately 18 percent for nighttime work based on overtime and premiums. The analysis indicated an estimated cost impact of 31 percent. The limited experience in nighttime operations may be one of the reasons for this expected change. Labor wages are a major part of the field labor cost and the anticipated increases in the wages account for a significant part of the overall labor cost impact.

Cost increases found in the literature regarding traffic control for night operations were 28 percent. The research indicates an expected increase of 24 percent for this same item.

The survey respondents commented that increased risk to construction workers during evening and nighttime operations would have adverse affects on worker safety, in part due to sleep deprivation and fatigue. The expected overall impact on safety for the DFW area was calculated to be 9 percent.

Various articles indicate that no conclusions can be drawn regarding the effects of nighttime operations on quality. The literature does not give quantitative values regarding impacts on quality. The respondents' data indicated that the expected impact of the different WSAs on quality is 9 percent.

## TxDOT Personnel Survey Results

The survey conducted with the TxDOT area engineers and district construction representatives in the DFW areas (see Appendix E), differed from the survey used during the interviews with the HG TxDOT personnel. The knowledge gained from the HG area regarding cost tracking and management methods helped to reconfigure the survey document. For the HG survey for TxDOT personnel, costs were broken down into cost elements; but for the DFW TxDOT personnel, only impact on project costs was requested. Additionally, as with the HG survey, the impacts on the project duration, the estimated work to be performed under each WSA, and the impacts on specific cost factors were included.

The cost factors included in the DFW TxDOT survey differed from those used during the HG interviews. The new factors were:

- agency costs,
- traffic control,
- construction lighting,
- labor, and

- materials/equipment.

The anticipated cost and schedule impacts determined from data supplied by from TxDOT personnel are shown in Table 42. The anticipated daily total cost impact is consistent with that provided by the DFW contractors (8 percent). However, the estimated increase in the project duration differs significantly from that provided by the area contractors. Accounting for the extended project duration, the overall cost impact expected by TxDOT personnel for the DFW was calculated to range from 6 percent to 12 percent, with a calculated average of 9 percent. The corresponding contractors' value is 16 percent.

**Table 42. TxDOT Personnel Overall Cost and Schedule Results (DFW).**

| **Overall Impact** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 6 % | + 3 % | + 10 % |
| Anticipated Change in Duration | + 5 % | + 2 % | + 9 % |
| Total Anticipated Cost Change | + 9 % | + 6 % | + 12 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

The major difference between the estimates provided by the contractors and by TxDOT personnel is on the project duration. The contractors estimate higher impacts with longer duration projects. Part of this difference lies in the selection of the WSA and the estimated average impact in project duration per WSA. Table 43 and Table 44 reflect the selection of the various alternatives and the average cost impacts by the contractors and by TxDOT.

**Table 43. WSA Selection by TxDOT and Area Contractors (DFW).**

| **WSA** | **TxDOT** | **Contractors** |
|---|---|---|
| A - Delayed, Continuous Operations | 62 % | 41 % |
| B - Partially Delayed, Continuous Operations | 23 % | 26 % |
| C - Delayed, Shortened Operations | 4 % | 11 % |
| D - Continuous Nighttime Operations | 11 % | 22 % |
| Total | 100 % | 100 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

**Table 44. Average Cost Impacts in Project Duration by TxDOT and Area Contractors (DFW).**

| WSA | TxDOT | Contractors |
|---|---|---|
| A - Delayed, Continuous Operations | 1 % | 12 % |
| B - Partially Delayed, Continuous Operations | 11 % | 11 % |
| C - Delayed, Shortened Operations | 34 % | 21 % |
| D - Continuous Nighttime Operations | 7 % | 18 % |
| Total | + 5 % | + 14 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

Table 43 shows that TxDOT personnel estimated a larger fraction of work to be performed under continuous day schedules, and table 44 shows a smaller cost impact than the contractors. The contractors expect to perform more work during nighttime than TxDOT personnel, and they also expect the project duration to increase more than TxDOT personnel.

The DFW contractors indicated that the project type that should experience the largest cost impact is bridge replacement, while TxDOT personnel expect these project types to experience the smallest impact. The other impacts on project types were consistent with those expected by the contractors.

TxDOT personnel mentioned their inability to increase the number of personnel allotted to a project without state legislation. Currently, the Fort Worth officehas the maximum staff size allowed and could not increase the number of personnel. Other TxDOT concerns included the probable reshuffle of the work structure and the potential social and domestic problems.

### Overall Cost and Schedule Impacts

Results from contractors in the DFW (see Appendix F) indicate that the proposed TNRCC rule may have adverse impacts to construction cost and schedule in the DFW area. Specific anticipated impacts are summarized in Table 45. Daily construction operations for TxDOT projects are projected to increase in cost by approximately 8 percent, while the project duration is expected to increase 14 percent on average. Thus, the overall total impact is estimated to range between 4 percent and 32 percent, with a most likely value of 16 percent.

**Table 45. Overall Cost and Schedule Results (DFW).**

| **Freeway Reconstruction and Widening** | Average | Low | High |
|---|---|---|---|
| Anticipated Change in Daily Cost | + 8 % | + 2 % | + 16 % |
| Anticipated Change in Duration | + 14 % | + 5 % | + 28 % |
| Total Anticipated Cost Change | + 16 % | + 4 % | + 32 % |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

If contractors are not exempt from the proposed TNRCC rules they will have to adjust their normal work schedules to comply with the proposed equipment restrictions. Table 46 shows the contractor preference for the WSAs developed for the survey. As in the HG area, the selection of a WSA is primarily based on the ability of conducting continuous operations. Another important consideration is the possibility of performing day work rather than night work. Night operations convey a series of additional costs and risks that contractors tend to avoid when possible. The ability to perform work without changing normal methods and sequences is another factor that is considered in the selection of a work schedule. Contractors tend to expect the majority of work to be performed under schedules that would allow them to use heavy equipment continuously and during the entire workday, instead of limiting its use during the first hours of the workday due to the proposed restrictions.

**Table 46. WSA Preference per Project Type (DFW).**

| WSA | Implementation of WSA per Project Type (%) | | | | | | Average (%) |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5a | 5b | |
| A - Delayed, Continuous Operations | 32 | 38 | 40 | 48 | 65 | 40 | 40 |
| B - Partially Delayed, Continuous Operations | 30 | 26 | 30 | 38 | 18 | 18 | 27 |
| C - Delayed, Shortened Operations | 13 | 11 | 8 | 9 | 7 | 15 | 11 |
| D - Continuous Nighttime Operations | 25 | 25 | 22 | 15 | 10 | 27 | 22 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

**(Note: for appropriate calculation procedure please refer to appendix G.)**

# CHAPTER V  CONCLUSIONS

In order to assess the cost and schedule impact of the proposed TNRCC rule, a survey of contractors and TxDOT engineers employed in HG and DFW ozone non-attainment areas was conducted. The highway construction work was grouped into five project types for analyzing the impacts. Different alternative work strategies that the contractors can adopt after this rule is implemented in 2005 were studied. Based on the project, four WSAs were suggested in the survey document. After analyzing the survey responses and comments provided by the respondents and studying the available literature, the following conclusions are be drawn:

- There are limited historical data available to support a cost impact evaluation; all data gathered are drawn from personal experience and judgement of those people that are most intimately familiar with the highway construction operations.
- As a result of thr TNRCC proposed rule, TxDOT may experience additional problems with staff, project funding, and logistics.
- Contractors have noted that there may be an impact on labor availability and associated costs due to decreased attractiveness of the industry if the restrictions are implemented.
- There are a considerable number of non-quantifiable factors that may further impact the cost and schedule to TxDOT projects. These include lower morale and increased safety concerns for TxDOT and contractor personnel.
- The anticipated average overall construction cost impact (including the costs of extended schedules) during the restriction period is anticipated to be between 8 percent and 16 percent.
- The average overall project duration is anticipated to increase project schedules between 6 percent and 12 percent during the restriction period. There is a consistent tendency by the contractors to select work schedules that provide continuous operation. This tendency is reflected in the cost and schedule impacts.

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# APPENDIX A

## SURVEY DOCUMENT FOR THE HG AREA CONTRACTORS AND TXDOT PERSONNEL

Dear Construction Professional:

The Texas Natural Resource Conservation Commission (TNRCC) has proposed new control requirements that would have direct impact on the Texas construction industry. These requirements specify that non-road, heavy-duty diesel construction equipment over 50 hp cannot operate from 0600 - 1200 daily during Daylight Savings time in the Houston/Galveston ozone nonattainment area (HGA), and from 0600 - 1000 in the Dallas/Fort Worth nonattainment area.

The Texas Department of Transportation (TxDOT) is evaluating cost and schedule impacts of these new control requirements. A survey has been developed in an effort to measure these impacts. This survey is being issued to TxDOT Contractors, as well as Area Engineers and Cost Estimators, and will form the basis of this study.

We appreciate your support in reviewing and completing the survey. Your input is invaluable in estimating the impacts of control requirements proposed by TNRCC. All information gathered will be held under strict confidentiality and aggregated to form results for this study; no particular set of data will be singled out without permission. The attached document contains details of the background, procedure and elements of the survey.

If you have any questions or comments, please contact us at (979) 845-9300 or (979) 845-6227; the research team will gladly assist you in any way possible. Thank you in advance.

Sincerely,


David Trejo, Ph.D., P.E.
Principal Investigator
Department of Civil Engineering
Texas A&M University

Stuart Anderson, Ph.D.
Principal Investigator
Department of Civil Engineering
Texas A&M University

## **Background**

The Texas Natural Resource Conservation Commission (TNRCC) has proposed new control requirements that would have direct impact on the Texas construction industry. These proposed requirements specify that non-road, heavy-duty diesel construction equipment over 50 hp cannot operate from 0600 - 1200 daily during Daylight Savings time in the Houston/Galveston ozone nonattainment area (HGA), and from 0600 - 1000 in the Dallas/Fort Worth nonattainment area. Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller Counties define the HGA area. The research team has been requested by the Texas Department of Transportation (TxDOT) to determine the cost and schedule impact of the proposed restrictions in these areas.

### SURVEY BASIS

This survey of TxDOT Contractors, as well as Area Engineers and Cost Estimators, will form the basis for the evaluation. Contractors and agency personnel will be surveyed to determine the anticipated cost and schedule impacts due to the proposed action. This survey utilizes "representative" project types in each of the major categories or types of work. Contractors and agency personnel will be surveyed to determine potential impacts on cost for direct and indirect labor, material, equipment, and home office for each of these project types. In addition, the impact on schedule and productivity will be gathered. The survey data will be supplemented by various existing reports conducted through an extensive literature search.

### TEXAS NATURAL RESOURCE CONSERVATION COMMISSION

As stated in the Texas Natural Resource Conservation Commission's Proposed State Implementation Plan (SIP), Chapter 114 - Control of Air Pollution from Motor Vehicles: The equipment to which the rules concerning restrictions on the operation of construction equipment apply includes all non-road, heavy-duty diesel equipment classified as “construction equipment,” rated at 50 hp and greater, regardless of how it is being used.

For example, equipment such as bulldozers used in sanitary landfills, non-road cranes used in demolition, and rubber tire loaders used in manufacturing operations are covered by these rules concerning restrictions on the operation of construction equipment.

Exemptions include construction equipment used exclusively for emergency operations to protect public health and the environment, and *for mixing, transporting, pouring, or processing wet concrete.*

**CONTRACTOR SURVEY**

**Cost and Schedule Impact Due to TRNCC's Proposed State Implementation Plan (SIP)**

**Respondent Name:** ________________________________ **Date:** ______________________

**Title**: ______________________________ **Division/Department**: _____________________

**Brief Description of Job Duties:** __________________________________________________

_____________________________________________________________________________________

**Company**: _______________________________________**Annual Volume of Work:** $____________

## Procedure

Construction contractor input is required to fully reflect the impact of TNRCC's proposed restrictions. Therefore, we request your cooperation in evaluating the cost and schedule impacts through the attached survey. This survey consists of five representative project types from the TxDOT Houston District. Please refrain from completing sections of the survey that you do not have the background or experience necessary to estimate potential cost impacts. Also, since contractors will alter their workday in varying fashions to respond to the TRNCC restrictions, the survey has been developed to incorporate five separate work schedule alternatives. These work schedule alternatives and the various elements are described in detail at the end of this package.

*When estimating the cost change for an element, do not include the cost due to increased/decreased project duration. Focus on the change in cost due to the characteristics of each Work Schedule Alternative, rather than changes in project duration based on lower or higher productivity. Schedule impacts determined in Part I (b) will be used to further adjust costs to labor, equipment, indirects, and home office. Also, when documenting estimated percentages, feel free to enter a range rather than a specific number, if necessary.*

### PART I.

- **Part I (a):** For each project type, we request that the respondent estimate the anticipated percentage change in cost for the various elements listed. These percentage increases should be provided for each of the five alternate work schedules. Additionally, for each of the elements, please identify the estimated percentage in cost compared to the total project cost.
- **Part I (b):** Estimate the percentage change for project duration and overall labor productivity. These percentage increases should be provided for each of the five alternate work schedules provided.
- If a particular cost or schedule element will not be impacted, please indicate this on the survey with "0%".
- If a particular work schedule alternative is not appropriate for the type of project, please indicate this by entering "N.A." in the corresponding space.

### PART II.

- For each of the project types, please anticipate your company's response to the new workday restrictions. Five possible work schedules have been developed as alternatives. Please estimate the percentage of each of the alternative work schedules that would be used in executing the particular project type.

### PART III.

- Estimate the percent change in cost for the various factors listed. These factors were identified in the literature as having the greatest change due to nighttime operations and are being analyzed for this study.

## Representative Project Types

The following representative project types have been selected from TxDOT categories and represent a majority of the construction projects conducted in the Houston/Galveston area.

1. ***Freeway Reconstruction and Widening***
   - Project Cost: > $20M
   - Traffic: 100,000 vehicles/day
   - 3-Span Overpass every 3/4 mile
   - Increase 2 lanes to 4 lanes in each direction with new frontage roads
   - Length: 2 - 4 miles
   - Pavement Cross section:
     - 13 - 15" CRCP (main lanes)
     - 8 - 10" CRCP (frontage roads)
     - 1" ASB Bond Breaker
     - 6" Portland Cement-Stabilized Base
     - 6" Lime-Treated Subgrade

2. ***Non-Freeway Reconstruction and Widening***
   - Project Cost: $10M - $20M
   - Traffic: 15,000 - 20,000 vehicles/day
   - Increase 2 lanes to 5 lanes
   - Center Left-Turn Lane
   - Length: 5 - 6 miles
   - One 3-Span water crossing
   -
     - 8 - 10" CRCP
     - 1" ASB Bond Breaker
     - 6" Portland Cement-Stabilized Base
     - 6" Lime-Treated Subgrade

3. ***New Construction***
   - Project Cost: $10M - $20M
   - Traffic: 0 vehicles/day
   - 5 lanes with Center Left-Turn Lane
   - Length: 5 - 6 miles
   - One 3-Span water crossing
   - Pavement Cross section:
     - 8 - 10" CRCP
     - 1" ASB Bond Breaker
     - 6" Portland Cement-Stabilized Base
     - 6" Lime-treated Subgrade

4. ***Bridge Replacement***
   - Project Cost: Approximately $500,000
   - Traffic: 1000 - 1500 vehicles/day
   - Concrete I-Beam Construction, 150-ft 3-span bridge with Asphalt tapers
   - Scope: 45-ft Width, 2-Lane, 2 Shoulders
   - Roadway consists of transitions and minimum embankment widening

5. ***Rehabilitation and Overlay (Broken into Rural and Urban Projects)***
   - Traffic: <30,000 vehicles/day (rural) and >100,000 vehicles/day (urban)
   - Width: 5 lanes Length: 5 miles
   - Full depth repair with Asphalt-stabilized base (black base)
   - 2" Asphalt surface overlay

## Cost Element Descriptions

### DIRECT FIELD LABOR:

Includes the Direct Field Labor regular and overtime wages plus burdens and benefits, including the Equipment Operators; Direct Field Labor personnel small tools, personal safety gear such as safety glasses, steel toe boots, hard hats, uniforms, etc; and their transportation to and from the site.

### MATERIALS:

Includes all permanent material such as steel, concrete, bolts, nails, wood, paint, etc, or its components such as water, sand, gravel, cement, etc. The Materials Cost includes the transport of the material to and from, if necessary, the construction site.

### EQUIPMENT:

Includes all construction equipment such as scrapers, cranes, trucks, etc; fuel, oil, equipment water, parts, maintenance, and all usual associated costs. The Equipment can be rented or owned. The Equipment Cost includes the transport of the Equipment from and to the construction site as necessary.

### FIELD INDIRECTS:

Includes regular and overtime salaries for all Indirect Field Personnel, such as Field Engineers, Field Project Control Engineers, Field Safety Engineers, Field Draftsman, Secretaries, Drivers, etc, including burdens and benefits; temporary on site facilities such as warehouses, offices, first aid installations, restrooms, etc; Field Staff transport vehicles such as Pick-up Trucks or small vans along with fuel, oil, parts, maintenance, and all usual associated costs; Field Office supplies such as paper, telephones and the use of the service, faxes and the use of the services, computers, furniture, copies, electricity, running water, drinking water, etc; also includes corresponding overhead.

### HOME OFFICE:

Includes regular and overtime salaries for all Home Office Personnel involved in the project, such as Project Manager, Project Control Managers, Cost Engineers, Procurement Personnel, etc, including burdens and benefits; Home Office supplies such as paper, telephones and the use of the service, faxes and the use of the services, computers, furniture, copies, electricity, etc; also includes corresponding overhead.

### PROJECT DURATION:

Includes the Project's Total Duration for the Original Scope of Work. Assume that projects are contracted using working days as a measure of project duration.

### OVERALL LABOR PRODUCTIVITY:

Includes the Project's Average Labor Productivity Rate for the Original Scope of Work.

### *SUBCONTRACTS:

For the purpose of this study, please estimate the cost and schedule impacts for the entire project, independent on how subcontractors are utilized.

## Work Schedule Alternative Description

To allow construction contractors to comply with The Texas Natural Resource Conservation Commission (TNRCC) proposed new control requirements, five different work schedule alternatives have been derived. These work schedule alternatives are described below.

### ALTERNATIVE A: FULLY DELAYED CONTINUOUS OPERATIONS

(10-hour workday)

Under Work Schedule Alternative A, all construction operations will be shifted to coincide with the end of the restriction period, 12 noon. The workday will consist of 10 continuous hours, thereby shifting the workday to 12:00 - 10:00 p.m. each day. In this case, preparation for construction work can start before the deadline, only if it does not affect the emission requirements. This work schedule alternative is compatible with those projects that don't interfere with traffic.

### ALTERNATIVE B: PARTIALLY DELAYED, CONTINUOUS OPERATIONS

(10-hour workday, Adjusted Work Processes)

Under Work Schedule Alternative B, construction operations will be analyzed to determine possible construction activities that do not require the use of heavy construction equipment (<50hp). These activities will be scheduled for morning operation, before the restriction deadline. All activities requiring heavy construction equipment will be scheduled after the restriction period, 12:00 noon. Therefore, the workday will start at approximately 10:00 a.m. and will proceed for 10 hours until 8:00 p.m.

### ALTERNATIVE C: DELAYED, NONCONTINUOUS OPERATIONS

(10-hour workday, 8-hour productive time)

For projects that directly impact traffic, Work Schedule Alternative C has been developed. For this work schedule alternative, all construction operations will be shifted to coincide with the end of the restriction period, 12 noon. Construction activities will be halted for approximately two hours in the evening to coincide with traffic restrictions. The contractor workday will consist of 10 hours, however, no work will be conducted during the two hour time period.

### ALTERNATIVE D: CONTINUOUS, NIGHTTIME OPERATIONS

(10-hour Workday)

Under Work Schedule Alternative D, the start time of any and all construction operations will be shifted to allow continuous nighttime operations for a 10-hour period. The approximate hours of this work schedule alternative are 7:00 p.m. - 5:00 a.m.

### ALTERNATIVE E: REDUCED RESTRICTION PERIOD ALTERNATIVE

(10-hour workday, Allowable Early Start)

This hypothetical work schedule alternative was developed to anticipate possible adjustments to the restriction period by the TNRCC. Under Work Schedule Alternative E, the restriction period spans from 6:00 - 10:00 a.m. for the Houston area. The start time of all construction operations will be shifted to after these new deadlines. A 10-hour, continuous workday will run from 10:00 a.m. until 8:00 p.m.

| #1 | Project Type: *Freeway Reconstruction and Widening* |
|---|---|

- Project Cost: > $20M
- Increase 2 lanes to 4 lanes each direction with new frontage roads
- Length: 2 - 4 miles
- 3-Span Overpass every 3/4 mile
- Traffic: 100,000 vehicles/day
- Pavement Cross section
  - 13 - 15" CRCP (main lanes)
  - 8 - 10" CRCP (frontage roads)
  - 1" ASB Bond Breaker
  - 6" Portland Cement-Stabilized Base
  - 6" Lime-treated Subgrade

| PART I. A. Cost Elements | Percentage of Total Cost | Percent Change in Cost for Work Schedule Alternative | | | | |
|---|---|---|---|---|---|---|
| | | A | B | C | D | E |
| **Direct Field Labor** | % | % | % | % | % | % |
| **Comments -** | | | | | | |
| **Materials** | % | % | % | % | % | % |
| **Comments -** | | | | | | |
| **Equipment** | % | % | % | % | % | % |
| **Comments -** | | | | | | |
| **Field Indirect** | % | % | % | % | % | % |
| **Comments -** | | | | | | |
| **Home Office** | % | % | % | % | % | % |
| **Comments -** | | | | | | |

| #1 | Project Type: *Freeway Reconstruction and Widening* | | | | |
|---|---|---|---|---|---|
| **Part I (Continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **PART II.** | **A** | **B** | **C** | **D** | **E** |
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| **Comments -** | | | | | |
| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |

| #2 | Project Type: *Non-Freeway Reconstruction and Widening* |
|---|---|

- Project Cost: $10 -$20M
- Increase 2 lanes to 5 lanes with center lane as left-turn lane
- Length: 5 - 6 miles
- One 3-Span water crossing
- Traffic: 15,000 - 20,000 vehicles/day
- Pavement Cross section
  8 - 10" CRCP
  1" ASB Bond Breaker
  6" Portland Cement-Stabilized Base
  6" Lime-treated Subgrade

| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|---|
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| **Direct Field Labor** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Materials** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Equipment** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Field Indirect** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Home Office** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |

| #2 | Project Type: *Non-Freeway Reconstruction and Widening* | | | | |
|---|---|---|---|---|---|
| **Part I (Continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | % | % | % | % | % |
| **Comments -** | | | | | |
| **Overall Labor Productivity** | % | % | % | % | % |
| **Comments -** | | | | | |
| **PART II.** | **A** | **B** | **C** | **D** | **E** |
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | % | % | % | % | Not Available |
| **Comments -** | | | | | |
| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | % | % | % | % | % |
| **Comments -** | | | | | |
| **Traffic Control** | % | % | % | % | % |
| **Comments -** | | | | | |
| **Construction Lighting** | % | % | % | % | % |
| **Comments -** | | | | | |
| **Safety: Insurance & Workers' Compensation** | % | % | % | % | % |
| **Comments -** | | | | | |
| **Quality: Rework** | % | % | % | % | % |
| **Comments -** | | | | | |

| #3 | Project Type: ***New Construction*** | |
|---|---|---|
| • Project Cost: $10 -$20M<br>• 5 lanes with center lane as left-turn lane<br>• Length: 5 - 6 miles | • One 3-Span water crossing<br>• Traffic: 0 vehicles/day<br>• <u>Pavement Cross section</u><br>8 - 10" CRCP | 1" ASB Bond Breaker<br>6" Portland Cement-Stabilized Base<br>6" Lime-treated Subgrade |

| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|---|
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| **Direct Field Labor** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Materials** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Equipment** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Field Indirect** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Home Office** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |

| #3 | Project Type: *New Construction* | | | | |
|---|---|---|---|---|---|
| **Part I (Continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **PART II.** | **A** | **B** | **C** | **D** | **E** |
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| **Comments -** | | | | | |
| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |

| #4 | Project Type: ***Bridge Replacement*** |
|---|---|

- Project Cost: Approx. $500,000
- Concrete I-beam construction, 150-ft, 3-span bridge with asphalt tapers
- Scope: 45-ft width, 2 lanes, 2 shoulders
- Roadway consists of transitions
- Minimum embankment widening

| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|---|
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| **Direct Field Labor** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Materials** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Equipment** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Field Indirect** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Home Office** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |

| **#4** | **Project Type:** ***Bridge Replacement*** | | | | |
|---|---|---|---|---|---|
| **Part I (Continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **PART II.** | **A** | **B** | **C** | **D** | **E** |
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| **Comments -** | | | | | |
| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |

| **#5 -Rural** | **Project Type: *Rehabilitation and Overlay (Rural)*** | | | | | |
|---|---|---|---|---|---|---|
| • Traffic: <30,000 vehicles/day<br>• Width: 5 lanes<br>• Length: 5 miles | • Full depth repair with asphalt-stabilized base (black base)<br>• 2" Asphalt surface overlay | | | | | |
| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| **Direct Field Labor** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Materials** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Equipment** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Field Indirect** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Home Office** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |

| **#5 -Rural** | **Project Type:** ***Rehabilitation and Overlay (Rural)*** | | | | |
|---|---|---|---|---|---|
| **Part I (Continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |

| **PART II.** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| **Comments -** | | | | | |

| **PART III.**<br>**Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |

| #5 -Urban | Project Type: *Rehabilitation and Overlay (Urban)* |
|---|---|
| • Traffic: >100,000 vehicles/day<br>• Width: 5 lanes<br>• Length: 5 miles | • Full depth repair with asphalt-stabilized base (black base)<br>• 2" Asphalt surface overlay |

| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|---|
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| **Direct Field Labor** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Materials** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Equipment** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Field Indirect** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Home Office** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |

| **#5 -Urban** | **Project Type:** ***Rehabilitation and Overlay (Urban)*** | | | | |
|---|---|---|---|---|---|
| **Part I (Continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **PART II.** | **A** | **B** | **C** | **D** | **E** |
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| **Comments -** | | | | | |
| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |

# APPENDIX B

# SURVEY DOCUMENT FOR THE DFW AREA CONTRACTORS AND TXDOT PERSONNEL

Dear Construction Professional:

The Texas Natural Resource Conservation Commission (TNRCC) has proposed new control requirements that would have direct impact on the Texas construction industry. These requirements specify that, unless exempted, non-road, heavy-duty diesel construction equipment over 50 hp cannot operate from 0600 - 1000 daily during Daylight Savings time in the Dallas/Fort Worth nonattainment area, and from 0600 - 1200 in the Houston/Galveston ozone nonattainment area (HGA).

The Texas Department of Transportation (TxDOT) is evaluating cost and schedule impacts of these new control requirements. A survey has been developed in an effort to measure these impacts. This survey is being issued to TxDOT Contractors, as well as Area Engineers and Cost Estimators, and will form the basis of this study.

We appreciate your support in reviewing and completing the survey. Your input is invaluable in estimating the impacts of control requirements proposed by TNRCC. All information gathered will be held under strict confidentiality and aggregated to form results for this study; no particular set of data will be singled out without permission. The attached document contains details of the background, procedure and elements of the survey.

If you have any questions or comments, please contact us at (979) 845-9300 or (979) 845-6227; the research team will gladly assist you in any way possible. Thank you in advance.

Sincerely,

David Trejo, Ph.D., P.E.
Principal Investigator
Department of Civil Engineering
Texas A&M University

Stuart Anderson, Ph.D.
Principal Investigator
Department of Civil Engineering
Texas A&M University

## Background

The Texas Natural Resource Conservation Commission (TNRCC) has proposed new control requirements that would have direct impact on the Texas construction industry. These proposed requirements specify that non-road, heavy-duty diesel construction equipment over 50 hp cannot operate from 0600 - 1000 daily during Daylight Savings time in the Dallas/Fort Worth nonattainment area, and from 0600 - 1200 in the Houston/Galveston ozone nonattainment area (HGA). The four core counties of Dallas, Tarrant, Denton, and Collin make up the affected Dallas/Fort Worth area. The research team has been requested by the Texas Department of Transportation (TxDOT) to determine the cost and schedule impact of the proposed restrictions in these areas.

### SURVEY BASIS

This survey of TxDOT Contractors, as well as Area Engineers and Cost Estimators, will form the basis for the evaluation. Contractors and agency personnel will be surveyed to determine the anticipated cost and schedule impacts due to the proposed action. This survey utilizes "representative" project types in each of the major categories or types of work. Contractors and agency personnel will be surveyed to determine potential impacts on cost for direct and indirect labor, material, equipment, and home office for each of these project types. In addition, the impact on schedule and productivity will be gathered. The survey data will be supplemented by various existing reports conducted through an extensive literature search.

Texas Natural Resource Conservation Commission
As stated in the Texas Natural Resource Conservation Commission's Proposed State Implementation Plan (SIP), Chapter 114 - Control of Air Pollution from Motor Vehicles: The equipment to which the rules concerning restrictions on the operation of construction equipment apply includes all non-road, heavy-duty diesel equipment classified as “construction equipment,” rated at 50 hp and greater, regardless of how it is being used.

For example, equipment such as bulldozers used in sanitary landfills, non-road cranes used in demolition, and rubber tire loaders used in manufacturing operations are covered by these rules concerning restrictions on the operation of construction equipment.

Exemptions include construction equipment used exclusively for emergency operations to protect public health and the environment, and for mixing, transporting, pouring, or processing wet concrete.

This survey is being conducted independent of TNRCC's Rule for Accelerated Purchase of Tier 2/Tier 3 Diesel Equipment. Also, please respond to the following questions assuming that you will not be exempt from the Construction Equipment Operating Restriction by submitting an alternative plan that outlines equivalent emission reductions.

# CONTRACTOR SURVEY

**Cost and Schedule Impact Due to TRNCC's Proposed State Implementation Plan (SIP)**

**Respondent Name:** _______________________________ **Date:** ______________________

**Title**: ____________________________ **Division/Department**: ____________________

**Brief Description of Job Duties:** ________________________________________________

_____________________________________________________________________________________

**Company**: _____________________________________ **Annual Volume of Work:** $___________

## Procedure

Construction contractor input is required to fully reflect the impact of TNRCC's proposed restrictions. Therefore, we request your cooperation in evaluating the cost and schedule impacts through the attached survey. This survey consists of five representative project types derived from TxDOT. Please refrain from completing sections of the survey that you do not have the background or experience necessary to estimate potential cost impacts. Also, since contractors will alter their workday in varying fashions to respond to the TRNCC restrictions, the survey has been developed to incorporate five separate work schedule alternatives. These work schedule alternatives and the various elements are described in detail at the end of this package.

*When estimating the cost change for an element, do not include the cost due to increased/decreased project duration. Focus on the change in cost due to the characteristics of each Work Schedule Alternative, rather than changes in project duration based on lower or higher productivity. Schedule impacts determined in Part I (b) will be used to further adjust costs to labor, equipment, indirects, and home office. Also, when documenting estimated percentages, feel free to enter a range rather than a specific number, if necessary.*

### PART I.

- **Part I (a):** For each project type, we request that the respondent estimate the anticipated percentage change in cost for the various elements listed. These percentage increases should be provided for each of the five alternate work schedules. Additionally, for each of the elements, please identify the estimated percentage in cost compared to the total project cost.
- **Part I (b):** Estimate the percentage change for project duration and overall labor productivity. These percentage increases should be provided for each of the five alternate work schedules provided.
- If a particular cost or schedule element will not be impacted, please indicate this on the survey with "0%".
- If a particular work schedule alternative is not appropriate for the type of project, please indicate this by entering "N.A." in the corresponding space.

### PART II.

- For each of the project types, please anticipate your company's response to the new workday restrictions. Five possible work schedules have been developed as alternatives. Please estimate the percentage of each of the alternative work schedules that would be used in executing the particular project type.

### PART III.

- Estimate the percent change in cost for the various factors listed. These factors were identified in the literature as having the greatest change due to nighttime operations and are being analyzed for this study.

## Representative Project Types

The following representative project types have been selected from TxDOT categories and represent a majority of the construction projects conducted in the Dallas/Fort Worth area.

***1. Freeway Reconstruction and Widening***

- Project Cost: > $20M
- Traffic: 100,000 vehicles/day
- 3-Span Overpass every 3/4 mile
- Increase 2 lanes to 4 lanes in each direction with new frontage roads
- Length: 2 - 4 miles
- Pavement Cross section:
  - 13 - 15" CRCP (main lanes)
  - 8 - 10" CRCP (frontage roads)
  - 1" ASB Bond Breaker
  - 6" Portland Cement-Stabilized Base
  - 6" Lime-Treated Subgrade

***2. Non-Freeway Reconstruction and Widening***

- Project Cost: $10M - $20M
- Traffic: 15,000 - 20,000 vehicles/day
- Increase 2 lanes to 5 lanes
- Center Left-Turn Lane
- Length: 5 - 6 miles
- One 3-Span water crossing
- Pavement Cross section:
  - 8 - 10" CRCP
  - 1" ASB Bond Breaker
  - 6" Portland Cement-Stabilized Base
  - 6" Lime-Treated Subgrade

***3. New Construction***

- Project Cost: $10M - $20M
- Traffic: 0 vehicles/day
- 5 lanes with Center Left-Turn Lane
- Length: 5 - 6 miles
- One 3-Span water crossing
- Pavement Cross section:
  - 8 - 10" CRCP
  - 1" ASB Bond Breaker
  - 6" Portland Cement-Stabilized Base
  - 6" Lime-treated Subgrade

***4. Bridge Replacement***

- Project Cost: Approximately $500,000
- Traffic: 1000 - 1500 vehicles/day
- Concrete I-Beam Construction, 150-ft 3-span bridge with Asphalt tapers
- Scope: 45-ft Width, 2-Lane, 2 Shoulders
- Roadway consists of transitions and minimum embankment widening

***5. Rehabilitation and Overlay (Broken into Rural and Urban Projects)***

- Traffic: <30,000 vehicles/day (rural) and >100,000 vehicles/day (urban)
- Width: 5 lanes Length: 5 miles
- Full depth repair with Asphalt-stabilized base (black base)
- 2" Asphalt surface overlay

## Cost Element Descriptions

### DIRECT FIELD LABOR:

Includes the Direct Field Labor regular and overtime wages plus burdens and benefits, including the Equipment Operators; Direct Field Labor personnel small tools, personal safety gear such as safety glasses, steel toe boots, hard hats, uniforms, etc; and their transportation to and from the site.

### MATERIALS:

Includes all permanent material such as steel, concrete, bolts, nails, wood, paint, etc, or its components such as water, sand, gravel, cement, etc. The Materials Cost includes the transport of the material to and from, if necessary, the construction site.

### EQUIPMENT:

Includes all construction equipment such as scrapers, cranes, trucks, etc; fuel, oil, equipment water, parts, maintenance, and all usual associated costs. The Equipment can be rented or owned. The Equipment Cost includes the transport of the Equipment from and to the construction site as necessary.

### FIELD INDIRECTS:

Includes regular and overtime salaries for all Indirect Field Personnel, such as Field Engineers, Field Project Control Engineers, Field Safety Engineers, Field Draftsman, Secretaries, Drivers, etc, including burdens and benefits; temporary on site facilities such as warehouses, offices, first aid installations, restrooms, etc; Field Staff transport vehicles such as Pick-up Trucks or small vans along with fuel, oil, parts, maintenance, and all usual associated costs; Field Office supplies such as paper, telephones and the use of the service, faxes and the use of the services, computers, furniture, copies, electricity, running water, drinking water, etc; also includes corresponding overhead.

### HOME OFFICE:

Includes regular and overtime salaries for all Home Office Personnel involved in the project, such as Project Manager, Project Control Managers, Cost Engineers, Procurement Personnel, etc, including burdens and benefits; Home Office supplies such as paper, telephones and the use of the service, faxes and the use of the services, computers, furniture, copies, electricity, etc; also includes corresponding overhead.

### PROJECT DURATION:

Includes the Project's Total Duration for the Original Scope of Work. Assume that projects are contracted using working days as a measure of project duration.

### OVERALL LABOR PRODUCTIVITY:

Includes the Project's Average Labor Productivity Rate for the Original Scope of Work.

### *SUBCONTRACTS:

For the purpose of this study, please estimate the cost and schedule impacts for the entire project, independent on how subcontractors are utilized.

## Work Schedule Alternative Description

To allow construction contractors to comply with The Texas Natural Resource Conservation Commission (TNRCC) proposed new control requirements, five different work schedule alternatives have been derived. These work schedule alternatives are described below.

### ALTERNATIVE A: FULLY DELAYED CONTINUOUS OPERATIONS

(10-hour workday)

Under Work Schedule Alternative A, all construction operations will be shifted to coincide with the end of the restriction period, 10:00 a.m. The workday will consist of 10 continuous hours, thereby shifting the workday to 10:00 - 8:00 p.m. each day. In this case, preparation for construction work can start before the deadline, only if it does not affect the emission requirements. This work schedule alternative is compatible with those projects or parts of projects that don’t interfere with traffic, such as working on inbound lanes during evening high peak traffic periods.

### ALTERNATIVE B: PARTIALLY DELAYED, CONTINUOUS OPERATIONS

(10-hour workday, Adjusted Work Processes)

Under Work Schedule Alternative B, construction operations will be analyzed to determine possible construction activities that do not require the use of heavy construction equipment (<50hp). These activities will be scheduled for morning operation, before the restriction deadline. All activities requiring heavy construction equipment will be scheduled after the restriction period, 10:00 a.m. Therefore, the workday will start at approximately 8:00 a.m. and will proceed for 10 hours until 6:00 p.m.

### ALTERNATIVE C: DELAYED, SHORTENED CONTINUOUS OPERATIONS

(Less than 8-hour workday)

For projects or parts of projects that directly impact traffic, Work Schedule Alternative C has been developed. For this work schedule alternative, all construction operations will be shifted to coincide with the end of the restriction period, 10:00 a.m. Construction operations will be continuous for approximately 6 hours until the evening high traffic period when temporary lane closures are reopened. Therefore, in certain instances, the contractor will employ a workday from 10:00 a.m. until approximately 3:30 or 4:00 p.m.

### ALTERNATIVE D: CONTINUOUS, NIGHTTIME OPERATIONS

(10-hour Workday)

Under Work Schedule Alternative D, the start time of any and all construction operations will be shifted to allow continuous nighttime operations for a 10-hour period. The approximate hours of this work schedule alternative are 7:00 p.m. - 5:00 a.m.

### ALTERNATIVE E: REDUCED RESTRICTION PERIOD ALTERNATIVE

(10-hour workday, Allowable Early Start)

This hypothetical work schedule alternative was developed to anticipate possible adjustments to the restriction period by the TNRCC. Under Work Schedule Alternative E, the restriction period spans from 6:00 - 8:00 a.m. for the Dallas/Fort Worth area. The start time of all construction operations will be shifted to after these new deadlines. A 10-hour, continuous workday will run from 8:00 a.m. until 6:00 p.m. This Alternative is currently not an available option and does not meet the proposed Rule. It will be used to gather data for informational purposes only.

# Area Engineer Survey

| #1 | Project Type: *Freeway Reconstruction and Widening* |
|---|---|

- Project Cost: > $20M
- Increase 2 lanes to 4 lanes each direction with new frontage roads
- Length: 2 - 4 miles
- 3-Span Overpass every 3/4 mile
- Traffic: 100,000 vehicles/day
- Pavement Cross section
  - 13 - 15" CRCP (main lanes)
  - 8 - 10" CRCP (frontage roads)
  - 1" ASB Bond Breaker
  - 6" Portland Cement-Stabilized Base
  - 6" Lime-treated Subgrade

| **PART I.** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| **A. Overall Project Impact** | **A** | **B** | **C** | **D** | **E** |
| Cost Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Schedule Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Anticipated percentage of work conducted under the differing work schedule alternatives: | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART II. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Agency Costs** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Labor** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Material/Equipment** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| #2 | **Project Type:** ***Non-Freeway Reconstruction and Widening*** |
|---|---|

- Project Cost: $10 -$20M
- Increase 2 lanes to 5 lanes with center lane as left-turn lane
- Length: 5 - 6 miles
- One 3-Span water crossing
- Traffic: 15,000 - 20,000 vehicles/day
- Pavement Cross section
  - 8 - 10" CRCP
  - 1" ASB Bond Breaker
  - 6" Portland Cement-Stabilized Base
  - 6" Lime-treated Subgrade

| **PART I.** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| **A. Overall Project Impact** | **A** | **B** | **C** | **D** | **E** |
| Cost Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Schedule Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Anticipated percentage of work conducted under the differing work schedule alternatives: | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART II. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Agency Costs** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Labor** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Material/Equipment** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| **#3** | **Project Type:** ***New Construction*** |
|---|---|

- Project Cost: $10 -$20M
- 5 lanes with center lane as left-turn lane
- Length: 5 - 6 miles
- One 3-Span water crossing
- Traffic: 0 vehicles/day
- Pavement Cross section
  - 8 - 10" CRCP
  - 1" ASB Bond Breaker
  - 6" Portland Cement-Stabilized Base
  - 6" Lime-treated Subgrade

| **PART I.** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| **A. Overall Project Impact** | **A** | **B** | **C** | **D** | **E** |
| Cost Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Schedule Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Anticipated percentage of work conducted under the differing work schedule alternatives: | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART II. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Agency Costs** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Labor** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Material/Equipment** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| **#4** | **Project Type:** ***Bridge Replacement*** |
|---|---|

- Project Cost: Approx. $500,000
- Concrete I-beam construction, 150-ft, 3-span bridge with asphalt tapers
- Scope: 45-ft width, 2 lanes, 2 shoulders
- Roadway consists of transitions
- Minimum embankment widening

| **PART I.** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| **A. Overall Project Impact** | **A** | **B** | **C** | **D** | **E** |
| Cost Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Schedule Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Anticipated percentage of work conducted under the differing work schedule alternatives: | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART II. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Agency Costs** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Labor** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Material/Equipment** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

**#5 -Rural** **Project Type:** ***Rehabilitation and Overlay (Rural)***

- Traffic: <30,000 vehicles/day
- Width: 5 lanes
- Length: 5 miles
- Full depth repair with asphalt-stabilized base (black base)
- 2" Asphalt surface overlay

| **PART I.** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| **A. Overall Project Impact** | **A** | **B** | **C** | **D** | **E** |
| Cost Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Schedule Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Anticipated percentage of work conducted under the differing work schedule alternatives: | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART II. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Agency Costs** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Labor** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Material/Equipment** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| **#5 -Urban** | **Project Type:** ***Rehabilitation and Overlay (Urban)*** |
|---|---|

- Traffic: >100,000 vehicles/day
- Width: 5 lanes
- Length: 5 miles
- Full depth repair with asphalt-stabilized base (black base)
- 2" Asphalt surface overlay

| **PART I.** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| **A. Overall Project Impact** | **A** | **B** | **C** | **D** | **E** |
| Cost Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Schedule Impact due to Work Schedule Change | **%** | **%** | **%** | **%** | **%** |
| Anticipated percentage of work conducted under the differing work schedule alternatives: | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART II.<br>Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Agency Costs** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Labor** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Material/Equipment** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

# Contractor Survey

| #1 | Project Type: *Freeway Reconstruction and Widening* | | | | | |
|---|---|---|---|---|---|---|
| • Project Cost: > $20M<br>• Increase 2 lanes to 4 lanes each direction with new frontage roads<br>• Length: 2 - 4 miles | • 3-Span Overpass every 3/4 mile<br>• Traffic: 100,000 vehicles/day<br>• Pavement Cross section<br>13 - 15" CRCP (main lanes) | 8 - 10" CRCP (frontage roads)<br>1" ASB Bond Breaker<br>6" Portland Cement-Stabilized Base<br>6" Lime-treated Subgrade | | | | |
| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| Direct Field Labor | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| Materials | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments – | | | | | | |
| Equipment | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| Field Indirect | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| Home Office | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |

| #1 | Project Type: *Freeway Reconstruction and Widening* | | | | |
|---|---|---|---|---|---|
| **PART I. (continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| **PART II.** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| #2 | Project Type: *Non-Freeway Reconstruction and Widening* |
|---|---|

- Project Cost: $10 -$20M
- Increase 2 lanes to 5 lanes with center lane as left-turn lane
- Length: 5 - 6 miles
- One 3-Span water crossing
- Traffic: 15,000 - 20,000 vehicles/day
- Pavement Cross section
  8 - 10" CRCP

1" ASB Bond Breaker
6" Portland Cement-Stabilized Base
6" Lime-treated Subgrade

| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|---|
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| Direct Field Labor | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| Materials | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments – | | | | | | |
| Equipment | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| Field Indirect | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| Home Office | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |

| #2 | Project Type: *Non-Freeway Reconstruction and Widening* | | | | |
|---|---|---|---|---|---|
| **PART I. (continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **PART II.** | **A** | **B** | **C** | **D** | **E** |
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |
| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| #3 | Project Type: *New Construction* | | | | | |
|---|---|---|---|---|---|---|
| • Project Cost: $10 -$20M<br>• 5 lanes with center lane as left-turn lane<br>• Length: 5 - 6 miles | • One 3-Span water crossing<br>• Traffic: 0 vehicles/day<br>• <u>Pavement Cross section</u><br>8 - 10" CRCP | 1" ASB Bond Breaker<br>6" Portland Cement-Stabilized Base<br>6" Lime-treated Subgrade | | | | |
| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| **Direct Field Labor** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Materials** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments –** | | | | | | |
| **Equipment** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Field Indirect** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |
| **Home Office** | **%** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | | |

| #3 | Project Type: *New Construction* | | | | |
|---|---|---|---|---|---|
| **PART I. (continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| **PART II.** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| **Comments -** | | | | | |

**#4** **Project Type:** ***Bridge Replacement***

- Project Cost: Approx. $500,000
- Concrete I-beam construction, 150-ft, 3-span bridge with asphalt tapers
- Scope: 45-ft width, 2 lanes, 2 shoulders
- Roadway consists of transitions
- Minimum embankment widening

| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|---|
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| **Direct Field Labor** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| **Materials** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments – | | | | | | |
| **Equipment** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| **Field Indirect** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| **Home Office** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |

| #4 | Project Type: *Bridge Replacement* | | | | |
|---|---|---|---|---|---|
| **PART I. (continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| **PART II.** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

**#5 -Rural** **Project Type:** ***Rehabilitation and Overlay (Rural)***

- Traffic: <30,000 vehicles/day
- Width: 5 lanes
- Length: 5 miles

- Full depth repair with asphalt-stabilized base (black base)
- 2" Asphalt surface overlay

| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|---|
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| **Direct Field Labor** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| **Materials** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments – | | | | | | |
| **Equipment** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| **Field Indirect** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| **Home Office** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |

| #5 -Rural | Project Type: *Rehabilitation and Overlay (Rural)* | | | | |
|---|---|---|---|---|---|
| **PART I. (continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| **PART II.** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |

| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

| #5 -Urban | **Project Type:** ***Rehabilitation and Overlay (Urban)*** | | | | | |
|---|---|---|---|---|---|---|
| • Traffic: >100,000 vehicles/day<br>• Width: 5 lanes<br>• Length: 5 miles | • Full depth repair with asphalt-stabilized base (black base)<br>• 2" Asphalt surface overlay | | | | | |
| **PART I.** | **Percentage of Total Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **E** |
| **Direct Field Labor** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| **Materials** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments – | | | | | | |
| **Equipment** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| **Field Indirect** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |
| **Home Office** | **%** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | | |

| **#5 -Urban** | **Project Type: *Rehabilitation and Overlay (Urban)*** | | | | |
|---|---|---|---|---|---|
| **PART I. (continued)** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **E** |
| **Project Duration** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Overall Labor Productivity** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **PART II.** | **A** | **B** | **C** | **D** | **E** |
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **%** | **%** | **%** | **%** | **Not Available** |
| Comments - | | | | | |
| **PART III. Specific Factors Affecting Cost** | **Percent Change in Cost for Work Schedule Alternative** | | | | |
| | **A** | **B** | **C** | **D** | **E** |
| **Labor Wage Rates** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Traffic Control** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Construction Lighting** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Safety: Insurance & Workers' Compensation** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |
| **Quality: Rework** | **%** | **%** | **%** | **%** | **%** |
| Comments - | | | | | |

# APPENDIX C

## TxDOT SURVEY RESULTS (HG AREA)

## TxDOT SURVEY RESULTS (HGA)

| Project Types | % Total Cost | Work Schedule Alternatives: A | | | | B | | | | C | | | | D | | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | Low | Ave | High | % | Low | Ave | High | % | Low | Ave | High | % | Low | Ave | High | Low | Ave | High |
| **Cost Totals** | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 36% | 38 | 1 | 10 | 25 | 12 | 1 | 11 | 25 | 9 | 1 | 14 | 25 | 41 | 2 | 12 | 30 | 2 | 11 | 27 |
| Project 2 | 21% | 38 | 1 | 12 | 25 | 12 | 1 | 14 | 25 | 9 | 1 | 16 | 25 | 41 | 2 | 14 | 30 | 2 | 13 | 27 |
| Project 3 | 11% | 57 | 1 | 12 | 25 | 21 | 2 | 13 | 25 | 3 | 1 | 16 | 25 | 11 | 2 | 13 | 30 | 1 | 11 | 24 |
| Project 4 | 5% | 38 | 1 | 10 | 25 | 31 | 1 | 10 | 25 | 3 | 0 | 13 | 25 | 29 | 2 | 13 | 25 | 1 | 11 | 25 |
| Project 5a | 14% | 62 | 0 | 8 | 20 | 15 | 0 | 10 | 20 | 14 | 0 | 10 | 23 | 9 | 0 | 11 | 21 | 0 | 9 | 20 |
| Project 5b | 14% | 37 | 0 | 7 | 25 | 8 | 0 | 7 | 25 | 11 | 0 | 8 | 25 | 45 | 0 | 8 | 30 | 0 | 8 | 28 |
| **Total** | 100% | 43 | 1 | 10 | 24 | 14 | 1 | 11 | 24 | 9 | 1 | 13 | 25 | 33 | 1 | 12 | 29 | 1 | 11 | 26 |
| **Project Duration** | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 36% | 38 | 5 | 17 | 30 | 12 | 10 | 21 | 50 | 9 | 10 | 21 | 40 | 41 | 10 | 20 | 30 | 8 | 19 | 33 |
| Project 2 | 21% | 38 | 5 | 20 | 40 | 12 | 10 | 23 | 50 | 9 | 15 | 25 | 40 | 41 | 10 | 23 | 40 | 9 | 22 | 41 |
| Project 3 | 11% | 57 | 0 | 15 | 30 | 21 | 0 | 18 | 30 | 3 | 0 | 18 | 30 | 11 | 0 | 17 | 30 | 0 | 15 | 28 |
| Project 4 | 5% | 38 | 0 | 20 | 40 | 31 | 0 | 23 | 50 | 3 | 10 | 25 | 40 | 29 | 0 | 23 | 40 | 0 | 22 | 43 |
| Project 5a | 14% | 62 | 0 | 17 | 33 | 15 | 0 | 18 | 50 | 14 | 0 | 17 | 40 | 9 | 0 | 16 | 30 | 0 | 17 | 36 |
| Project 5b | 14% | 37 | 0 | 11 | 30 | 8 | 0 | 13 | 50 | 11 | 0 | 11 | 40 | 45 | 0 | 14 | 30 | 0 | 13 | 33 |
| **Total** | 100% | 43 | 3 | 17 | 33 | 14 | 6 | 20 | 48 | 9 | 7 | 20 | 39 | 33 | 6 | 19 | 33 | 5 | 18 | 35 |
| **Compounded Costs (includes Project Duration Derived Costs)** | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 36% | 38 | 8 | 17 | 34 | 12 | 9 | 20 | 36 | 9 | 10 | 24 | 36 | 41 | 10 | 21 | 40 | 9 | 20 | 37 |
| Project 2 | 21% | 38 | 11 | 22 | 37 | 12 | 12 | 26 | 38 | 9 | 13 | 30 | 39 | 41 | 13 | 26 | 43 | 12 | 25 | 40 |
| Project 3 | 11% | 57 | 7 | 18 | 33 | 21 | 9 | 22 | 35 | 3 | 9 | 25 | 34 | 11 | 10 | 22 | 39 | 7 | 18 | 31 |
| Project 4 | 5% | 38 | 10 | 20 | 36 | 31 | 11 | 22 | 38 | 3 | 11 | 26 | 39 | 29 | 12 | 24 | 38 | 11 | 22 | 38 |
| Project 5a | 14% | 62 | 4 | 13 | 25 | 15 | 5 | 15 | 26 | 14 | 4 | 15 | 28 | 9 | 4 | 16 | 26 | 4 | 13 | 26 |
| Project 5b | 14% | 37 | 4 | 11 | 30 | 8 | 4 | 12 | 30 | 11 | 4 | 12 | 30 | 45 | 5 | 14 | 36 | 4 | 13 | 33 |
| **Total** | 100% | 43 | 8 | 17 | 33 | 14 | 9 | 20 | 34 | 9 | 9 | 23 | 35 | 33 | 9 | 20 | 38 | 8 | 19 | 35 |

**Project Types**
1: Freeway Reconstruction and Widening
2: Non-Freeway Reconstruction and Widening
3: New Construction
4: Bridge Replacement
5a: Rehabilitation and Overlay (Rural)
5b: Rehabilitation and Overlay (Urban)

**Work Schedule Alternatives**
A: Fully Delayed Continuous Operations
B: Partially Delayed, Continuous Operations
C:Delayed Non Continuous Operations
D: Continuous, Nighttime Operations

# APPENDIX D

# CONTRACTOR SURVEY RESULTS (HG)

## CONTRACTOR SURVEY RESULTS (HGA)

| Project Types | % Total Cost | Work Schedule Alternatives: A | | | | B | | | | C | | | | D | | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | Low | Ave | High | % | Low | Ave | High | % | Low | Ave | High | % | Low | Ave | High | Low | Ave | High |
| **Cost Totals** | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 36% | 31 | 2 | 6 | 12 | 18 | 2 | 7 | 15 | 6 | 4 | 9 | 17 | 45 | 5 | 11 | 22 | 4 | 9 | 17 |
| Project 2 | 21% | 45 | 2 | 7 | 13 | 25 | 2 | 7 | 15 | 5 | 4 | 9 | 18 | 25 | 5 | 11 | 22 | 3 | 8 | 16 |
| Project 3 | 11% | 60 | 2 | 6 | 13 | 34 | 2 | 7 | 15 | 3 | 3 | 9 | 17 | 4 | 5 | 10 | 21 | 2 | 7 | 14 |
| Project 4 | 5% | 51 | 4 | 8 | 13 | 21 | 4 | 8 | 14 | 1 | 4 | 11 | 18 | 26 | 7 | 15 | 29 | 5 | 10 | 17 |
| Project 5a | 14% | 77 | 3 | 7 | 12 | 7 | 3 | 7 | 13 | 0 | 3 | 8 | 14 | 17 | 5 | 9 | 14 | 3 | 7 | 12 |
| Project 5b | 14% | 13 | 0 | 5 | 11 | 0 | 0 | 6 | 12 | 13 | 0 | 6 | 14 | 75 | 0 | 6 | 12 | 0 | 6 | 12 |
| **Total** | **100%** | **42** | **2** | **6** | **12** | **17** | **2** | **7** | **14** | **5** | **3** | **9** | **16** | **36** | **4** | **10** | **20** | **3** | **8** | **15** |
| **Project Duration** | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 36% | 31 | 3 | 6 | 10 | 18 | 5 | 10 | 20 | 6 | 8 | 20 | 30 | 45 | 4 | 12 | 25 | 4 | 10 | 20 |
| Project 2 | 21% | 45 | 3 | 6 | 10 | 25 | 5 | 10 | 20 | 5 | 8 | 20 | 30 | 25 | 4 | 12 | 25 | 4 | 9 | 17 |
| Project 3 | 11% | 60 | 3 | 6 | 10 | 34 | 5 | 10 | 20 | 3 | 8 | 20 | 30 | 4 | 4 | 12 | 25 | 4 | 8 | 14 |
| Project 4 | 5% | 51 | 3 | 8 | 15 | 21 | 5 | 13 | 20 | 1 | 8 | 20 | 30 | 26 | 4 | 17 | 25 | 4 | 12 | 19 |
| Project 5a | 14% | 77 | 3 | 6 | 10 | 7 | 5 | 12 | 20 | 0 | 8 | 19 | 30 | 17 | 4 | 15 | 25 | 3 | 8 | 13 |
| Project 5b | 14% | 13 | 0 | 2 | 4 | 0 | 0 | 5 | 10 | 13 | 0 | 13 | 30 | 75 | 0 | 6 | 15 | 0 | 7 | 16 |
| **Total** | **100%** | **42** | **3** | **5** | **9** | **17** | **4** | **10** | **19** | **5** | **7** | **19** | **30** | **36** | **3** | **12** | **24** | **3** | **9** | **17** |
| **Compounded Costs (includes Project Duration Derived Costs)** | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 36% | 31 | 3 | 9 | 17 | 18 | 4 | 11 | 25 | 6 | 7 | 18 | 32 | 45 | 7 | 16 | 34 | 5 | 13 | 27 |
| Project 2 | 21% | 45 | 4 | 9 | 18 | 25 | 5 | 12 | 26 | 5 | 8 | 20 | 35 | 25 | 7 | 17 | 36 | 5 | 12 | 25 |
| Project 3 | 11% | 60 | 3 | 9 | 17 | 34 | 4 | 12 | 25 | 3 | 7 | 18 | 33 | 4 | 6 | 16 | 34 | 4 | 10 | 21 |
| Project 4 | 5% | 51 | 5 | 12 | 20 | 21 | 6 | 14 | 25 | 1 | 8 | 21 | 35 | 26 | 9 | 24 | 43 | 6 | 16 | 27 |
| Project 5a | 14% | 77 | 3 | 8 | 15 | 7 | 4 | 10 | 19 | 0 | 5 | 13 | 23 | 17 | 6 | 13 | 22 | 4 | 9 | 16 |
| Project 5b | 14% | 13 | 0 | 6 | 12 | 0 | 0 | 8 | 16 | 13 | 0 | 11 | 26 | 75 | 0 | 8 | 18 | 0 | 8 | 18 |
| **Total** | **100%** | **42** | **3** | **9** | **17** | **17** | **4** | **11** | **23** | **5** | **6** | **17** | **31** | **36** | **6** | **15** | **31** | **4** | **12** | **23** |

**Project Types**

1: Freeway Reconstruction and Widening
2: Non-Freeway Reconstruction and Widening
3: New Construction
4: Bridge Replacement
5a: Rehabilitation and Overlay (Rural)
5b: Rehabilitation and Overlay (Urban)

**Work Schedule Alternatives**

A: Fully Delayed Continuous Operations
B: Partially Delayed, Continuous Operations
C:Delayed Non Continuous Operations
D: Continuous, Nighttime Operations

# APPENDIX E

# TxDOT SURVEY RESULTS (DFW)

## TxDOT SURVEY RESULTS (DFW)

| | | Work Schedule Alternatives | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Project Types** | **% Total Cost** | **A** | | | | **B** | | | | **C** | | | | **D** | | | | **Average** | | |
| | | % | Low | Ave | High | % | Low | Ave | High | % | Low | Ave | High | % | Low | Ave | High | Low | Ave | High |
| **Cost Totals** | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 24% | 55 | 0 | 2 | 5 | 33 | 10 | 13 | 15 | 8 | 20 | 26 | 40 | 5 | 5 | 10 | 20 | 5 | 8 | 12 |
| Project 2 | 25% | 60 | 0 | 2 | 5 | 30 | 10 | 13 | 15 | 8 | 20 | 26 | 40 | 1 | 5 | 10 | 20 | 5 | 7 | 11 |
| Project 3 | 22% | 85 | 0 | 2 | 5 | 15 | 10 | 13 | 15 | 0 | 20 | 26 | 40 | 1 | 5 | 10 | 20 | 1 | 4 | 7 |
| Project 4 | 6% | 39 | 0 | 2 | 4 | 54 | 1 | 2 | 4 | 3 | 5 | 13 | 25 | 5 | 5 | 10 | 20 | 1 | 3 | 5 |
| Project 5a | 12% | 85 | 1 | 3 | 5 | 10 | 15 | 20 | 25 | 0 | 30 | 38 | 50 | 5 | 5 | 10 | 15 | 3 | 5 | 8 |
| Project 5b | 12% | 25 | 1 | 3 | 5 | 0 | 15 | 20 | 25 | 0 | 30 | 38 | 50 | 75 | 5 | 10 | 15 | 4 | 8 | 13 |
| **Total** | 100% | 62 | 0 | 2 | 5 | 23 | 11 | 14 | 17 | 4 | 21 | 28 | 41 | 11 | 5 | 10 | 19 | 3 | 6 | 10 |
| **Project Duration** | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 24% | 55 | 0 | 2 | 5 | 33 | 5 | 9 | 10 | 8 | 20 | 31 | 45 | 5 | 0 | 7 | 15 | 3 | 6 | 10 |
| Project 2 | 25% | 60 | 0 | 2 | 5 | 30 | 5 | 9 | 10 | 8 | 20 | 31 | 45 | 1 | 0 | 7 | 15 | 3 | 6 | 10 |
| Project 3 | 22% | 85 | 0 | 2 | 5 | 15 | 5 | 9 | 10 | 0 | 20 | 31 | 45 | 1 | 0 | 7 | 15 | 1 | 3 | 6 |
| Project 4 | 6% | 39 | 0 | 1 | 2 | 54 | 0 | 1 | 2 | 3 | 10 | 26 | 40 | 5 | 0 | 6 | 15 | 0 | 2 | 4 |
| Project 5a | 12% | 85 | 0 | 2 | 5 | 10 | 20 | 20 | 20 | 0 | 30 | 45 | 60 | 5 | 0 | 8 | 15 | 2 | 4 | 7 |
| Project 5b | 12% | 25 | 0 | 2 | 5 | 0 | 20 | 20 | 20 | 0 | 30 | 45 | 60 | 75 | 0 | 8 | 15 | 0 | 6 | 13 |
| **Total** | 100% | 62 | 0 | 1 | 5 | 23 | 8 | 11 | 12 | 4 | 22 | 34 | 48 | 11 | 0 | 7 | 15 | 2 | 5 | 9 |
| **Compunded Costs (includes Project Duration Derived Costs)** | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 24% | 55 | 1 | 3 | 6 | 33 | 15 | 18 | 20 | 8 | 40 | 47 | 63 | 5 | 9 | 14 | 24 | 9 | 11 | 16 |
| Project 2 | 25% | 60 | 1 | 3 | 6 | 30 | 15 | 18 | 20 | 8 | 39 | 47 | 62 | 1 | 9 | 14 | 24 | 8 | 11 | 15 |
| Project 3 | 22% | 85 | 1 | 3 | 6 | 15 | 15 | 17 | 20 | 0 | 39 | 46 | 62 | 1 | 9 | 14 | 24 | 3 | 5 | 8 |
| Project 4 | 6% | 39 | 0 | 2 | 4 | 54 | 1 | 3 | 4 | 3 | 18 | 27 | 41 | 5 | 8 | 13 | 24 | 2 | 3 | 6 |
| Project 5a | 12% | 85 | 2 | 4 | 6 | 10 | 24 | 30 | 35 | 0 | 54 | 63 | 78 | 5 | 8 | 13 | 19 | 4 | 7 | 9 |
| Project 5b | 12% | 25 | 2 | 4 | 6 | 0 | 25 | 30 | 35 | 0 | 54 | 63 | 78 | 75 | 8 | 13 | 19 | 7 | 11 | 15 |
| **Total** | 100% | | 1 | 3 | 6 | | 16 | 20 | 23 | | 41 | 49 | 65 | | 9 | 14 | 23 | 6 | 9 | 12 |

**Project Types**
1: Freeway Reconstruction and Widening
2: Non-Freeway Reconstruction and Widening
3: New Construction
4: Bridge Replacement
5a: Rehabilitation and Overlay (Rural)
5b: Rehabilitation and Overlay (Urban)

**Work Schedule Alternatives**
A: Fully Delayed Continuous Operations
B: Partially Delayed, Continuous Operations
C:Delayed Non Continuous Operations
D: Continuous, Nighttime Operations

# APPENDIX F

## CONTRACTOR SURVEY RESULTS (DFW)

## CONTRACTOR SURVEY RESULTS (HGA)

| | | Work Schedule Alternatives | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Project Types** | **% Total Cost** | **A** | | | | **B** | | | | **C** | | | | **D** | | | | **Average** | | |
| | | % | Low | Ave | High | % | Low | Ave | High | % | Low | Ave | High | % | Low | Ave | High | Low | Ave | High |
| **Cost Totals** | | | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 36% | 31 | 2 | 6 | 12 | 18 | 2 | 7 | 15 | 6 | 4 | 9 | 17 | 45 | 5 | 11 | 22 | 4 | 9 | 17 |
| Project 2 | 21% | 45 | 2 | 7 | 13 | 25 | 2 | 7 | 15 | 5 | 4 | 9 | 18 | 25 | 5 | 11 | 22 | 3 | 8 | 16 |
| Project 3 | 11% | 60 | 2 | 6 | 13 | 34 | 2 | 7 | 15 | 3 | 3 | 9 | 17 | 4 | 5 | 10 | 21 | 2 | 7 | 14 |
| Project 4 | 5% | 51 | 4 | 8 | 13 | 21 | 4 | 8 | 14 | 1 | 4 | 11 | 18 | 26 | 7 | 15 | 29 | 5 | 10 | 17 |
| Project 5a | 14% | 77 | 3 | 7 | 12 | 7 | 3 | 7 | 13 | 0 | 3 | 8 | 14 | 17 | 5 | 9 | 14 | 3 | 7 | 12 |
| Project 5b | 14% | 13 | 0 | 5 | 11 | 0 | 0 | 6 | 12 | 13 | 0 | 6 | 14 | 75 | 0 | 6 | 12 | 0 | 6 | 12 |
| **Total** | **100%** | **42** | **2** | **6** | **12** | **17** | **2** | **7** | **14** | **5** | **3** | **9** | **16** | **36** | **4** | **10** | **20** | **3** | **8** | **15** |
| **Project Duration** | | | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 36% | 31 | 3 | 6 | 10 | 18 | 5 | 10 | 20 | 6 | 8 | 20 | 30 | 45 | 4 | 12 | 25 | 4 | 10 | 20 |
| Project 2 | 21% | 45 | 3 | 6 | 10 | 25 | 5 | 10 | 20 | 5 | 8 | 20 | 30 | 25 | 4 | 12 | 25 | 4 | 9 | 17 |
| Project 3 | 11% | 60 | 3 | 6 | 10 | 34 | 5 | 10 | 20 | 3 | 8 | 20 | 30 | 4 | 4 | 12 | 25 | 4 | 8 | 14 |
| Project 4 | 5% | 51 | 3 | 8 | 15 | 21 | 5 | 13 | 20 | 1 | 8 | 20 | 30 | 26 | 4 | 17 | 25 | 4 | 12 | 19 |
| Project 5a | 14% | 77 | 3 | 6 | 10 | 7 | 5 | 12 | 20 | 0 | 8 | 19 | 30 | 17 | 4 | 15 | 25 | 3 | 8 | 13 |
| Project 5b | 14% | 13 | 0 | 2 | 4 | 0 | 0 | 5 | 10 | 13 | 0 | 13 | 30 | 75 | 0 | 6 | 15 | 0 | 7 | 16 |
| **Total** | **100%** | **42** | **3** | **5** | **9** | **17** | **4** | **10** | **19** | **5** | **7** | **19** | **30** | **36** | **3** | **12** | **24** | **3** | **9** | **17** |
| **Compounded Costs (includes Project Duration Derived Costs)** | | | | | | | | | | | | | | | | | | | | | | |
| Project 1 | 36% | 31 | 3 | 9 | 17 | 18 | 4 | 11 | 25 | 6 | 7 | 18 | 32 | 45 | 7 | 16 | 34 | 5 | 13 | 27 |
| Project 2 | 21% | 45 | 4 | 9 | 18 | 25 | 5 | 12 | 26 | 5 | 8 | 20 | 35 | 25 | 7 | 17 | 36 | 5 | 12 | 25 |
| Project 3 | 11% | 60 | 3 | 9 | 17 | 34 | 4 | 12 | 25 | 3 | 7 | 18 | 33 | 4 | 6 | 16 | 34 | 4 | 10 | 21 |
| Project 4 | 5% | 51 | 5 | 12 | 20 | 21 | 6 | 14 | 25 | 1 | 8 | 21 | 35 | 26 | 9 | 24 | 43 | 6 | 16 | 27 |
| Project 5a | 14% | 77 | 3 | 8 | 15 | 7 | 4 | 10 | 19 | 0 | 5 | 13 | 23 | 17 | 6 | 13 | 22 | 4 | 9 | 16 |
| Project 5b | 14% | 13 | 0 | 6 | 12 | 0 | 0 | 8 | 16 | 13 | 0 | 11 | 26 | 75 | 0 | 8 | 18 | 0 | 8 | 18 |
| **Total** | **100%** | **42** | **3** | **9** | **17** | **17** | **4** | **11** | **23** | **5** | **6** | **17** | **31** | **36** | **6** | **15** | **31** | **4** | **12** | **23** |

**Project Types**

1: Freeway Reconstruction and Widening
2: Non-Freeway Reconstruction and Widening
3: New Construction
4: Bridge Replacement
5a: Rehabilitation and Overlay (Rural)
5b: Rehabilitation and Overlay (Urban)

**Work Schedule Alternatives**

A: Fully Delayed Continuous Operations
B: Partially Delayed, Continuous Operations
C:Delayed Non Continuous Operations
D: Continuous, Nighttime Operations

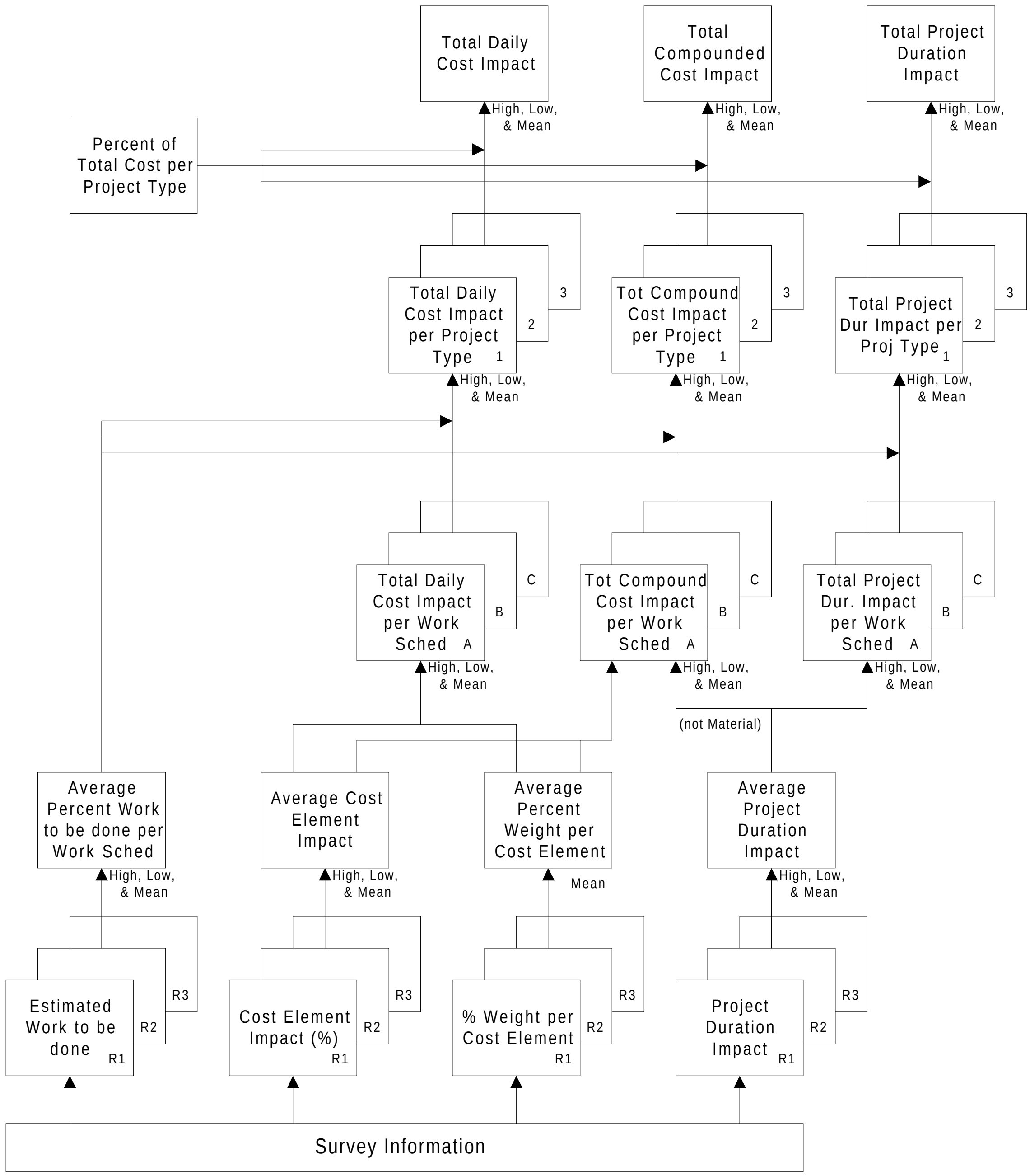
# APPENDIX G

# CALCULATION EXAMPLE

The following example follows the calculation method used to arrive at the cost and schedule impacts for the HG and the DFW areas. All calculations are based on information supplied by the contractors through the surveys and by funding allocation data furnished by TxDOT. The data used in this example are fictitious and do not represent the information supplied by any of the respondents.

The respondents provided data regarding the survey elements from which the total cost and schedule impacts were calculated. The total cost and schedule impacts were calculated by aggregating data starting with the data supplied by the respondents for the individual cost and schedule elements.

The overall calculation procedure is diagrammed in Figure G1.




**Legend:**
R1, R2, R3: Respondent information supplied in the surveys
A, B, C: Work schedule alternatives
1, 2, 3: Project types
High, Low, Mean: High, low and mean (average) values were calculated for the element

**Figure G1 Calculation Procedure for Overall Cost and Schedule Impact.**

The example will first calculate the total daily cost impact, then the total project duration impact, and finally the total compounded cost impact.

## Total Daily Cost Impact

### Survey Elements

The survey information was furnished by the contractors as a percent change for the different survey elements:

- cost elements: direct field labor, materials, equipment, field indirect, and home office;
- cost elements percent weight: the relative cost of each cost element compared to total project cost;
- schedule elements: project duration and overall labor productivity;
- estimated work to be completed under each WSA; and
- individual cost factors .

For purposes of this example, the base data represent the information supplied for one project type (freeway reconstruction and widening) by one respondent. Since survey information on the cost factors is not used to calculate the overall cost and schedule impacts, it has not been included in the calculation example. Table G1 consists of the hypothetical information that was used as the database in this example.

## Table G1. Hypothetical Survey Data

**#1** **Project Type:** ***Freeway Reconstruction and Widening***

- Project Cost: > $20M
- Increase 2 lanes to 4 lanes each direction with new frontage roads
- Length: 2 - 4 miles
- 3-Span Overpass every 3/4 mile
- Traffic: 100,000 vehicles/day
- Pavement Cross section
  13 - 15" CRCP (main lanes)
  8 - 10" CRCP (frontage roads)
  1" ASB Bond Breaker
  6" Portland Cement-Stabilized Base
  6" Lime-treated Subgrade

| **PART I.** | **Percentage of Total Cost** | **Percentage Change in Cost for Work Schedule Alternative** | | | | |
|---|---|---|---|---|---|---|
| **A. Cost Elements** | | **A** | **B** | **C** | **D** | **N/A** |
| **Direct Field Labor** | **20 %** | **10 – 20 %** | **15 – 22 %** | **30 – 40 %** | **20 – 25 %** | **-- %** |
| Comments - | | | | | | |
| **Materials** | **50 %** | **1 – 5 %** | **1 – 5 %** | **10 – 15 %** | **10 – 15 %** | **-- %** |
| Comments – | | | | | | |
| **Equipment** | **14 %** | **3 – 8 %** | **4 – 10 %** | **15 – 20 %** | **10 – 15 %** | **-- %** |
| Comments - | | | | | | |
| **Field Indirect** | **8 %** | **2 – 6 %** | **2 – 6 %** | **3 – 8 %** | **10 - 15 %** | **-- %** |
| Comments - | | | | | | |
| **Home Office** | **8 %** | **2 – 4 %** | **2 – 4 %** | **5 – 10 %** | **10 – 15 %** | **-- %** |
| Comments - | | | | | | |

## Table G1. Hypothetical Survey Data (continued)

| #1 | Project Type: *Freeway Reconstruction and Widening* | | | | |
|---|---|---|---|---|---|
| **PART I. (continued)** | **Percentage Change in Cost for Work Schedule Alternative** | | | | |
| **B. Schedule Elements** | **A** | **B** | **C** | **D** | **N/A** |
| **Project Duration** | **15 – 25 %** | **20 – 25 %** | **30 – 40 %** | **25 – 30 %** | **-- %** |
| Comments - | | | | | |
| **Overall Labor Productivity** | **15 – 20 %** | **15 – 25 %** | **30 – 40 %** | **20 – 30 %** | **-- %** |
| Comments – **Decrease in Productivity** | | | | | |
| **PART II.** | **A** | **B** | **C** | **D** | **N/A** |
| **Anticipated percentage of work conducted under the differing work schedule alternatives:** | **40 %** | **25 %** | **5 %** | **30 %** | **Not Available** |
| Comments - | | | | | |
| **PART III. Specific Factors Affecting Cost** | **Percentage Change in Cost for Work Schedule Alternative** | | | | |
| | **A** | **B** | **C** | **D** | **N/A** |
| **Labor Wage Rates** | **-- %** | **-- %** | **-- %** | **-- %** | **-- %** |
| Comments - | | | | | |
| **Traffic Control** | **-- %** | **-- %** | **-- %** | **-- %** | **-- %** |
| Comments - | | | | | |
| **Construction Lighting** | **-- %** | **-- %** | **-- %** | **-- %** | **-- %** |
| Comments - | | | | | |
| **Safety: Insurance & Workers' Compensation** | **-- %** | **-- %** | **-- %** | **-- %** | **-- %** |
| Comments - | | | | | |
| **Quality: Rework** | **-- %** | **-- %** | **-- %** | **-- %** | **-- %** |
| Comments - | | | | | |

The survey elements were provided as a range with a low and a high value. Only the percent weight for each cost element was given as a single value. For each survey element, an average value was calculated based on the data provided by the respondent.

$$Average\ Percent\ Weight\ per\ Cost\ Element = \frac{\sum_{i}^{n}(Percent\ weight\ per\ Cost\ Imp)}{n} \tag{G 1}$$

For i = 1 to n, where n = number of respondents

Calculating the direct field labor average cost impact, for example:

$$Direct\ Field\ Labor\ Average\ Cost\ Impact = \frac{20 + 10}{2} = \frac{30}{2} = 15\% \tag{G 2}$$

Table G2 indicates the average cost impact for the cost elements for WSA A used in the example.

**Table G2. Example of Average Cost Impact for Work Schedule A Cost Elements.**

| | **Impact** | | |
|---|---|---|---|
| **Cost Element** | **Low (%)** | **High (%)** | **Average (%)** |
| Direct Field Labor | 10 | 20 | 15 |
| Materials | 1 | 5 | 3 |
| Equipment | 3 | 8 | 5.5 |
| Field Indirect | 2 | 6 | 4 |
| Home Office | 2 | 4 | 3 |

Average Percent Weight per Cost Element

The percent weight per cost clement represents the relative allocation of funds on a cost element compared to the total project's cost. The percent weight per cost elements was provided by the respondents as a single value. The average percent weight per cost element was calculated as the mean of the individual percent weights for each cost element.

$$\text{Average Percent Weight per Cost Element} = \frac{\sum(\text{Percent weight per Cost Imp})}{n}$$

(G 3)

where n = number of respondents

Average Cost Elements Impact

For each cost element, the average cost element impact was calculated from the data supplied by the respondents. Three values were derived from the respondents' surveys: a low value, an average or mean value, and a high value for each cost element impact. The overall low value is the minimum of the values provided by the various respondents for a particular cost element.

$$\text{Low Cost Element Impact} = \text{MIN(Low Cost Element Imp)}$$

(G 4)

The overall high value is the maximum of the values provided by the various respondents for a particular cost element.

$$\text{High Cost Element Impact} = \text{MAX(High Cost Element Imp)}$$

(G 5)

The average or mean value is the average of the averages calculated from the respondents' information for a particular cost element.

$$\text{Average Cost Element Impact} = \frac{\sum(\text{Average cost element imp}_i)}{n}$$

(G 6)

for i = 1 to n, where n = number of respondents

Table G3 indicates the results for the direct field cost for this example.

**Table G3. Example of Low, High, and Mean Average Direct Field Cost Impact.**

| Respondent | Percent Weight (%) | Low (%) | High (%) | Average (%) |
|---|---|---|---|---|
| 1 | 20 | 10 | 20 | 15 |
| 2 | 30 | 20 | 30 | 25 |
| 3 | 25 | 5 | 25 | 15 |
| 4 | 18 | 10 | 18 | 14 |
| **Average/Min/Max** | **23** | **5** | **30** | **17** |

Work Schedule Alternative Total Daily Cost Impact

Each of the cost element calculations was performed for the WSAs available on the survey. The WSA total daily cost impact ($TDCI_{WSA}$) represents the expected total cost change for a project performed under a particular WSA as a result of day-to-day cost impacts.

$TDCI_{WSA}$ for a particular WSA was calculated from the individual average cost element impacts and the corresponding average percent weights per cost element. Each average cost element percent impact was multiplied by its corresponding average percent weight and the totals added to arrive at the $TDCI_{WSA}$. This was done for the high, low, and average values.

$$Average\ TDCI_{WSA} = \sum_{i}^{n} (\ Average\ Cost\ Element\ Impact \times Average\ Percent\ We$$

(G 7)

$$Low\ TDCI_{WSA} = \sum_{i}^{n} \left(Low\ Cost\ Element\ Impact_i \times Average\ Percent\ Wei\right)$$

(G 8)

$$High\ TDCI_{WSA} = \sum_{i}^{n} \left(High\ Cost\ Element\ Impact_i \times Average\ Percent\ Wei\right)$$

(G 9)

where n = number of respondents

Table G4 indicates the $TDCI_{WSA}$ results for WSA A and project type 1 (freeway reconstruction and widening) for the hypothetical example.

**Table G4. Example of Total Daily Cost Impact calculation for a Particular WSA.**

| Cost Element | Average Percent Weight (%) | Weighted Low (%) | Weighted High (%) | Average (%) |
|---|---|---|---|---|
| Direct Field Labor | 23 | 5 | 30 | 17 |
| Materials | 52 | 2 | 8 | 5 |
| Equipment | 12 | 3 | 10 | 7 |
| Field Indirect | 7 | 1 | 11 | 6 |
| Home Office | 6 | 2 | 10 | 6 |
| **$TDCI_{WSA}$** | **23** | **3** | **14** | **8** |

$$\text{Average TDCI}_{WSA} = (0.23 \text{ x } 17 + 0.52 \text{ x } 5 + 0.12 \text{ x } 7 + 0.07 \text{ x } 6 + 0.06 \text{ x } 6) = 8\%$$

$$\text{Low TDCI}_{WSA} = (0.23 \text{ x } 5 + 0.52 \text{ x } 2 + 0.12 \text{ x } 3 + 0.07 \text{ x } 1 + 0.06 \text{ x } 2) = 3\%$$

$$\text{High TDCI}_{WSA} = (0.23 \text{ x } 30 + 0.52 \text{ x } 8 + 0.12 \text{ x } 10 + 0.07 \text{ x } 11 + 0.06 \text{ x } 10) = 14\%$$

Average Percent Work to Be Completed under a Work Schedule Alternative

Each project type was projected to utilize various WSAs. The average percent work to be completed under a WSA ($APW_{WSA}$) indicates the expected relative application of a particular WSA. For example, the average percent work to be completed for WSA A is calculated as follows:

$$APW_{WSA\text{-}A} = \frac{\sum_{i}^{n} (\text{Estimated Work to be Completed under AW})}{n} \qquad \text{(G 10)}$$

for I = 1 to n, where n = number of respondents

Table G5 indicates the average percent of work to be completed under the various WSAs for a project type from the information gathered from the surveys.

**Table G5. Average Percent of Work to be Completed under WSA for a particular Project Type.**

| **Respondent** | Estimated Work to Be Completed under Each WSA | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 1 | 50 | 30 | 3 | 15 |
| 2 | 50 | 35 | 8 | 12 |
| 3 | 40 | 25 | 4 | 20 |
| 4 | 60 | 30 | 5 | 13 |
| **$APW_{WSA}$** | **50** | **30** | **5** | **15** |

For example, the $APW_{WSA\text{-}A}$ is calculated as follows:

$$APW_{WSA\text{-}A} = \left( \frac{50 + 50 + 40 + 60}{4} \right) = 50\%$$

Project Type Total Daily Cost Impact

The daily cost impact for each project type considered the cost impacts for each WSA. The project type total daily cost impact ($TDCI_{pt}$) represents the estimated day-to-day total cost change for a particular project type.

For each project type, the $TDCI_{PT}$ was calculated using the various total daily cost impact for each WSA ($TDCI_{WSA}$), and the average percent work to be completed under a WSA ($APW_{WSA}$).

The $TDCI_{WSA}$ values obtained previously were multiplied by the $APW_{WSA}$, and then the totals were added to produce the $TDCI_{PT}$. This process was repeated for low, the high, and average values.

$$Average\ TDCI_{PT} = \sum_{j}^{n} \left( Average\ TDCI_{WSAj}\ x\ AP\ W_{WSAj} \right) \tag{G 11}$$

$$Low\ TDCI_{PT} = \sum_{j}^{n} \left( Low\ TDCI_{WSAj}\ x\ AP\ W_{WSAj} \right) \tag{G 12}$$

$$High\ TDCI_{PT} = \sum_{j}^{n} \left( High\ TDCI_{WSAj}\ x\ AP\ W_{WSAj} \right) \tag{G 13}$$

where n = number of WSA

Table G6 indicates the $TDCI_{PT}$ results for the Project Type 1 (freeway reconstruction and widening) for the example.

**Table G6. Example of Project Type 1 (Freeway Reconstruction and Widening) Total Daily Cost Impact.**

| Work Schedule Alternative | Average Percent Weight ($APW_{WSA}$) (%) | Low (%) | High (%) | Average (%) |
|---|---|---|---|---|
| Alternative A | 50 | 3 | 14 | 8 |
| Alternative B | 30 | 5 | 20 | 13 |
| Alternative C | 5 | 10 | 35 | 23 |
| Alternative D | 15 | 8 | 30 | 19 |
| **$TDCI_{PT}$** | | **5** | **19** | **12** |

$$\text{Average TDCI}_{PT} = (0.5 \text{ x } 8 + 0.3 \text{ x } 13 + 0.05 \text{ x } 23 + 0.15 \text{ x } 19) = 12\%$$

$$\text{Low TDCI}_{PT} = (0.5 \text{ x } 3 + 0.3 \text{ x } 5 + 0.05 \text{ x } 10 + 0.15 \text{ x } 8) = 5\%$$

$$\text{High TDCI}_{PT} = (0.5 \text{ x } 14 + 0.3 \text{ x } 20 + 0.05 \text{ x } 35 + 0.15 \text{ x } 30) = 19\%$$

Total Daily Cost Impact

The total daily cost impact (TDCI) indicates the estimated cost change for all construction projects within an area (HG and DFW) due to day-to-day cost impacts.

The evaluation used the total daily cost impacts for each project type ($TDCI_{PT}$) as well as the percentage of the total cost for each project type. The percent of total cost per project type ($PTC_{PT}$) represented the relative funding expended by TxDOT on highway construction projects for each Project Type with respect to its total funding. These values were calculated using historical data for the HG and for the DFW areas for 1997, 1998, 1999, and 2000.

TxDOT provided data regarding the funds allocated to each project type for 1997 through 2000. This information was used to aggregate the calculated partial impacts to the overall total impacts. Table G7 indicates the percent allocation of funds for each project type for the HG.

**Table G7. Relative Percent Weight of Project Types (HG).**

| Project Type | | | | | | Total |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5a/5b | | |
| Freeway | Non-Freeway | New Construction | Bridge Replacement | Rehab & Overlay | | |
| | | | | Rural | Urban | |
| 36.0% | 21.4% | 10.8% | 4.6% | 13.7% | 13.7% | 100% |

The total daily cost impact is a weighted average of the individual total daily cost impacts for each project type and the percents of total costs for each project type. This process was repeated for the high, low, and average values.

$$Average\ TDCI = \sum_{k}^{n}\left(Average\ TDCI_{PT\ k} \times PTC_{PT\ k}\right) \tag{G 14}$$

$$Low\ TDCI = \sum_{k}^{n}\left(Low\ TDCI_{PT\ k} \times PTC_{PT\ k}\right) \tag{G 15}$$

$$High\ TDCI = \sum_{k}^{n}\left(High\ TDCI_{PT\ k} \times PTC_{PT\ k}\right) \tag{G 16}$$

where n = number of project types

Table G8 indicates the total daily cost impact (TDCI) results for the HG for our example.

**Table G8. Example HG Area Total Daily Cost Impact.**

| Project Type | $PTC_{PT}$ (%) | Low (%) | High (%) | Average (%) |
|---|---|---|---|---|
| Freeway Reconstruction | 36.0 | 5 | 19 | 12 |
| Non-Freeway Reconstruction | 21.4 | 6 | 20 | 13 |
| New Construction | 10.8 | 8 | 28 | 18 |
| Bridge Replacement | 4.6 | 6 | 25 | 16 |
| Overlay and Rehab (Rural) | 13.7 | 10 | 30 | 20 |
| Overlay and Rehab (Urban) | 13.7 | 2 | 10 | 6 |
| **TDCI** | | **6** | **21** | **13** |

$$\text{Average TDCI} = (0.36 \text{ x } 12 + 0.214 \text{ x } 13 + 0.108 \text{ x } 18 + 0.046 \text{ x } 16 + 0.137 \text{ x } 20 + 0.137 \text{ x } 6) = 13\%$$

$$\text{Low TDCI} = (0.36 \text{ x } 5 + 0.214 \text{ x } 6 + 0.108 \text{ x } 8 + 0.046 \text{ x } 6 + 0.137 \text{ x } 10 + 0.137 \text{ x } 2) = 6\%$$

$$\text{High TDCI} = (0.36 \text{ x } 19 + 0.214 \text{ x } 20 + 0.108 \text{ x } 28 + 0.046 \text{ x } 25 + 0.137 \text{ x } 30 + 0.137 \text{ x } 10) = 21\%$$

## Total Project Duration Impact (TPDI)

The total project duration impact (TPDI) represents the overall expected change in the project's duration. The procedure used followed the same sequence as the one used to determine the total daily cost impact. Impact on project duration was dependent upon which WSA was selected for a particular portion of a project type. The total project duration impact ($TPDI_{WSA}$) for each WSA indicates the expected project duration changes for each WSA. The data provided by the respondents as a range was used to determine the average expected project duration.

$$Average\ TPDI_{WSA} = \frac{Project\ Duration\ High\ Value + Project\ Duration\ Low\ Va}{2}$$

(G17)

From the data provided in the example for WSA A:

$$\text{Average TPDI}_{\text{WSA}} = \frac{15+25}{2} = \frac{40}{2} = 20\%$$

$$\text{Low TPDI}_{\text{WSA}} = \text{Low Project Duration Impact} = 15\%$$

$$\text{High TPDI}_{\text{WSA}} = \text{High Project Duration Impact} = 25\%$$

The total project duration impact ($TPDI_{PT}$) was calculated for each project type based on the project duration impact estimated by the respondents for each WSA. The $TPDI_{WSA}$ values were multiplied by the average percent work to be done under a WSA, and the results added. This process was repeated for the low, the high, and the average values.

$$Average\ TPDI_{PT} = \sum_{j}^{n}\left(Average\ TPDI_{WSA_j}\ x\ AP\ W_{WSA_j}\right)$$

(G 18)

$$Low\ TPDI_{PT} = \sum_{j}^{n}\left(Low\ TPDI_{WSA_j}\ x\ AP\ W_{WSA_j}\right)$$

(G 19)

$$High\ TPDI_{PT} = \sum_{j}^{n}\left(High\ TPDI_{WSAj}\ x\ AP\ W_{WSAj}\right)$$

(G 20)

where n = number of WSAs

Table G9 indicates the $TPDI_{PT}$ results for the Project Type 1 (freeway reconstruction and widening) in our hypothetical example.

**Table G9. Example of Project Type 1 (Freeway Reconstruction and Widening) Total Project Duration Impact.**

| WSA | Average Percent Weight ($APW_{WSA}$) | Low (%) | High (%) | Average (%) |
|---|---|---|---|---|
| Alternative A | 50 | 15 | 25 | 20 |
| Alternative B | 30 | 18 | 30 | 24 |
| Alternative C | 5 | 30 | 44 | 37 |
| Alternative D | 15 | 22 | 30 | 26 |
| **$TPDI_{PT}$** | | **18** | **28** | **23** |

$$\text{Average TPDI}_{PT} = (0.5 \text{ x } 20 + 0.3 \text{ x } 24 + 0.05 \text{ x } 37 + 0.15 \text{ x } 26) = 23\%$$

$$\text{Low TPDI}_{PT} = (0.5 \text{ x } 15 + 0.3 \text{ x } 18 + 0.05 \text{ x } 30 + 0.15 \text{ x } 22) = 18\%$$

$$\text{High TPDI}_{PT} = (0.5 \text{ x } 25 + 0.3 \text{ x } 30 + 0.05 \text{ x } 44 + 0.15 \text{ x } 30) = 28\%$$

The TPDI for the HG and the DFW areas represents the overall expected impacts on the projects' duration for each of the two areas. The TPDIs were calculated from the $TPDI_{PT}$ for each project type and from the project type percent of total cost ($PTC_{PT}$). Each $TPDI_{PT}$ was multiplied by the percent total cost per project type ($PTC_{PT}$) and the results summed to arrive at the TPDI. This process was repeated by for the low, high, and average values.

$$Average\ TPDI = \sum_{i}^{n}\left(Average\ TPDI_{PT\,i}\ x\ PTC_{PT\,i}\right)$$

(G 21)

$$Low\ TPDI = \sum_{i}^{n} \left( Low\ TPDI_{PT\ i}\ x\ PTC_{PT\ i} \right)$$

(G 22)

$$High\ TPDI = \sum_{i}^{n} \left( High\ TPDI_{PT\ i}\ x\ PTC_{PT\ i} \right)$$

(G 23)

where n = number of project Types

Table G10 indicates the TPDI results for the HG area for our example.

**Table G10. Example of HG Area Total Project Duration Impact.**

| Project Type | $PTC_{PT}$ (%) | Weighted Low (%) | Weighted High (%) | Average (%) |
|---|---|---|---|---|
| Freeway Reconstruction | 36.0 | 18 | 28 | 23 |
| Non-Freeway Reconstruction | 21.4 | 20 | 30 | 25 |
| New Construction | 10.8 | 10 | 14 | 12 |
| Bridge Replacement | 4.6 | 22 | 32 | 26 |
| Overlay and Rehab (Rural) | 13.7 | 10 | 30 | 20 |
| Overlay and Rehab (Urban) | 13.7 | 26 | 36 | 32 |
| **TDCI** | | **18** | **29** | **23** |

Average TDCI =
$(0.36 \text{ x } 23 + 0.214 \text{ x } 25 + 0.108 \text{ x } 12 + 0.046 \text{ x } 26 + 0.137 \text{ x } 20 + 0.137 \text{ x } 32) = 32\%$

Low TDCI =

$(0.36 \text{ x } 18 + 0.214 \text{ x } 20 + 0.108 \text{ x } 10 + 0.046 \text{ x } 22 + 0.137 \text{ x } 10 + 0.137 \text{ x } 26) = 18\%$

High TDCI =

$(0.36 \text{ x } 28 + 0.214 \text{ x } 30 + 0.108 \text{ x } 14 + 0.046 \text{ x } 32 + 0.137 \text{ x } 30 + 0.137 \text{ x } 36) = 29\%$

**Total Compounded Cost Impact**

The total compounded cost impact (TCCI) represents the overall cost impact including the daily cost and the schedule driven cost impacts. A project's cost is affected not only by the day-to-day cost variations but also by the total project's duration. A project's cost, however, is typically not directly proportional to the project's duration changes. Certain cost elements are affected by the project schedule while others are not. Materials is the only cost element used in this research that is not significantly affected by time. All other cost elements (direct field labor, equipment, field indirect, and home office costs) vary proportionally to the impacts to the project duration.

The procedure used in the determination of the total compounded cost impact is essentially the same process used to determine the total daily cost impact. The average cost and project duration elements impacts were calculated previously. The daily impacts for direct field labor, equipment, field indirect, and home office costs are compounded by the project duration impacts to arrive at the compounded cost element impacts ($CC_{EI}$) as follows:

$$\text{Average } CC_{EI} = (\text{Average Cost Element Impact x Average Project Duration Impact}) - 1.0$$
$$\text{Low } CC_{EI} = (\text{Low Average Cost Element Impact x Average Project Duration Impact}) - 1.0$$
$$\text{High } CC_{EI} = (\text{High Average Cost Element Impact x Average Project Duration Impact}) - 1.0$$

Table G11 indicates the calculation performed to determine the direct field labor compounded cost impacts for our example.

**Table G11. Example of Direct Field Labor Compounded Cost Impact.**

| | **Impact** | | |
|---|---|---|---|
| | **Low (%)** | **High (%)** | **Average (%)** |
| Direct Field Labor | 10 | 20 | 15 |
| Average Project Duration Impact | 25 | 25 | 25 |
| Compounded Cost Impact | 38 | 50 | 44 |

$$\text{Average Direct Field Labor Compounded Cost} = (1.15 \times 1.25) - 1 = 44\%$$

$$\text{Low Average Direct Field Labor Compounded Cost} = (1.10 \times 1.25) - 1 = 38\%$$

$$\text{High Direct Field Labor Compounded Cost} = (1.20 \times 1.25) - 1 = 50\%$$

While all other cost elements were compounded by project duration impacts, the materials cost element was assumed not to be impacted by duration. Therefore, the compounded cost impact values for the materials element are the same as for the average cost impacts values.

$$\textit{Average Material Compounded Cost} = \textit{Average Material Cost Im} \tag{G 24}$$

The compounded cost information served as the basis to calculate the WSA total compounded cost impact ($TCCI_{WSA}$). The WSA total compounded cost impact represents the expected total cost change for a project performed under a particular WSA as a result of day-to-day cost impacts and schedule-driven impacts.

The total compounded cost impact for a particular WSA was calculated from the individual average compounded cost element impacts and the corresponding average percent weights per cost element. Each average compounded cost element percent impact was multiplied by its corresponding average percent weight and the totals added to arrive at the $TCCI_{WSA}$. This was done for the high, low, and average values.

$$\textit{Average } TCCI_{WSA} = \sum_{j}^{n} \left( \textit{Average } CC_{EI\,j} \times \textit{Average Percent Weig}_{j} \right) \tag{G 25}$$

$$\textit{Low } TCCI_{WSA} = \sum_{j}^{n} \left( \textit{Low } CC_{EI\,j} \times \textit{Average Percent Weig}_{j} \right) \tag{G 26}$$

$$High\ TCCI_{WSA} = \sum_{j}^{n} \left( High\ CC_{El\ i}\ x\ Average\ Percent\ Weig_{i} \right)$$

(G 27)

where n = number of Cost Elements

Table G12 indicates the $TDCI_{WSA}$ results for WSA A and Project Type 1 (freeway reconstruction and widening) for the hypothetical example.

**Table G12. Example of Total Daily Cost Impact Calculation for a Particular WSA**

| Cost Element | Average Percent Weight (%) | Weighted Low (%) | Weighted High (%) | Average (%) |
|---|---|---|---|---|
| Direct Field Labor | 23 | 38 | 50 | 44 |
| Materials | 52 | 2 | 8 | 5 |
| Equipment | 12 | 29 | 38 | 34 |
| Field Indirect | 7 | 26 | 39 | 33 |
| Home Office | 6 | 28 | 38 | 33 |
| **$TDCI_{WSA}$** | | **17** | **25** | **21** |

$$\text{Average TCCI}_{WSA} = (0.23 \text{ x } 44 + 0.52 \text{ x } 5 + 0.12 \text{ x } 34 + 0.07 \text{ x } 33 + 0.06 \text{ x } 33) = 21\%$$

$$\text{Low TCCI}_{WSA} = (0.23 \text{ x } 38 + 0.52 \text{ x } 2 + 0.12 \text{ x } 29 + 0.07 \text{ x } 26 + 0.06 \text{ x } 28) = 17\%$$

$$\text{High TDCI}_{WSA} = (0.23 \text{ x } 50 + 0.52 \text{ x } 8 + 0.12 \text{ x } 38 + 0.07 \text{ x } 39 + 0.06 \text{ x } 38) = 25\%$$

The compounded cost impact for each project type considered the compounded cost impacts for each WSA. The total compounded cost impact for each project type ($TCCI_{PT}$) represents the estimated overall total cost change for a particular project type.

For each project type, the $TCCI_{PT}$ was calculated using the various total compounded cost impact for each WSA, and the average percent work to be completed under a WSA.

The $TCCI_{WSA}$ obtained previously were multiplied by the $APW_{WSA}$, and then the totals were added to produce the $TCCI_{PT}$. This process was repeated for the low, the high, and the average values.

$$Average\ TCCI_{PT} = \sum_{j}^{n}\left(Average\ TCCI_{WSAj}\ x\ AP\ W_{WSAj}\right)$$

(G 28)

$$Low\ TCCI_{PT} = \sum_{j}^{n}\left(Low\ TCCI_{WSAj}\ x\ AP\ W_{WSAj}\right)$$

(G 29)

$$High\ TCCI_{PT} = \sum_{j}^{n}\left(High\ TCCI_{WSAj}\ x\ AP\ W_{WSAj}\right)$$

(G 30)

where n = number of WSAs

Table G13 indicates the $TCCI_{PT}$ results for the project type 1 (freeway reconstruction and widening) for our example.

**Table G13. Example of Project Type 1 (Freeway Reconstruction and Widening) Total Compounded Cost Impact.**

| WSA | Average Percent Weight ($APW_{WSA}$) | Weighted Low (%) | Weighted High (%) | Average (%) |
|---|---|---|---|---|
| Alternative A | 50 | 17 | 25 | 21 |
| Alternative B | 30 | 20 | 33 | 27 |
| Alternative C | 5 | 33 | 53 | 43 |
| Alternative D | 15 | 28 | 41 | 35 |
| **$TCCI_{PT}$** | | **20** | **31** | **26** |

$$\text{Average TCCI}_{PT} = (0.5 \text{ x } 21 + 0.3 \text{ x } 27 + 0.05 \text{ x } 43 + 0.15 \text{ x } 35) = 26\%$$

$$\text{Low TCCI}_{PT} = (0.5 \text{ x } 17 + 0.3 \text{ x } 20 + 0.05 \text{ x } 33 + 0.15 \text{ x } 28) = 20\%$$

$$\text{High TCCI}_{PT} = (0.5 \text{ x } 25 + 0.3 \text{ x } 33 + 0.05 \text{ x } 53 + 0.15 \text{ x } 41) = 31\%$$

The total compounded cost impact indicates the estimated cost change for all construction projects within an area (HG and DFW) due to day-to-day cost impacts and schedule based cost impacts.

The evaluation used the total compounded cost impacts for each project type as well as the percentage of the total cost for each project type.

TCCI is a weighted average of the individual $TCCI_{PT}$ and the percents of total costs for each project type ($PTC_{PT}$). This process was completed for the high, low, and average values.

$$Average\ TCCI = \sum_{k}^{n} \left( Average\ TCCI_{PT\,k}\ x\ PTC_{PT\,k} \right)$$

(G 31)

$$Low\ TCCI = \sum_{k}^{n} \left( Low\ TCCI_{PT\,k}\ x\ PTC_{PT\,k} \right)$$

(G 32)

$$High\ TCCI = \sum_{k}^{n} \left( High\ TCCI_{PT\,k}\ x\ PTC_{PT\,k} \right)$$

(G 33)

where n = number of WSAs

Table G14 indicates the TCCI results for the HG for our example.

**Table G14. Example of HG area Total Daily Cost Impact.**

| Project Type | $PTC_{PT}$ (%) | Weighted Low (%) | Weighted High (%) | Average (%) |
|---|---|---|---|---|
| Freeway Reconstruction | 36.0 | 20 | 31 | 26 |
| Non-Freeway Reconstruction | 21.4 | 22 | 36 | 29 |
| New Construction | 10.8 | 16 | 36 | 26 |
| Bridge Replacement | 4.6 | 12 | 28 | 20 |
| Overlay and Rehab (Rural) | 13.7 | 18 | 46 | 32 |
| Overlay and Rehab (Urban) | 13.7 | 8 | 18 | 13 |
| **TCCI** | | **18** | **33** | **25** |

$$\text{Average TDCI} = (0.36 \text{ x } 26 + 0.214 \text{ x } 29 + 0.108 \text{ x } 26 + 0.046 \text{ x } 20 + 0.137 \text{ x } 32 + 0.137 \text{ x } 13) = 25\%$$

$$\text{Low TDCI} = (0.36 \text{ x } 20 + 0.214 \text{ x } 22 + 0.108 \text{ x } 16 + 0.046 \text{ x } 12 + 0.137 \text{ x } 18 + 0.137 \text{ x } 8) = 18\%$$

$$\text{High TDCI} = (0.36 \text{ x } 31 + 0.214 \text{ x } 36 + 0.108 \text{ x } 36 + 0.046 \text{ x } 28 + 0.137 \text{ x } 46 + 0.137 \text{ x } 18) = 33\%$$