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16. Abstract

To answer questions being raised by abutting residents and businesses about proposed elevated and/or depressed freeway improvements in the urban and suburban areas of Texas, a four year study has been conducted to estimate the social, economic, and environmental effects of such freeway designs. Eight existing, two under construction, and one approved for construction freeway sections have been studied on a before, during, and after construction basis. The sections selected for study range from being in predominately residential-suburban areas to predominantly commercial-industrial downtown areas. The specific effects of the three types estimated for each study section are as follows: (1) social impacts: population changes, neighborhood accessibility, neighborhood cohesion, and community services; (2) economic impacts: relocation and mitigation costs, business sales, property uses and values, tax revenues, employment and income, and user costs; and (3) environmental impacts: aesthetics, drainage and erosion, noise and air pollution, vibration, and hazardous spills. The literature review and a survey of highway agencies in other states were used to determine the appropriate procedures or models and mitigation measures to implement in estimating the social, economic, and environmental impacts of elevated and depressed freeways. Appropriate study site, local , state, and federal agency data were collected, reduced, and analyzed in the conduct of this study.

The findings of the study, presented in five separate reports according to types of effect and summarized in this report, can be used with the recommended estimating procedures to estimate the social, economic, and environmental effects of proposed elevated and depressed freeway projects in urban and suburban areas. Then, transportation planning and designing engineers can use such estimates to prepare environmental statements and conduct public hearings on the recommended grade level of each of the proposed freeway projects. The findings from prior studies indicate that freeway grade level differences in selected measures of social and economic activity are statistically significant. However, these differences are negative or positive, depending largely on various locational factors. The results of this study tend to confirm those findings.

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Dallas District:

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Houston District:

Hans C. Olavson, Director of District Transportation Planning; Dennis W. Warren, Director of Construction; and Thomas N. Lou, Assistant to Director of Transportation and Planning.

Harris County Toll Road Authority:

Wesley E. Freise, Executive Director.

Lubbock District:

Carl R. Utley, District Engineer; V. G. Chetty, Former Deputy District Engineer; John E. Rantz, Director of Operations and Construction; Steven P. Warren, Director of Transportation Planning and Development; Ted Copeland, Traffic Engineer; Mike Craig, Assistant District Design Engineer; Davis Melton, Environmental Coordinator; and Claude C. Kneisley, Right-of-way Supervisor.

San Antonio:

John P. Kelly, District Engineer; Julie Brown, Director of Transportation Planning and Development; Mary T. Richards, Environmental Coordinator; Gilbert G. Gavia, District Design Engineer; Felix A. Lemra, District Design Section; and Herbie L. Belvin, District Right-of-way Administrator.

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Last, thanks are due all of the cooperating businesses and residents who furnished survey data.

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SUMMARY

To answer questions being raised by abutting residents and businesses about proposed elevated and/or depressed freeway improvements in the urban and suburban areas of Texas, a four year study has been conducted to estimate the social, economic, and environmental effects of such freeway designs. Eight existing, two under construction, and one approved for construction freeway sections have been studied on a before, during, and after construction basis. The sections selected for study range from being in predominately residential- suburban areas to predominantly commercial-industrial downtown areas. The specific effects of the three types estimated for each study section are as follows: (1) social impacts: population changes, neighborhood accessibility, neighborhood cohesion, and community services; (2) economic impacts: relocation and mitigation costs, business sales, property uses and values, tax revenues, employment and income, and user costs; and (3) environmental impacts: aesthetics, drainage and erosion, noise and air pollution, vibration, and hazardous spills. The literature review and a survey of highway agencies in other states were used to determine the appropriate procedures or models and mitigation measures to implement in estimating the social, economic, and environmental impacts of elevated and depressed freeways. Appropriate study site, local , state, and federal agency data were collected, reduced, and analyzed in the conduct of this study.

The findings from prior studies indicate that freeway grade level differences in selected measures of social and economic activity are statistically significant. However, these differences are negative or positive, depending largely on various locational factors. The results of this study tend to confirm those findings. The preferred grade level is the elevated type for businesses and the depressed type for residents. Therefore, the dominant abutting and nearby land use should be a major determinant of grade level design. Depressed sections tend to out perform elevated sections with regard to business sales, tax revenue, and noise mitigation effects. On the other hand, elevated sections out performed depressed sections with regard to overall property value changes (regardless of use), construction employment, neighborhood cohesion, and air pollution effects.

The general recommendation supported by the study findings might be that transportation agencies should continue to choose the at-grade freeway design unless social, economic, and environmental effects support either an elevated or depressed freeway design in a given situation. The findings of the study, presented in five separate reports according to types of effect and summarized in this report, can be used with the recommended estimating procedures to estimate the social, economic, and environmental effects of proposed elevated and depressed freeway projects in urban and suburban areas. Then, transportation planning and designing engineers can use such estimates to prepare environmental statements and conduct public hearings on the recommended grade level of each of the proposed freeway projects.

INTRODUCTION

STUDY PROBLEM STATEMENT

The Texas Department of Transportation (TxDOT) is continually upgrading the existing highway system in the state, especially in urban and suburban areas. This upgrading involves improving existing highways or freeways on the existing route or on a new route paralleling the old route or bypassing the central city. Such freeway improvements are made at varying grade levels, i.e, at-grade, elevated grade, and depressed grade, depending on the terrain, land use, and other factors. The choice of grade level at a particular point may be an attempt to mitigate negative noise and aesthetics impacts on a residential neighborhood. The current trend in design is toward elevated and depressed sections to gain additional lanes. The elevated sections may be either earthen or bridge in form. Many sections of each type of grade level have been built over the years since the late 1950s. Many are over 20 years old. However, quite a few sections have been built during last five to 10 years, and some sections are either under construction or in the planning stages.

Even though many sections of elevated and depressed freeways have been built over the years in the state, more and more questions are being raised by abutting or nearby residents and businesses about the possible negative impacts of such freeways. In recent years, stiff resistance has been given to the proposed elevated section of the Dallas North Central Expressway and more recently to the proposed elevated or depressed section of U.S. Highway 287 in Wichita Falls. Also, the elevated sections of U.S. Highway 183 now under construction in Austin have caused similar concerns.

Any highway improvement, regardless of grade level, not only impacts users but also impacts abutting and nearby property owners, businesses, and residents in some manner. Even the whole city or community is impacted in some way during and after construction. Elevated and depressed freeway designs raise particular questions concerning noise and air quality impacts, but vibration in moving vehicles and in structures adjacent to the freeway and flooding of depressed freeways are additional concerns. The recent flooding of a depressed section of I-10 in Houston dramatized the latter problem. Soil erosion, at the point of drainage discharge, can cause a problem. Last, aesthetic qualities of elevated and depressed sections are matters of concern.

Impacts that result from elevated and depressed freeway improvements can be classified into three major types: (1) social, (2) economic, and (3) environmental. A partial list of the specific impacts of each of the major types is given below. The social impacts are: population changes, neighborhood accessibility, neighborhood cohesion, and community services. The economic impacts are: relocation and mitigation costs, business sales, land uses and proper values, tax revenues, employment and income, and user costs. The environmental impacts are: aesthetics, drainage and erosion, air quality, noise and vibration, and hazardous spills.

A preliminary search of the literature reveals very few case studies that have measured many of the social, economic, and environmental impacts of depressed and elevated freeways, especially those in Texas. Therefore, the highway decision-makers have very little relevant impact data to write and support the environmental assessment statements and to present at public hearings for proposed elevated and depressed sections of existing or proposed freeway.

STUDY OBJECTIVES

The general objective of the study is to determine the social, economic, and environmental effects of elevated and depressed freeway in urban and suburban areas. The more specific objectives of the study are as follows:

1. Determine the appropriate estimating procedures or models and mitigation measures to be used in this study to estimate the social, economic, and environmental effects of elevated and depressed freeways.
2. Estimate the social, economic, and environmental effects of several existing, contracted, and proposed elevated and depressed freeway sections situated in urban areas in Texas and recommend a final set of impact estimating procedures for use by TxDOT.

SELECTION OF FREEWAY STUDY SECTIONS

At the beginning of this study, researchers conducted a survey of all of TxDOT's districts to locate all elevated and depressed freeway sections at least 0.805 kilometers (one-half mile) long that were planned, under construction, or recently constructed during the last 10 years.

(Copies of the survey forms appear in Appendix A of Research Report 1327-1.) Also, the survey asks for TxDOT to indicate the location (downtown or suburban), abutting land use, and age (less than five years or more than five years) of each qualifying freeway section. Later, a determination was made whether each freeway section was on an existing highway route or a new location. These were considered primary characteristics to be used in selecting the freeway study sections.

TxDOT districts identified and reported a total of 30 freeways (11 elevated and 19 depressed). A total of 12 (six elevated and six depressed) was planned; three (one elevated and two depressed) were under construction; and 15 (four elevated and 11 depressed) were recently constructed. Each of the 30 candidate study sections was personally inspected by TTI researchers accompanied by a TxDOT district official.

With the help of TxDOT's study panel members, a total of 11 freeway section sections was selected for study. Of those selected, two (one elevated and one depressed) were planned; two (one elevated and one depressed) were under construction; and seven (three elevated and four depressed) were built. Of the seven already built, three (two elevated and one depressed) were less than four years old, and four (one elevated and three depressed) were over four years old.

LOCATION AND CHARACTERISTICS OF STUDY FREEWAY SECTIONS

Table 1 shows the selected study sections, type of grade level, location, abutting land use, and age. As can be seen, an attempt was made to have a fairly good mix of study sections representing different types of location, stages of construction, ages, and land uses for each of the study grade levels.

The 11 study sections are located in four Texas cities: one depressed section on U.S. Highway 75 in Dallas; one depressed section on the Sam Houston Tollway in Houston; and four sections in Lubbock. Two of these were located on I-27 (one elevated and one depressed), and two are located on the planned East-West Freeway (U.S. 62/82), one elevated and one depressed. Figures 1-4 show the specific location of the study sections within Dallas, Houston, Lubbock, and San Antonio, respectively. Tables 2 and 3 show other important characteristics of each study section by study grade level. Some of these characteristics are used in evaluating the different impacts considered under this study.

Table 1. Freeway Sections Selected for Study by Type of Grade Level Design and Key Characteristics

TYPE OF DESIGN, NUMBER, AND STATUS	CITY & HIGHWAY TYPE/NUMBER	ROUTE LOCATION	SECTION LOCATION	ABUT LAND USE
Elevated Sections				
No. 11-Planned	Lubbock-U.S. 62/82	Existing	Suburban	Res/Com
No. 8-Built Under 4 Years	Lubbock-I-27	New	Downtown	Com/Ind
Depressed Sections				
No. 10-Planned	Lubbock-U.S. 82	Existing	Downtown	Com/Pub/Res
No. 7-Under Construction	Dallas-U.S. 75	Existing	Downtown & Suburban	Com/Res
No. 9-Built Under 4 Years	Lubbock-I-27	New	Suburban	Res/Com
No. 5-Built Under 4 Years	San Antonio-U.S. 281	Existing	Suburban	Vacant/Res/ Com
No. 1-Built Over 4 Years[1]	San Antonio-I-35	Existing	Downtown	Res/Com
No. 6-Built Over 4 Years	Houston-Beltway 8	New	Suburban	Res/Com
Combination Elevated & Depressed Sections				
No. 2-Built Under 4 Years	San Antonio-I-35	Existing	Downtown	Res/Com
No. 3-Built Under 4 Years	San Antonio-I-10	Existing	Downtown	Res/Com
No. 4-Built Over 4 Years	San Antonio-I-10/35	Existing	Downtown	Com/Ind

[1]No basic grade level change in this section, but adjacent to a new elevated/depressed section having feeder ramps extending into this section.

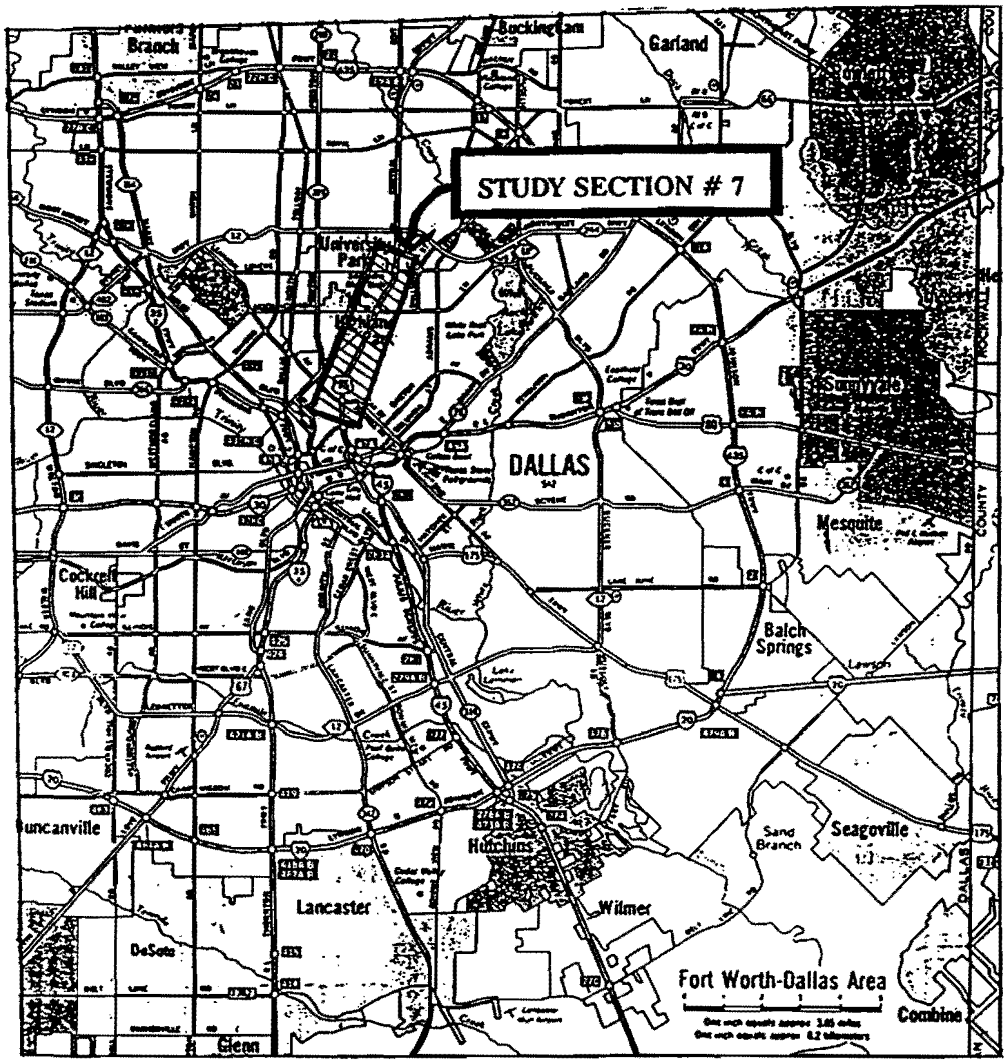

Figure 1. Location of Study Section 7 on U.S. 75 (Central Expressway) Near Downtown Dallas

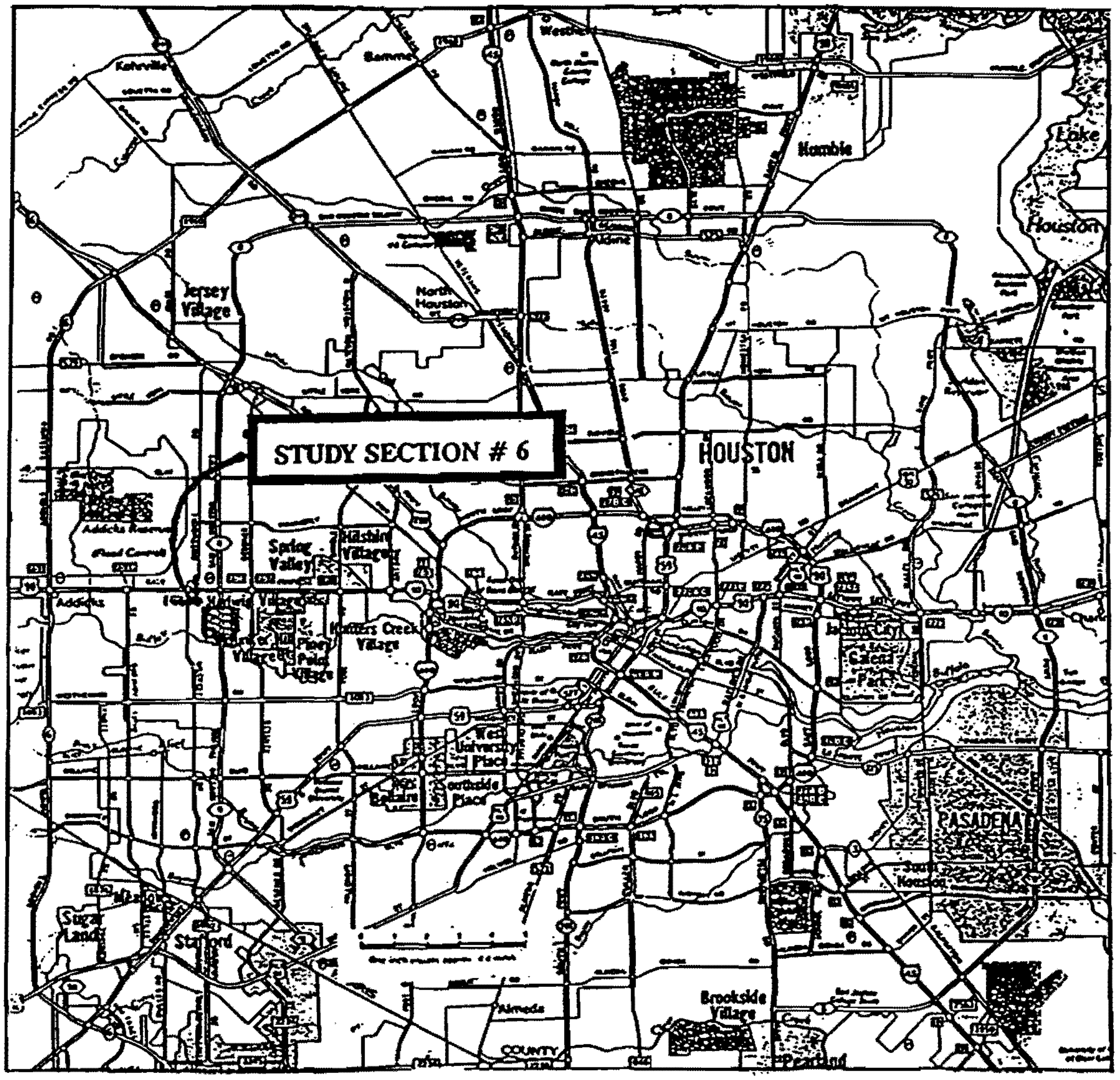

Figure 2. Location of Study Section 6 on the Sam Houston Tollway in Southwestern Part of Houston

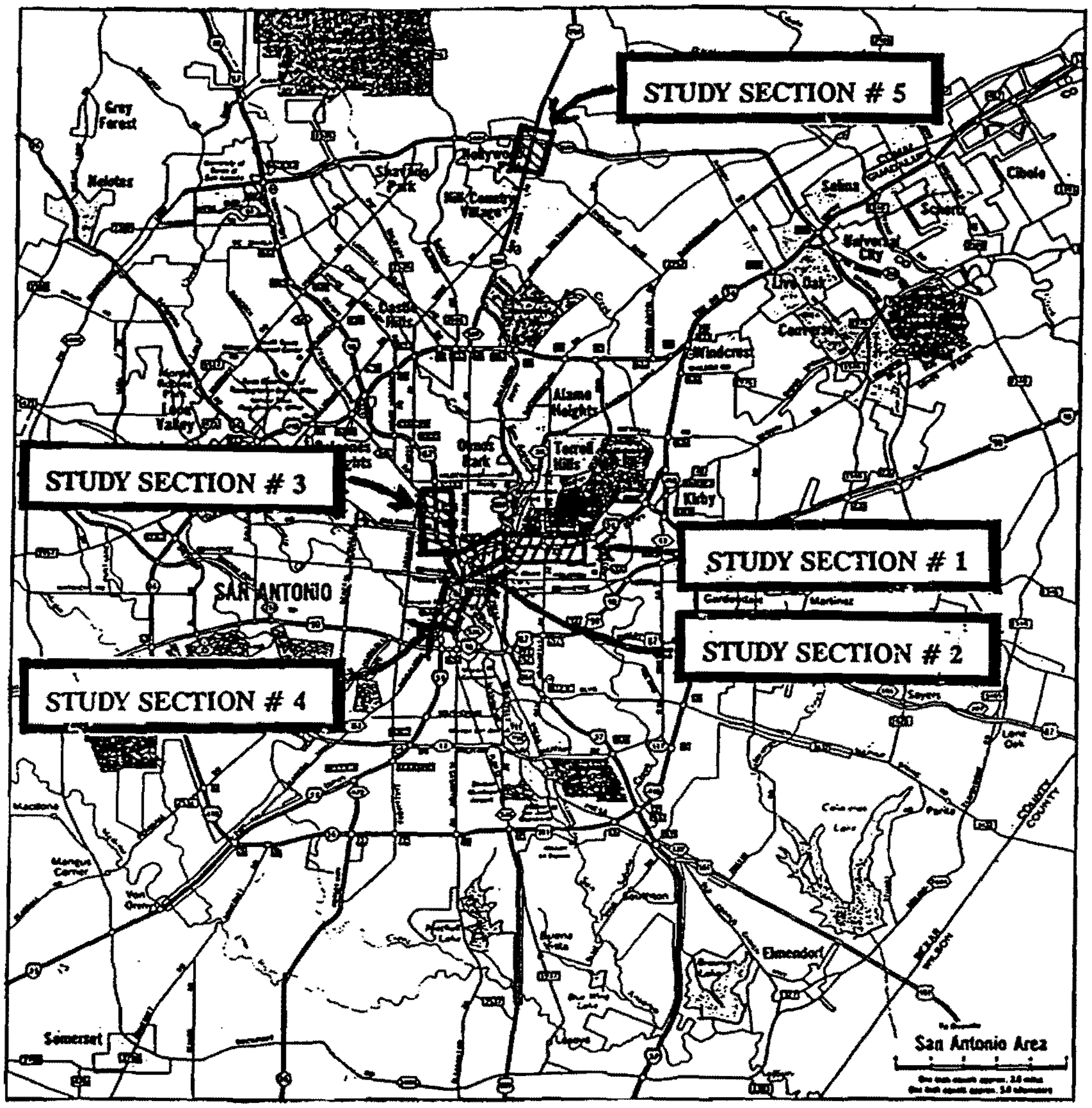

Figure 3. Location of Study Sections 1-5 on I-10, I-10/35, I-35, and U.S. 281 in San Antonio

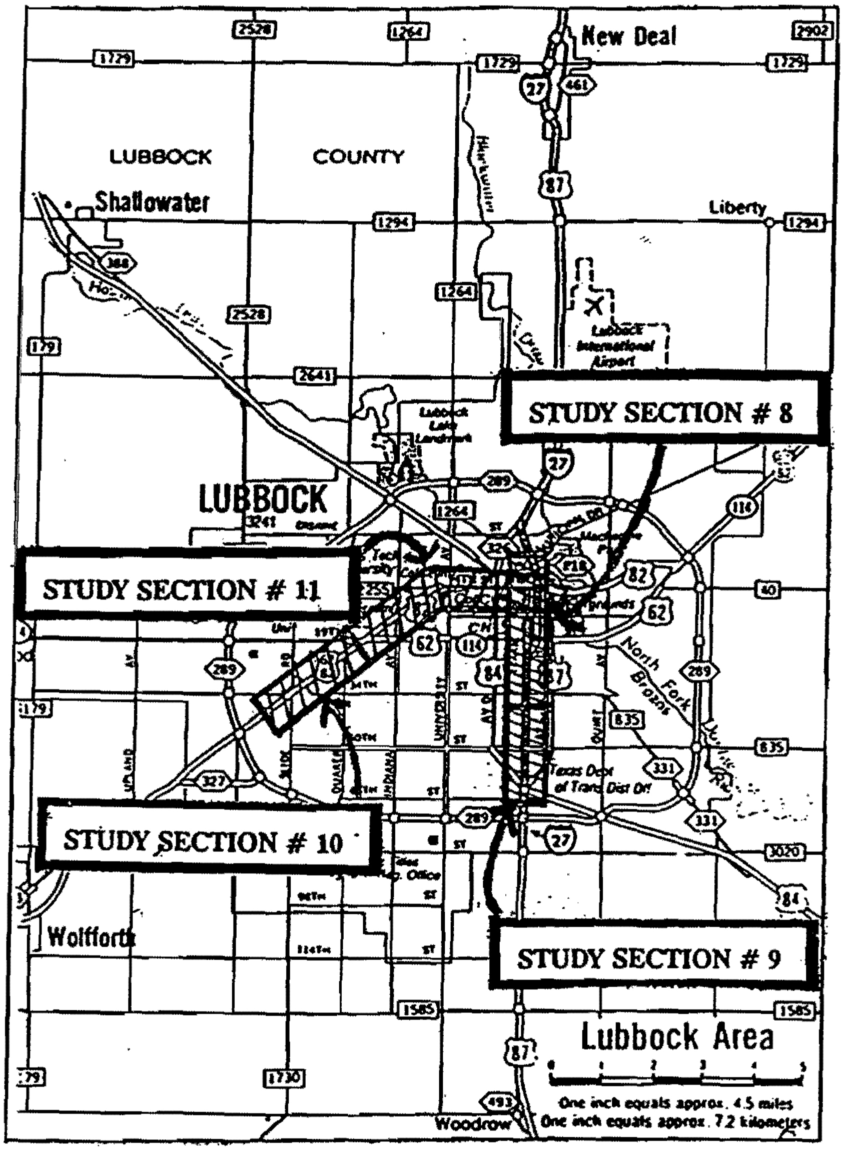

Figure 4. Location of Study Sections 8-11 on I-27 and U.S. 62/82 (Proposed East-West Freeway) in Lubbock

Table 2. Study Freeway Sections by Age, Grade Level Before, Length, Grade Level Depth, Right-of-Way Width, Type of Mainlane Access, and ADT Before and Projected ADT 20 Years After Construction

STUDY NO./ TYPE OF GRADE LEVEL AFTER CONSTRUCTION	AGE AFTER (yrs)	GRADE LEVEL BEFORE	LENGTH AFTER km (mi)	GRADE LEVEL HEIGHT/DEPTH m (ft)		RIGHT-OF-WAY WIDTH m (ft)		TYPE OF ACCESS TO MAINLANES		ADT	
				BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Elevated/Combination Elevated & Depressed											
No. 2 I-35-San Antonio	1	depressed	2.01 (1.25)	-4.6 (-15)	+6.1 (+20)	64.0 (210)	70.7 (232)	full	limited	75,600	188,300
No. 3 I-10- San Antonio	3	depressed	2.96 (1.84)	0 (0)	+6.1 (+20)	65.5 (215)	74.7 (245)	limited	limited	94,100	198,500
No. 4 I-10/35- San Antonio	6	elevated/ depressed	2.28 (1.42)	+6.1 (+20)	+6.1 (+20)	61.0 (200)	76.2 (250)	limited	limited	79,800	186,500
No. 8 I-27 Lubbock	3	at-grade	3.02 (1.88)	0 (0)	5.5 (+18)	38.1 (125)	121.9 (400)	full	limited	42,352	77,350
No. 10 U.S.62/82-Lubbock	0	at-grade	2.32 (1.44)	0 (0)	+6.4 (+21)	53.6 (176)	97.5 (320)	full	limited	22,493	52,533
Depressed											
No. 6 Sam Houston Beltway-Houston	6	at-grade	2.09 (1.30)	0 (0)	-5.2 (-17)	91.4 (300)	91.4 (300)	full	limited	84,000	168,000
No. 7 U.S. 75-Dallas	0	at-grade	6.47 (4.02)	0 (0)	-6.7 (-22)	67.1 (220)	85.3 (280)	limited	limited	155,000	217,700
No. 9 I- 27 Lubbock	3	at-grade	4.84 (3.01)	0 (0)	-5.2 (-17)	38.1 (125)	121.9 (400)	full	limited	42,356	77,350
No. 11 S.H. 62/82-Lubbock	0	at-grade	2.56 (4.12)	0 (0)	-6.7 (-22)	53.7 (176)	102.1 (335)	full	limited	22,656	34,483
No. 1 I-35- San Antonio	10	depressed	2.22 (1.38)	-4.6 (-15)	-4.6 (-15)	91.4 (300)	91.4 (300)	limited	limited	50,000	150,000
No. 5 U.S. 281- San Antonio	5	at-grade	2.85 (1.77)	0 (0)	-6.4 (-21)	91.4 (300)	91.4 (300)	full	limited	12,700	94,000

Table 3. Study Freeway Sections by Number of Structures, Crossing Streets, Mainlanes, On Ramps, and Off Ramps

STUDY NO./ TYPE OF GRADE LEVEL AFTER CONSTRUCTION	STRUCTURES (NO.)		CROSSING STREETS (NO.)		MAINLANES (NUMBER)		ON RAMPS (NUMBER)		OFF RAMPS (NUMBER)	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Elevated/Combination Elevated & Depressed										
No. 2 I-25-San Antonio	11	12	11	11	4	10	4	8	6	8
No. 3 I-10- San Antonio	9	11	6	6	4	10	3	6	5	6
No. 4 I-10/35-San Antonio	6	8	8	8	6	10	4	6	4	3
No. 8 I-27- Lubbock	2	6	21	6	4	6	0	4	0	3
No. 10 U.S. 62/82-Lubbock	2	4	5	3	4	6	0	3	0	3
Depressed										
No. 6 Sam Houston Beltway-Houston	0	3	7	3	4	6	0	2	0	2
No. 7 U.S.75-Dallas	13	14	13	13	4	8	16	5	16	5
No. 9 I-27- Lubbock	0	7	11	4	4	6	0	2	0	2
No. 11 U.S.62/82-Lubbock	4	21	22	15	4	6	0	8	0	8
No. 1 I-35- San Antonio	9	9	7	7	6	6	3	3	3	3
No. 5 U.S.281- San Antonio	1	2	2	2	4	6	0	3	0	3

REPORTS OF FINDINGS

Since this study involves the study of many different impacts elements, the findings are presented in several reports by type of impact. The reports are as follows:

- Research Report 1327-1:
  Social and Economic Effects of Elevated and Depressed Freeways in Texas
- Research Report 1327-2:
  Land Value and Use Effects of Elevated and Depressed Freeways in Texas
- Research Report 1327-3:
  Noise Pollution Effects of Elevated and Depressed Freeways in Texas
- Research Report 1327-4:
  Air Pollution Effects of Elevated and Depressed Freeways in Texas
- Research Report 1327-5:
  Drainage, Erosion, Hazardous Spill, Vibration, and Aesthetic Effects of Elevated and Depressed Freeways in Texas

This report (Research Report 1327-6F) contains a summary of the findings presented in the above study. The major sections of this report are as follows: Introduction, Review of Previous Work, Research Approach and Procedures, Findings on Freeway Grade Level Effects, Conclusions, Recommendations for Implementation, and Cited References.

Finally, Floyd D. Scurry, a young TxDOT employee in the Employee Development Program and a Civil Engineering graduate student enrolled at Texas A & M University, wrote a Master's Thesis entitled "The Economic Effects of Elevated and Depressed Freeways on Adjacent Property Owners" collecting and using the I.H. 27 study section database.

REVIEW OF PREVIOUS WORK

This section of the report summarizes the previous work found in an extensive literature search and national survey, presented in that order. The previous work is summarized by two major types of impact categories as follows: (1) social and economic and (2) environmental. The first category includes land value/use impacts. For more detail on specific studies, refer to the specific reports listed in the previous chapter.

LITERATURE REVIEW FINDINGS

As mentioned in the introductory section, only a few relevant studies were found in the literature.

Social and Economic

Many sections of elevated and depressed freeways have been built for many years now, and we would expect that the economic and social changes that might be expected during and after construction have been well-studied. However, an interesting issue is the evidence of the potential economic effects of these freeway sections on the nearby/abutting residents, businesses, and properties is very limited. An exhaustive literature review revealed only few studies (1,2,3,4,5,6,7,8,9,14). Some of these studies were conducted almost three decades ago with respect to freeway effects. Further, a few studies researched the effects of elevated heavy rail transit stations (10,11,12). However, most of these earlier studies share a common factor in that they examine only one economic aspect—the effect of elevated/depressed freeways on property values and/or land use. Some of the references cited include environmental impact statements which also evaluate some other socioeconomic effects of alignment variations of the freeway.

Thiel (1962) discussed some of the effects on relocation of residents and businesses, employment conditions, and public services, among other factors, and presented cogent reasons as to why we may expect to observe some of these effects (13). Residents' attitudes and opinions towards the highway facility were suggested as an important indication of the social impact that the highway has on the community. This is also discussed by Buffington et al. (14). While it may suggest that some of these changes are the direct result of the highway, these effects have multiple causes and can be traced to the highway itself only in part. This is an important factor to keep in mind during the analysis of such impacts. Some studies address the socioeconomic impacts of highway alternatives which include elevated or depressed configurations as has been mentioned above. Since the available literature on the differing effects of elevated versus depressed freeways is very sparse, the following strategy will be adopted. First, the results of the earlier studies and impact statements will be summarized to the extent that those results have a bearing on the choice of elevated, depressed, and/or at-grade highway configuration from a socioeconomic standpoint. Second, an attempt will be made to trace out the criteria from other highway improvement/widening studies as well as the anticipated effects and the methodologies used to assess the same.

The environmental impact statements are ambiguous as regards the economic impacts of alternative highway configurations and abstract from methodological details. An example will substantiate the comment made above. For example, some of these environmental impact statements furnish the readers with residential, business displacement, and land use information due to the highway facility. In terms of costs, some note that the elevated concept would be more expensive than the depressed alternative. These studies are aware of the differing effects of alternative highway configurations; however, only overall economic impacts of the construction of the highway facility are presented. It is further noted that the results would vary depending on the alignment configuration. The only economic aspect for which the differing impacts of elevated/depressed freeways are discussed is joint use development of land. However, Buffington's study (9) provides some concrete evidence on economic effects of elevated versus depressed alternatives. The results of his study are summarized briefly below in Table 4. These results used in conjunction with the results of the highway widening studies will provide guidance in the analyses of the impacts in this report. The depressed alternative was found to be inferior to all elevated alternatives on all counts mentioned in Table 4.

Although social effects are not addressed directly in the above cited reports, these references consist of environmental impact statements and results from opinion-based surveys. It is noted that a depressed or at-grade configuration of the highway would affect neighborhood accessibility conditions to the extent that certain local streets would be terminated at the freeway. This would minimize through traffic and provide an opportunity for neighborhood preservation. An elevated configuration would essentially retain existing access patterns (5).

Table 4. Depressed Versus Elevated Highway Alternatives: Summary of Findings on Economic Impacts

Impact Category	Effect
Business Impacts	1. Abutting businesses gross sales for depressed alternative were negatively impacted during construction compared to elevated and other highway alternatives, and especially large effects on traffic-serving businesses. 2. A negative gross sales impact on abutting businesses after construction for traffic-serving and other businesses for the depressed alternative. 3. Individual highway configuration effects for impact on wholesale and manufacturing firms are not presented.
Tax Revenue Impacts	1. Both depressed and elevated configurations have a negative impact on taxable sales during the construction period, but depressed configuration had a more negative impact than the elevated.
User Costs	1. Depressed alternative had lower benefit-cost ratios compared to all elevated alternatives.
Relocation Costs	1. Do not clearly separate out individual highway configuration effects on relocation costs.
Employment and Income	1. The depressed alternative would generate the lowest amount of business employment in comparison to elevated and other alternatives. 2. Depressed alternative would generate the lowest impact employment impact resulting from commercial/industrial building construction expenditures.

Considerable research has been done over the last few decades on economic and social impacts of highway projects in general. These impacts could be adapted to assess the effects of elevated versus depressed freeways, but very little guidance is available in that form at the present time as is evident from the discussion so far. The economic effects discussed in the review presented in Research Reports 1327-1 and 2 include those on businesses, land value/use, relocation, tax revenues, employment and income, and user costs. The social effects discussed in Research Report 1327-1 include those pertaining to population changes, neighborhood accessibility, neighborhood cohesion, community services, and resident attitudes and opinions.

For each of the above categories, the following are addressed: its relationship to highway infrastructure, nature of the effect, general character of the criteria, and the techniques and methodological aspects used to analyze the effect. Two types of impacts have been identified in the literature, short and long range. Short range impacts, such as business displacements, have been and will continue to be a key issue for highway officials and planners in comparison to long range impacts (15). More specifically, two types of impacts need to be examined: 1) those which occurred *during* the construction and 2) those which occurred after the construction was completed.

Concerning land value/use impacts, the literature review shows that studies of freeway impacts on adjacent and peripheral properties were initiated as early as the mid-1950s. These studies analyzed changes in land use and land values from the perspective of properties adjacent to or removed from the facility. Some studies focused on the freeway elevation, while some did not. In large measure, however, the previous research indicates that the construction of a freeway and its grade influence adjacent property values. In cases where the freeway opens major travel corridors and improves travel, adjacent owners consider the facility to positively impact their land values. However, the literature does not generally explore the relationship or magnitude of other variables.

Miller (1971) indicates that land value is derived by a variety of factors which include, but are not limited to, location and accessibility, overall economic health of the locale, growth rates, and subsequent demand for various types of property (16). Langley, Jr. (1981) says that for those parcels adjacent to a freeway, differences in elevation affects on land values are really due to visual and noise effects; whereas, those properties removed from the freeway experience lesser elevational affects on property values (17). Downs (1982) indicates that a differentiation in land values exists also for properties that are adjacent to the freeway by land use type as a result of the type of land use, as well as grade level (18). He found that commercial land uses typically command higher values than residential uses. A study conducted by the Institute of Traffic Engineers (1976) found that the presence or absence of an elevated or depressed freeway structure does not halt residential development or habitation (19).

Environmental

The subject of transportation noise has been thoroughly researched and documented over the years. In fact there are, for example, documented cases of noise control ordinances dating from the Romans. It was not until more modern times that environmental factors were considered formally in any major transportation decisions. It was not until the early 1960s and 1970s that the environmental quality of transportation was recognized as a powerful force affecting the course of new development. The planning and building of urban freeways affects the lives and livelihoods of many members of the urban community, particularly those living near the freeway right-of-way. Although the development of highway systems has produced both economic and social benefits to large numbers of people, traffic can also pollute the environment.

An excellent text edited by Nelson (1987) covers many aspects of transportation noise, such as the effects of elevated and depressed roads (20). Observations in the text indicated that elevated structures provide lower levels of noise below the roadway (65 dBA L_{eq}) than at the road height at 25 m (82 ft) distance (70–75 dBA L_{eq}). Harmelink and Hajek (1973) addressed elevated and depressed sections as governed by the same relationship as sound attenuation due to barriers (21). They indicate those sound level reductions obtained are likely to be less than the design charts predict and that the most effective section appears to be a depressed section with some barrier on the crest. Anderson (1983) conducted a study of noise reflecting from the underside of an elevated versus reflection from a split level depressed and elevated freeway and found an amplification range between zero and 12 dB for the split level freeway and zero to 3 dB amplification range for an elevated freeway (22).

Finally, Buffington and others (1971) in a study of the experiences and opinions of residents living along elevated, depressed, and on-grade freeway sections found that "the most often mentioned negative effect was noise" (14). Most of the respondents, who were 60 years of age and older, said that the freeway noticeably raised the noise level. The higher percentage of complaints came from the at-grade and elevated locations. Many respondents said that "the noise annoyed them at first, but that they got accustomed to it as time passed." The results of the current study, reported in Research Report 1327-3, showed the same trend as found in this earlier study, which is that depressed freeways produce the least noise impact or noticeable increase among 76 percent of the residents. The elevated sections produced the next higher increase at 85 percent of the residents, and the highest level of 100 percent noticed a noise increase with the at-grade conditions. These residents were all within 183 m (600 ft) of the right-of-way. Those interviewed beyond that distance reported noticeable increases of 21 percent, 86 percent, and 62 percent for the depressed, elevated, and at-grade conditions, respectively. This again agrees with this study in that the elevated sections tend to block noise near or under the roadway, but the noise travels further because of the lack of shielding from buildings and foliage at the higher altitude. The study did not indicate if the guardrail on the elevated section was a solid or open design.

The primary pollutants produced by internal combustion engines are carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), lead (Pb), and particulate matter. The principle secondary pollutant of concern is ozone (O_3), which forms in the presence of sunlight and the primary pollutants. The major variables affecting downwind pollutant concentration are distance from emission source, source strength, wind speed, wind direction, atmospheric and induced turbulence, and mixing layer height. Many mathematical models have been developed to aid in the prediction of pollutant concentrations near roadways (TXLINE 2, CALINE 3 & 4) and at intersections (TEXIN 2, IMM)(23, 24, 25). Current trends in city planning favor the construction of elevated and depressed roadways over at-grade roadways, to relieve congestion in crowded areas. The most popular of the impact prediction programs (CALINE 3 & 4) are designed for use with at-grade systems, although CALINE 4 has "cut" and "bridge" options, and assume a smooth terrain surrounding the roadway. This study intends to determine the validity of using current impact prediction models when dealing with elevated and depressed roadways. Several studies have been conducted that dealt with freeway grade level differences (26,27,28,29).

A few environmental studies have been conducted that contain data on ground water run off, vegetation cover to prevent erosion, and vibration effects of freeways with different grade levels (19,30,31). These environmental factors are generally regarded as less important than noise and air pollution, perhaps because they are not as quantifiable (19).

NATIONAL SURVEY FINDINGS

The Texas Transportation Institute canvassed all of the state or provincial transportation agencies in the United States and Canada regarding the social, economic, and environmental effects of elevated and depressed freeways in urban and suburban areas. The objective of the survey of the states and Canadian provinces was to determine, to the extent possible, the "state-of-the-art" with regard to data collection and procedures used to measure such impacts, recognizing that while published studies may be limited, much information may have been acquired through experience and data collection across the United States and Canada.

Survey Response

As was indicated above, the survey questionnaire was sent to all 50 states and the 10 Canadian Provinces. No responses were received from the Canadian Provinces, but 31 of the States did provide a response. As shown in Table 5, 16 of the responding states reported 64 elevated and 42 depressed freeways, a total of 106, that had been previously constructed, currently under construction, or planned during the past 10 years. Only six of the 16 states expressed a preference of freeway level. One preferred elevated freeways due the high water table in the southern part of the state; two preferred depressed freeways, and three preferred at-grade freeways but gave no reason for their preference.

Collection of Data and Development of Procedures to Measure Effects

Only six (19.4 percent) of the 31 responding states had collected data and/or developed procedures to measure one or more of the following types of effects: social, economic, and environmental. When asked how many of each type of freeway reported had been studied in detail to estimated their social, economic, and environmental impacts, only 37 (34.9 percent) of the 106 freeways had been studied in detail. Several of the states listed the types of data used to measure different effects as follows:

Table 5. Number of Elevated and Depressed Freeways Built During 10 Prior Years, Under Construction or Planned as of Early 1993.

Question	Elevated	Depressed
Estimate the number of recently completed (within the past 10 years) elevated and depressed freeway sections in your State.	28	16
How many elevated and depressed freeway sections are currently under construction in your State?	16	7
How many elevated and depressed freeway sections are currently planned in your State?	20	5
Total number of freeways reported	64	42

Note: Elevated and depressed freeway sections refer to sections that involve at least two over/ underpasses, or are at least 1/2 mile in length.

* Social effects—demographic, housing, employment, opinion survey, traffic, and noise level data;
* Economic effects—number of businesses and residences displaced, employment data, property values, retail sales, and parking and accessibility analysis; and
* Environmental effects—air quality, noise, habitat, hazardous, flooding/runoff, and archaeological, aesthetic, roadkill, and salt spray data.

The respondents indicated that they used the above types of data to prepare environmental impact statements on these types of freeway designs.

RESEARCH APPROACH AND PROCEDURES

The general methodology planned for this study was to conduct a "before and after" construction period comparative analysis across time supplemented with a cross-sectional analysis at one point-in-time. The eight completed freeway study sections were selected to provide data for both types of analyses. The three others were to be used to provide current before and/or construction period data to supplement these analyses. The two planned study sections can be used to estimate anticipatory effects by grade level.

The before and after period analysis can compare the elevated freeway sections with depressed freeway sections to ascertain any significant differences in various types of impact elements, i.e., air pollution, noise pollution, soil erosion, and land value/use, business sales, road neighborhood cohesion, etc. The one point-in-time analysis, before and/or after period, can compare prior or current level unit values of each impact element to determine significant differences between elevated and depressed freeway grade levels. Such an approach takes changes due to time out of the picture in determining grade level differences. For either of these analytical approaches, you can compare elevated study sections with depressed study sections and also compare these two grade levels with adjacent or nearby at-grade level control sections.

As the study got underway, the study approach changed slightly. In order to compare sections having similar abutting and general area characteristics, it was decided that we should collect data for all three grade levels on each of the study freeway even though five of the seven study freeways did not have adjacent or nearby grade level sections that met the one-fourth mile length requirement. In most cases, only the study section, i.e., elevated or depressed, on each freeway met this length requirement. Also, the research team encountered considerable trouble and expense trying to collect enough data for all three types of grade levels on each study freeway within the time span of the study. In addition, limited field crew sizes, safety concerns, and cost of test equipment needed to comply with the change in study approach all contributed to the data collection problem. Finally, due to personnel and cost constraints. state agencies and city officials could not furnish all of the data requested from them.

Sources of data used in the study ranged from a review of the literature to 'on-site' data collection. The prior studies found in the literature, as well as data obtained from a national survey of state transportation agencies, helped to determine the different methodologies used in the study. The data obtained to estimate the effects of the different impact elements came from the literature, national survey, United States Census Bureau, Texas State Comptroller, Employment Commission, TxDOT, Environmental Impact Statements (EIS) of each of the study sections, city criss-cross directories, site surveys of businesses and residents, traffic volumes and composition, air and noise levels, drainage, erosion, and other environmental conditions.

The detailed procedures used to collect and analyze the social, economic, and environmental effects of elevated and depressed freeway are given in the appropriate reports listed in the introductory section. They are summarized below by major types of effects.

SOCIAL AND ECONOMIC EFFECTS

Businesses and Residents

On site surveys of a sample abutting or nearby businesses and residents were conducted to obtain data to identify the characteristics of such businesses and residents and to obtain and examine the opinions and perceptions of these businesses and residents. Actually, attempts were made to survey 100% of the abutting businesses and residents and at least 25% of the nonabutting business and residents located within several blocks of the freeway study and control sections.

Priority was given to the results of data obtained from abutting businesses and residents because the study focuses on grade level differences of freeway projects and these effects can reasonably be expected to be magnified in the proximity of the freeway. However, the results for non-abutting businesses and residents are presented as a comparison wherever appropriate. For businesses, the surveys attempted to obtain information like age, type of business, estimated dollar value of property and gross sales levels. They were also asked their opinion on the number ramps, over and underpasses, parking spaces, the changes in the employment levels, noise levels, air pollution levels, travel safety, crime, etc. Residents were asked information pertaining to their households, opinions concerning the location of their present location, opinions regarding the effect of the freeway construction on their homes, neighborhoods and general preferences on the design of the adjacent freeway grade level, and travel experience on the study freeways.

Percentage distributions of the information furnished respondent businesses and residents are presented by design sub-area and combined area in tabular form in order to highlight the differences between elevated versus depressed versus at-grade freeway sections. The percentages reported are based on the actual number of respondents. Where appropriate, the Chi-Square statistical test of significance is performed on these percentage distributions.

Land Value/Use

The land value analysis is based on a database of appraised values of land and improvement of properties abutting the study and control freeway sections for selected before, during and after construction years. The land value data was acquired from the respective county appraisal districts. Also, the total appraised values of all property by type of use located in each city and county having a study freeway in order to study property value trends in relation to changes in study freeway grade level property values. Land use data on abutting and nearby properties and demographic data on adjacent census tracts were collected from the cities involved and U.S. Bureau of Census, respectively. These data and a detailed analysis of it are presented in Research Report 1327-2.

It is important to note that demographic or land value changes may occur in response to influences by variables in the general market. Thus, there will be some portion of changes in land values or social characteristics that has not been included in this analysis. However, the principle is that freeway elevation does influence land value with the depressed condition being the preferred condition, the at-grad representing a neutral influence, and the elevated structures representing the most negative effects across all categories under investigation.

The primary land value analysis is based on the average value per unit (square meter) per abutting property and is presented in tabular form showing the range of individual abutting properties and the mean value for all abutting properties combined for each year used in the analysis for individual and combined freeway study and control section. Researchers performed secondary analysis on the land/use database using a linearly defined "land value index model." This model provides the basis by which the freeway grade levels and land uses are examined to determine if yearly changes in land value for elevated and depressed sections would differ significantly from each other and from changes recorded for at-grade sections. The model calculates separate land value indices for each land use and gives a value for each year making up the database. Research Report 1327-2 describes the model in detail.

Relocation, Employment and Income

The study plan called for the collection of freeway relocation and construction cost data, as well as, business construction costs and employment change data in an attempt to estimate the relocation, employment and income differential effects of freeway grade using relocation and construction cost database. However, in the case of relocation costs, the freeway sections selected for study yielded very few relocated businesses and residents, except for one freeway, I-27, in Lubbock. Even that database presented problems in differentiation of the elevated, depressed, and at-grade section relocation costs. Also, the literature does not separate out individual highway/freeway configuration effects on relocation costs. Therefore, the study presents a very limited evaluation of the relocation effects by number of relocates.

The database for estimating the employment and income effects was a little more completed. Typically, the gross employment effects would be a composite of the three following individual cost components: (1) portion due to the net change (existing businesses before construction less displaced businesses plus new businesses after construction) in employment by businesses locating abutting the existing and proposed freeway section, (2) portion from construction expenditures by the highway contractor to build the facility, and (3) portion from construction expenditures by building contractors to build new businesses and residences or renovate old businesses or residences abutting the freeway sections. However, so little data was available on the first and third component that estimating the employment and income effects was limited to the second component, namely, employment effects from freeway contractor's construction expenditures. To estimate the employment impact of this component, the 1986 Texas Input-Output employment and output multipliers available from the report published by the Texas Comptroller of Public Accounts in 1986 were updated and utilized.

Tax Revenues

As confirmed in the literature, changes in freeway grade level can impact business sales and abutting property values and, in turn, the tax revenues derived by the counties, cities, and school districts involved . This study attempted to estimate these effects.

The land value database was used to estimate the property tax revenue effect of the study freeway grade level changes. The property tax rates of the respective counties, cities, and school districts were applied to changes in the land values attributed to the freeway grade level changes. This analysis of property tax impacts does not consider any exemptions. Furthermore, improvement values were not available for three of the study areas in the scope of the study. Therefore, the property tax revenue effects are base on land values alone. Land value normally appreciates when compared to the property value itself, the latter of which may be subject to some obsolescence and depreciation.

To estimate the tax revenue effect resulting from changes in abutting businesses' gross sales attributed to study freeway grade level changes. The ideal database to use would be the responses of these businesses to the survey questions pertaining to the sales level before, during and after construction of the freeway grade level changes. However, most the business surveyed failed to furnish such confidential information. As and alternative, the study used publicly available information in order to arrive at an approximate effect on broad groups of abutting businesses. The major data source came from the State Comptroller's Office and City Directories.

The specific steps taken in arriving at the property and business tax revenue effects are presented in Research Report 1327-1.

User Benefit-Cost

As mentioned in Research Report 1327-1, it is very desirable to estimate the user benefits and costs of particular freeway improvements. The user benefits are usually based on savings in time or delay costs, vehicle operating costs, accident costs, routine maintenance costs, discomfort costs, and pollution costs. The user costs are based on the right-of-way, relocation, and construction costs. As can been seen, the database requirements are extensive. Although not completely applicable, the recently developed MicoBENCOST computer algorithm or model developed by McFarland, et al., was going to be used to perform these calculations. Although the use of the default values in the this model would reduce the amount of data needed to obtain an estimate of the net benefits of each freeway grade level change, the database requirements are still extensive. An attempt was made to collect the additional data, but was unsuccessful in collecting enough viable data to conduct the benefit-cost analysis.

ENVIRONMENTAL EFFECTS

The procedures used to estimate studied environmental effects of the study and control freeway section grade levels are summarized below. For more details, the reader is referred to the respective research reports covering those aspects of the study.

Noise Pollution

To establish existing sound levels at the case study and control sections, measurement procedures were used that are in line with current TxDOT and FHWA guidelines. According to FHWA procedures (7), the following instrumentation, except for the optional type, is required to measure existing traffic sound levels: Sound Level Meter (Type 2), Sound Level Calibrator, earphones or headphones (optional), Wind Speed Indicator, Sling Psychrometer (optional), watch with "seconds" display, windscreen, data sheet, microphone cable, tripod, and spare batteries. All of these items were used during this study except those that were optional.

The sound level meters chosen for the study were Quest Electronics (8) Model 1800 Precision Integrating Sound Lever Meters. Two of these units were used in the study and were chosen because of features needed for traffic noise surveys. The Model 1800 functions as a Precision Sound Level Meter, Impulse or Integrating Sound Level Meter and is classified as Type 1. The Type 1 units provide a ±1dB accuracy, while the FHWA recommended Type 2 provides a ±2dB accuracy.

Though not required in the FHWA procedure, a hand-held traffic radar was used to determine average traffic speed at each study site. The first part of the project used an X-band unit similar to a police radar to measure speed only. The latter part of the measurements used a Laser Radar that provided both vehicle speeds and distance readings. The Laser distance readings proved to be very beneficial since the site diagram could be scaled by reflecting the beam off objects in the median and points of interest across the roadway to take accurate measurements to the nearest 0.3 m (1 ft).

To arrive at a basis for comparing sound level readings in this study, previous studies and future studies, traffic was counted during the measurements. This was done using two people and two hand-operated, mechanical counters. With three buttons on each counter, the total count for three categories of vehicles could be displayed on each unit. The three categories were passenger cars, light trucks, and heavy trucks. Each person counting traffic would observe and count vehicles in one direction. The count was initiated shortly after the sound meter or meters were started in the L_{eq} mode of operation. The counts were then terminated just after the 10 minute measurement period was completed.

Air Pollution

Air quality impact studies usually fit into one of three categories: Microscale, mesoscale, or macroscale. Each type has an increased study area. This study focuses on CO monitoring on a microscale regime, i.e. over linear distances up to 100 m (247 ft) from the edge of the freeway section and where CO concentrations are expected to deviate more than 20% over the distance. There were microscale monitoring sites selected for all three grade levels. The study attempts to gain "good" temporal resolution by continuous monitoring at 1 min. intervals for at least 3 days at each study area, and acceptable spatial resolution with a minimum of five CO monitors placed in a straight line horizontal to the roadway.

The following variables were recorded during the study, for comparison with existing CALINE and TXLINE model predictions: CO concentrations (values 2-50 ppm), wind speed and direction (horizontal and vertical components), temperature, barometric pressure, relative humidity, solar radiation, traffic vehicle count, traffic mix (cars, trucks, buses, light- vs. heavy-duty), and average vehicle speed.

Current mathematical models are based upon at-grade roadways. Some of these models provide options for "cut" or "bridge" sections when defining links. However, all models assume simple surrounding topography. Monitors were placed near the roadway at different distances to record CO concentrations, for comparison to current model predictions. Monitor placement was based upon previous studies conducted by Bullin and co-workers (23,24,25). Monitors were located on masts in a straight line perpendicular to the freeway.

The upwind CO monitor was used to determine the local background CO concentration. The downwind CO monitors, placed on the opposite side of the freeway measured the combined CO concentration profile of the background and the freeway. The apparent CO concentration due to traffic was calculated by simple difference between downwind values and the upwind background level. The recorded data were compared to model predictions.

Drainage, Erosion, Vibration, Aesthetics, and Hazardous Spills

The before mentioned study by the Institute of Traffic Engineers in 1976 indicated that environmental factors such as visual quality, drainage, and erosion have to be rated qualitatively. Therefore, the procedure used for the evaluation of the drainage, erosion, vibration, aesthetics, and hazardous spills consisted of a review of Environmental Impact Statements (EIS), project plans, on-site inspections and interviews with the TxDOT design and maintenance engineers to identify grade level problems experienced on each of the study freeways. For each problem identified, a determination was made as to how each problem could be corrected and the amount of cost incurred in doing so. Then, the findings from the on-site evaluation were compared with those from the literature review to arrive at study conclusions and recommendations regarding freeway grade level differences.

FINDINGS ON FREEWAY GRADE LEVEL EFFECTS

The findings of the study of freeway grade level effects are summarized in this section of the report by the two major types of effects, as follows: social, economic, and environmental. The detailed findings are given in the respective reports listed in the introductory section of this report.

SOCIAL AND ECONOMIC

As indicated earlier in this report, much of the social and economic findings are based on data obtained through responses from personal contact surveys of abutting or nearby businesses and residents. However, most of the findings of some of the specific types of impact, such as land values, tax revenue, and employment and income are based on non-survey databases.

A more detailed analysis of changes in property values, average total employment, parking spaces, and sales volumes was also conducted using changes in ranges and changes in means. Further, a detailed analysis of changes in land values of all types based on actual data obtained from appraisal offices, can be found in Research Report 1327-2. Actual sales are also analyzed in a more detailed fashion using the State Comptroller's data in this report. These analyses were conducted in order to assess whether there were any systematic differences or similarities in the opinions of the businesses and residents both by design sub-area and overall. Wherever appropriate, we will draw on the results of the actual analysis and compare them to the survey type information by study area.

Business Effects

The majority of the businesses surveyed were retail types of businesses. The second largest category of surveyed businesses belonged to the services category. Most of the businesses were located in rented buildings and were observed to be in good condition. A very small percentage of businesses surveyed belonged to other categories, such as manufacturing or construction. The mean age of surveyed businesses ranges from 10.2 years in the Lubbock study area to 8.2 years in the San Antonio area. The mean length of stay for businesses was also the highest in the Lubbock, I.H.-27, study area while Dallas Central Expressway businesses had the shortest length of stay. Therefore, since the average of the respondent businesses was at least eight years, most of the businesses had before, during, and after grade level change experience.

In all study areas, the mean commercial property values, parking spaces, employment, and sales were sometimes found to be higher on sections adjacent to at-grade segments and sometimes on sections adjacent to elevated segments of the study freeways than on sections adjacent depressed segments. The pattern was found to be fairly similar, even in the non-abutting sections.

Satisfaction with Freeway Location

When asked to describe their locations, businesses cited accessibility and convenience most frequently. Other attributes cited in the Houston, San Antonio, and Dallas study areas include well-kept and nice areas. There were found to be differences in the response pattern by design sub-area, particularly in Lubbock's I.H.-27 study area. Business respondents from this study area cited more positive neighborhood attributes on at-grade and elevated sections of I.H.-27 in comparison to the depressed sections of the freeway. The most frequently cited reasons for locating in the area included convenience, in most study areas. Customer market was cited in all areas other than the Lubbock study area. Price was cited in both the Lubbock and Dallas study areas. Traffic patterns were also cited as important reasons in the Lubbock and Houston areas. Of the advantages of the area, accessibility, convenience, and visibility were often cited on elevated and at-grade segments. Lack of accessibility was the most frequently cited disadvantage on depressed segments, and lack of convenience was often cited on elevated segments, sometimes on at-grade segments, and never on depressed segments. Furthermore, all the problems cited by Lubbock businesses were cited most frequently by those located adjacent the depressed section #9.

Opinions of businesses regarding extent of change in the area since at present location did not reveal any significant differences by design sub-area. Businesses, in all study areas, by and large agreed that there was an improvement in the area since they had located there. The responses of Houston businesses did not provide a clear cut direction of change. Furthermore, no grade level differences were observed when businesses were asked about change in the area since construction of the study freeways, except in the Lubbock study area. Again, the direction of change was felt to be in the positive direction in all study areas. Overall, the opinion of businesses in the Lubbock area suggested a change in the positive direction; however, 47 percent of businesses located adjacent the depressed section believed there had been a decline in comparison to only 15 percent and 20 percent on the elevated and at-grade control sections, respectively. Therefore, the construction of the study freeways had a positive impact on the neighborhood from the perspective of businesses. Negative impacts were largely limited to the Lubbock area, depressed section.

Preferred Freeway Grade Level

The majority of businesses on all freeway sections in all study areas also agreed that construction was necessary. The preferred grade level of freeways in three of the four study areas was elevated. Businesses in the Dallas study area preferred the depressed type more frequently than they preferred the elevated type; however, the overall direction was unclear because the largest percentage of respondents indicated no preference over one or the other design.

Effects of Freeway Design Characteristics

Some of the negative effects most frequently reported in all study areas as having increased since construction include increase in noise, pollution, and crime levels. Responses of businesses indicate that commercial property values and business sales volumes were positively affected in some areas and negatively in others. Property values and business volumes were believed to have decreased in the Houston and Dallas (mostly in the depressed segment) areas. Business volumes were also believed to have decreased more frequently in the depressed section of the I.H.-27 study area and the San Antonio study area.

Positive effects of the freeways include increased travel safety, travel convenience, and travel time—all of these are factors which would lead an enhancement of direct user benefits. Commercial property values and business volumes improved since construction in some situations, particularly in the San Antonio and Lubbock areas (mostly on elevated sections). Dallas presents a unique situation, essentially because most of the changes experienced by businesses and residents are a reflection of pure construction period affects. All negative changes were experienced in the Dallas area which include increased travel time, noise, pollution, and crime levels. They also include decreased travel safety, travel convenience, business volumes, and property values.

Businesses in all study areas indicated that they liked the appearance of the freeways in all study areas and a very small percentage, less than 5 percent overall, said that they disliked the appearance, while 15 percent had no opinion. When asked some design type aspects pertaining to the number of under and overpasses and number of on and off ramps, businesses by and large had no opinion or said that there were plenty of on/off ramps or overpasses/underpasses. Furthermore, in most study areas, no design sub-area differences nor distance effects in the responses were observed.

Changes in Employment

Negative during construction period effects are observed in all study areas, as expected. When considered by design sub-area, the results show that sometimes the change is in the positive direction, indicating an improvement in the after construction period and sometimes in the negative direction. The change was observed to be in the positive direction for the at-grade control sections, in most cases, both during and after construction and either minimal negative change, no change, or a change in the positive direction for the non-abutting sections—the true controls. However, the changes were not found to be statistically significant across grade levels for either abutting or non-abutting sections in any study area. Changes in means and an assessment of the number of businesses reporting increases/decreases/no change indicate that the Lubbock elevated section #8 and at-grade control section, San Antonio depressed and at-grade sections were positively impacted in the after construction period. Further, Lubbock I.H.-27 depressed section #9, Dallas study area (elevated and depressed segments), San Antonio (elevated sections), and Houston (all sections) were negatively impacted both during and after construction. These changes were found to be related to the construction of the freeway in all study areas since, in all cases, the observed change in the non-abutting sections was minimal.

Changes in Parking Spaces

Again, negative during construction period affects in all study areas were observed, and the extent of impact varied by design sub-area from no impact in some design areas to negative impact in others. Again, design sub-area differences in the changes were not statistically significant for all study areas. The largest impact was observed in the Lubbock study area and this is probably due to extensive right-of-way acquisitions in the Lubbock study area, as reported in another section of this report. The number of relocations on the at-grade sections was the lowest, in comparison to the elevated and depressed sections of I.H.-27 as also shown in this report. There were only 14 relocatees per kilometer on at-grade segments in comparison to 61 and 33 relocatees per kilometer in the elevated and depressed sections, respectively. The impact was found to be minimal in all other study sections. In the after construction period, almost all study areas either regained their original number of parking spaces or improved. Only the depressed I.H.-27 section #9 in Lubbock continued to be negatively impacted, even in the after period.

Changes in Gross Sales of Businesses

Negative during construction period effects are once again indicated for all study areas as indicated by means derived from ranges of gross sales reported by businesses. The results for the Dallas study area are pure construction period effects. Further, grade level differences in opinions on changes in sales were statistically significant only for the Lubbock study area.

In the after period, all other elevated and depressed study sections were affected negatively and only one at-grade section was positively impacted in real terms. The Houston at-grade segment was the only one that was positively impacted.

The opinions of businesses concur with the results from the means analysis by design sub-area for the Lubbock and Dallas study areas in actual terms. The opinions and results of means analysis are not in agreement for all grade level segments in the Houston area and all elevated and depressed segments in the San Antonio area. While the opinion data for Houston indicates a decline in sales, the means data indicates an improvement in sales. Also, the opinion data for the San Antonio segments suggest a decline in gross sales for businesses abutting the elevated and depressed sections, but the means data suggest the opposite.

The analysis of actual sales data from the State Comptroller confirmed the findings of the means analysis only in the case of the Lubbock segments, the elevated and at-grade segments in Dallas, and only the at-grade segment in Houston. The means analysis indicated a decline in gross sales on depressed segments in Dallas. However, the analysis of actual sales indicated an increase for the depressed segment. In the case of Houston (elevated and depressed segments), the means analysis indicated a decline in sales (real dollars) of businesses adjacent to the elevated segments, and no information was available for businesses on the depressed segment. The actual sales data analysis for Houston indicated an increase on all segments. In the case of San Antonio, the means analysis indicated a decline in sales for all sections, while the analysis of U.S. 281 data from the State Comptroller indicated an increase in sales. Again, the discrepancies in the two results are primarily because 1) the means analysis uses means which are derived from broad gross sales ranges and 2) the means analysis is based on a sample of firms reporting sales in all periods, while the other approach is based on all businesses abutting the highway. It is also observed that changes in employment levels closely match the changes in gross sales levels. This is to be expected to a certain degree.

Overall, pooling in the results of the studies, there is evidence that depressed sections, as defined in the introductory chapter, have outperformed elevated sections in terms of changes in gross sales levels. Analysis of sales of relevant zip codes surrounding the study areas and non-abutting sections showed a positive increase in sales for all areas in real terms. However, the approach based on State Comptroller data indicated that the net impact on the Lubbock abutting study areas was in the negative direction and positive for Houston and San Antonio study areas. On a combined basis, the Dallas study section performed just as well; however, individual segments, like the elevated and at-grade segments, were negatively impacted. These impacts can be attributed to the construction of study freeways, and, in the case of Lubbock, grade level differences were also a contributing factor. In general, the abutting businesses in the depressed section (#9) in Lubbock were the worst affected on all counts; property values, gross sales levels, parking spaces, and employment declined. Dallas study area businesses were also negatively impacted on all counts; however, these are purely during construction period effects. San Antonio study area businesses were, in general, positively affected in terms of sales, parking spaces, and employment. Houston study area businesses were also positively impacted, in some cases (sales and parking spaces), and negatively affected in others cases (property values and employment). Lubbock elevated sections were positively impacted only in terms of employment and parking spaces and negatively impacted in terms of property value and sales; at-grade sections were positively impacted in terms of employment only.

Residential Effects

Most of the residential respondents lived in single family detached housing and lived in houses sometimes as old as 26 years, with approximately five to nine rooms in the house. Most of the respondents in all study areas were homeowners and had lived in the neighborhood for longer than 15 years on abutting sections and 12 years on non-abutting sections. The average length of stay of residential respondents was, in general, higher on abutting sections than other non-abutting sections, except in the Dallas study area. Property values were observed to be highest on non-abutting sections rather than abutting sections, in general. There did not appear to be any consistent pattern by design sub-area. In the case of the I.H.-27 study area in Lubbock, however, the abutting properties had higher mean property values than non-abutting properties, and further, properties both abutting and non-abutting the depressed section of I.H.-27 had the highest mean property values in comparison to other grade levels.

In both Lubbock and San Antonio study areas, the majority of respondents were Hispanic while the majority of respondents were Anglo in the Houston and Dallas study areas. Household size ranged between three to five members in most study areas, members typically being couples living with their children. In the Dallas study area, however, the household size consisted of either one or two members and the typical composition being married couples. A very high percentage of respondents from the Lubbock I.H.-27 study area (74 percent) and San Antonio study areas (54 percent) were not highly educated and had either a high school degree, trade or technical degree, or less. On the contrary, the educational background of respondents from the Houston Beltway-8 study area and Dallas Central Expressway study area was much stronger, with a large majority of respondents possessing at least a college degree.

Two aspects were considered as indicators of financial characteristics of the respondents. The first variable was the number of cars owned, and the second variable was the annual income range. Majority of the responding households possessed at least two cars in most study areas. Mean income ranges within abutting sections of the study areas were the highest on depressed sections or segments of the concerned freeways. This was not the case in the Dallas study area, where mean income was highest on the elevated segment of Central Expressway. In the non-abutting sections, elevated sections had higher mean incomes than depressed sections. The exception to this case was in Lubbock's non-abutting sections where the reverse was observed. Furthermore, mean incomes were higher for respondents on abutting sections in the Lubbock and

San Antonio study areas; mean incomes were higher on non-abutting sections in the Dallas and Houston study areas.

Satisfaction with Location and Neighborhood

All of the study area neighborhoods were found to be cohesive; however, in terms of quality, there were found to be wide differences, with the Houston and Dallas study areas at the upper end of the scale and Lubbock at the lower end of the scale. An inverse relation was observed between distance from the freeway and the incidence of reported problems. Price and convenience were found to be the leading reasons for locating in the neighborhood in all study areas. Neighborhood type was another critical deciding variable in the case of the Houston and Dallas study areas. The most frequently reported advantages of the study areas include:

Lubbock: Proximity to work and schools, freeway access.

Houston: Convenient, neighborhood type, good schools.

San Antonio: Convenient and central location, freeway access.

Dallas: Prestige and beauty, neighborhood type, proximity to schools, convenient and central location.

The most frequently cited disadvantages of the study areas typically include:

Lubbock: Neighborhood upkeep, traffic level, noise.

Houston: Traffic level, noise, proximity to the freeway.

San Antonio: Traffic level, noise, and neighborhood people.

Dallas: Traffic level, noise.

Effects on Travel Habits and Patterns

As regarding the travel habits of the respondents, most of the respondents in the Lubbock and Houston study areas usually traveled a distance exceeding five miles for shopping, running personal errands, or commuting to work. Most respondents in the Dallas and San Antonio study areas traveled between one and five miles for purposes of shopping and running personal errands.

Although there was a large percentage of respondents who believed that the study freeways had not changed the travel pattern, there is some evidence that the construction of the study freeways improved accessibility in all study areas. No grade level differences were observed either in the change in travel patterns after construction of study freeways or opinions on extent of change in the area while at location or since completion of study freeways. However, there is some evidence to show that the distance from the freeway may be an important determinant of these perceptions. The incidence of opinions suggesting decline increased on some abutting zones. Opinions of change in the study areas since at location and since completion of study freeways differed considerably in two of the four study areas, Dallas and Houston. In the case of Lubbock, the responses to both the questions indicated a change in the negative direction rather than positive; the reverse was observed in the case of San Antonio. While a greater percentage of respondents from the Houston and Dallas study areas felt the areas had improved rather than deteriorated since at location, when asked about extent of change since completion of study freeways, these opinions were completely reversed. These factors lead us to believe that the construction of the study freeways have had some negative impact on the perceptions and opinions of residents regarding area effects in the Lubbock, Dallas, and Houston study areas and a positive impact in the San Antonio study area. However, in the case of Dallas, the responses are a reflection of construction period effects.

Preferred Freeway Grade Level

All study area respondents believed that construction of the study freeways was necessary. No grade level effects were detected in the responses, and the responses were not different even by distance zone. Some of the reasons for construction provided by respondents include increased traffic due to growth in the respective cities and increased congestion levels. Respondents in most study areas indicated a strong preference for the depressed type of freeway over the elevated type, particularly as distance to the freeway decreased. The incidence of no preference type of responses increased as distance to the freeway increased, i.e., on non-abutting zones. In the Houston and Dallas study areas, depressed type of freeways were the preferred choice regardless of distance from the freeway or the current location of the respondents.

Effectiveness of Noise Barriers

Regarding the effectiveness of noise barrier walls in the Houston and Dallas study areas, the evidence suggests that a greater percentage of respondents believed that they are effective rather than ineffective in mitigating noise problems. In the Houston study area, these percentages are 91 percent and 50 percent on abutting and non-abutting sections, respectively. In the Dallas study area, these percentages are 89 percent and 64 percent, respectively. Again, no grade level differences were found in the opinions of residents. However, distance from the freeway was found to be an important variable in determining opinions. As expected, an inverse relation was observed between the degree of effectiveness as reported by the respondents and distance from the freeway. Nevertheless, even on non-abutting sections, more respondents felt the noise were effective rather than ineffective.

Other Effects of Freeway

Some positive effects of the freeway were reported by respondents from all study areas. The effects were found to be different, based on distance from freeway. In addition, some benefits were reported in some areas and others in other areas. The positive effect that was cited in all study areas (abutting sections) as having improved after construction was an improvement in travel times. An increase in travel convenience and travel safety was also observed from responses in all study areas, with the exception of Dallas. Again, this is because of the ongoing construction activity on Central Expressway. Other benefits, such as an improvement in property values, was observed only in the San Antonio study area. On non-abutting sections, travel time was reported to have improved in Lubbock and Dallas only. Travel convenience was reported to have increased in all areas, except Dallas. Travel safety was observed to have increased in Lubbock and San Antonio areas only. Property values were observed to have improved in the San Antonio study area and non-abutting sections of the Lubbock I.H.-27 study area.

Among the negative effects most frequently cited on both abutting and non-abutting sections were increased noise, pollution, and crime levels. Neighborhood quality was more frequently reported to have declined on all abutting sections. In the non-abutting sections, the responses suggest an improvement in the Lubbock and San Antonio study areas, no change in the Houston area, and a deterioration in the Dallas area. Property values were reported more often to have decreased rather than increased in the Lubbock (abutting sections), Houston, and Dallas study areas.

Property Values/Uses

As indicated earlier in this report, more than one database was used to assess property value/use effects, i.e., data from a survey (which includes hard and opinion data) and hard data from the respective county appraisal districts. The findings on the land value/use effects of the study freeway segments by grade level are summarized below from an analysis of both databases. The more detailed findings from the survey database are presented in Research Report 1327-1, and the findings from the appraisal district database are presented in Research Report 1327-2.

Findings from Survey Database

The means based on property value ranges indicate that during construction, some decline was observed in many sections. Some other sections were unaffected during construction. In the after construction period, there seems to be no systematic pattern in the property value changes observed within each design sub-area for all study areas. Grade level differences in property value changes were observed only in the case of Lubbock and Dallas abutting businesses.

All sections, both abutting and non-abutting, were negatively impacted in real terms in the during and after construction periods. This suggests that the construction of the highways itself did not cause this decline in property values. However, the construction may have contributed to this decline on abutting sections, although property values would be more vulnerable to economy-wide changes. This contention is also supported when the change in property values in the county as a whole is considered in addition to change in the non-abutting sections. For example, total market values of properties in the Bexar County area increased by 6.3 percent from $33.8 billion (1994 dollars) to $36.1 billion in 1994. Since no responses were available from non-abutting sections of Beltway-8, it was not possible to infer anything about the impact of the construction of Beltway-8 on the Houston study area commercial property values. However, considering the decrease by 14.7 percent in total assessed market values of properties from $203 billion in 1982 (1994 dollars) to $173 billion in 1994, we are led to believe that the construction of Beltway-8 in itself did reduce the growth in the value of adjacent commercial properties in real terms. The total market values declined over the 1988-1994 period in Lubbock (total property values were $6.0 billion (1994 dollars) in 1988 and only $5.3 billion in 1994). Similarly, Dallas County reports a decline of approximately 28 percent in total market values of properties over the 1985-1994 period (total market values were $37 billion (1994 dollars) in 1985 and $29 billion in 1994). It is interesting that grade level effects in the responses of businesses were also observed for Dallas and Lubbock, reinforcing the notion that the construction activity could have indirectly contributed to the observed decline, particularly in these two areas.

The results of the means analysis in actual dollars closely followed the opinions expressed by businesses within each design sub-area in many cases. There were situations when discrepancies were observed and they include:

- Lubbock (at-grade and depressed sections). The means analysis indicated an increase in the mean property values on at-grade sections and a decline on depressed sections. Opinions indicate the reverse direction of change for each design sub-area.
- Houston (elevated and at-grade segments). The means analysis indicated no change in mean property values after construction for properties adjacent the elevated segment and an increase in mean property values for properties adjacent the at-grade segment. Opinions, however, indicate no change on at-grade segments and a decrease on elevated segments of Beltway-8.

Findings from Appraisal District Database

Also, as indicated earlier, the appraisal district database was analyzed on a mean average basis and a regression value index basis. In both analyses, the land value per square meter of each parcel of land is used as the unit of value to analyze changes in value by land use and freeway grade level. The assessment of the mean square meter data from the four cities can be compared in several ways, including comparing before and after construction percentage changes of the mean of individual and combined cities, comparing after construction mean values (1994) of individual and combined cities, and comparing land value indexes of individual and combined cities.

On a percentage change basis, properties adjacent to at-grade sections of the mature freeways in Houston and San Antonio experienced more positive value changes than parcels adjacent to elevated sections, although the difference for Houston is minimal. These findings are consistent with previous research. In Houston, the value of properties abutting the depressed section did not perform as well as the elevated or at-grade sections. While all values in Lubbock decreased, those parcels adjacent to elevated parcels decreased the least. In Dallas, depressed parcels decreased more than at-grade parcels. It should be noted that freeway construction in Dallas was still in progress. In San Antonio, the percentage change in the values of depressed section properties was higher than for elevated or at-grade properties. Averages of the values, with the under-construction section included for Dallas, show elevated section properties to be higher in value than those of the at-grade and depressed properties. When Dallas is excluded, the elevated parcels show the greatest percentage increase, while depressed section parcels tend to have a lower percentage increase in value than the elevated section parcels.

The average percent change indicates that properties located in depressed sections had a higher performance in terms of land values than those parcels adjacent to the elevated sections in the study. Depressed sections had a 13.86 percent increase in the aggregate, while the double-decked sections remained positive at 4 percent. Elevated values appeared to experience a decrease in aggregate average value of 8.47 percent. When compared to at-grade, elevated and depressed sections were varied in terms of percentage change. Land value adjacent to elevated section parcels, though small in terms of aggregate average values, had a positive value. The depressed and double-decked section values were more negative than those of at-grade sections.

Another way to analyze grade level land value differences is by using the one-point-in-time (1994 value) approach. Using the 1994 square meter values of each grade level for comparison, the value of land next to depressed and elevated freeways is slightly higher than that of land adjacent to at-grade sections for all four cities combined. The at-grade properties have the lowest value per square meter with the values of elevated and depressed sections at 45.2 percent and 44.94 percent greater, respectively.

The findings, based on the regression based land value index, for a before and after construction analysis on the Houston, Lubbock, and San Antonio database show similar results. In Houston, the residential property increased from the before period base index value of 100 to an after period index value of 239 for both the elevated and at-grade section compared to 215 for the depressed section. There was no land value advantage or disadvantage for being elevated, in comparison with the at-grade control section. However, the at-grade section would have a 24 point value advantage over the depressed section. In Lubbock, the residential index values also are surprising in that all are negative (below 100), suggesting a decline in land values per square meter. Residential elevated section values are highest at 81, followed by at-grade and depressed section values of 75 and 47, respectively. In San Antonio, the residential elevated index value was highest at 134, followed by at-grade and depressed section values of 99.5 and 83.6, respectively.

The difference between the before and after residential land indices in Lubbock and San Antonio are statistically significant, but those of Houston are not. This result infers that the Houston land value indices for elevated and depressed section residential properties are not different from the at-grade index, which is the control index value. In other words, there is no land value advantage or disadvantage for a residential property that is located adjacent to a depressed or elevated section of the freeway in Houston. In the case of Lubbock and San Antonio, land values for residential properties adjacent to elevated freeways show the greatest appreciation.

All of the Houston commercial index values are positive, with the at-grade section index being the highest at 241 followed by the elevated and depressed section indexes being -237 and 192, respectively. The Lubbock commercial index values are negative, with the depressed section index being the highest at 95, followed by the at-grade and elevated section index values of 88 and 86, respectively. The San Antonio commercial index values are all positive, with the at-grade section values being the highest at 142.8, followed by depressed and elevated section values of 125.9 and 115.5, respectively.

The commercial land value coefficients are statistically significant only for Houston. The land values for commercial properties adjacent to elevated sections show approximately a 45 percent greater increase than properties adjacent to depressed freeway sections. Properties adjacent to at-grade sections show the greatest increase overall. The analysis suggests that residential elevated properties and commercial at-grade properties exhibit the greatest increase in land values, followed by commercial elevated land.

Many areas of consistency exist between the land value index and the mean analysis. For instance, in Houston, the elevated land value changes before and after construction were similar or equal to changes for at-grade parcels. Also, elevated residential parcels in Lubbock (per the land value index) and land value for aggregate land uses (per the mean analysis) had better after construction responses than at-grade parcels. However, the land value and mean analysis show contrasting results for San Antonio, with the former indicating elevated property performed better than at-grade property where the latter methodology reflects the reverse. The depressed freeway assessments for the two methods concur for Houston, with the land adjacent to depressed sections having greater decreases in value than at-grade section land. The residential land value index and the mean analysis also show depressed section values having greater decreases after construction than at-grade section parcels. The land value index reflects depressed section land values performing less well than at-grade section land; the mean analysis shows depressed section land in San Antonio as having larger increases in value than at-grade land. These variations in results may be due to the strong influences of values in suburban U.S. 281 that are smoothed somewhat in the regression analysis.

An alternative procedure was also conducted in order to check the robustness of the conclusions. In this approach, the database for the three cities (San Antonio, Houston, and Lubbock) having completed freeway sections were combined (pooled) and analyzed together. In order to make the data comparable across cities, only two years of data were retained for Houston. The differences in cities were accounted for by including appropriate city dummy variables. The results suggest residential elevated freeway properties show a greater increase in land values than for the at-grade, depressed, and double-decked freeway properties. For commercial properties, at-grade freeway properties show the greatest appreciation followed by elevated, depressed, and double-decked properties, in that order.

In general, the various approaches lead to the same conclusions; elevated residential properties show the greatest appreciation over the base year. Residential depressed land values exhibited the least appreciation. For commercial land, at-grade parcels showed the greatest increase, followed by properties adjacent to elevated sections. Previous research confirms that commercial properties benefit from the greater visibility afforded by at-grade and elevated freeway locations.

Construction Employment and Income Effects

The analysis of employment effects of contractors' expenditures on construction lead us to believe that elevated/elevated-depressed sections have led to the largest increases in employment and related output effects. This is primarily because construction costs for elevated types of freeways are typically much higher than for either the depressed or at-grade types.

Tax Revenue Impacts

The combined property and sales tax revenue impact analysis indicated that, overall, depressed sections have outperformed elevated sections. On an individual section basis, in most cases and excluding Dallas, the at-grade control sections have shown the maximum positive appreciation in property and sales tax revenues than other sections within the same study area.

ENVIRONMENTAL

Noise Pollution

As addressed in the introductory section, four cities were selected for conducting traffic noise studies of at-grade, elevated, and depressed freeway sections. These cities were San Antonio, Dallas, Lubbock, and Houston. The study sites in these cities were chosen because of either proposed construction, current construction, or recently finished construction. This would allow comparisons of the various grade levels in a before and after improvement condition. In some study sites, this was accomplished. In others, only one condition was observed since the length of time needed for freeway improvements was not in the time frame of this study. Still, valuable information was gathered that can be compared with previous measurements made by TxDOT or may be compared with future measurements in subsequent research.

The findings on each of the study freeways in the four cities are summarized below on an individual freeway basis within each city.

San Antonio—I.H. 35 & I.H. 10 Downtown 'Y'

Study sections 1, 2, 3, and 4 make up the downtown 'Y' part of the San Antonio freeway study areas. These sections were more or less studied since sections 2, 3, and 4 have elevated portions. Prior to improvements in the "Y," extensive noise analyses were performed by TxDOT in 1985 and 1986. Their analysis involved field measurements and modeling of existing and design year levels. As part of this current TTI study, field measurements were conducted in 1994 after improvements were completed. The same techniques were used with other sites in this report. Sound measurements were made using the Leq10 dBA method. The receptors were located 24.40 m (80 ft) from the R.O.W. Since these readings were obtained at one point in time, they can only reflect the conditions at that moment. Day-to-day and hour-to-hour traffic volumes and speeds will introduce some uncertainty into the data. Despite this, the trend from location-to-location does show consistent patterns that are discussed in the observation section of these study sites. This study was made six years before the design year 2000. Considering that, the predicted levels for the year 2000 may be quite close since the measured values were three to four dBA lower and will probably increase that much in the next six years due to increased traffic flow.

The following observations can be made from the findings of the study of the 'Y' sections:

- The conclusions of the 1984 study by Grant Anderson (22) concerning the possible amplification of traffic noise by combined depressed/elevated sections in San Antonio were proven correct. He stated that there should be insignificant amplification of noise, off the R.O.W., by adding elevated roadways above existing roadways using the composite wing girder design.
- Measurements during this study showed noise levels less than or equal to the 1985 measurements in approximately the same locations before improvement.
- Measurements during this study showed noise levels 3 to 6 dBA less than the predicted design year 2000 levels.
- In the locations measured, noise levels were below the noise abatement criteria.
- Measured noise levels made during this study were less than the 1985 measurements by about an 8 dBA average.
- Measurements during this study were nearly equal to the 1985 computed design year 2000 predictions, within 1 dBA.
- The lowest readings were obtained from depressed sections. The next best readings were obtained from elevated sections, followed by readings from at-grade sections. All sections were within 3 dBA, which could be considered an undetectable difference. This small difference could be partly due to traffic on the frontage roads that were all at-grade.
- In the locations measured, noise levels were below the noise abatement criteria, except some at-grade conditions.

San Antonio—U.S. 281

The noise study section 5 is in a suburban area of San Antonio on U.S. 281. In 1987, TxDOT submitted a noise analysis for the above described project. The study indicated that "recommended levels are currently exceeded and will also be exceeded in the design year." In this study, three business establishments and one church adjacent to the right-of-way were selected for analysis. These same locations were found during this study, and two were measured.

The following observations can be made from the noise measurements at these sites:

- The 1995 measured noise levels, after construction, are less (better) than the 1987 measured values before improvement, and less than the design year predicted values. The at-grade conditions of this could be due to the solid 813 mm (32 in) concrete median barrier that shields the tire noise from the far lanes. Another theory is that standards for automobile noise emission have produced quieter passenger vehicles between 1987 and 1995.
- The three church values, which were all at-grade, show a small difference of less than 3 dBA, which is undetectable by the human ear. This shows the highway improvement caused little change in noise at this location, as predicted.
- The large difference in the commercial #2 values are due to U.S. 281 being depressed at that location. This may not have been considered or accurately modeled in the 1987 design year prediction. By depressing the highway at this location, traffic noise was reduced by about 8 dBA, even though the business in question was at the edge of the right-of-way. Another reason for the low noise level is the treatment of the far wall of the depression. It has a corrugated texture which, though visible from the receptor, scatters rather than reflects noise in the depression.

The preceding study investigated the noise differences in before and after conditions. The next investigation looks at differences in distance from the roadway at the three grade levels. This was accomplished by locating the three conditions on U.S. 281 and measuring traffic noise at 15.2 m (50 ft), 45.7 m (150 ft), and 76.2 m (250 ft) from the right-of-way. The results of these tests allow the following observations to made:

- All noise values are within the 23 CFR, Part 772, recommendations for commercial land use.
- All noise values except, "at-grade 15.2 m (50 ft)," are within recommendations for residences and churches.
- Depressed and elevated main lanes produce lower noise levels than those at-grade.
- Depressed main lanes produce the lowest noise levels.
- The reduction in noise as distance from the roadway increases follows the normal logarithmic function, in the at-grade condition.
- The elevated section produces less noise than the at-grade section up to 122 m (400 ft) from the right-of-way. Past that point, they are about the same. This is due to the shielding effect of the solid concrete barriers on either side of the elevated roadway.
- The new 813 mm (32 in), concrete median barriers appear to have a significant benefit in reducing vehicle tire and exhaust noise, which are the primary sources of automobile noise.

One of the test sites, a church site, on the U.S. 281 study section was used to evaluate the STAMINA 2.0 FHWA noise traffic noise prediction model in this area; one site was chosen and modeled in the computer. The site was the church that was an at-grade condition. The roadway geometries were entered into the program as well as the 813 mm (32 in) concrete median barrier on the center line. The two receptor or sound meter locations were modeled in the same locations used for the actual measurements. Traffic volume counts during the measurements were also used in the model. The following results were produced:

Distance from center line	Measured L_{eq}	STAMINA Predicted L_{eq}
59.5 m (195 ft)	70.5 dBA	70.5 dBA
106.7 m (350 ft)	62.7 dBA	64.8 dBA

As can be seen, the near location was measured at the same value as the computer prediction. The further location was different by about 2 dBA. The reason for the distant measurement being lower than the predicted model could be that the church building was shielding some sound from the north part of the roadway, which was not accounted for in the model. Also, the far receptor was slightly downhill, which was modeled but may need refining. Overall, the STAMINA model did an excellent job of predicting the traffic noise at this location. Other comparisons between actual measured noise levels and STAMINA 2.0 results are shown in the study section results.

Dallas—U.S. 75 (Central Expressway)

This traffic noise study section (#7) involves the reconstruction of U.S. 75 (North Central Expressway) between Spur 366 (Woodall Rodgers Freeway) and I.H. 635 (Lyndon B. Johnson Freeway) in Dallas. The project corridor is approximately 14.8 km (9.2 mi) long. This corridor is made up of a large mix of land use areas located close to the right-of-way (ROW). These land use areas include retail and commercial buildings, offices, industrial sites, residential areas, parks, and churches.

This section was selected for this study because it provided an excellent "before" and "after" situation that used several grade level conditions. The study section was visited twice, once at the beginning of construction in March 1994 and again in August 1996. Unfortunately, the reconstruction project was not totally complete at the end of this study, but valuable information was gathered on the portions that were completed. After the completion of construction, any subsequent follow-up can gather the remaining data. Used in conjunction with the site visits was the final environmental impact statement produced by TxDOT in July 1986. This very detailed and extensive study did a thorough examination of the expressway corridor for noise-sensitive land uses; a group of 30 individual sites was selected for noise measurements. Nineteen additional sites were monitored in November 1985 for specific inclusion in the report. Eleven of these sites were selected for this study.

The results of the TTI 1994 measurements compared favorably with the TxDOT study in 1985 in the areas not yet improved, in the south end of the project. These values are shown below.

Location	Edge of Pavement	Grade	TxDOT dBA L_{eq}	TTI dBA L_{eq}
Retirement Home	21.3 m (70 ft)	At-grade	70	68.5
Park	114.4 m (375 ft)	Depressed	65	63.8
Church	41.2 m (135 ft)	At-grade	64	63.5
Cemetery	38.1 m (125 ft)	Elevated	70	69.8

In areas of completion in the north end of the project, the sound levels showed a definite improvement between the 1985 TxDOT readings and the 1994 TTI readings at the same locations. These are illustrated below.

Location	Edge of Pavement	Grade	TxDOT dBA L_{eq}	TTI dBA L_{eq}
Motel	36.6 m (120 ft)	At-grade	69.0	64.9
Town homes	24.4 m (80 ft)	Slight Ele.	74.0	65.8
Recreation Area	244 m (800 ft)	At-grade	63.0	57.5

The construction of concrete barriers and sound walls resulted in a lessening of traffic noise. At the motel and town homes, a 1.2 m (4 ft) wall provides shielding between the main lane vehicles and the noise-sensitive areas. Also, 813 mm (32 in) concrete median barriers are located on the main lane center lines, providing additional shielding at the tire level of the far main lane traffic. As with many sites evaluated in this study, a great amount of effort has been devoted to the main lanes, but the frontage roads usually remain at-grade, near to the edge of the right-of-way, and close to noise sensitive areas. If the traffic is light on these roads, there is no problem. It is when the frontage or access roads contain a high volume of medium to high speed traffic that the treatment of the main lanes is defeated by the noise generated on these roadways. To illustrate, one study site was 45.7 m (150 ft) from the edge of the frontage road. Part of the new construction was the addition of a 1.2 m (4 ft) aesthetically pleasing sound wall.

Sound measurements made with only main lane traffic at the apartment complex produced only 69 dBA L_{eq} noise levels, while measurements during main lane and frontage traffic produced 80 dBA L_{eq} for the short time the traffic was present.

North of Lover's Lane on the west side of Central Expressway was another study location for both TxDOT and TTI. In both the original TxDOT study and the 1994 TTI study, this location near a church was at grade level. Upon our return in 1996, the roadway had been depressed below grade and a 4.3 m (14 ft) tall, aesthetically pleasing, sound wall built. Sound level measurements were made in the same location as the previous TxDOT and TTI studies, which placed the microphone behind the sound wall. The measured L_{eq} value was 56.3 dBA at a distance of 45.8 m (150 ft) from the main lanes. The sound wall ended just north of this site, and another reading was obtained 45.8 m (150 ft) from the main lanes with no sound wall. The result was a level of 68 dBA L_{eq}. This impressive difference is a 11.7 dBA insertion loss. The insertion loss is the amount of acoustical energy loss encountered when sound rays are required to travel over and around a wall by diffraction. This large reduction in the traffic noise level is due primarily to the sound wall and to some extent on the depressed roadway.

Lubbock—U.S. 82 (Proposed East-West Freeway)

The proposed east-west (U.S. 82) freeway in Lubbock was chosen as a study section for part of this project. This freeway will undergo substantial improvements in the next few years. The study section runs from Southwest Loop 289 to 19th Street. Sound level data were taken along this corridor in anticipation of returning after the construction project. The proposed improvements include depressed sections that would provide excellent research sites for this project. Since this research project concluded before the completion of the east-west freeway, subsequent projects will need to complete the work.

The noise levels measured recently for this study agree with the TxDOT computed levels for 1990. As stated in the TxDOT study, "the 2010 No Build" noise levels would be approximately 1.8 Decibels higher than the 1990 levels." This is due solely to increased traffic volume. Again, the following observations can be made:

- The TxDOT Environmental noise study appears comprehensive, with 76 locations on the study highway modeled.
- Locations sampled during this study closely match the modeled 'No Build' between 1990 and 2010, with a few ambiguous readings.
- Noise levels will generally decrease on both sides of depressed main lanes.
- Future measurements will determine if the *STAMINA* 2.0 program accurately models the depressed sections of the roadway.

- The TxDOT study states, "Roads that are built at ground level are noisier than depressed or elevated roadways." This agrees with the findings of this study.

Lubbock—I.H. 27

Study sections 8 and 9 in Lubbock were chosen because of recent rebuilding of Interstate Highway 27 through the center of the city; that was completed in 1992. This north-south corridor is 9.66 km (6 mi) long, from Loop 289 North to Loop 289 South. Prior to construction, the corridor was entirely at-grade level. Upon completion, I.H. 27 between Loop 289 North and 36th St. is primarily elevated, and between 36th St. and Loop 289 South is primarily depressed below grade. All frontage roads remained at-grade level.

In November 1978, TxDOT completed an "environmental impact statement" for the proposed project. The study was revised in March 1981. The "Sound Evaluation Study" portion of the Impact Statement was used in this project as a "before" condition of the traffic noise at that time. It also contained model data to predict what the traffic noise impact would be in the year 2007. In 1994, as part of this study, TTI researchers measured sound levels along the newly completed I.H. 27, at elevated, depressed, and at-grade levels. These included some of the same locations measured and modeled in the 1978 study. It is not clear if the engineers modeled the roadway as elevated and depressed in those locations. The following observations are made from the analysis of the test results:

- 1994 traffic noise levels along this corridor did not increase over the 1978 levels and, in fact, were reduced by an average of 3.3 dBA.
- The model data developed in the 1978 study appears to overestimate the future noise levels by about 7 dBA. In other words, the model thought there would be more noise than there actually is. This could be due to overestimating the traffic volume or not considering the elevated and depressed main lanes.
- All 1994 study locations along this corridor were below the federal noise abatement criteria, except one that was at-grade level. The 1978 study predicted the majority to be above the recommended limits.
- Traffic noise level measurements should not be taken on the right-of-way line. This location is not typical of living and working conditions. It is also quite close to traffic on

the frontage road that would outweigh traffic noise from the main lanes and cloud the results.

- Average depressed sections were 4 dBA quieter than the at-grade control sections, and average elevated sections were 1.7 dBA quieter than the at-grade control sections.

Houston—Sam Houston Tollway

The project study site in Houston was the W. Sam Houston Tollway. This roadway provided elevated, depressed, and at-grade sections of eight main lanes and three frontage lanes on the east and west sides. Measurements, which represent an after construction study situation, were made during the day, during non-rush hour traffic times. The total vehicle per hour count ran between 4800 and 6000 at a nominal speed of 88 km/h (55 mph).

The same problem was encountered at these sites as in other cities, with the difficulty of separating traffic noise of the main lanes and the frontage roads. Obtaining a pure elevated or depressed condition was not possible because the three lane frontage roads were all at-grade level. The frontage roads, then, would produce the majority of the noise since they were at-grade and closer to the receptors than the main lanes. The problem is not only one of acquiring research measurements but one that annoys those living and working near the right-of-way by high noise levels from the frontage roads. This should be considered in future designs.

Measurements at this study section were taken at two distances from the nearest road edge. At each location, these were nominally 15.3 m (50 ft) and 45.8 m (150 ft). At the 15.3 m (50 ft) location, all the traffic in a depressed section was visible, and all line of sight noise was recorded. This is obviously a worse case situation as indicated by the reading at Harwin Rd. of 76.7 dBA L_{eq}, one of the highest in this study. The benefit of depressed sections is obvious at this location by the much lower reading 30.5 m (100 ft) away of 66.7 dBA, a 10 dBA reduction. This large reduction in traffic noise can be attributed to the greater than normal depth of the depression and sloped concrete side walls. This slope allows the noise to be reflected upwards instead of back to the people on the opposite side of the roadway.

Though there exists a considerable scatter in the data because of the complexity of each site, the trends are evident, especially in the depressed sections, which show a much more rapid reduction in noise as distance from the roadway is increased. The elevated sections show traffic noise levels comparable to the at-grade conditions, but based on other study sites, values should be lower. The explanation for this could be the amount of traffic flowing under the elevated sections. The noise from this traffic is not only recorded directly, but what is reflected from the bottom of the elevated section is added in for an apparent amplification. Though sound walls are not part of this study, they should be considered in the at-grade and elevated situations where the FHWA noise abatement criteria (NAC) cannot be met.

Air Pollution

The effects of elevated and depressed freeways on air quality were experimentally studied, as part of the broader study on the social, economic, and environmental effects of elevated and depressed freeways. Carbon monoxide (CO) concentrations were measured in the vicinity of a number of elevated, depressed, and at-grade freeway sites in Dallas, Lubbock, Houston, and San Antonio. In Dallas, along U.S. 75 (Central Expressway), eight days of CO data were collected at five different sites, two at-grade, two depressed, and one elevated. Three sites were monitored two days. In Lubbock, along I.H. 27, eight days of data were also collected at five different sites, four depressed and one elevated. In Houston, along Sam Houston Tollway, 10 days of data were collected at three different sites, one for each grade level. Last, in San Antonio, along U.S. 281, nine days of data were collected at three different sites, one for each grade level. Due to personnel limitations, no data were collected in the downtown "Y" area close to I.H. 10/35.

Traffic and meteorological measurements were also taken and used as inputs to standard computer models that predict CO concentration near at-grade freeways. The traffic data for each freeway were collected by TTI traffic personnel and used in the analysis of the estimating model. Some of the CO data were eliminated, based on wind direction. When the wind direction was less than 90 degrees from the perpendicular to the roadway, corresponding data points were eliminated.

Comparisons between model predictions and measurements suggest that no substantial air quality deterioration is evident near depressed freeways. Moreover, elevated freeways seem to result in slightly lower CO concentration levels in their vicinity, a fact supported by earlier experimental and theoretical studies by other investigators. If more data could have been collected at additional elevated sites, such as along the downtown "Y" freeways, the findings on elevated freeways might have told a different story. Because of resource limitations, data were collected by one person, one site at a time. While the evidence provided by our studies is strong, we feel that a more thorough study would provide even more conclusive evidence, as follows: Data should be *simultaneously* collected on elevated, depressed, and at-grade sections of the same freeway. Provided that these freeway sections are not far apart from each other (so that traffic, landscape, and wind patterns could be the same), any differences in CO levels in the vicinity of each section of the freeway would be attributed to its configuration as elevated, depressed, or at-grade. Comparison with mathematical models would be useful but not necessary. In fact, correction factors could be developed for existing models to account for more accurate predictions for elevated or depressed freeway sections. This kind of simultaneous collection of data at three locations of a freeway would require additional equipment (10 additional CO sensors and two additional weather stations) and personnel (two additional workers).

Drainage, Erosion, Vibration, Aesthetics, and Hazardous Spills

Drainage and Erosion

Except for the Sam Houston Tollway in Houston and I.H. 27 in Lubbock where new locations were involved, the basic infrastructure and drainage protocols were established earlier for each location. However, the additional impacts generated by the improvements to each route have resulted in some alteration of existing mitigative practices. In general, San Antonio is prone to flooding, so problems may be anticipated on some depressed sections of I.H. 10 and 35. The downtown "Y" study sections have depressed portions that are somewhat vulnerable to flooding. The elevated portions of these sections are not flood-prone since they are supported above at-grade level. Wider pavements on these sections can be designed with sufficient crossfall and collector systems to assure adequate pavement drainage for safety. Yet, there is no evidence of active erosion along the study sections.

The study section of San Antonio's U.S. 281 is situated in more rolling topography, and is transversed by major drainage ways. Also, it lies above the Edwards Aquifier, so surface drainage should not be a problem for the depressed portion. Water quality is a concern, and certain procedures are specified for water entering the Edwards Aquifier. Again, since the side slopes are vertical cuts from native limestone and the undisturbed areas support a cover of native grasses and scattered trees and shrubs, there was not evidence of active erosion.

In Houston, along the Sam Houston Tollway (Beltway 8) study section, water is collected and pumped into the Buffalo Bayou which traverses it. Erosion is not of concern, as all elements within the vertical walls are paved. Vegetation is restricted to a very narrow strip along the frontage roads.

In Dallas, along the U.S. 75 (Central Expressway) study section, drainage is managed by using a unique underground conduit system. The main roadway is paved over the full width and bordered with vertical concrete walls. Consequently, the is no erosion from the right-of-way.

In Lubbock, the planned east-west freeway on U.S. 62/82 has not been contracted. Drainage along both study sections on I.H. 27 is adequate for all grade levels. Along the elevated section, grass was planted on the median, and soil blankets were installed between the main lanes and frontage roads. Along the depressed section, grass was sodded on the narrow median, and additional erosion control was to be installed. Some natural vegetation is volunteering on non-mow areas, and erosion is evident on areas without vegetative cover.

Vibration

Vibration has not been a noted concern on any of the elevated freeway study sections.

Aesthetics

A lack of aesthetics has been noted along San Antonio's older freeways, but the recently constructed elevated study sections of the downtown "Y" as well as the depressed study section of U.S. 281 are aesthetically pleasing. The elevated section of I.H. 27 in Lubbock is on embankment, and some of the vegetative cover has volunteered. Visual quality ranges from good for structures and pedestrian walkways to poor for eroded areas and those bare of vegetative cover. Aesthetics are a major focus in Dallas on U.S. 75 in the depressed study section still under construction. Vertical walls are softened with strategic plantings of crepe myrtle, and edges of off-ramps are screened with a variety of designated plant materials. Some grassed areas are proposed. The depressed study cross section on the Sam Houston Tollway in Houston is aesthetically pleasing because the landscaping in the median and in planters in the side walls of the freeway provide beauty and variety to the roadway and offer subtle reminders of off-ramps from the freeway. The vertical walls are formed from textured panels.

Hazardous Spills

Hazardous spills are managed by cooperative agreement with designated regulatory agencies. Treatment of hazardous spills is a developing technology. There is a continuing need for training at all levels of operation, and the procedures for handling spills must modified with each new development.

CONCLUSIONS

The following conclusions can be made based on the findings of this study. They are made by major type of effect studied, i.e., social, economic, and environmental.

SOCIAL AND ECONOMIC

- Negative during construction period effects are observed on both businesses and residents surveyed, especially for the Dallas study area where the U.S. 75 (Central Expressway) is still under construction.

- Some grade level differences in responses to business and resident surveys were observed. For businesses, they occurred mostly in the Lubbock study area with regard to preferred grade level, extent of change in the area since construction, changes in property values, and changes in actual sales. Grade level impacts were also observed in the responses of businesses in the Dallas study area only with regard to the effect of construction of Central Expressway on the locality. As far as residential surveys are concerned, little grade level differences were observed in the responses. However, residents' opinions changed as distance from the freeway increased. An inverse relation was observed between distance from the freeway and the incidence of reported negative responses.

- Neighborhood effects were found to be both positive and negative in all study areas. The positive effects stem mostly from increased accessibility for both businesses and residents, while negative effects arise due to increased noise, pollution, and crime levels. A reduction of the negative effects during the after construction period seems to be due to construction itself rather than due to grade level differences.

- The construction of the freeways brings with it a host of benefits to businesses and residents, especially in areas where the freeways have been operative for a while. These direct benefits include increased travel safety, a reduction in travel time, and an increase in travel convenience. All these factors would tend to enhance user benefits.

- Community cohesion declined the most along elevated and depressed sections of I.H.-27 in Lubbock, where extensive relocations were undertaken. The resident survey responses indicated a greater decline of cohesion on the depressed segments of Sam Houston Tollway and Central Expressway than elevated or at-grade segments, confirming the findings of the literature review. Further, the resident survey responses also indicate an improvement in accessibility since construction of study freeways.

- Business and resident survey responses from all study sections indicated the need for expanding the freeway in all study areas. One of the reasons most frequently cited includes increased congestion levels due to increased traffic and growth in the cites.

- Overall, sales impacts in the after construction period were positive in all sections of the Houston and San Antonio study areas and negative in the Lubbock and Dallas study areas, and the depressed sections outperformed elevated sections. Employment effects follow a pattern similar to sales in all cases, except in Houston.

- Impacts on sales of abutting businesses, parking spaces, and employment can all be linked to the construction of study freeways. Negative impacts on parking spaces of businesses were limited to the during construction period only, and the after construction period effects were either small, positive changes, or no change.

- Commercial property value effects of study freeways were found to be negative in all study sections. But in the Lubbock and Dallas areas, there was a concomitant decline in the total market values of all county properties over roughly the same period, suggesting that local economy trends could have been responsible for the observed decline. Further, grade level effects were observed only in these two study areas in the responses of businesses, indicating actual range of property values rather than pure perceptions of change. This suggests that the construction could have magnified a problem which was originally brought about by factors other than the construction for these two areas.

- Construction employment effects due to highway contractor expenditures were found to be the highest for the elevated sections. Before and after construction tax revenue effects were found to be highest for the at-grade sections but higher on depressed sections than elevated sections. Relocation employment impacts were found to be minimal for at-grade sections and highest for elevated sections of I.H.-27.

- Based on before and after analysis, statistically significant grade level differences in abutting land values occurred very infrequently and only for specific land uses, especially residential, in each study section.

- Overall, on a combined use basis, land values along elevated study sections outperformed those along depressed sections, compared to values along the control at-grade sections. However, the differences were not statistically significant, in most cases.

- Based on before and after construction period analysis of properties abutting the Dallas U.S. 75 (Central Expressway), residential land values along the depressed section were statistically different from those along the at-grade section.

ENVIRONMENTAL

Noise Pollution

- The majority of the residents in both the Houston and Dallas study areas unanimously felt that noise barriers were effective in reducing noise. No grade level differences were observed in the responses.

- By making prudent choices in the early design stages of a freeway construction project and by working with the residents as a team, workable compromises may be met that produce maximum transportation with minimum impact on the environment. It has been apparent throughout this project that the TxDOT planners have been following this course. Noise levels along North Central Expressway in Dallas were measured twice during this project—once near the beginning of construction and again recently. Although construction is not finished, improvements in noise levels were observed in many locations, including those at-grade, elevated, and depressed. As studies have shown, improvements increase the property values. A dramatic reduction in traffic noise along this corridor was measured at the location of a newly installed noise wall. The neighborhood level before the wall was 68 dBA and after the wall was installed was 56.3 dBA, which is near the 55 dBA level used for rural neighborhood background sound.

- It became obvious early in the project that depressed roadways provided the superior grade level for the suppression of traffic noise. The walls of the depression provided a natural sound wall that substantially reduced traffic noise near and far from the freeway. A problem with depressed roadways is noise reflecting from vertical, flat walls toward the opposite side of the right-of-way at ground level. This can be and has been eliminated by sloping the walls at least 15 degrees or by the application of a sound absorbing or scattering surface to the walls.

- The elevated roadways evaluated provided good noise reduction near the roadway. The shadow zone extends out to about 100 m (328 ft). After that distance, the noise level was similar to at-grade or ground level roads. This was only true if the elevated sections used solid concrete guardrails to provide shielding. This improvement was negated when the post and rail systems were used on the elevated roadways, allowing tire and engine noise to pass under the rail.

- The at-grade condition with no guardrails or the post and rail type provided the highest amount of traffic noise for the same speed and volume as the other two cases. When solid concrete guardrails or median barriers were added, the tire and engine noise from passenger cars was significantly reduced. The heavy and medium trucks still presented a noise problem with the engine and exhaust stacks above the height of the barriers.

- Modeling, or predicting, what noise levels will be in the future on new or remodeled roadways is currently done with a computer program called STAMINA 2.0. This program, developed for the Federal Highway Administration (FHWA), was released to the TxDOT District offices in 1990 for use on personal computers. The program operates by asking a series of data questions about traffic volumes, roadway geometries, receiver locations, and barrier information. This program has undergone minor input changes but has remained essentially the same over the years. The program has been thoroughly validated using actual traffic noise measurements and compares very well, within 1 or 2 dBA where 3 dBA is a detectable difference by ear. Selected locations in this study were measured and modeled by STAMINA with comparable results. This program will model depressed, elevated, and at-grade roadways, with and without solid guardrails, with good results. The depressed and elevated conditions require special considerations when entering the roadway geometric data. Those not completely understanding the procedure should contact the Division of Highway Design, Environmental Section. STAMINA 2.0 has been proven to provide good results in prediction of traffic noise if all data are entered correctly.

Air Pollution

- The main conclusion of the preceding analysis is that, on the basis of our data and analysis, there is no evidence of increased CO levels in the vicinity of elevated or depressed freeways, in comparison to grade level freeways. In fact, elevated freeways appear to result in slightly lower CO levels than usual. This result is in agreement with what would be expected from elevated freeways, given the possibilities they offer for increased turbulent dispersion of pollutants.

- While the evidence provided by our studies is strong, we feel that a more thorough study would provide even more conclusive evidence, as follows: Data should be *simultaneously* collected on elevated, depressed, and at-grade sections of the same freeway. Provided that these freeway sections are not far apart from each other (so that traffic, landscape, and wind patterns could be the same), any differences in CO levels in the vicinity of each section of the freeway would be attributed to its configuration as elevated, depressed, or at-grade. Comparison with mathematical models would be useful but not necessary. In fact, correction factors could be developed for existing models, to account for more accurate predictions for elevated or depressed freeway sections. This kind of simultaneous collection of data at three locations of a freeway would require additional equipment (10 additional CO sensors and two additional weather stations) and personnel (two additional workers).

Drainage, Erosion, Vibration, Aesthetics, and Hazardous Spills

The findings do not reveal major differentiating drainage, erosion, vibration, aesthetics, or hazardous spill problems for the elevated or depressed freeway study sections. The specific conclusions are as follows:

- In most cases, the entire width of the right-of-way is paved and eliminates the need to maintain vegetation, which imposes a greater drainage load.

- Poor design of one of the depressed sections makes it very difficult, if not impossible, to accommodate mowing equipment accessing the median areas behind the retaining walls. The project may have been over-designed with fixtures (retaining walls) or the access requirements were not anticipated in design. Step-downs to more level areas or landscape designs which eliminate vegetated areas are possible alternatives to a grass median.

- The features incorporated into freeway design in Dallas show the results which can be achieved with team designs and reviews. Innovative solutions are common in handling drainage and other problems peculiar to the different grade levels. Generally, some needs may be encountered in these sections, but the magnitude may vary by type of section.

RECOMMENDATIONS FOR IMPLEMENTATION

This study set out to determine the social, economic, and environmental effects of elevated, depressed, and at-grade freeway grade levels, using the at-grade levels as the control. In the past, many previous decisions regarding freeway construction have been made based on mainly local traffic conditions without much regard to possible social, economic, or environmental effects. This fact is partly due to the limited amounts of prior research that establish the extent to which these types of effects occur as a result of those decisions. The findings of this study close some large holes in the prior database with regard to choosing the grade level of freeways serving urban and suburban areas. However, the grade level findings of this study are not completely consistent across land uses and/or study freeways and, thus, support the need for further study. Yet, these findings essentially support the following recommendations for implementation as presented below by major impact categories.

Before presenting these recommendations, the general recommendation supported by the study findings might be that transportation agencies should continue to choose the at-grade freeway design unless social, economic, and environmental effects support either an elevated or a depressed freeway design in a given situation.

SOCIAL AND ECONOMIC

- The research indicates that the preferred grade level choice for businesses is the elevated type of design in Lubbock, Houston, and San Antonio. Dallas businesses preferred the depressed design more than the elevated design. The preferred choice for residents is the depressed design. Therefore, the dominant abutting and nearby land use should be a major determinant of grade level design.

- The research indicates that depressed sections tend to outperform elevated sections with regard to business sales effects and tax revenue effects. On the other hand, elevated sections outperform depressed sections in overall property value changes regardless of use. Also, construction employment related effects are greater, because they are more expensive to construct. Again, some of the findings indicate that elevated freeways have somewhat less intrusive effects on neighborhood cohesion than depressed freeways, but quality related variables are found to be more of a function of construction of the freeway itself rather than the grade level of freeway constructed. Therefore, since some effects will be positive and others negative, freeway grade level decisions should take all such factors into consideration. When undertaking a construction project in an area which is going through an economic slowdown, even more caution should be exercised because even grade level variations could further hurt the area in terms of property values and business sales.

- The negative during construction period effects observed in all study areas and Dallas specifically suggest that transportation agencies should continue to adopt mitigation measures in planned future undertakings, such as maintaining access and visibility of businesses.

- Considering the residents' opinions regarding the effectiveness noise barriers in lowering noise levels, mitigation efforts should continue to consider the use of noise barriers as tools to lower noise levels both due to highway construction and highway induced traffic after construction.

- Findings from this study and similar case studies conducted in the future should be used to develop a database of findings on different socio-economic impacts considered in this report and could be used to develop a methodology to be used for predictive purposes in the construction of future elevated/depressed highways. This pooled database of findings could also be categorized by location of project construction to ascertain the differential effects of different types of projects. For example, it may not be reasonable to expect that construction projects undertaken near the Central Business District will have the same overall effects as construction on a loop around the city or other projects which aim at the enhancement of connectivity.

- Additional research could be undertaken at a later date when construction work on currently planned freeway Lubbock U.S. 62/82 and Dallas U.S. 75 (Central Expressway) is completed to assess whether the effects are any different from the Lubbock I.H.-27 study area results for reasons mentioned above.

- Construction of at-grade and depressed freeways should be the preferred designs where terrain, cost, and other conditions allow. However, the findings from the county appraisal district database showed that the land values along some elevated sections outperformed those depressed sections using at-grade values as the base.

ENVIRONMENTAL

Noise Pollution

- To provide the least impact on property values adjacent to a proposed new freeway or freeway improvement, one area of consideration by the planners must be to choose designs that reduce traffic noise. Below are listed points to consider during roadway planning to help produce the lowest noise impact on existing and future property values. These recommendations were obtained from observations during this study, which include: good TxDOT designs, publications, results from other states, and international studies. These are general recommendations that should be further tested with computer models or other means because of the very complex nature of traffic noise in real-world situations.

- If a choice of grade condition is available between at-grade (same as other ground level in the area), depressed (below surrounding ground), or elevated (above surrounding ground), the choice should be depressed. By placing the flowing traffic below ground level, a natural sound barrier is created between the traffic and people adjacent to the roadway. Studies have shown that as the depth of the cut increases, between 3 m (9.8 ft) and 9 m (30 ft), the noise levels were not greatly affected because the improved screening provided by the increased depth of cut is offset by the increase in reflected noise from the opposite wall of the cut (1). With a depressed roadway of 3 m (9.8 ft) or more, traffic noise has been shown to decrease from 74 dBA at the cut, to 63 dBA at 10 m (32.8 ft) from the edge of the cut. This noise level remains at about the same level out to 50 m (164 ft).

- Reflections from the walls of a depressed roadway should be considered and reduced if possible. This may be accomplished in several ways. The first is sloping the reflecting wall away from vertical. A slope of 15 degrees is usually sufficient to ensure a substantial reduction in reflected noise. The next is the addition of a sound absorbent lining to a vertical wall starting 1.5 m (5 ft) above the roadway and ending at the top of the cut. It was found that sound absorbent lining placed on the retaining walls generally resulted in an additional noise reduction of 3 dBA within 25 m (82 ft) from the edge of the cutting and up to 6 dBA at greater distances. The effect of the slope of the reflecting wall has almost the same effect on noise reduction as the sound absorbent linings of the walls. Another treatment was observed in San Antonio in a depressed section of U.S. 281 near Donella Drive. This location used a corrugated concrete finish that worked well for aesthetics and for scattering the noise so as to not reflect to the opposite side.

- The next best grade level condition observed is elevated. The reason for the elevated sections producing less noise than at-grade conditions was the fact that the sites measured used 915 mm (36 in) solid concrete guardrails on each side and in the median. Along with the solid bridge deck, an elevated trough for the traffic was provided. With many of the vehicles out of sight, a straight line path did not exist for the noise. With the majority of the noise from passenger vehicles coming from the tires and engines, the solid rail provided shielding for the majority of the noise producers. When the choice is available, solid guard barriers should be used instead of the post and rail type for noise control. The elevated sections of this type have been shown to reduce noise up to 6 dBA near the roadway out to about 92 m (300 ft). After that, the noise levels are about the same as at-grade because the angle of diffraction is less.

- When noise is a major consideration, designs that place traffic under an elevated roadway that uses steel "I" girder construction should be avoided. The noise from the lower level of traffic is reflected from the underside of the elevated section back toward the ground, off the R.O.W. This noise adds to the direct line of sight noise to produce an amplification. This effect exists if the lower level is at-grade or depressed. The use of "Composite Wing Girder" construction reduces this effect significantly due to the smooth underside of the elevated section, confining the reflected noise to within the R.O.W.

- One way noise has been reduced in the at-grade condition is to locate the right-of-way further from the people affected. It is obvious that the further one gets from a noise, the quieter it becomes. With traffic noise, this rule of thumb becomes a little more complicated. Traffic noise is not in a spot but rather a line, which becomes a spot if the distance is great enough. In general, the noise from a spot source will be attenuated by approximately 6 dBA per doubling of distance from the source or $20\log_{10}d$ decibels for 'd' distance. With a high traffic flow, the geometric spreading approaches that of a line source that attenuates only 3 dBA per doubling or $10\log_{10}d$. With other reflections and diffractions, a typical value for increasing distance is a 3–4.5 dBA noise reduction each time distance doubles.

- As the concrete guardrails and median barriers on the elevated sections reduced the noise transmitted downward, the same types of rails would provide some improvement of traffic noise in an at-grade condition. The amount of screening provided varies according to the amount of sound energy diffracted over the top of the barrier, which can be easily modeled by the STAMINA 2.0 computer program. The standard post and rail system provides almost no noise shielding since the tire/road interface waves are passed under the rail.

- Another excellent noise abatement device observed is the full-size noise wall. This rather expensive form of noise abatement provides from 5 to greater than 20 dBA reduction in traffic noise. The wall tested in Dallas during this study showed a reduction from 63.5 dBA to 56.3 dBA in exactly the same location before and after the installation of a 4.3 m

(14 ft) noise wall. This level is near 55 dBA, used for neighborhood background levels with no nearby traffic, but within 46 m (150 ft) of the North Central Expressway in Dallas.

- In all grade level conditions, an improvement of 3 dBA can be realized by road surface texture treatment. Road surface texture affects the noise level generated by traffic because it partially controls the road/tire interaction noise. Generally, the noise generated by vehicles traveling on coarse textured surfaces can emit up to 3 dBA more noise than vehicles traveling on a smooth concrete or asphalt surface.

- Though main traffic lanes of a freeway are depressed, elevated, or shielded for noise reduction, the frontage roads are usually still at-grade, near the edge of the right-of-way, and near noise sensitive areas (NAC Category A and B). Depending on the volume and mix of traffic on these frontage roads, the efforts to quiet the main lanes may be negated. This was noted while taking sound level measurements for this study in the various cities. Measurements would be indicating a low level of noise from the main lanes until trucks or a string of cars passed on the frontage road. These types of occasional, loud, and close-by noises are not always apparent on a L_{eq} type of sound measurement. The L_{eq} method integrates sound over a long time period where the short, loud noises disappear from the reading and modeling. For this reason, the L_{eq} method is not favored by some groups. By their nature, frontage roads must be where they are but should be taken into consideration when evaluating future noise levels.

- Modeling, or predicting, what noise levels will be in the future on new or remodeled roadways is currently done with a computer program called STAMINA 2.0. This program has undergone minor input changes but has remained essentially the same over the years. Actual traffic noise measurements compare very well to those predicted, to within 1 or 2 dBA. Selected locations in this study were measured and modeled by STAMINA 2.0 with comparable results. This program will model depressed, elevated, and at-grade roadways, with and without solid guardrails, with good results. The depressed and elevated conditions require special considerations when entering the roadway geometric data. STAMINA 2.0 has been proven to provide very good results in predicting traffic noise if all data are entered correctly, and its use should be continued practice until an improved program is available.

- Proposed freeway noise could be presented to the public by using technology that demonstrates the audio level of the future noise compared to the audio level of current traffic noise. Instead of relating decibel numbers, actual audio of the present and future levels and traffic mix may be more understandable. In working with the public early in the design phases of a construction project, a team approach has been shown to work well to produce benefits for all.

Air Pollution

- While the evidence provided by our studies is strong, we feel that a more thorough study would provide even more conclusive evidence, as follows: Data should be *simultaneously* collected on elevated, depressed, and at-grade sections of the same freeway. Provided that these freeway sections are not far apart from each other (so that traffic, landscape, and wind patterns could be the same), any differences in CO levels in the vicinity of each section of the freeway would be attributed to its configuration as elevated, depressed, or at-grade. Comparison with mathematical models would be useful but not necessary. In fact, correction factors could be developed for existing models to account for more accurate predictions for elevated or depressed freeway sections. This kind of simultaneous collection of data at three locations of a freeway would require additional equipment (10 additional CO sensors and two additional weather stations) and personnel (two additional workers).

Drainage, Erosion, Vibration, Aesthetics, and Hazardous Spills

- Environment is a relatively new technology to design engineers. Close review of plans and conferences with operations personnel during the course of this study revealed that most design engineers possess a superb knowledge of engineering. However, not all designers are capable of effecting a seamless connection between design and environment. Ideally, with the close oversight by regulations, harmonization between environment and highway design should begin early in the design phase and be evaluated continuously in the planning review.

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