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16. Abstract

This report provides a comprehensive assessment of strategies for alleviating urban traffic congestion. In particular, this report provides a macroscopic, areawide assessment of traffic congestion problems in Texas and insight to the potential for alleviating these problems.

In examining the potential of various strategies for alleviating congestion, historical quantifications and estimates of future congestion in major Texas urban areas and associated costs were computed. The results of this particular phase of the analysis should provide a clearer picture of the extent of the congestion problem in Texas.

The strategies for alleviating congestion identified in this study were assessed based on both independent and simultaneous application. Groups of strategies that appear to work well when applied simultaneously were identified. These assessments were made based on urban area size and severity of existing congestion and, where possible, were related directly to major Texas urban areas.

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IMPLEMENTATION STATEMENT

As a means of assisting the Texas Department of Transportation in planning future urban area transportation needs, this report examines the following: 1) historical trends in, and future estimates of, traffic congestion in major Texas urban areas; 2) strategies that are either currently or will in the foreseeable future be available for alleviating urban area traffic congestion; and 3) the impacts of both the independent and simultaneous application of these strategies on urban area congestion. The information provided in this report should be useful in conducting a preliminary assessment of Texas urban area transportation needs and possible solutions for these needs. In addition, the material included in this report could be utilized in the initial phases of developing urban area congestion management plans now required as a result of the Clean Air Act Amendments of 1990.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. In addition, this report is not intended for construction, bidding, or permit purposes.

SUMMARY

Traffic congestion has become a well-recognized problem in Texas as well as many other areas in the nation. The severity of congestion in many areas has now reached the point that there exists a general consensus that no single agency or mode will be able to successfully address this problem. A wide variety of actions will need to be pursued.

This report makes available to transportation professionals a comprehensive assessment of strategies for alleviating urban traffic congestion. In particular, this study focuses on the seven largest urban areas in Texas. In meeting the objectives of this study, the following analyses were conducted: 1) the quantification of historical trends in, and the estimation of future levels of, congestion in the seven largest Texas urban areas; 2) the identification of strategies available for alleviating congestion and the costs and benefits associated with these strategies; 3) the quantification of the impacts certain strategies have on urban area congestion; 4) an assessment of the interaction between various strategies when applied simultaneously; and 5) the formulation of general relationships between the level of expenditure required to implement strategies and associated reductions in urban area congestion.

Extent of the Congestion Problem

Prior to assessing the potential of various approaches for reducing urban traffic congestion, it was necessary to first identify the magnitude of the congestion problem. In order to accomplish this task, a means by which to quantify urban area congestion levels was needed. A Roadway Congestion Index (RCI) developed in previous research by the Texas Transportation Institute (TTI) was deemed most appropriate for the purposes of this study.

The RCI is based on research indicating that urban area roadway congestion can be estimated using freeway and principal arterial daily vehicle-miles of travel (DVMT) per lane-mile. When areawide freeway and principal arterials volumes reach 13,000 DVMT and 5,000 DVMT respectively, the beginning of congested conditions (level of service D) is

Table S-1. Historical Congestion Levels and Costs for Major Texas Urban Areas

Urban Area	Year	Congestion Level (RCI)	% Increase[1]	Congestion Cost[2] ($ Millions)
Austin	1975	0.69	39	2
	1980	0.74		20
	1985	0.91		100
	1989	0.96		136
Corpus Christi	1975	0.56	27	0
	1980	0.63		0
	1985	0.71		9
	1989	0.71		9
Dallas	1975	0.60	70	1
	1980	0.78		282
	1985	0.98		692
	1989	1.02		807
El Paso	1975	0.47	57	0
	1980	0.60		0
	1985	0.70		10
	1989	0.74		31
Fort Worth	1975	0.60	45	0
	1980	0.71		98
	1985	0.82		232
	1989	0.87		303
Houston	1975	0.89	27	256
	1980	1.11		772
	1985	1.23		1,191
	1989	1.13		1,132
San Antonio	1975	0.59	47	0
	1980	0.73		36
	1985	0.87		170
	1989	0.87		210

[1] The total percent increase in the RCI between 1975 and 1989

[2] The total urban area cost due to congestion based on travel delay and excess fuel consumption; in 1989 dollars

Table S-2. Future Congestion and Cost Estimates for Major Texas Urban Areas

Urban Area	Expected Growth Rate (%)		Year	Urban Area Population (Millions)	Congestion Index (RCI)	Congestion Cost	
	Pop'n[1]	DVMT[2]				Per Capita[3] ($)	Total[4] ($ Millions)
Austin	2.8	3.4	1989	0.505	0.96	270	136
			1995	0.595	0.99	300	178
			2000	0.685	0.96	270	185
			2010	0.900	1.20	505	454
Corpus Christi	2.5	3.5	1989	0.275	0.71	35	9
			1995	0.320	0.78	105	33
			2000	0.360	0.82	140	50
			2010	0.460	1.06	375	173
Dallas	2.7	2.5	1989	1.970	1.02	410	807
			1995	2.310	1.10	490	1,132
			2000	2.640	1.09	480	1,267
			2010	3.445	1.20	585	2,017
El Paso	2.4	4.0	1989	0.520	0.74	60	31
			1995	0.600	0.94	255	153
			2000	0.675	1.08	390	263
			2010	0.855	1.46	760	650
Fort Worth	2.7	2.5	1989	1.165	0.87	260	303
			1995	1.365	0.98	370	505
			2000	1.560	1.00	385	601
			2010	2.040	1.18	560	1,142
Houston	2.0	2.9	1989	2.865	1.13	395	1,132
			1995	3.225	1.07	340	1,097
			2000	3.560	1.02	290	1,032
			2010	4.340	1.02	290	1,259
San Antonio	2.0	4.3	1989	1.165	0.87	180	210
			1995	1.310	1.05	355	465
			2000	1.450	1.18	480	696
			2010	1.765	1.60	1000	1,765

[1] The expected annual growth in population for the respective urban areas
[2] The estimated future annual growth rate in daily vehicle-miles of travel for the respective urban areas
[3] The cost due to congestion expressed on a per-person basis
[4] The total urban-area cost due to congestion

Strategies Available for Alleviating Urban Congestion

As a part of this study, a comprehensive review of strategies for alleviating urban congestion was conducted. The strategies identified as a result of this effort are summarized in Table S-3. These strategies represent the most promising techniques by which urban area congestion can be alleviated both at present and in the foreseeable future. General cost figures (low, medium, high, etc.) are provided in the absence of detailed cost data. As a point of reference, ramp metering could be considered "medium-to-low" and the construcion of a freeway considered "high" in terms of relative costs. A detailed discussion of the costs, benefits, and implementation issues associated with the strategies presented in Table S-3 is included in the body of this report.

Application of Strategies

Faced with the fact that traffic congestion problems in major urban areas can no longer be adequately addressed by simply constructing additional roadway lane-miles of supply, information was needed regarding the interaction between various congestion-reducing strategies when applied simultaneously. This information was developed and/or identified in this research study.

All strategies shown in Table S-3 can reduce peak period traffic congestion when applied properly. Their impact on traffic congestion and implementation costs are, however, contingent on many factors such as urban area size, existing levels of congestion, and individual traffic characteristics of a corridor or subarea. Therefore, the interactions between strategies developed in this study varied depending upon urban area size and existing level of congestion. The categories used for these factors are indicated in Table S-4.

Table S-3. Summary of Congestion-Alleviating Strategies

General Category	Specific Strategies	Cost[1]	Benefit[2]	B/C Ratio[3]
Construction/ expansion of system	Construction of: - Principal arterials	$1.5 million/lane-mile	Added lane-miles	2-4
	- Super arterials	$3-4 million/lane-mile	30-70% more capacity than normal arterial	2-4
	- Freeways	$4.5 million/lane-mile	Added lane-miles	2-4
	- Toll roads	High	Self-supporting	
	- HOV facilities:			
	- Barrier-separated	$4-10 million/lane-mile	Added capacity	2-6
	- Concurrent/ contraflow lanes	$0.5-2 million/lane-mile	Added capacity	2-10
	- Arterial HOV lanes	$0.5-2 million/lane-mile	Added capacity	
	- Commuter rail	$5-10 million/mile	Added capacity	
	- Light rail transit	$10-30 million/mile	Added capacity	
	- Heavy rail transit	$40-100 million/mile	Added capacity	
	Addition of: - Principal arterial lane	$0.5-1 million/lane-mile	Added lane-miles	9
	- Freeway lane	$2.5 million/lane-mile	Added lane-miles	3
	Reducing lane width/using shoulder as a lane	$0.5 million/lane-mile	Added lane-miles	7
	Grade-separated arterial intersections	$6 million/intersection	Increased capacity	
Operational improvements	Ramp metering	$50,000/unit	Increased capacity	
	Surveillance, communication and control (SC&C) system	$1 million/mile	Up to 30% increase in capacity	12
	Traffic management teams	Low	Coordinated actions	15
	Accident investigation sites	Low	Decreased delay	28
	Signal-timing optimization	Low	Decreased delay	16
	Signal interconnection/ optimization	Medium	Decreased delay	10
Travel demand management	Carpooling/vanpooling programs	Low	Decreased VMT	
	Parking management/pricing	Low	Decreased VMT	
	Alternate work hours	Low	Decreased delay	
	Express bus service	Low to medium	Added capacity	
	Telecommuting	Low	Decreased VMT	20
Land-use strategies	Mixed-use zoning	Low	Decreased VMT	
	Home/neighborhood work centers	High	Decreased VMT	
High-tech strategies	Road pricing	Medium	Decreased VMT; self-supporting	
	Motorist information systems: Pre-trip information	Medium to high	Decreased delay	
	Intelligent veh. highway system (IVHS)	Medium to very high	Decreased delay	

[1] Actual cost is shown if available; otherwise, the general magnitude of the cost associated with a strategy is displayed
[2] At least one, but not necessarily all of the benefits associated with a strategy
[3] Benefit-to-cost ratios are listed, if the necessary data are available

Table S-4. Categories of Urban Area Size and Level of Congestion Used for Developing Strategy Interaction Matrices

Factor	Category	Urban Area Population	Factor	Category	Urban Area Roadway Congestion Index (RCI)
Urban Area Size	Small	<300,000	Level of Congestion	Slight	≤ 0.70
	Medium	300,000 - 750,000		Moderate	0.71 - 0.89
	Large	751,000 - 1,250,000		Heavy	0.90 - 1.09
	Very Large	> 1,250,000		Severe	≥ 1.10

The interactions identified as a result of this analysis were illustrated in the form of matrices. These matrices were developed for all likely combinations of urban area size and existing level of congestion. The interactions illustrated in these matrices should be useful in making preliminary assessments of the applicability of certain strategies. These matrices, as well as discussions providing more detailed explanations, are included in the body of this report.

Based on how the individual strategies related to one another in the matrices, the strategies were grouped into packages. These packages were designed to combine strategies that work especially well together in reducing traffic congestion. Each of the packages developed in this study was designed to treat a different sized urban area and level of congestion.

Relationships Between Expenditure and Reduction in Congestion

The final objective of this study was to identify general levels of expenditure required to bring about varying reductions in urban area congestion. Utilizing data identified in previous tasks of this research study, macroscopic assessments of the costs and reductions in congestion associated with the implementation of certain strategies were developed.

Since signal system upgrades and surveillance, communication and control (SC&C) systems are planned for eventual implementation in major Texas urban areas, these strategies were chosen for this particular analysis. Comprehensive databases also exist regarding the implementation of these two strategies in major urban areas.

In particular, this analysis examined the upgrade of principal arterial signal systems from their existing status to the condition of being 25% monitored/coordinated (an advanced form of local coordinated signal control where pre-determined timing plans developed off-line can be down-loaded if the need arises) and 75% central coordinated. In addition, this analysis examined the implementation of SC&C capabilities for all congested freeway lane-miles within an urban area.

The urban areas of Corpus Christi, Houston, and San Antonio were chosen for this phase of the analysis to provide a comparison between areas of varying size and severity of congestion. In the case of Houston, the cost and benefits associated with the existing high-occupancy vehicle (HOV) lane system were also included in this analysis.

The results of these analyses are summarized in Table S-5. Principal arterial signal system upgrades and freeway SC&C systems are designed to decrease congestion on two different components of an urban area roadway system. The impacts of these two strategies on urban area congestion can, therefore, be considered to be additive. As indicated in Table S-5, the strategies examined in these analyses can have a significant impact on congestion and can be implemented on a very cost-effective basis.

Table S-5. Summary of Costs and Benefits Associated with the Implementation of Signal System Upgrades, SC&C Systems, and HOV Lane Systems

Urban Area	Type of Improvement	Level of Expenditure ($ millions)		Congestion Index					B/C[7]
					After Improvements		Percent Decrease		
		Individual[1]	Total[2]	Existing	Individual[3]	Total[4]	Individual[5]	Total[6]	
Corpus Christi	Signal system upgrade	$ 2	$ 7	0.70	0.67	0.67	2.7	4.6	20
	SC&C system	5		0.70	0.69		1.9		7
San Antonio	Signal system upgrade	13	68	0.87	0.85	0.81	2.7	7.2	18
	SC&C system	55		0.87	0.83		4.5		11
Houston	Signal system upgrade	20	355	1.13	1.11	0.99	1.8	11.9	25
	SC&C system	205		1.13	1.03		7.1		15
	HOV lane system	130		1.13	1.10		3.0		10

[1] The level of expenditure associated with respective individual improvements

[2] The total expenditure associated with implementing signal system upgrades and an SC&C system; in the case of Houston, this total cost also includes expenditures related to the Houston HOV lane system

[3] The roadway congestion index (RCI) reflecting the impacts of respective strategies applied individually

[4] The RCI reflecting the total impact of the strategies applied simultaneously

[5] The percent decrease in the RCI corresponding to respective strategies applied individually

[6] The total percent decrease in the RCI corresponding to the strategies being applied simultaneously

[7] The estimated B/C associated with respective improvements

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I. INTRODUCTION

Urban traffic congestion has become a well-recognized problem in Texas during the last 10 to 15 years. The severity of congestion has become so serious that there is now a general consensus that no single agency or mode will be able to successfully address the problem. A whole range of actions will need to be pursued.

Purpose of The Study

This study is intended to make available to transportation professionals a comprehensive assessment of strategies for alleviating urban traffic congestion. This assessment includes the identification of strategies applied both independently and simultaneously. Where possible, this assessment is related directly to Texas urban areas.

In addition, this study is designed to provide a clearer picture of the extent of the congestion problem in Texas. This particular phase of the study includes both historical quantifications and estimates of future urban area congestion and associated costs.

It is important to note that this study is **not** intended to replace or supersede plans that may have already been developed by different agencies. Rather, it is meant to develop quantitative planning tools that may be of use to the various agencies and help identify what impacts certain plans already scheduled for implementation might have on urban area congestion.

Scope

As alluded to previously, the scope of this study is the urban area. This study is not intended to examine the impacts of specific roadway or corridor improvements; rather, it is designed to provide a macroscopic, areawide assessment of the urban traffic congestion problems in Texas and provide insight as to the potential for alleviating these problems. The specific urban areas addressed in this study include Austin, Corpus Christi, Dallas, El Paso, Fort Worth, Houston, and San Antonio.

Organization of the Report

Following this introductory section is a discussion of the extent of the urban traffic congestion problem in Texas (Chapter 2). This discussion focuses on both historical trends and future estimates of congestion based on existing plans for transportation system improvements. Also included in Chapter 2 is a brief discussion of the methodology chosen for this study to quantify urban area roadway congestion. A detailed discussion of this particular methodology, otherwise referred to as the Roadway Congestion Index (RCI), and how the RCI was formulated are included in Appendix A.

Chapter 3 presents a general inventory of strategies for alleviating urban congestion. Also included in this section of the report is the identification of costs and benefits associated with these strategies. Where possible, these costs and benefits are related directly to Texas urban areas. In addition, where appropriate data are available, the impact of certain strategies on urban area congestion is expressed in terms of the roadway congestion index.

Several issues regarding the implementation of congestion alleviating strategies are addressed in Chapter 4. These issues include: 1) the appropriateness of strategies based on urban-area size and severity of congestion; 2) the interaction between two individual strategies when applied simultaneously; and 3) the multiple interaction between three or more strategies (i.e., the impact of packages of strategies on urban area congestion).

General relationships between levels of expenditure and reductions in urban area congestion are presented in Chapter 5. This section of the report serves to bring together relevant findings of earlier sections of the report to provide a macroscopic assessment of the investments and/or actions needed to bring about varying degrees of reductions in congestion.

Additional information on specific topics discussed in the body of the report is included in the appendices. Bibliography sections referencing the material examined in the study are also included at the end of appropriate chapters.

II. EXTENT OF THE CONGESTION PROBLEM

In recent years, urban traffic congestion has become a serious problem throughout the nation; Texas is certainly no exception. In fact, individuals in some major urban areas have identified traffic congestion as the most serious problem in their region (1, 2).

This cause for concern is well substantiated. A recent study by the Texas Transportation Institute (TTI) indicated that the annual costs due to congestion in 50 major urban areas across the nation totalled $32.5 billion during 1989; the seven largest urban areas in Texas contributed $2.6 billion to this total (3). These cost figures were based on the excess fuel consumption and travel delay caused by the two basic types of traffic congestion -- recurring and non-recurring congestion.

Recurring congestion can be defined as that which occurs in the same general location on a daily basis due to the combination of heavy travel demand and some form of geometric constraint(s). Non-recurring congestion is caused by random, but not necessarily infrequent, events such as accidents, disabled vehicles, or adverse weather conditions (2). A study by Lindley (4) reported that approximately 50 percent of freeway system delay in cities with populations greater than one million persons is due to non-recurring congestion.

Roadway Congestion Index

In assessing the potential of various approaches for reducing urban traffic congestion in Texas, it was necessary to first identify the existing magnitude of the congestion problem. In order to accomplish this task, a means by which to quantify urban area congestion levels was needed. While other methods for quantifying congestion exist, a Roadway Congestion Index (RCI) developed in previous research by TTI was deemed most appropriate for the purposes of this study (3, 4, 5).

The RCI is based on research indicating that urban area roadway congestion can be estimated using freeway and principal arterial daily vehicle-miles of travel (DVMT) per lane-mile. The RCI utilizes daily values, as they represent readily available data that are normally collected as part of the transportation planning process in cities throughout the U.S.

When areawide freeway travel volumes reach 13,000 DVMT per lane-mile, the beginning of congested conditions (level of service D) is estimated to occur. For principal arterial streets, the corresponding level of service is represented by a system average of 5,000 DVMT per lane-mile. Gauging the existing freeway and principal arterial DVMT versus these thresholds produces a value which can be used as an indicator of relative mobility in urban areas (Equation 1).

$$\begin{array}{c}\text{Roadway}\\ \text{Congestion}\\ \text{Index}\end{array} = \frac{\text{Freeway DVMT/Ln-Mi} \; X \; \text{Freeway DVMT} \; + \; \text{Princ. Art. DVMT/Ln-Mi} \; X \; \text{Princ. Art. DVMT}}{13{,}000 \; X \; \text{Freeway DVMT} \; + \; 5{,}000 \; X \; \text{Princ. Art. DVMT}} \qquad \text{Eq. 1}$$

Weighing the DVMT per lane values by the amount of DVMT in each functional class provides flexibility in applying Equation 1 to areas with very different roadway travel characteristics. An RCI value greater than 1.0 represents the beginning of undesirable congestion levels. It is important to note that the RCI provides an areawide assessment of congestion, and while certain corridors or portions of urban areas may be more congested than others, the values produced using Equation 1 reflect overall urban area mobility. A more detailed discussion of how the RCI was formulated is included in Appendix A.

Historical Congestion Levels and Costs in Texas Urban Areas

Historical DVMT per lane-mile data have been identified for the seven largest Texas urban areas for the time frame of 1975 to 1989 (Table 1). As indicated in Table 1, the percentage growth rate in DVMT per lane-mile is quite significant in most of the urban areas for this period of time. The application of the previously mentioned RCI formula to these data results in the congestion estimates shown in Figures 1 and 2.

Table 1. Daily Vehicle-Miles of Travel and Lane-Miles of Supply
Associated With Major Texas Urban-Area Roadway Systems, 1975 to 1989

Urban Area	Year	Freeway				Principal Arterial			
		DVMT [1] (x1000)	Ln-Mi [2]	DVMT/ Ln-Mi	Growth (%) [3]	DVMT [1] (x1000)	Ln-Mi [2]	DVMT/ Ln-Mi	Growth (%) [3]
Austin	1975	1,780	215	8,280	51	1,120	245	4,570	6
	1980	2,130	240	8,875		1,460	310	4,710	
	1985	4,890	420	11,640		2,000	400	5,000	
	1989	5,300	425	12,470		2,050	425	4,825	
Corpus Christi	1975	1,020	150	6,800	21	960	285	3,370	34
	1980	1,190	160	7,440		1,185	300	3,950	
	1985	1,400	165	8,485		1,370	320	4,280	
	1989	1,520	185	8,215		1,450	320	4,530	
Dallas	1975	10,445	1,350	7,735	73	4,150	1,320	3,145	54
	1980	15,015	1,485	10,110		5,730	1,475	3,885	
	1985	21,100	1,640	12,860		7,950	1,675	4,745	
	1989	22,645	1,690	13,400		8,230	1,695	4,855	
El Paso	1975	1,415	260	5,440	73	1,945	675	2,880	33
	1980	2,155	295	7,305		2,470	725	3,405	
	1985	3,120	345	9,045		2,880	800	3,600	
	1989	3,300	350	9,430		3,175	830	3,825	
Fort Worth	1975	5,275	720	7,325	52	2,560	665	3,850	27
	1980	7,535	855	8,815		3,255	745	4,370	
	1985	10,070	975	10,330		4,140	840	4,930	
	1989	11,280	1,015	11,115		4,220	865	4,880	
Houston	1975	13,190	1,145	11,520	29	5,875	1,310	4,485	15
	1980	18,405	1,255	14,665		8,565	1,655	5,175	
	1985	24,380	1,480	16,295		10,850	1,930	5,620	
	1989	27,640	1,860	14,860		10,400	2,010	5,175	
San Antonio	1975	4,755	660	7,205	54	2,750	740	3,715	29
	1980	7,115	750	9,485		3,090	870	3,550	
	1985	9,080	800	11,350		4,285	1,020	4,200	
	1989	9,175	825	11,120		5,180	1,080	4,795	

[1] Daily vehicle-miles of travel expressed in thousands
[2] Lane-miles of supply associated with the urban roadway system
[3] The percentage growth rate in daily vehicle-miles of travel (DVMT) per lane-mile for the time period of 1975 to 1989

The level of congestion in all seven urban areas has increased significantly since 1975, with Houston and Dallas having surpassed the undesirable level (1.0) of urban area congestion (Table 2). The recent decline in the RCI for Houston is due primarily to the addition of a significant amount of freeway and principal arterial lane-miles.

The urban areas of Dallas and El Paso have experienced an increase in congestion of over 50% (as measured by the RCI) for the time period from 1975 to 1989. Fort Worth and

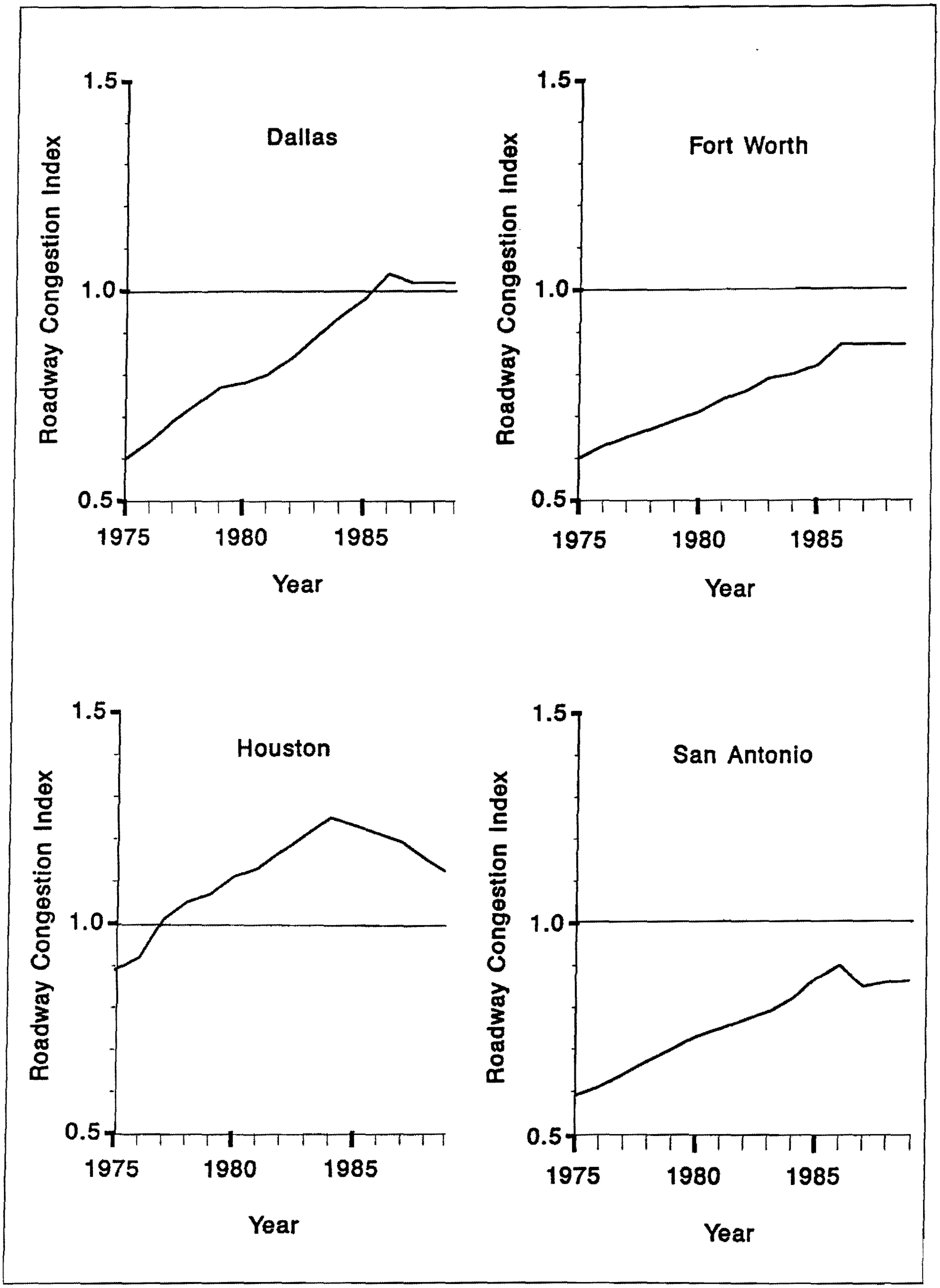

Figure 1. Historical Trends In Congestion for Major Texas Urban Areas

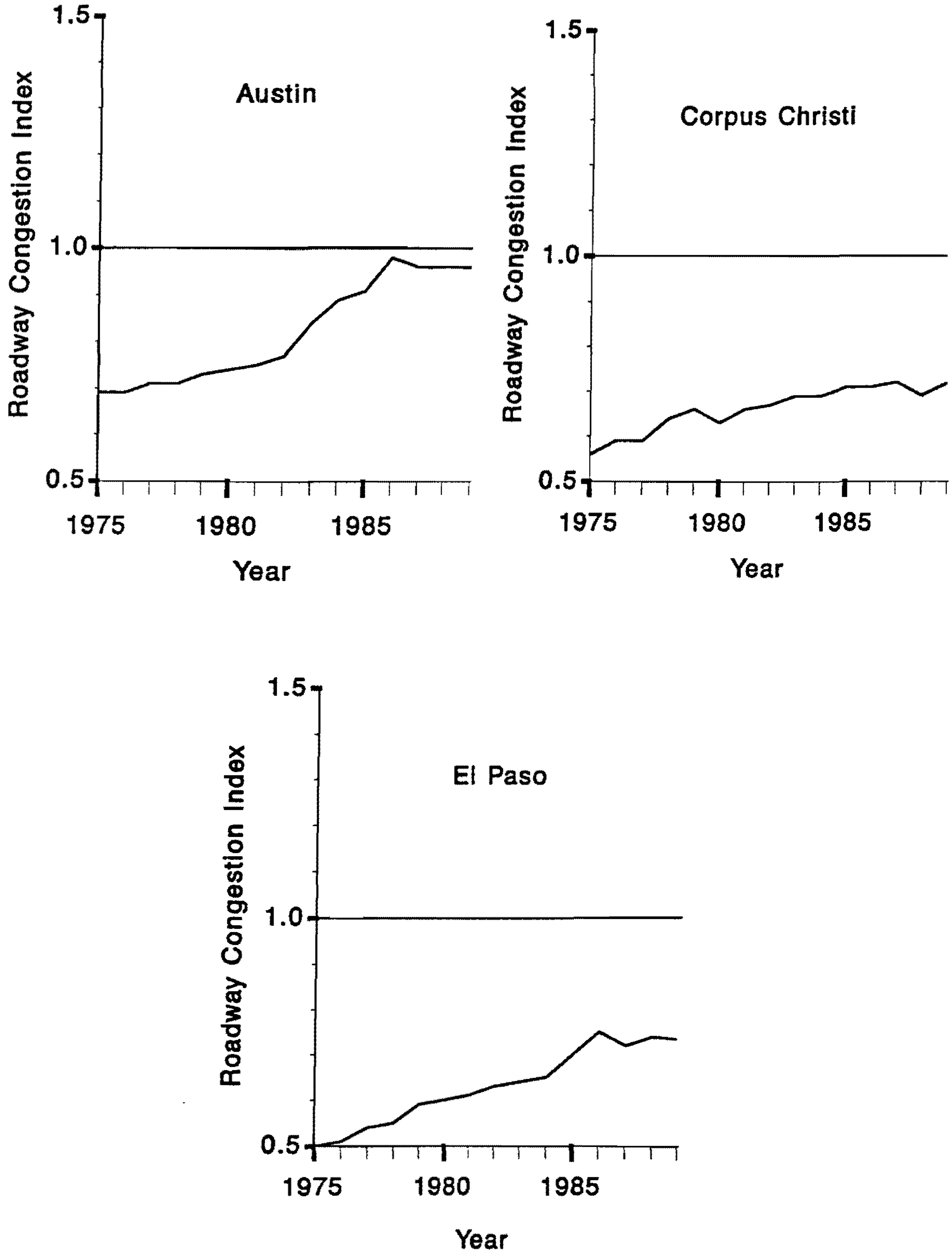

Figure 2. Historical Trends In Congestion for Major Texas Urban Areas

San Antonio have realized a similar growth in congestion, with RCI increases of 45% and 47% for these urban areas over the same time period.

In addition to relative congestion levels, costs due to congestion have also been estimated (Table 2). The cost estimates shown in Table 2 and Figures 3 and 4 are based on the costs incurred from travel delay and excess fuel consumption associated with traffic congestion and represent the total urban area costs due to congestion. As illustrated in Figures 3 and 4, the costs due to congestion have increased significantly since 1975 in the five largest Texas urban areas.

Table 2. Historical Congestion Levels and Costs for Major Texas Urban Areas

Urban Area	Year	Congestion Level (RCI)	% Increase[1]	Congestion Cost[2] ($ Millions)
Austin	1975	0.69	39	2
	1980	0.74		20
	1985	0.91		100
	1989	0.96		136
Corpus Christi	1975	0.56	27	0
	1980	0.63		0
	1985	0.71		9
	1989	0.71		9
Dallas	1975	0.60	70	1
	1980	0.78		282
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El Paso	1975	0.47	57	0
	1980	0.60		0
	1985	0.70		10
	1989	0.74		31
Fort Worth	1975	0.60	45	0
	1980	0.71		98
	1985	0.82		232
	1989	0.87		303
Houston	1975	0.89	27	256
	1980	1.11		772
	1985	1.23		1,191
	1989	1.13		1,132
San Antonio	1975	0.59	47	0
	1980	0.73		36
	1985	0.87		170
	1989	0.87		210

[1] The total percent increase in the RCI between 1975 and 1989

[2] The total urban area cost due to congestion based on travel delay and excess fuel consumption; in 1989 dollars

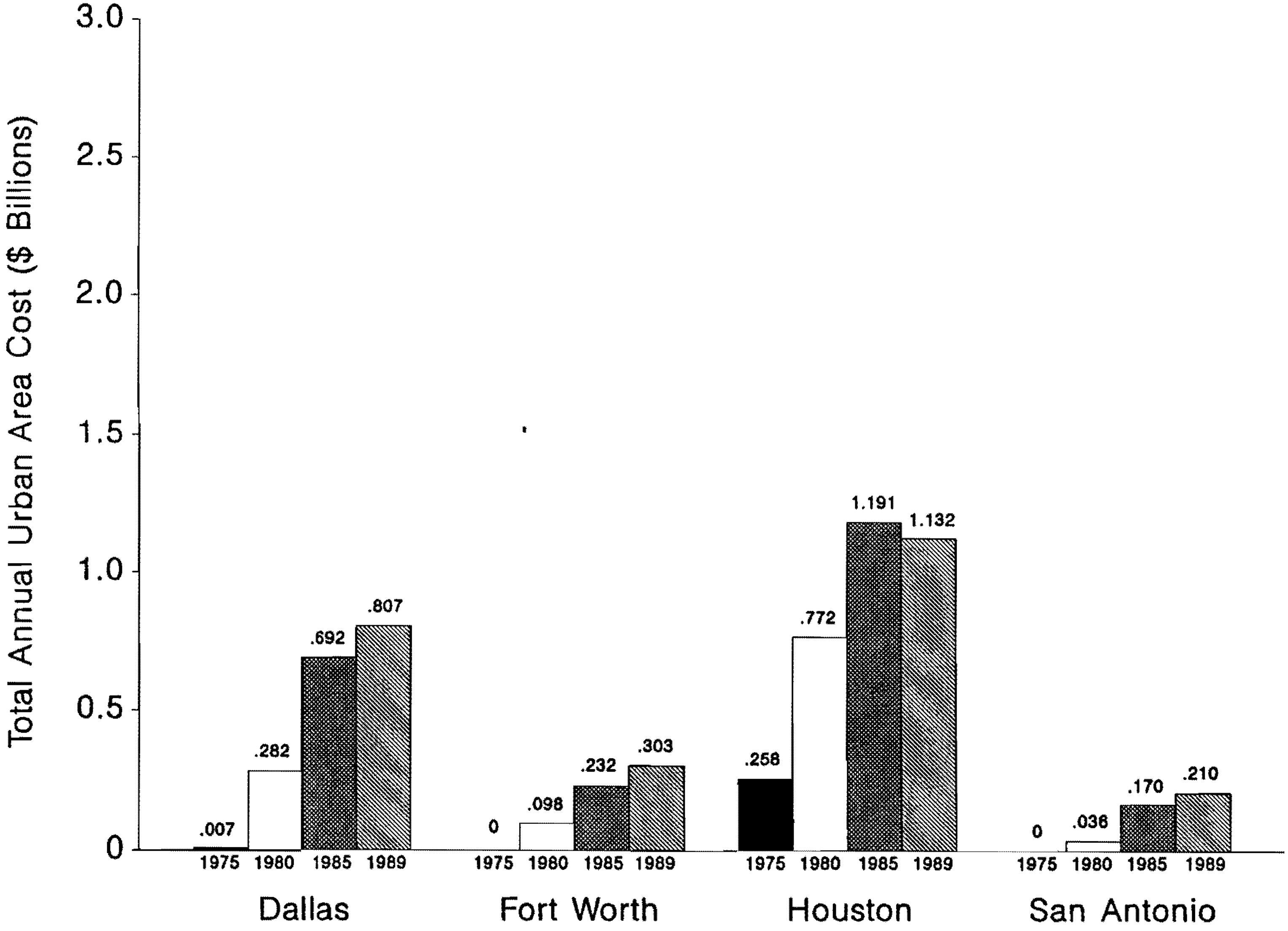

Figure 3. Total Urban Area Costs Due To Congestion In Major Texas Urban Areas

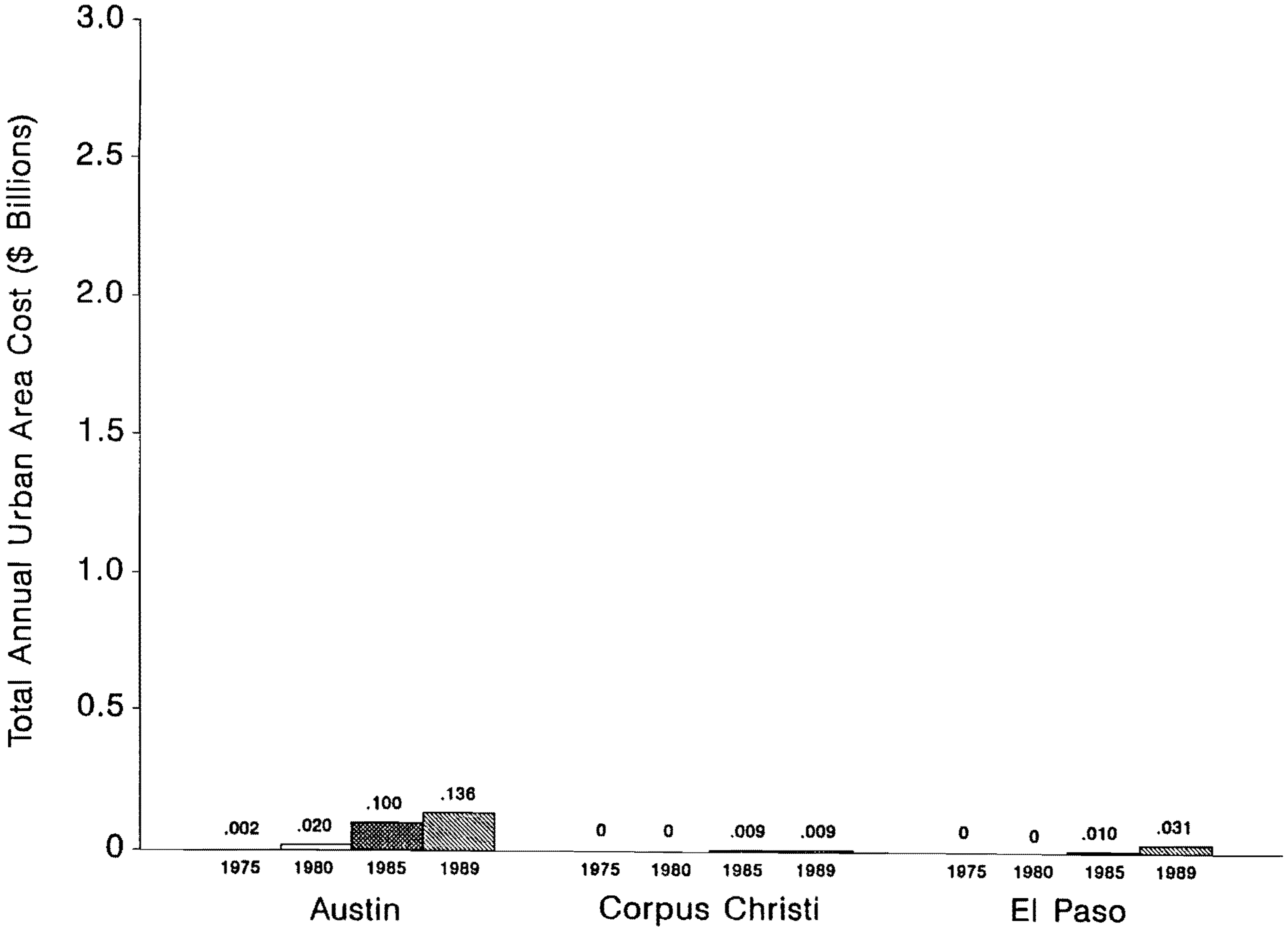

Figure 4. Total Urban Area Costs Due To Congestion In Major Texas Urban Areas

Estimates of Future Congestion and Costs

The values shown in Table 3 were used, in combination with future plans for improvement to the urban roadway systems, to develop estimates of future roadway congestion levels in the seven largest Texas urban areas. This procedure specifically consisted of: 1) applying the annual growth rates shown in Table 3 to 1989 DVMT data and 2) applying percentage funding level rates to improvement plans found in the Project Development Plan (PDP) at the state level and the Transportation Improvement Program (TIP) at the local level. The funding levels shown in Table 3 represent the funds allocated in 1990 for the construction of additional roadway lane-miles expressed as a percentage of the funds requested, as listed in the PDP and TIP.

Table 3. Urban-Area Characteristics

Urban Area	Funding Level (%)[1]	Annual Growth in DVMT (%)[2]
Austin	50	3.4
Corpus Christi	30	3.5
Dallas	48	2.5
El Paso	30	4.0
Fort Worth	45	2.5
Houston	60	2.9
San Antonio	58	4.3

Note: State average funding level = 40%

[1] The funds allocated in 1990 for the construction of additional roadway lane-miles expressed as a percentage of the funds requested, as listed in the PDP and TIP

[2] Estimated future annual growth rate in daily vehicle-miles of travel

The estimates developed as a result of this procedure consisted of congestion level and associated cost approximations for the horizon years of 1995, 2000, and 2010. While the annual traffic growth rates in DVMT shown in Table 3 were held constant, the three following funding levels were used in arriving at these estimates: 1) the current state average of 40%; 2) the current level of funding for each individual urban area (Table 3); and 3) a 100% level of funding. Graphical representations of congestion levels for these three different scenarios are included in Figures 5 through 11, while the specific RCI values depicted in these figures are included in Table 4.

Table 4. Estimates of Future Roadway Congestion Indices At Various Levels of Funding

Urban Area	Roadway Congestion Index (RCI)									
	1989, Existing	1995			2000			2010		
		40%[1]	Current Level[2]	100%[3]	40%[1]	Current Level[2]	100%[3]	40%[1]	Current Level[2]	100%[3]
Austin	0.96	1.05	0.99	0.79	1.02	0.96	0.80	1.27	1.20	0.93
Corpus Christi	0.71	0.75	0.78	0.64	0.78	0.82	0.68	1.01	1.06	0.78
Dallas	1.02	1.11	1.10	0.99	1.12	1.09	0.93	1.25	1.20	0.88
El Paso	0.74	0.92	0.94	0.86	1.06	1.08	0.97	1.41	1.46	1.01
Fort Worth	0.87	0.98	0.98	0.92	1.01	1.00	0.89	1.20	1.18	0.95
Houston	1.13	1.18	1.07	0.96	1.10	1.02	0.85	1.17	1.02	0.78
San Antonio	0.87	1.08	1.05	0.99	1.24	1.18	1.11	1.70	1.60	1.38

[1] The Roadway Congestion Index assuming that 40% of the projects listed in the PDP and TIPs are funded and completed

[2] The Roadway Congestion Index assuming that the current level of funding (Table 3) in each of the respective urban areas continues in the future

[3] The Roadway Congestion Index assuming that 100% of the projects listed in the PDP and TIPs are funded and completed

Under the first two scenarios (current individual urban area and state average levels of funding), congestion is estimated to surpass the undesirable (1.0) level in all seven major urban areas by 2010. It should be noted that the future estimates for San Antonio and El Paso in the year 2010 reflect substantial growth rates in travel demand being held constant over a period of 20 years. At this point in time, however, these growth rates are considered to reflect the general trends for these areas in the future.

While Figures 5 through 11 graphically illustrate the application of the previously described scenarios, the values shown in Tables 5 through 7 provide a more detailed explanation of the specific values associated with these three projections. For instance, Table 5 illustrates that, in the case of a 40% level of funding being held constant over the next 20 years, El Paso would be provided a 20% increase in freeway lane-miles and a 35%

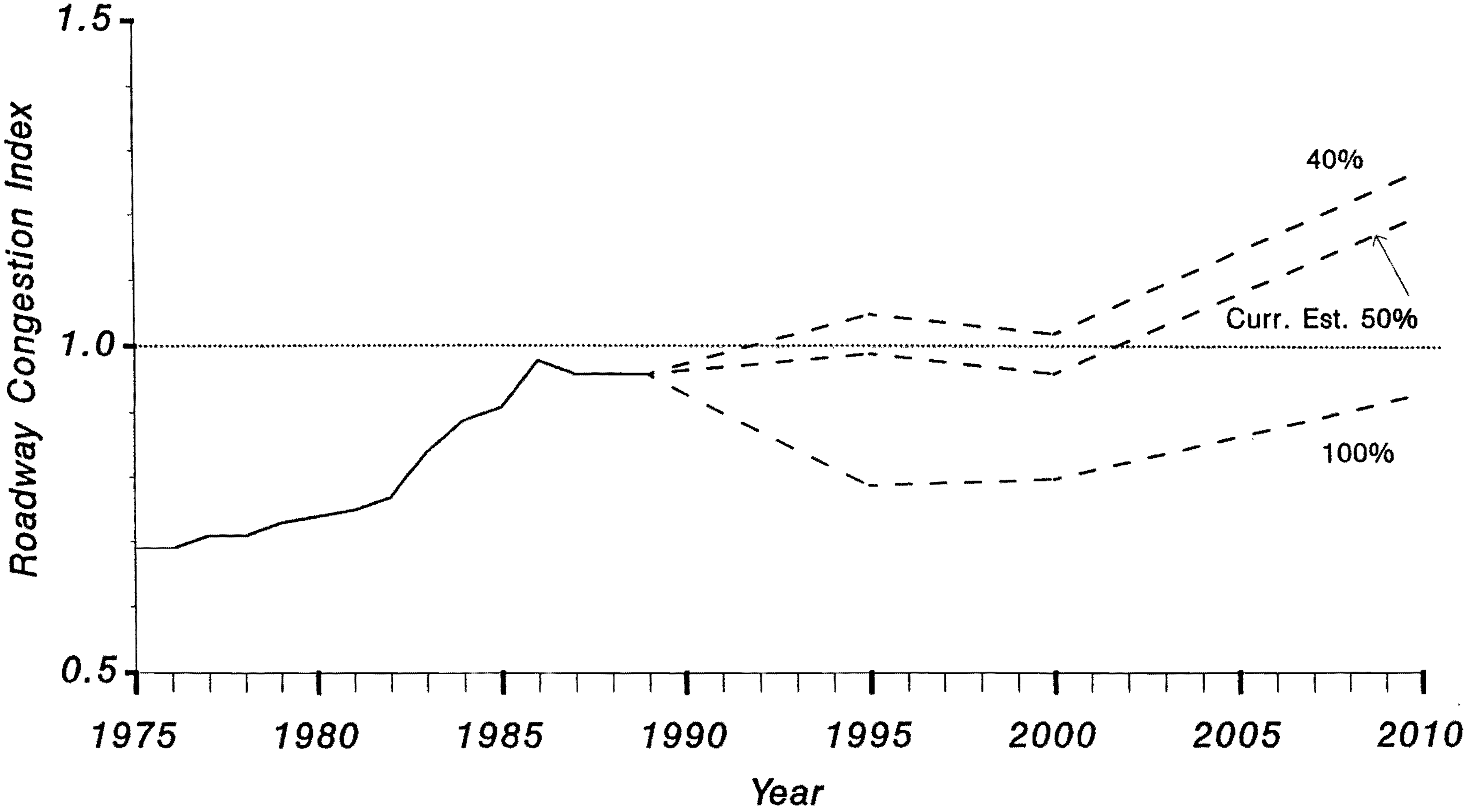

Figure 5. Roadway Congestion Index Estimates for Austin

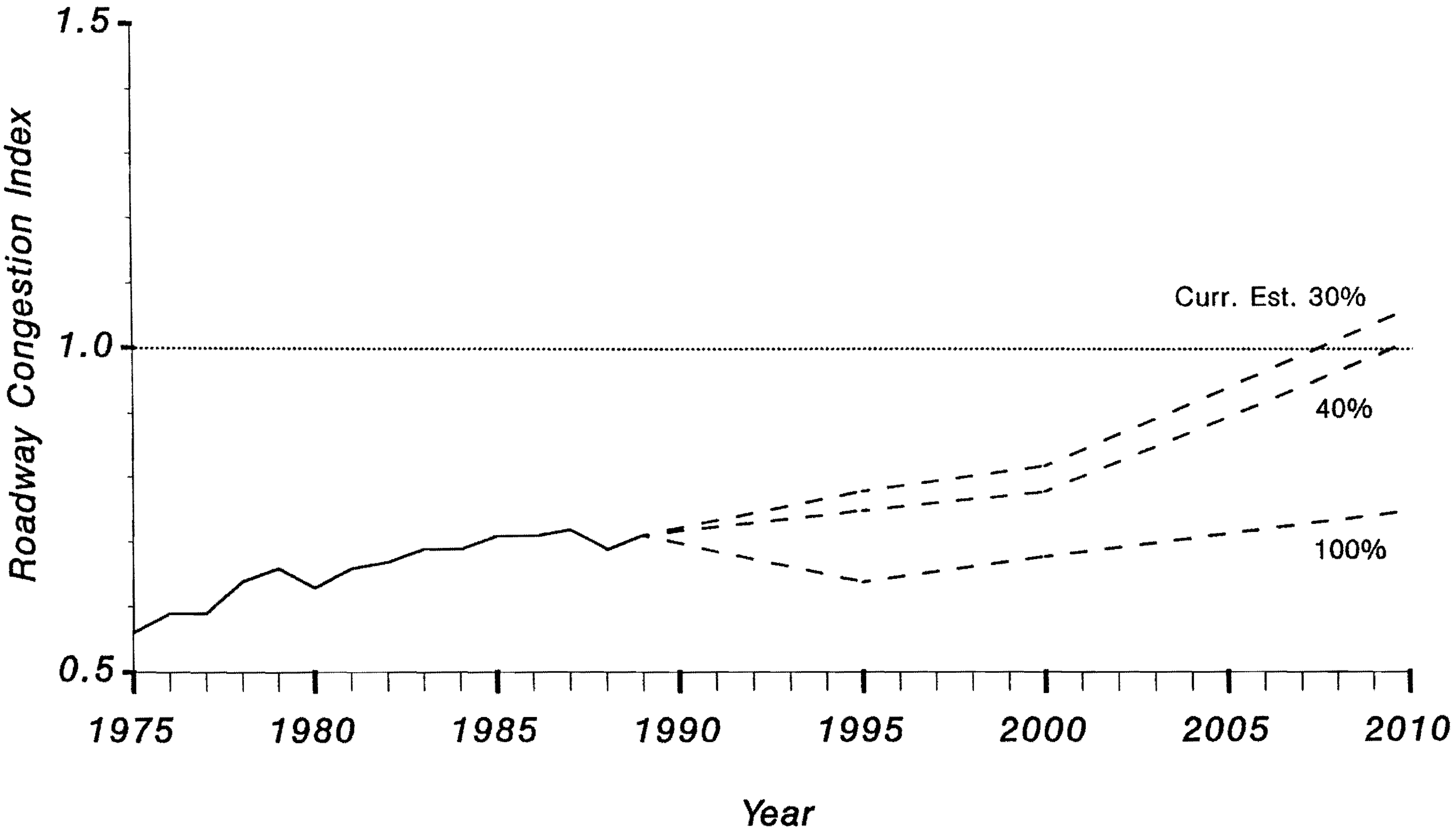

Figure 6. Roadway Congestion Index Estimates for Corpus Christi

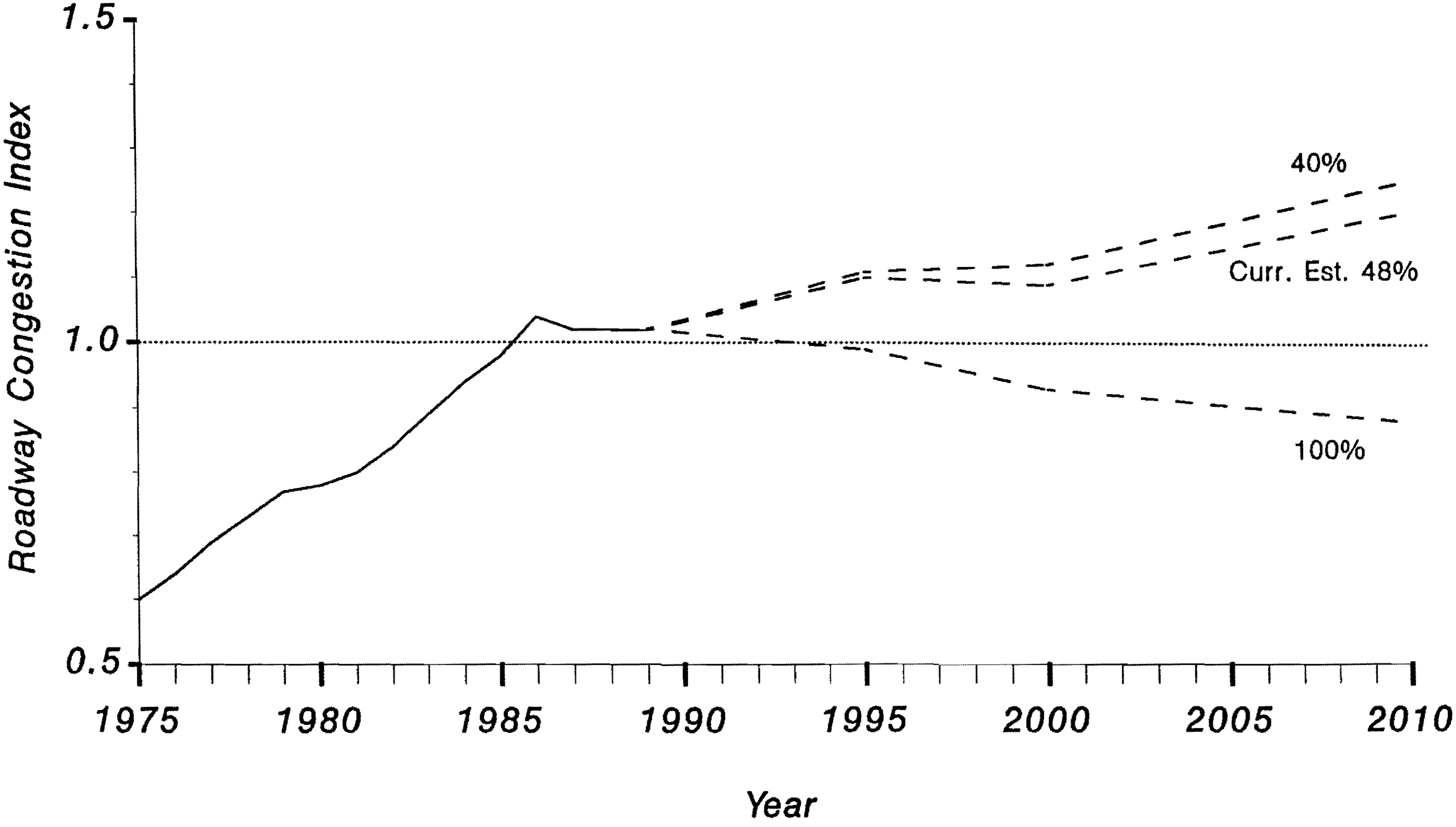

Figure 7. Roadway Congestion Index Estimates for Dallas

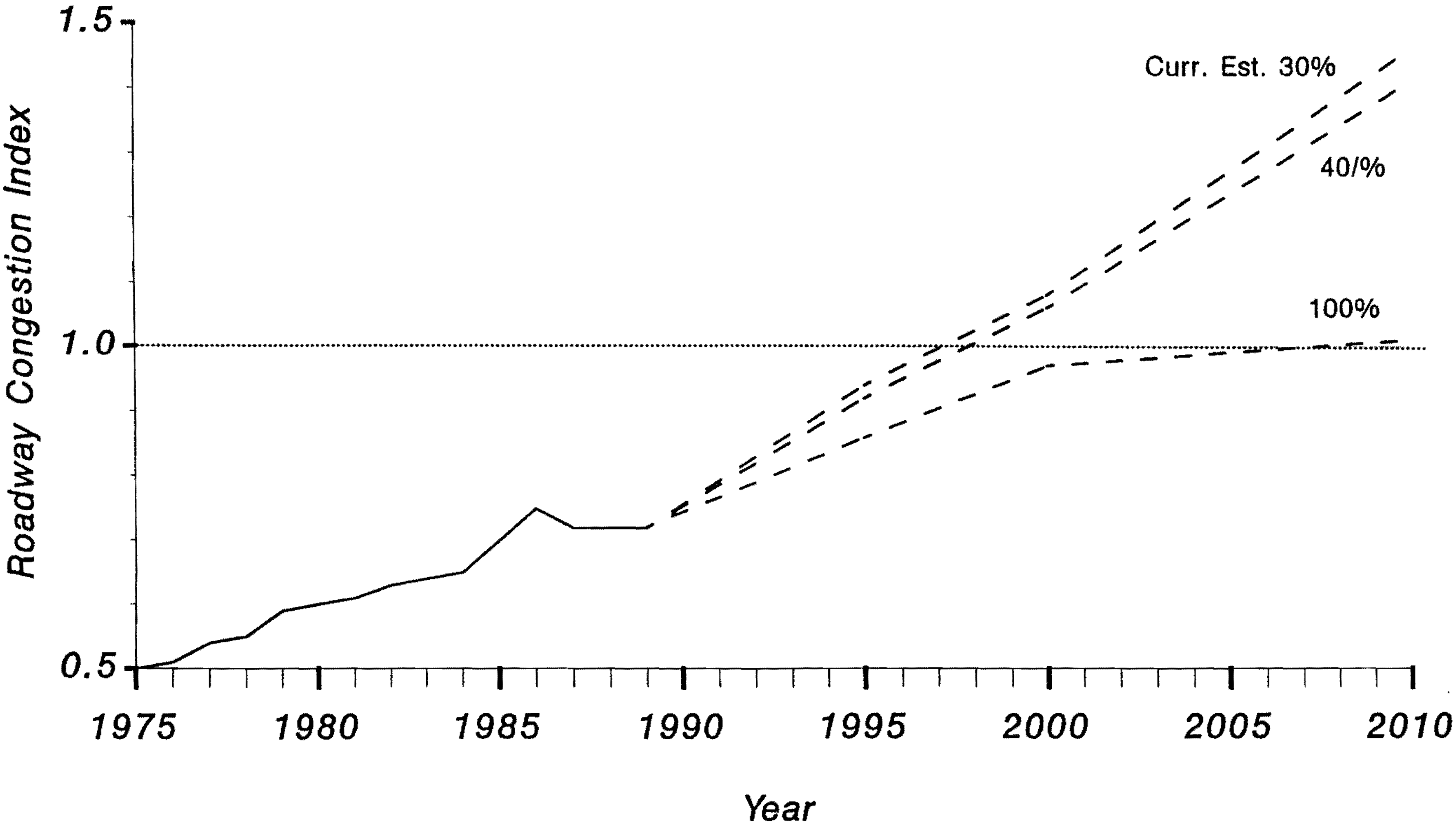

Figure 8. Roadway Congestion Index Estimates for El Paso

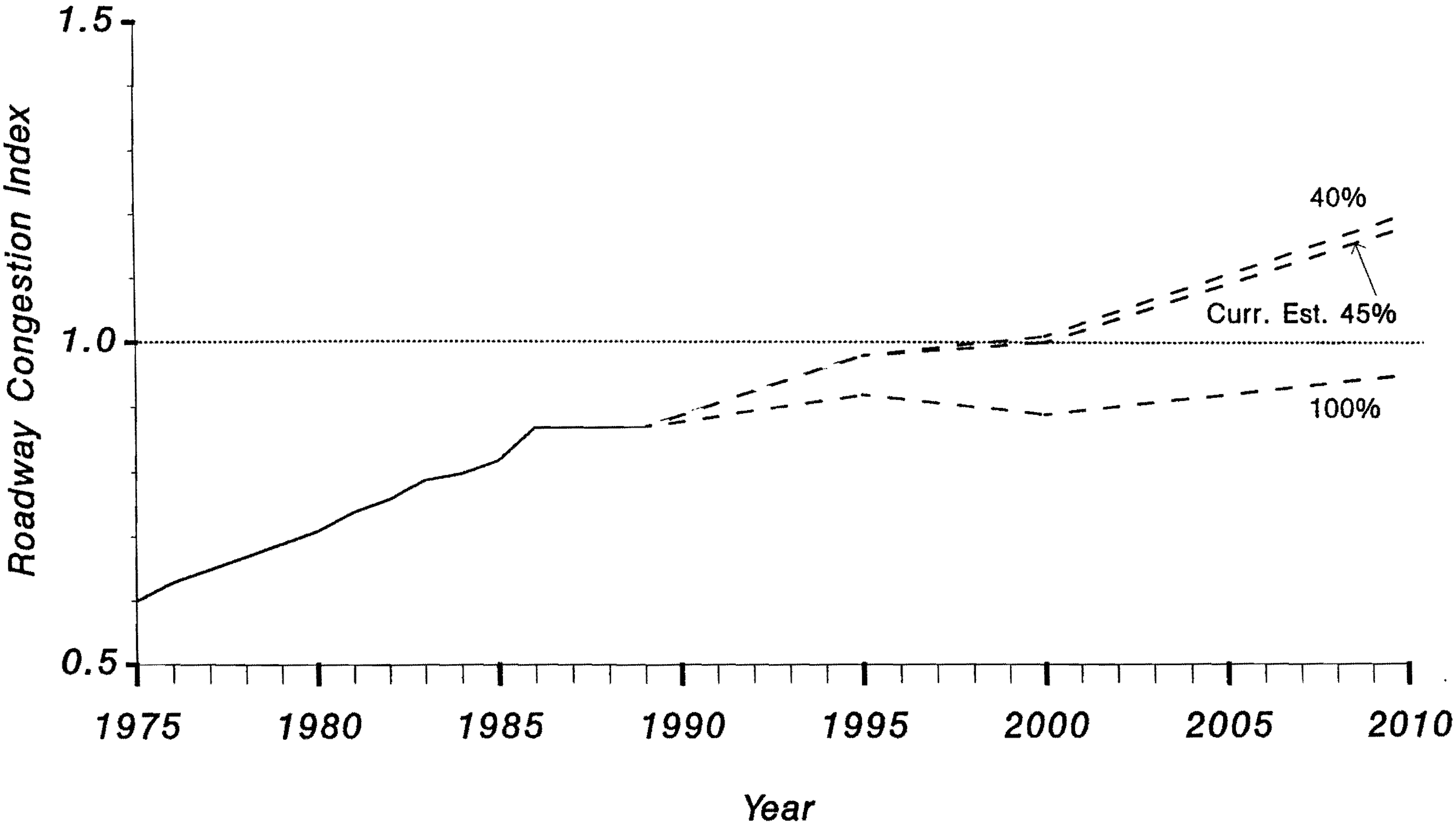

Figure 9. Roadway Congestion Index Estimates for Fort Worth

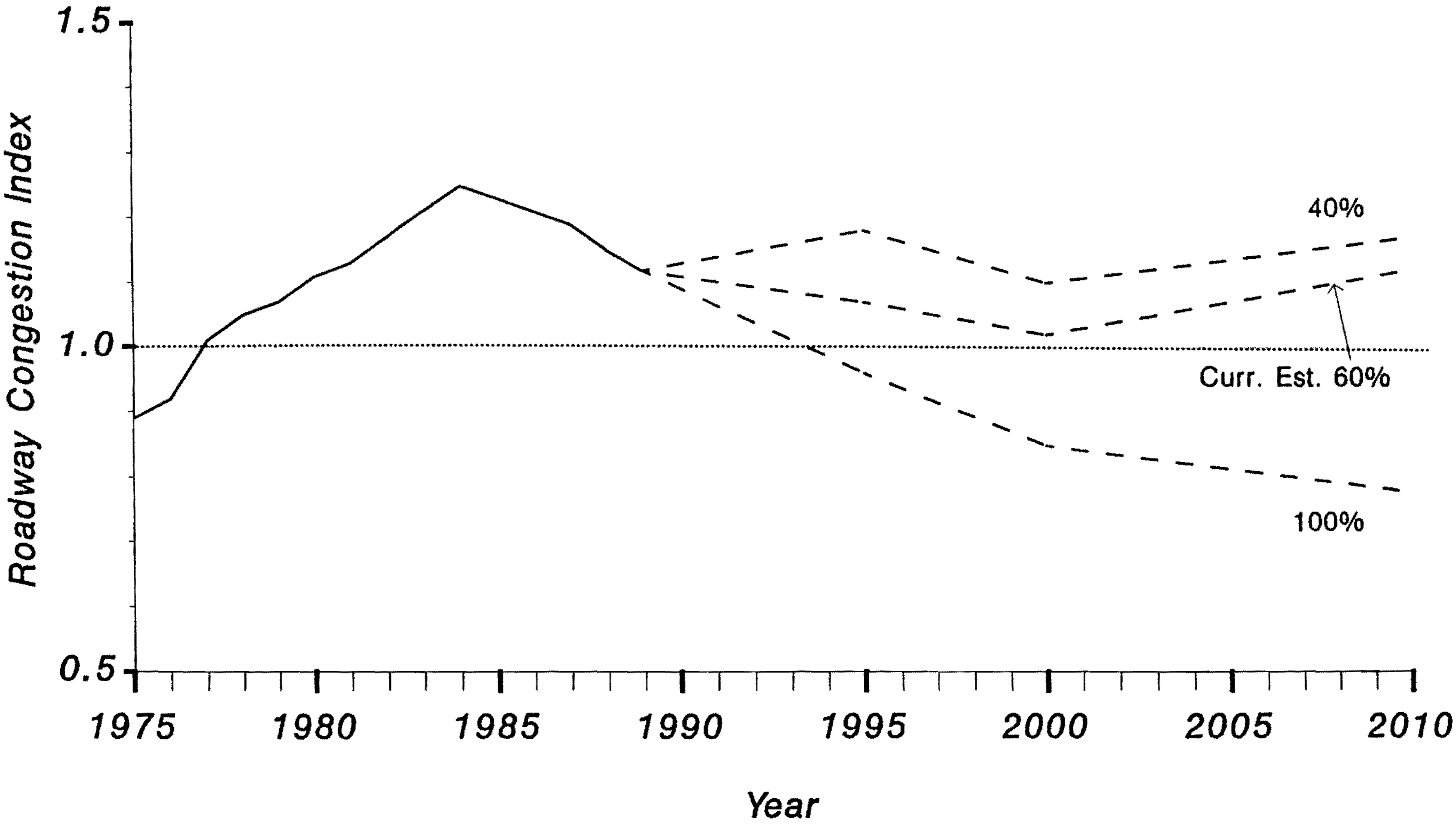

Figure 10. Roadway Congestion Index Estimates for Houston

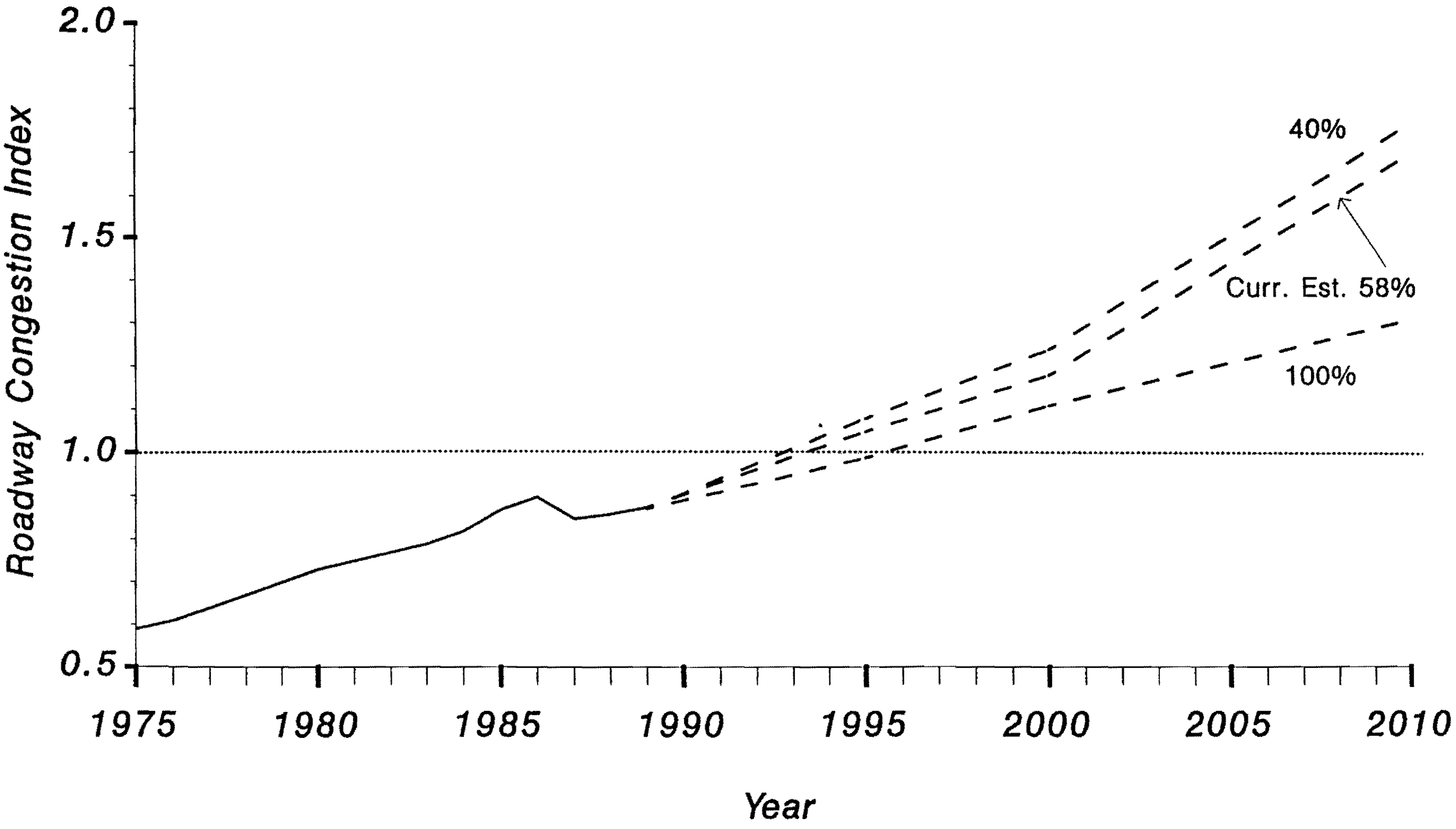

Figure 11. Roadway Congestion Index Estimates for San Antonio

increase in arterial lane-miles. Over the same period of time, however, the growth in demand (DVMT) is estimated to be 135%. Consequently, the RCI under this scenario is projected to increase from 0.74 to 1.41 (Table 4 and Figure 8).

Table 5. Supply and Demand Characteristics in the Year 2010
Assuming a 40% Level of Funding

Urban Area	% Increase in DVMT[1]	Freeways		Principal Arterials	
		Addn. Ln-Mi[2]	% Increase[3]	Addn. Ln-Mi[2]	%Increase[3]
Austin	110	320	75	405	95
Corpus Christi	115	40	20	460	145
Dallas	70	700	40	540	30
El Paso	135	75	20	280	35
Fort Worth	70	245	25	255	30
Houston	90	1,480	85	2,025	100
San Antonio	150	205	25	520	15

[1] The percentage increase in daily vehicle-miles of travel by the year 2010, assuming the annual growth rates in Table 3 remain constant
[2] The additional lane-miles of roadway which could be constructed by the year 2010 under an assumed funding level of 40%
[3] The percentage increase in roadway lane-miles with reference to the existing (1989) number of lane-miles

Table 6. Supply and Demand Characteristics in the Year 2010
Assuming Current Levels of Funding

Urban Area	% Increase in DVMT[1]	Freeways		Principal Arterials	
		Addn. Ln-Mi[2]	% Increase[3]	Addn. Ln-Mi[2]	%Increase[3]
Austin	110	360	85	480	115
Corpus Christi	115	30	15	380	120
Dallas	70	800	50	605	35
El Paso	135	60	15	220	30
Fort Worth	70	265	25	275	30
Houston	90	1,945	110	2,505	125
San Antonio	150	250	30	750	20

[1] The percentage increase in daily vehicle-miles of travel by the year 2010, assuming the annual growth rates in Table 3 remain constant
[2] The additional lane-miles of roadway which could be constructed by the year 2010 under the assumed levels of funding in Table 3
[3] The percentage increase in roadway lane-miles with reference to the existing (1989) number of lane-miles

Table 7. Supply and Demand Characteristics in the Year 2010
Assuming a 100% Level of Funding

Urban Area	% Increase in DVMT[1]	Freeways		Principal Arterials	
		Addn. Ln-Mi[2]	% Increase[3]	Addn. Ln-Mi[2]	%Increase[3]
Austin	110	430	105	730	175
Corpus Christi	115	60	30	665	210
Dallas	70	1,355	80	810	50
El Paso	135	130	35	500	60
Fort Worth	70	385	40	400	45
Houston	90	2,500	140	2,875	145
San Antonio	150	300	35	1,295	25

[1] The percentage increase in daily vehicle-miles of travel by the year 2010, assuming the annual growth rates in Table 3 remain constant
[2] The additional lane-miles of roadway which could be constructed by the year 2010 under an assumed level of funding of 100%
[3] The percentage increase in roadway lane-miles with reference to the existing (1989) number of lane-miles

The cost estimates associated with the congestion levels discussed previously are summarized in Figures 12 through 17 and Tables 8 through 10. These estimates were developed through the utilization of the relationship between congestion costs per capita and the RCI (Figure 18). This procedure specifically consisted of the following steps: 1) maintaining a constant slope, the best-fit line (determined through a regression analysis) depicted in Figure 18 was shifted such that the line intersected a Texas urban area data point (i.e., Houston); this procedure accomplished the application of the general relationship between the RCI and cost per capita to local data; 2) the predicted RCI value for an urban area was applied to the equation generated by the best-fit line producing an estimate of cost per capita; and 3) the projected population was multiplied by the estimated cost per capita to obtain an estimate of the total urban area cost due to congestion. This general procedure was carried out for the future years of 1995, 2000, and 2010 and for the three funding levels cited previously.

Assuming that the current level of funding for roadway improvements continues, the costs due to congestion are estimated to grow substantially by the year 2010 in the urban areas of Austin, Corpus Christi, Dallas, El Paso, Fort Worth, and San Antonio (Figures 12 and 13). Conversely, the Houston urban area is expected to show little growth in congestion

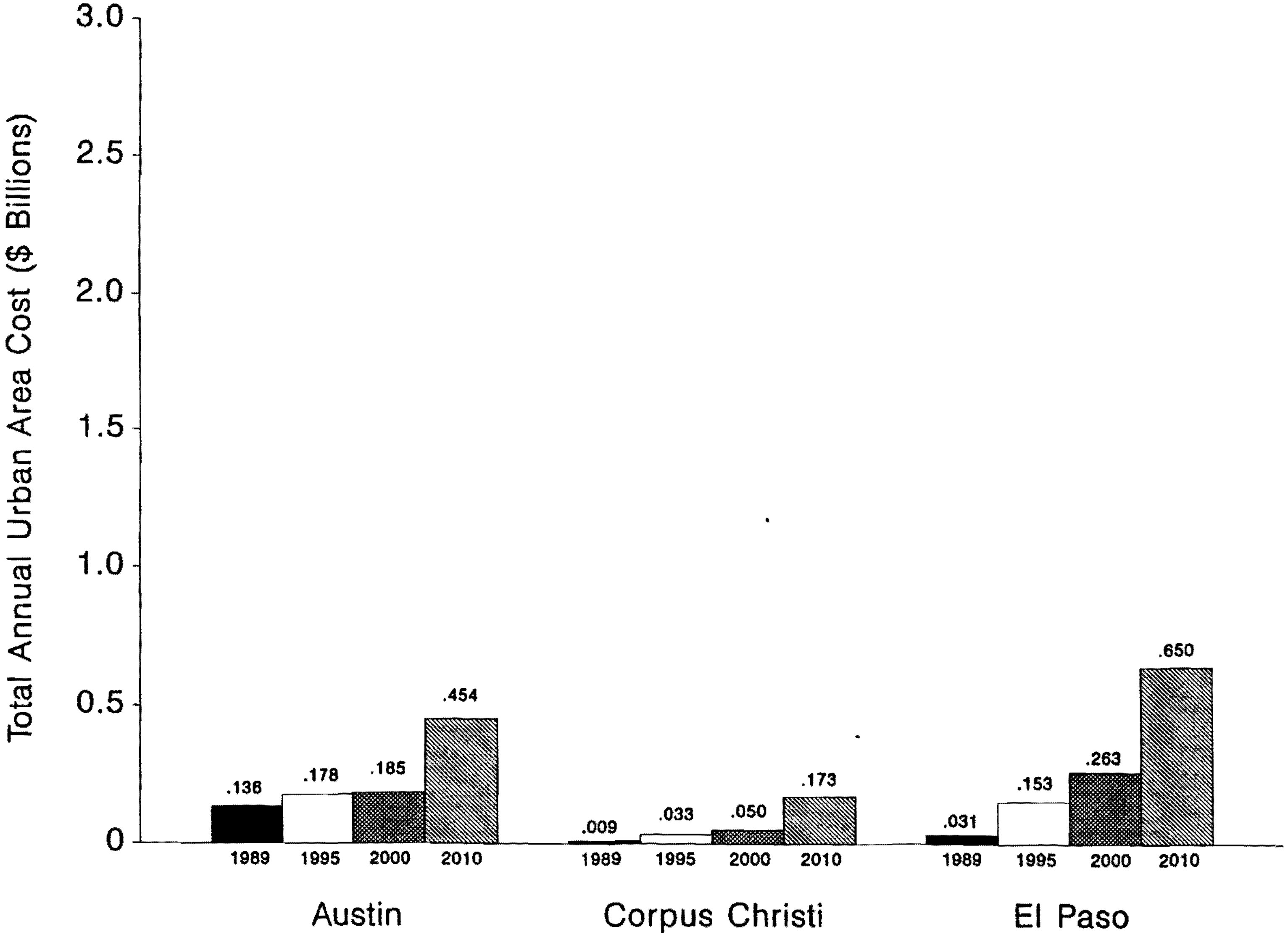

Figure 12. Total Urban Area Congestion Costs for Current Level of Funding

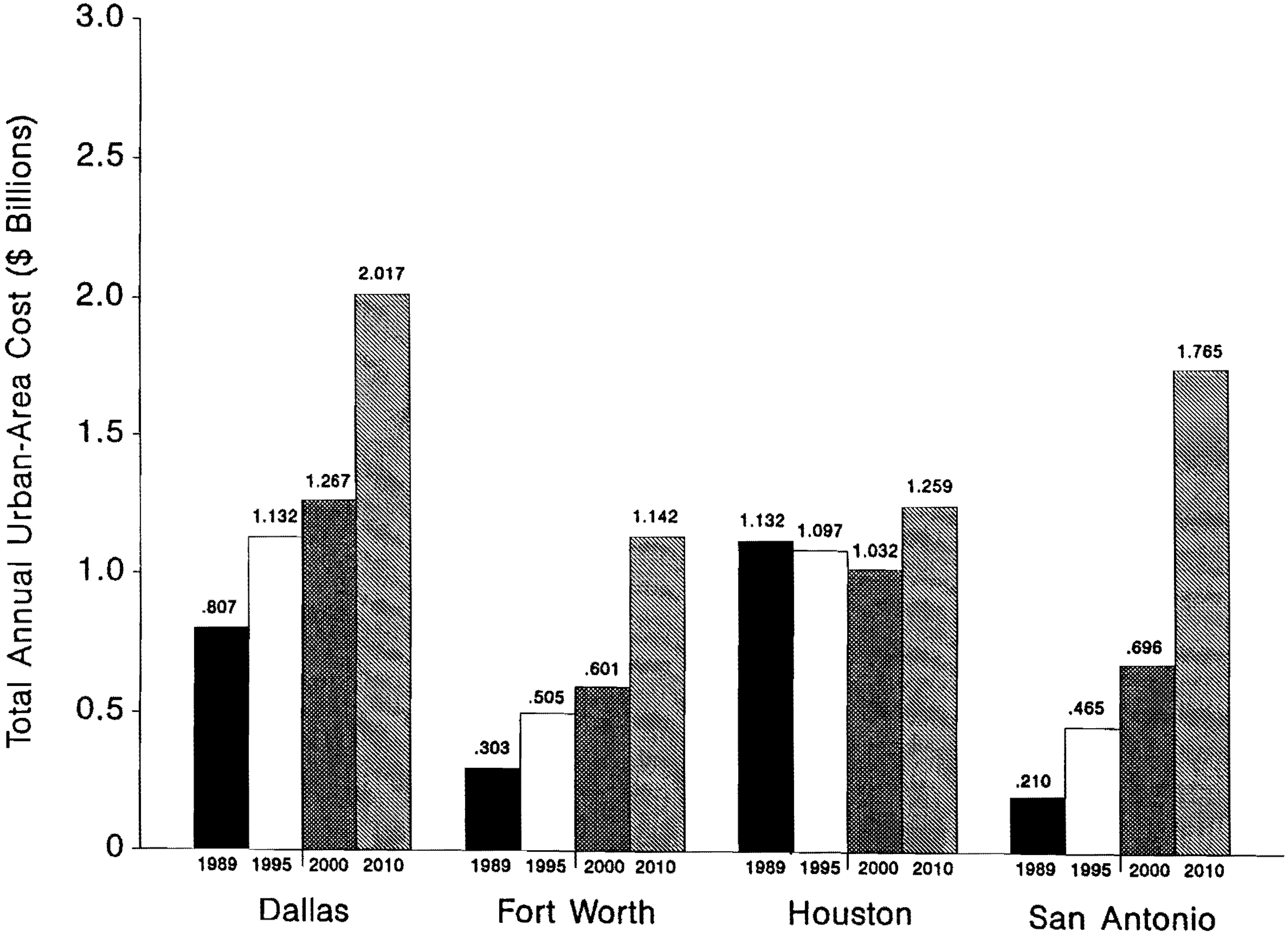

Figure 13. Total Urban-Area Costs for Current Level of Funding

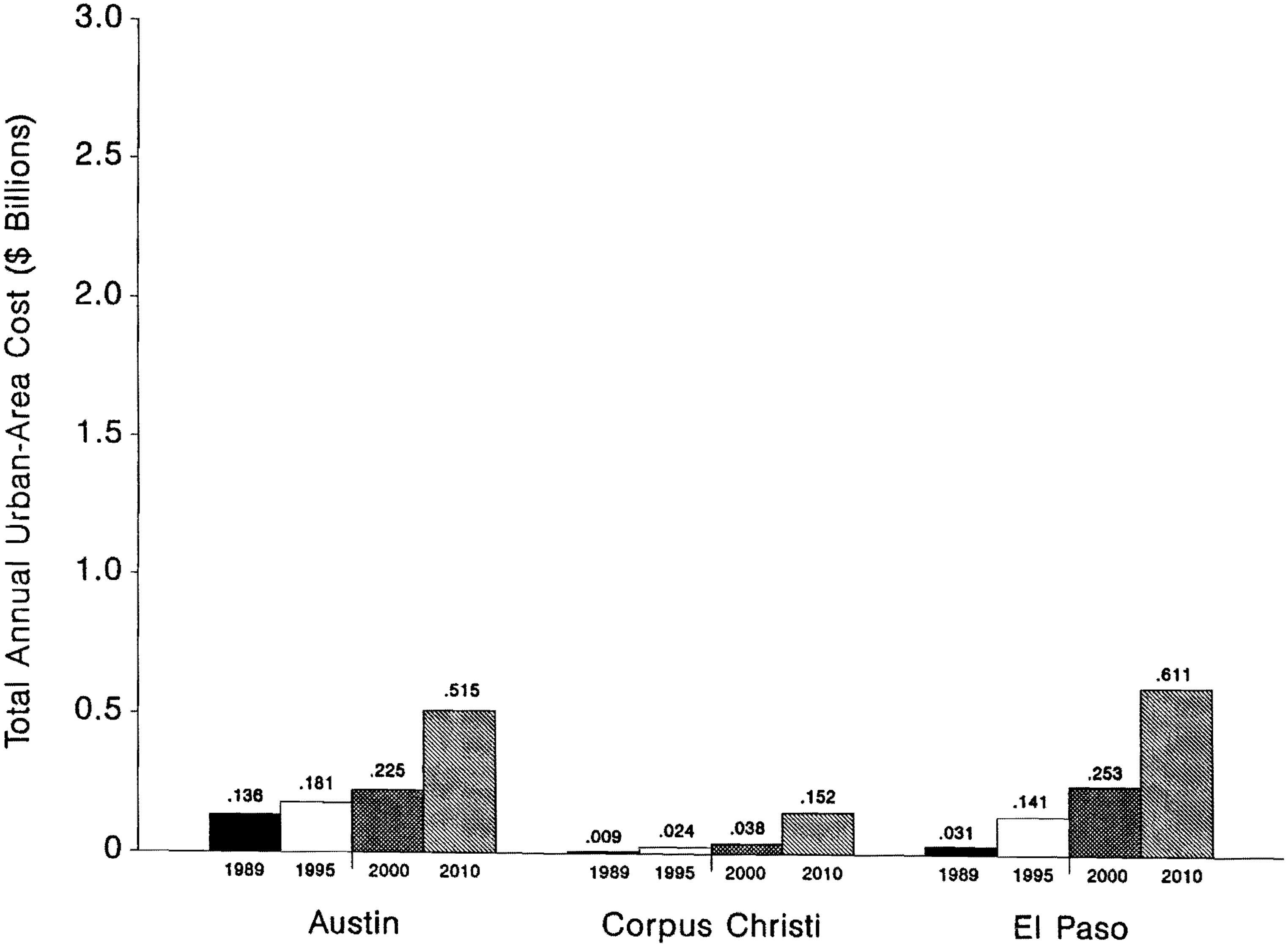

Figure 14. Total Urban-Area Costs Assuming a 40% Level of Funding

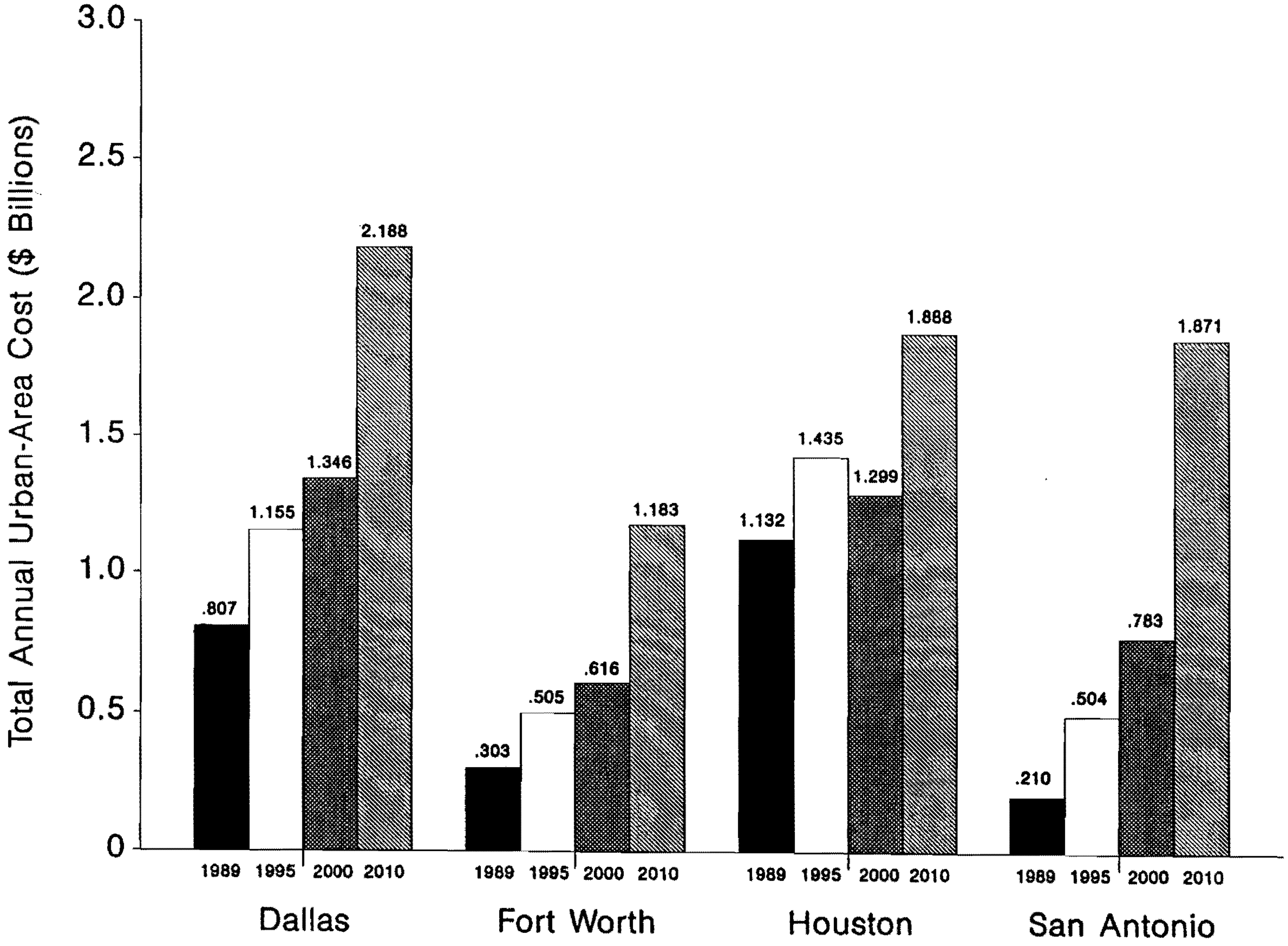

Figure 15. Total Urban-Area Costs Assuming a 40% Level of Funding

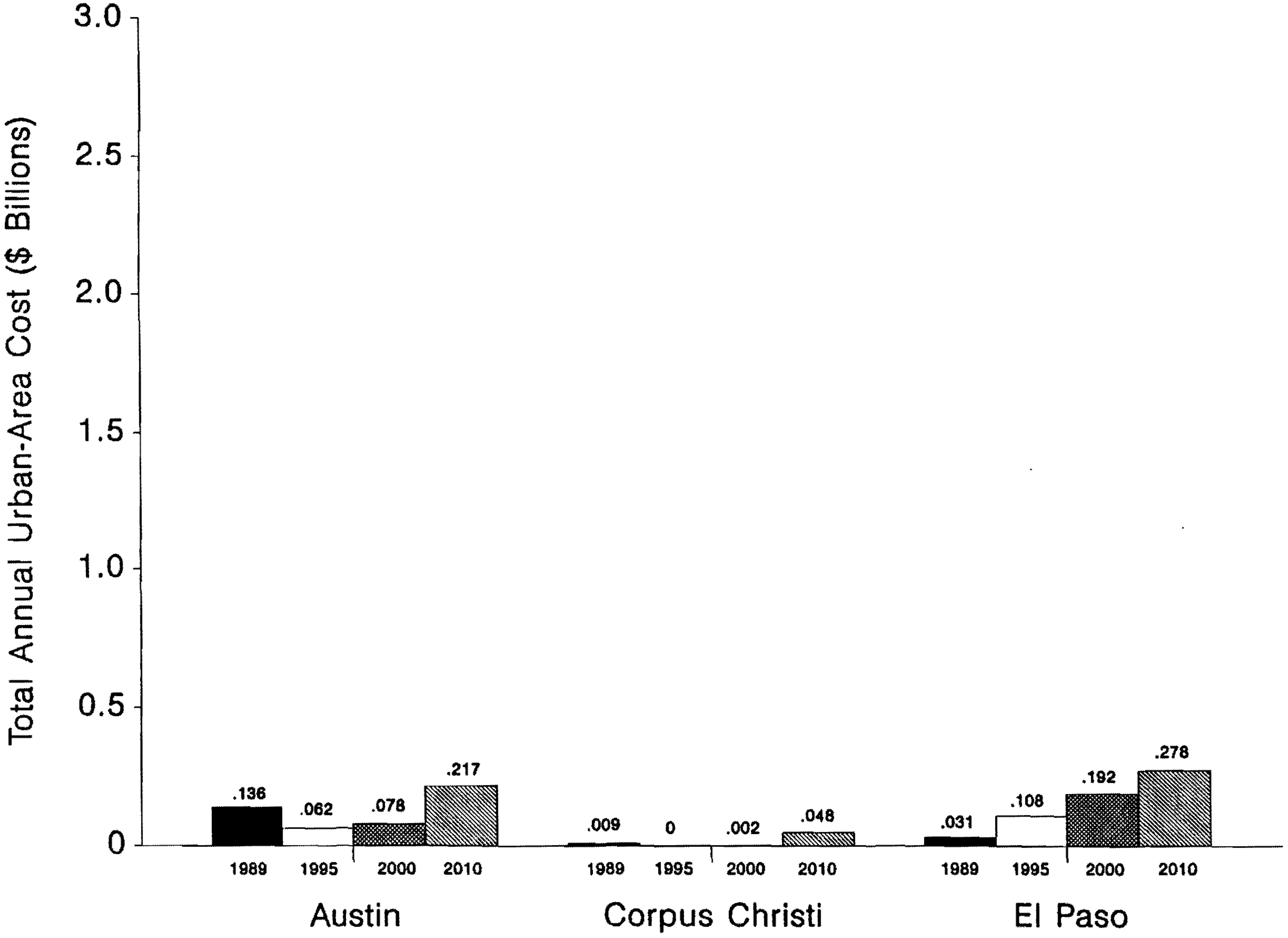

Figure 16. Total Urban-Area Costs Assuming a 100% Level of Funding

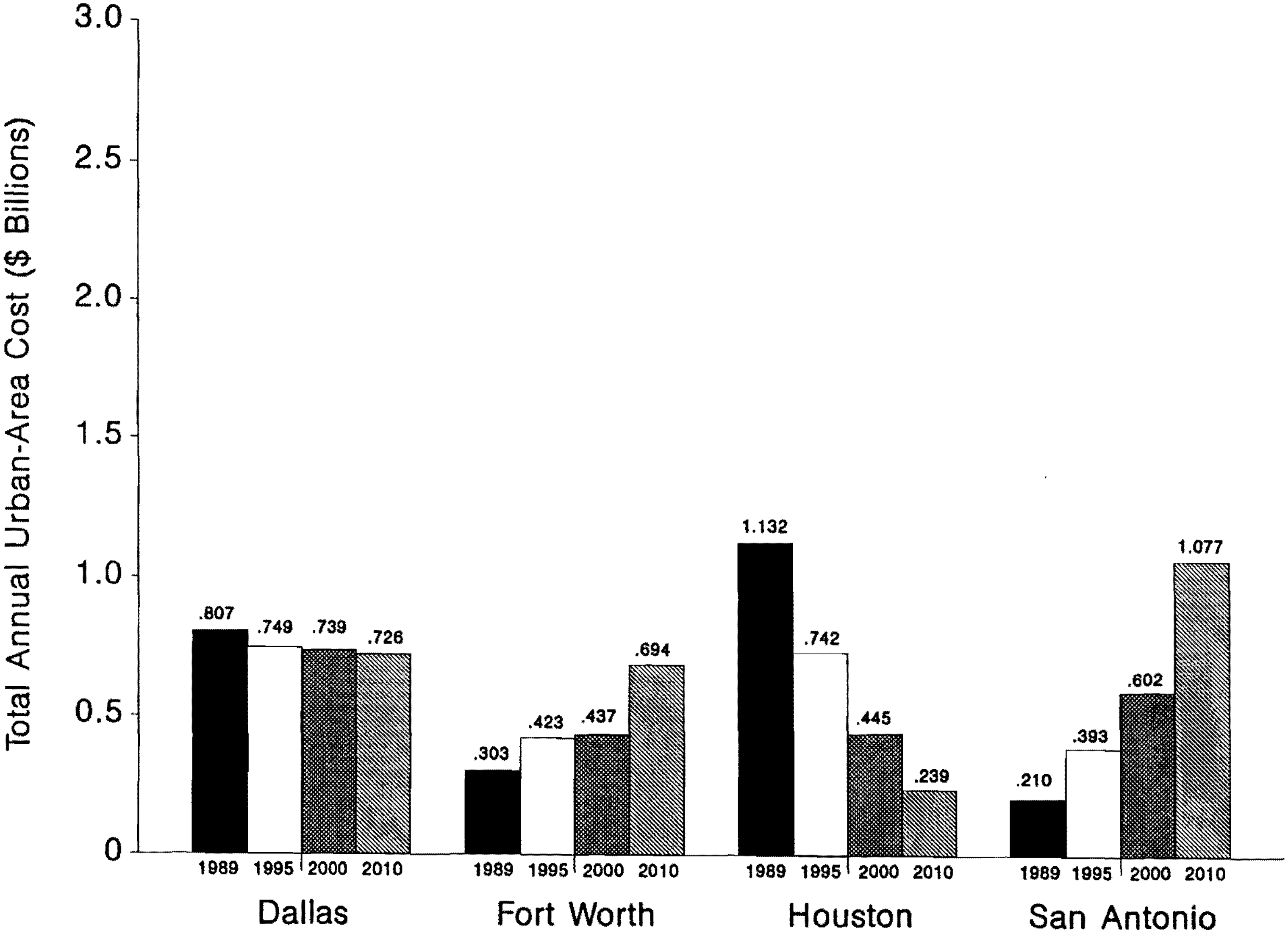

Figure 17. Total Urban-Area Costs Assuming a 100% Level of Funding

costs under this scenario. This minimal growth in congestion cost is due to the extensive roadway improvements scheduled for the Houston urban area in the future.

Table 8. Future Congestion-Cost Estimates, Current Level of Funding

Urban Area	Expected Growth Rate (%)[1]	Year	Urban Area Population (Millions)	Congestion Index (RCI)	Congestion Cost	
					Per Capita[2] ($)	Total[3] ($ Millions)
Austin	2.8	1989	0.505	0.96	270	136
		1995	0.595	0.99	300	178
		2000	0.685	0.96	270	185
		2010	0.900	1.20	505	454
Corpus Christi	2.5	1989	0.275	0.71	35	9
		1995	0.320	0.78	105	33
		2000	0.360	0.82	140	50
		2010	0.460	1.06	375	173
Dallas	2.7	1989	1.970	1.02	410	807
		1995	2.310	1.10	490	1,132
		2000	2.640	1.09	480	1,267
		2010	3.445	1.20	585	2,017
El Paso	2.4	1989	0.520	0.74	60	31
		1995	0.600	0.94	255	153
		2000	0.675	1.08	390	263
		2010	0.855	1.46	760	650
Fort Worth	2.7	1989	1.165	0.87	260	303
		1995	1.365	0.98	370	505
		2000	1.560	1.00	385	601
		2010	2.040	1.18	560	1,142
Houston	2.0	1989	2.865	1.13	395	1,132
		1995	3.225	1.07	340	1,097
		2000	3.560	1.02	290	1,032
		2010	4.340	1.02	290	1,259
San Antonio	2.0	1989	1.165	0.87	180	210
		1995	1.310	1.05	355	465
		2000	1.450	1.18	480	696
		2010	1.765	1.60	1000	1,765

[1] The expected annual growth in population for the respective urban areas

[2] The cost due to congestion expressed on a per-person basis; this value obtained by using the predicted RCI value for an urban area in conjunction with the relationship illustrated in Figure 18.

[3] The estimated total urban-area cost due to congestion (congestion cost due to excess fuel consumption and person-hours of delay); this value obtained by multiplying the per-capita cost determined from Figure 18 by the projected urban-area population.

Table 9. Future Congestion-Cost Estimates, 40% Level of Funding

Urban Area	Expected Growth Rate (%)[1]	Year	Urban Area Population (Millions)	Congestion Index (RCI)	Congestion Cost	
					Per Capita[2] ($)	Total[3] ($ Millions)
Austin	2.8	1989	0.505	0.96	270	136
		1995	0.595	1.05	360	181
		2000	0.685	1.02	330	225
		2010	0.900	1.27	570	515
Corpus Christi	2.5	1989	0.275	0.71	35	9
		1995	0.320	0.75	75	24
		2000	0.360	0.78	105	38
		2010	0.460	1.01	330	152
Dallas	2.7	1989	1.970	1.02	410	807
		1995	2.310	1.11	500	1,155
		2000	2.640	1.12	510	1,346
		2010	3.445	1.25	635	2,188
El Paso	2.4	1989	0.520	0.74	60	31
		1995	0.600	0.92	235	141
		2000	0.675	1.06	375	253
		2010	0.855	1.41	715	611
Fort Worth	2.7	1989	1.165	0.87	260	303
		1995	1.365	0.98	370	505
		2000	1.560	1.01	395	616
		2010	2.040	1.20	580	1,183
Houston	2.0	1989	2.865	1.13	395	1,132
		1995	3.225	1.18	445	1,435
		2000	3.560	1.10	365	1,299
		2010	4.340	1.17	435	1,888
San Antonio	2.0	1989	1.165	0.87	180	210
		1995	1.310	1.08	385	504
		2000	1.450	1.24	540	783
		2010	1.765	1.70	1060	1,871

[1] The expected annual growth in population for the respective urban areas.

[2] The cost due to congestion expressed on a per-person basis; this value obtained by using the predicted RCI value for an urban area in conjunction with the relationship illustrated in Figure 18.

[3] The total urban-area cost due to congestion; this value obtained by multiplying the per-capita cost determined from Figure 18 by the projected urban-area population.

Table 10. Future Congestion-Cost Estimates, 100% Level of Funding

Urban Area	Expected Growth Rate (%)[1]	Year	Urban Area Population (Millions)	Congestion Index (RCI)	Congestion Cost	
					Per Capita[2] ($)	Total[3] ($ Millions)
Austin	2.8	1989	0.505	0.96	270	136
		1995	0.595	0.79	105	62
		2000	0.685	0.80	115	78
		2010	0.900	0.93	240	217
Corpus Christi	2.5	1989	0.275	0.71	35	9
		1995	0.320	0.64	0	0
		2000	0.360	0.68	5	2
		2010	0.460	0.78	105	48
Dallas	2.7	1989	1.970	1.02	410	807
		1995	2.310	0.99	380	749
		2000	2.640	0.93	320	739
		2010	3.445	0.88	275	726
El Paso	2.4	1989	0.520	0.74	60	31
		1995	0.600	0.86	180	108
		2000	0.675	0.97	285	192
		2010	0.855	1.01	325	278
Fort Worth	2.7	1989	1.165	0.87	260	303
		1995	1.365	0.92	310	423
		2000	1.560	0.89	280	437
		2010	2.040	0.95	340	694
Houston	2.0	1989	2.865	1.13	395	1,132
		1995	3.225	0.96	230	742
		2000	3.560	0.85	125	445
		2010	4.340	0.78	55	239
San Antonio	2.0	1989	1.165	0.87	180	210
		1995	1.310	0.99	300	393
		2000	1.450	1.11	415	602
		2010	1.765	1.38	610	1,077

[1] The expected annual growth in population for the respective urban areas.

[2] The cost due to congestion expressed on a per-person basis; this value obtained by using the predicted RCI value for an urban area in conjunction with the relationship illustrated in Figure 18.

[3] The total urban-area cost due to congestion; this value obtained by multiplying the per-capita cost determined from Figure 18 by the projected urban-area population.

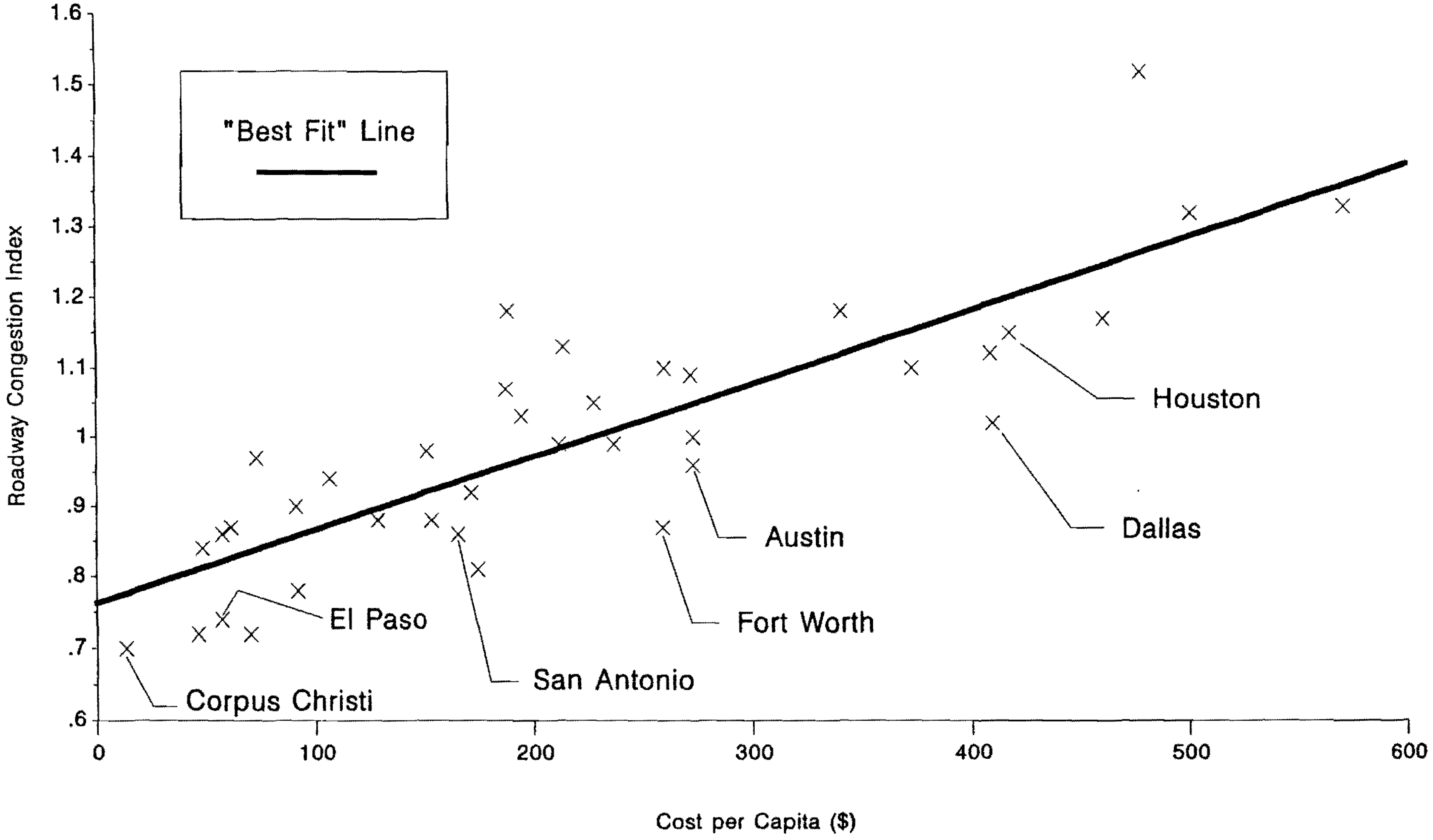

Figure 18. Cost Per Capita vs. Roadway Congestion Index for U.S. Urban Areas, 1989

As is noted in Figure 18, the data used to develop the relationship between the RCI and congestion cost per capita come from 1989. The future estimates shown in Figures 12 through 17 are not adjusted for inflation and should, therefore, be considered conservative.

The cost estimates shown in Figures 16 and 17 (representing a 100% future level of funding) should serve to illustrate the point that even if all projects listed in the PDP and TIPs were funded (which, judging from historic funding levels, would be very unrealistic), the total cost due to congestion in Texas' seven largest urban areas in 2010 would **still** amount to approximately $3.3 billion in 2010 -- an increase over the existing congestion costs in these areas which were $2.6 billion in 1989.

Summary

In summary, the estimates of congestion presented in this section demonstrate that, even with a significant amount of future investment in roadway lane-miles, the increasing travel demands in Texas' major urban areas will continue to cause congestion to increase substantially in the future, unless the state and local transportation agencies pursue other means by which to address the urban congestion problem. In order to identify what other options exist in addressing this problem, the following chapter consists of a comprehensive review of strategies available for alleviating urban congestion.

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III. STRATEGIES AVAILABLE FOR ALLEVIATING URBAN CONGESTION

As a part of this study, a comprehensive review of strategies for alleviating urban congestion was conducted. The strategies identified as a result of this effort can be grouped into the following five categories: 1) construction/expansion of the transportation system; 2) operational improvements; 3) travel demand management strategies; 4) land-use strategies; and 5) high-tech strategies.

This chapter presents the costs, benefits, and implementation issues associated with strategies falling within the aforementioned categories. While the options available for addressing traffic congestion problems vary widely in terms of their scope, the strategies discussed subsequently are those that are more applicable on an urban-area or corridor-wide basis.

Construction/Expansion of the Transportation System

The strategies identified within the category of construction and/or expansion of the transportation system are summarized in Table 11; these strategies range from the construction of new, and expansion of existing, arterials and freeways to the implementation of rail transit. Also included in this category are low-cost improvements such as reducing freeway lane widths to provide additional lanes and using structurally-upgraded shoulders as additional freeway lanes.

The following discussion highlights the description, costs and benefits, and implementation issues associated with the following commonly constructed facilities: 1) arterials and freeways; 2) toll roads; 3) high-occupancy vehicle (HOV) lanes; and 4) rail lines.

Table 11. Strategies Included Within the Category of Construction/Expansion of the Transportation System

Specific Strategies	Cost[1]	Benefit[2]	B/C Ratio[3]
Construction of:			
- Principal arterials	$1.5 million/lane-mile	Added lane-miles	2-4
- Super arterials	$3-4 million/lane-mile	30-70% more capacity than normal arterial	2-4
- Freeways	$4.5 million/lane-mile	Added lane-miles	2-4
- Toll roads	High	Self-supporting	
- HOV facilities:			
- Barrier-separated	$4-10 million/lane-mile	Added capacity	2-6
- Concurrent/contraflow lanes	$0.5-2 million/lane-mile	Added capacity	2-10
- Arterial HOV lanes	$0.5-2 million/lane-mile	Added capacity	
- Commuter rail	$5-10 million/mile	Added capacity	
- Light rail transit	$30 million/mile	Added capacity	
- Heavy rail transit	$100 million/mile	Added capacity	
Addition of:			
- Principal arterial lane	$0.5-1 million/lane-mile	Added lane-miles	9
- Freeway lane	$2.5 million/lane-mile	Added lane-miles	3
Reducing lane width/using shoulder as a lane	$0.5 million/lane-mile	Added lane-miles	7
Grade-separated arterial intersections	$6 million/intersection	Decreased delay	

[1] Actual cost is shown if available; otherwise, the general magnitude of the cost associated with a strategy is displayed.
[2] At least one, but not necessarily all of the benefits associated with a strategy.
[3] Benefit-to-cost ratios are listed, if the necessary data are available.

Construction of New Facilities

Arterials and Freeways

As illustrated in Chapter 2, the construction of new arterials and freeways alone will not continue to successfully meet the growing travel demands in major Texas urban areas. This does not mean, however, that the continued implementation of such facilities is no longer required. The construction of these facilities can play an important role as part of a comprehensive plan for meeting future travel demands in an urban area. Traffic congestion in many of the larger urban areas has simply become so significant that no single strategy will solve the problem.

A relatively new approach to the construction and/or expansion of arterials is the concept of super-arterials. This approach utilizes the following to enhance arterial mobility: 1) turning lanes/bays at intersections; 2) improved signal timing; 3) control of access, especially in the functional areas of intersections; 4) parking restrictions; and 5) grade separations of pedestrian movements and intersections with other super-arterials or congested arterials. When used continuously along a travel corridor, these features can improve arterial capacity and provide an effective means of support for nearby freeways (1). The specific impacts of these individual super-arterial characteristics will be discussed later in this chapter.

Costs and Benefits. While the cost of constructing new roadways can vary widely due to right-of-way (ROW) costs and numerous other physical constraints, the total cost of new arterials and freeways is approximately $1.5 million per lane-mile and $4.5 million per lane-mile, respectively (2). As indicated in Table 11, these improvements can typically be implemented cost-effectively with benefit-to-cost ratios (B/C) between 2:1 and 4:1. The cost associated with constructing new super-arterials falls between that of freeways and normal arterials and is approximately $3 to 4 million per lane-mile. Benefit-cost analyses of super-arterials have indicated that, even though more expensive than conventional arterials, super-arterials can be a better long-term investment (3).

A primary benefit of new roadways is the reduction in traffic congestion on adjacent roadways due to increased capacity in a travel corridor. Secondary benefits of new major roadways include decreased accident rates and the diversion of through traffic and/or trucks from local streets (4).

Implementation Issues. The newest, and perhaps the most important issue related to the implementation of new roadways in major urban areas is the Clean Air Act Amendments of 1990. These amendments require, among other things, that major urban areas throughout Texas (and the nation) prepare congestion management plans by the mid-1990s aimed at reducing the growth of vehicle emissions and vehicle-miles of travel; this will have a significant impact on the amount of construction and/or expansion of roadways in the future.

An additional issue regarding new roadways is that of latent travel demand (those individuals that desire to use a roadway facility or general route but do not because of the severity of congestion). In travel corridors experiencing significant congestion, this type of demand has led to newly-constructed facilities being filled to capacity shortly after their implementation (5). The end result of such an occurrence is no reduction in traffic congestion. So, while new roadways appear to offer a congestion solution, other actions may also be needed.

Toll Roads

With the onset of greater financial burdens on state and local governments for transportation infrastructure expansions, toll roads are gaining popularity as a means by which to handle growing travel demands. There are currently 28 states operating 36 different toll-road systems in the United States, and 1,300 miles of new toll facility projects are currently in the planning stages (6). Specific examples of these facilities that are currently in operation in Texas include the: 1) Dallas North Tollway; 2) Hardy Toll Road (Houston); and 3) Sam Houston Tollway (Houston).

Costs and Benefits. In one sense, the cost of toll roads is less than conventional highways in that some federal and/or state reviews and regulations can be avoided. For example, a toll facility could be operated such that large trucks are prohibited. A significant amount of money can, therefore, be saved on construction costs since the facility need not be designed to handle heavy vehicles.

The cost of toll facilities in the eyes of the public, however, is sometimes higher than that of conventional roadways. Some commuters/roadway users feel that they are having to pay twice for a service that is supposed to be covered by federal and/or state gas taxes.

The primary benefits of toll facilities are: 1) they provide a means by which to directly charge users for premium travel services; 2) they can usually be completed faster than tax-supported facilities since, if approved, the funding is available up-front and some federal and/or state review processes can be avoided; 3) they offer the potential for congestion management through dynamic toll fees; and 4) the increased attention given to the facilities by toll authorities typically results in an increased level of service as compared to conventional roadways.

Implementation Issues. Toll facilities can meet with political opposition. This opposition is primarily due to the issue of double-taxation and typically comes from organized road-user groups such as automobile and trucking associations. Experience with the successful implementation of toll facilities has led to the following suggested steps (4):

1. Clearly define, in understandable terms, the needs that will be addressed by the facility.
2. Have advanced negotiations with key actors in the policy process (e.g., mayor, legislative leadership, business community, transportation organizations, etc.).
3. Provide opportunities for public input and build support among public groups.
4. Work with the media to get favorable coverage.
5. Establish a credible focal point of overall leadership.

Until recently, one of the major drawbacks of toll facilities had been the delays incurred by users at the toll-collection booths. With the advent of automatic vehicle identification (AVI) systems, however, these and other related problems may be a thing of the past. These systems utilize sensors installed at designated stations along a toll facility to read coded tags (similar to bar codes on grocery merchandise) that are mounted on vehicles. The sensors are linked to computer systems such that roadway users with "tolltags" can set up a pre-paid account that can automatically be debited any time the toll facility is used. These systems have been implemented successfully on many toll projects throughout the U.S., including the Dallas North Tollway.

High-Occupancy Vehicle Facilities

High-occupancy vehicle (HOV) facilities are roadways or lanes dedicated for use by buses, carpools, and vanpools over all or parts (peak travel periods) of the day. The primary goal of these facilities is to increase the person-moving capacity of a congested roadway or travel corridor by providing priority treatments to HOVs.

There are four basic types of HOV facilities:

1. *HOV facilities in separate ROW* - a roadway or lane(s) constructed in a separate ROW and designated for exclusive use by HOVs.

2. *Barrier-separated HOV facility within freeway ROW* - a roadway or lane(s) constructed within the freeway ROW (usually in the freeway median), physically separated from the general-purpose freeway lanes, and designated for the exclusive use of HOVs during at least portions of the day.

3. *Concurrent flow lane* - a lane in the peak direction of flow (typically the inside lane), not barrier-separated from the freeway lanes, and designated for the exclusive use of HOVs during at least portions of the day. These types of lanes are sometimes separated from the adjacent general purpose lane by a 2 to 4-foot buffer, but access/egress is basically continuous.

4. *Contraflow lane* - a lane in the off-peak direction of flow (typically the inside lane) designated for use by HOVs in the peak direction of flow during the peak hours/peak periods of the day. These lanes have historically been separated from the off-peak direction general-purpose lanes by plastic pylons

or posts. Movable concrete barriers have, however, recently been implemented on an I-30E (East R.L. Thornton Freeway) contraflow lane project in Dallas, providing a more definitive separation between opposing lanes of traffic.

As of 1990, 40 different freeway HOV facilities were in operation in 20 North American urban areas, accounting for approximately 332 miles of HOV lanes, as well as additional dedicated lanes operated on arterial streets (7).

Costs and Benefits. As is indicated in Table 11, the cost of HOV facilities depends on the type of facility being implemented. HOV facilities constructed in separate rights-of-way are typically more expensive ($7 to 10 million per lane-mile) than barrier-separated facilities constructed within freeway right-of-way ($4 to 6 million per lane-mile).

Concurrent flow and contraflow lanes are less expensive to construct than HOV lanes that provide permanent physical separation from general-purpose lanes. Concurrent flow facilities typically cost approximately $1 to $2 million per lane-mile to implement, while contraflow lanes cost $0.5 to $1 million per lane-mile. If, however, movable concrete barriers are utilized in conjunction with a contraflow lane, the capital costs might increase to $1 to $1.5 million per lane-mile. Depending upon the amount of ROW required for implementation, arterial HOV lanes typically cost $0.5 to $2 million per lane-mile. Depending upon the length of the facility and the level of enforcement, annual operating costs are normally between $0.2 and $0.5 million.

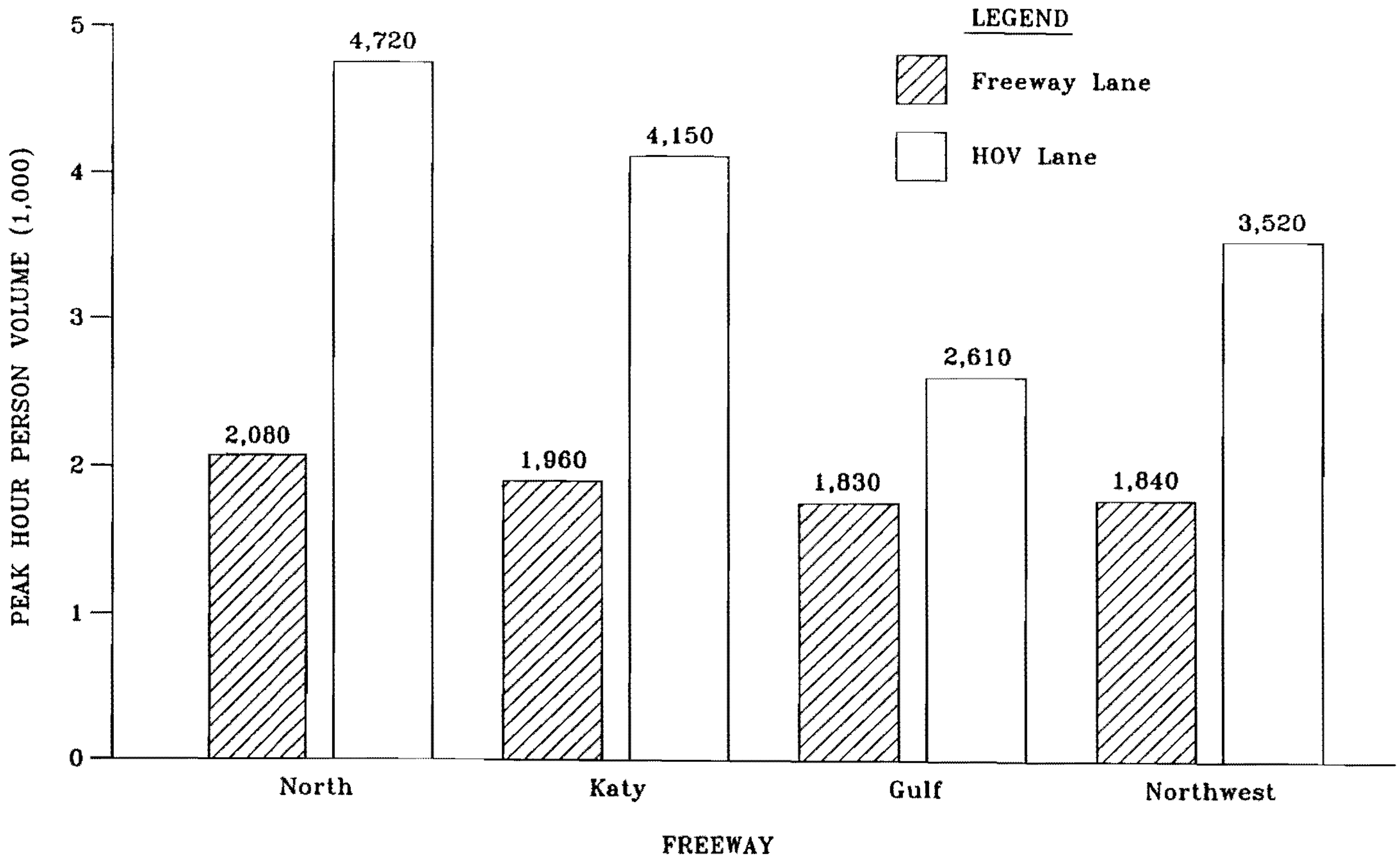
The primary benefits of HOV facilities are the travel-time savings and improved travel-time reliability experienced by their users. Additional benefits of HOV facilities can include: 1) increasing the person-moving capacity of a roadway/corridor; 2) reducing air pollutants and fuel consumption per person-miles of travel (PMT); 3) improving safety in a roadway corridor (decrease in accidents per PMT); 4) improving reliability of bus service; 5) increasing transit's share of corridor commuters; and 6) providing for future growth in travel demand.

The superior person-moving efficiency of HOV lanes, as compared to general-purpose freeway lanes, is illustrated in Figure 19. The North and Katy HOV lanes in Houston (both single lane reversible facilities) provide mobility to more than twice the number of persons than the average adjacent freeway lane. In addition to moving more persons, these particular HOV lanes also provide an average time savings of 10 to 15 minutes during the peak hour.

Implementation Issues. The basic implementation issues associated with HOV facilities can be divided into the three categories of planning, design, and operations. Related to planning is the issue of estimating the demand for an HOV facility. The specific methodology used can vary significantly, but most analyses utilize the results of vehicle occupancy counts or surveys for a roadway or travel corridor.

Support facilities, such as park-and-ride lots and/or additional bus terminals, should also be considered during the planning and/or design phases of HOV facility implementation. Support facilities are highly recommended as they can contribute greatly to the utilization and overall success of an HOV facility.

The selection of an appropriate minimum vehicle occupancy requirement is also a key aspect of HOV facility implementation. Specific issues associated with the selection of a minimum occupancy requirement include: 1) maintaining free-flow conditions on the HOV facility to ensure reliable travel times for HOVs and 2) maintaining an HOV volume high enough to make the HOV facility appear well utilized. In order to accomplish both of these objectives, the minimum occupancy requirement must sometimes be adjusted according to site-specific travel demands. Both increases in and reductions of minimum-occupancy requirements have been successfully implemented for HOV facilities. The most important factor in maintaining desirable operations on an HOV facility is the enforcement of whatever minimum-occupancy requirement is chosen for a facility.



Source: Texas Transportation Institute, "The High-Occupancy Vehicle Facility System: Houston, Texas," Metropolitan Transit Authority of Harris County and Texas State Department of Highways and Public Transportation, 1991.

Figure 19. Peak-Hour Persons on HOV Lanes vs. General-Purpose Lanes, Houston Freeways

It is important to note that HOV facilities are not always an appropriate choice for reducing congestion. Furthermore, eliminating an existing general-purpose lane in order to provide an HOV facility should be avoided if possible.

Rail Transit

Rail transit can be subdivided into the categories of: 1) commuter rail; 2) light rail; and 3) heavy rail.

Commuter rail can generally be defined as single or multiple-car passenger trains operating on mainline rail lines. This type of rail transit service typically operates between central business districts (CBDs) and major suburban residential areas and utilizes existing rail lines.

Light rail transit (LRT) can generally be defined as a medium-capacity (passenger capacities of 2,000 to 20,000 per hour) rail transit service that is characterized by low-level platform loading (passengers must take steps up into the train to reach their seats) and manual operation. Light rail can be operated on either grade-separated or barrier-separated ROW and in mixed traffic on city streets (4).

Heavy rail transit, otherwise referred to as rapid rail transit, can be defined as a high-capacity (passenger capacities of 20,000-40,000 per hour) rail transit service that is characterized by high-level platform loading (passengers enter the train at the same level as the vehicle floor), rapid acceleration, third-rail electric power supply, and a high degree of automation. Heavy rail systems are operated in exclusive ROW with no crossing traffic (4).

Costs and Benefits. Rail transit service is, in general, a costly measure for reducing traffic congestion. Commuter rail service is typically the least costly of the rail services described previously; commuter rail utilizes existing tracks, so the only costs involved are those associated with obtaining locomotives and passenger cars, and conducting operations and maintenance activities (i.e., upgrading tracks, signals, stations, etc.).

Light rail, while typically more expensive to implement than commuter rail, is becoming a popular transportation system improvement in many urban areas. For newer cities with lower population densities, LRT offers an upscale transit option to increase travel corridor capacity at a cost which is normally significantly less than heavy rail transit.

While heavy rail lines require the greatest amount of capital investment, the benefits of successful heavy rail transit systems can be quite significant. The primary benefits of rail transit include: 1) the ability to move a large number of persons; 2) the improvement of air quality through the reduction of exhaust emissions; and 3) a more efficient utilization of energy resources.

Additional long-term benefits of rail transit are the economic growth and high-density land development that can occur adjacent to rail lines with the proper encouragement of parking and land use controls. While these are recognized impacts of rail transit, these types of benefits are not readily quantifiable. Some potential long-term benefits of rail transit are, therefore, sometimes not included in typical benefit-cost analyses.

Implementation Issues. One of the keys to the successful implementation of a rail line/system is that the transit service be designed for the density of population, employment, and/or commercial development in the areas it serves; density of development adjacent to the rail line will directly impact the extent to which the service is utilized. Historically, rail transit has, thus, been more common in higher-density areas such as the large urban areas in the northeastern United States.

With the onset of regulations regarding the reduction in vehicle emissions in many areas throughout the nation, the implementation of rail transit as a means for providing additional mobility without increasing vehicle-miles of travel (VMT) is being considered in many lower-density urban areas, including Austin, Dallas, Fort Worth, Houston, and San Antonio.

Support facilities and/or service (i.e., park-and-ride lots, bus service to and from rail stations, etc.) that provide added convenience and/or travel time benefits can enhance the utilization of rail transit facilities. Such treatments are especially important in lower density areas where a significant amount of ridership cannot be induced from the areas immediately adjacent to the rail line.

Expansion of Existing System

The following discussion highlights the description, costs and benefits, and implementation issues associated with the following forms of expanding the transportation system: 1) the addition of freeway and principal arterial lanes; 2) the reduction of freeway lane widths and using the shoulder to provide an extra lane; 3) grade-separating arterial intersections; and 4) adding turning lanes/bays at arterial intersections.

Addition of Freeway/Principal Arterial Lanes

In conjunction with the construction of new facilities, the addition of freeway and principal arterial lanes has historically been the most common means by which to address increasing traffic congestion. Travel demands in many major urban areas have, however, reached the point that adding physical roadway capacity will no longer solve the traffic congestion problem.

Costs and Benefits. Similar to the construction of new roadways, the costs of adding lanes to freeways and principal arterials can vary widely due to ROW and other costs. The total costs of freeway and principal arterial lane additions are typically on the order of $2.5 million per lane-mile and $0.5 to $1 million per lane-mile, respectively (2). As indicated in Table 11, the B/C ratios for the addition of roadway lane-miles can be well above 1.0. The higher B/C ratio for the addition of principal arterial lane-miles, as opposed to the construction of new arterials, is attributable to the fact that the benefits are similar in magnitude while the costs are significantly lower for adding capacity to an existing roadway.

The primary benefit of adding lanes to existing roadways is the reduction in traffic congestion on the existing facility. A secondary benefit which normally follows from decreased congestion is a decrease in the accident rate on the facility.

Implementation Issues. Similar to the construction of new roadways, the impact of the Clean Air Act Amendments of 1990 on roadway expansion should be significant in the future. Even in urban areas that will simply be required to show a decrease in the growth rate of VMT and/or vehicle emissions (as opposed to an actual decrease in existing levels of VMT and vehicle emissions), the question of whether additional lanes of capacity should be general-purpose lanes or designated for use by HOVs (in order to decrease the growth in VMT) will likely be raised.

As mentioned previously, latent travel demand can also have a significant impact in heavily congested travel corridors. This type of phenomenon has been known to occur on expanded roadways in addition to new facilities (5).

Reducing Lane Width/Using Shoulder As A Lane

In an attempt to cost-effectively address increasing traffic congestion on freeways, some urban areas have upgraded the structural integrity of the inside shoulder and restriped the mainlanes (reducing their width) to provide an extra lane of capacity. An example of how this has typically been accomplished is shown in Figure 20.

By reducing the mainlane widths by one foot (from 12 feet to 11 feet) and leaving a three foot lateral clearance for the inside lane, a four-lane freeway with two ten-foot shoulders can be transformed into a five-lane freeway with a full ten-foot outside shoulder (Figure 20). While the number of freeway lanes involved and before-and-after width

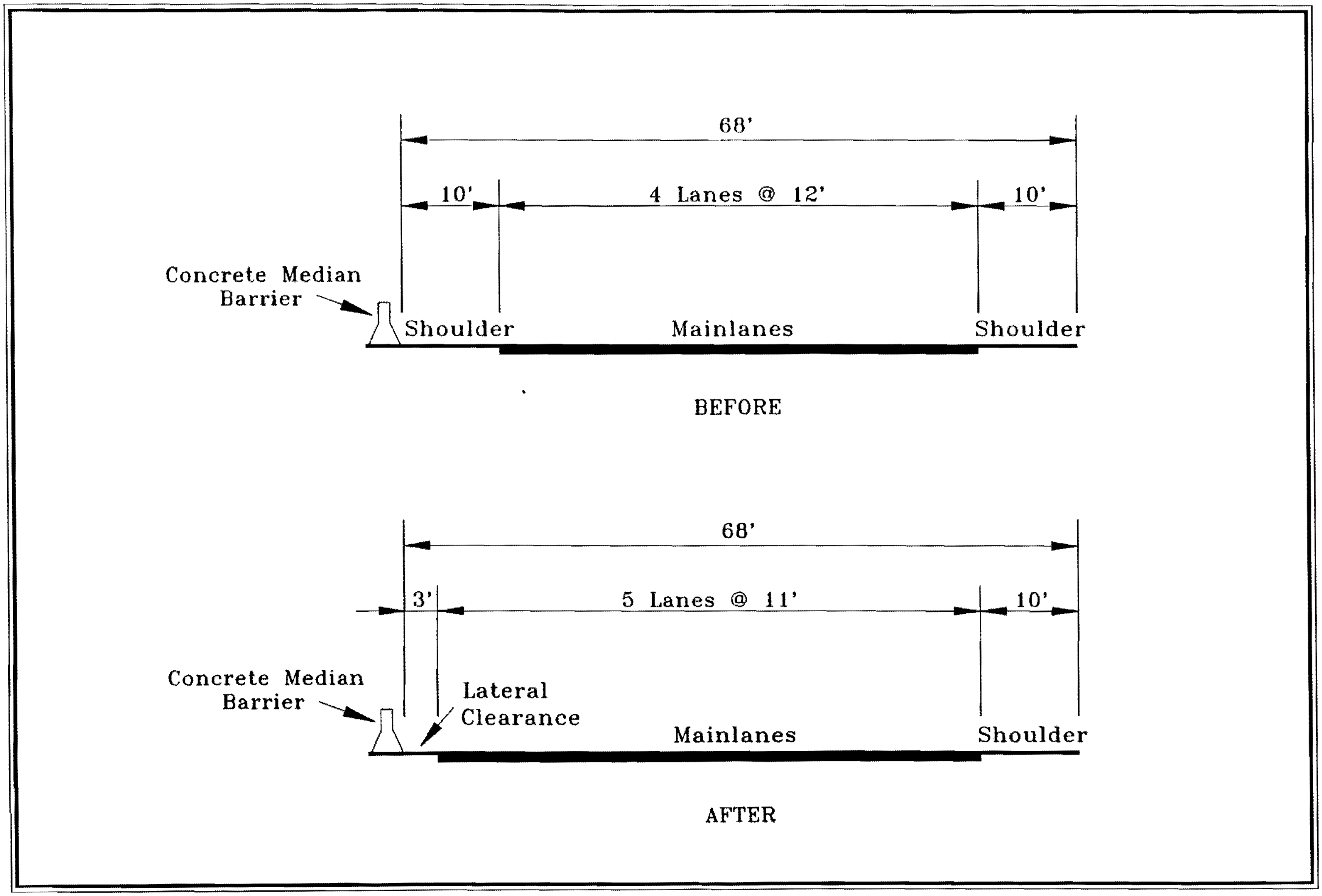


Figure 20. Cross-Sections Illustrating the Reduction of Lane Widths and the Use of the Inside Shoulder As An Additional Lane

combinations may change for site-specific conditions, this discussion illustrates the basic concept associated with this procedure.

Costs and Benefits. The cost associated with the restriping described previously is typically on the range of $0.5 million per lane-mile. The bulk of the costs are those associated with upgrading the structural integrity of the shoulder being used for general purpose travel.

A recent study of inside shoulder removals and the addition of a freeway lane indicated that, for the study sites examined, accident rates either showed no significant change or reduced significantly (8). This study examined twelve different sites in California and suggests that the decreased accident rates were attributable to decreased traffic congestion.

As is the case with conventional lane additions, the primary benefit of this approach is added capacity and, thus, a reduction in congestion and the accident rate for the freeway mainlanes. The combination of these benefits and a relatively low implementation cost produces a treatment that is typically very cost effective (Table 11). This approach is especially effective in areas where geometric bottlenecks occur and the procurement of additional ROW is not feasible.

Implementation Issues. In addition to the issues cited previously related to the construction and expansion of roadways (i.e., environmental concerns, latent demand, etc.), this particular approach may not be approved by the Federal Highway Administration (FHWA). The long-term removal of an existing shoulder is not currently consistent with design standards. This approach is usually a short-term improvement and is typically scheduled to be replaced by a superior design with both inside and outside shoulders and full (12-foot) lane widths.

In general, it is recommended that any pavement located between the travel lanes and the edge of the roadway (on the inside or outside) be either less than 4 feet or greater than 8 feet. If a paved area of 4 to 8 feet (a partial shoulder) is provided adjacent to the travel lanes, it will be attractive enough to a motorist in trouble to induce the motorist to use this area as a refuge. An area of 4 to 8 feet is, however, inadequate and will likely create more operational problems and a greater potential for serious injury to motorists than if there had merely been a 1 to 3-foot lateral clearance (8).

Grade-Separating Arterial Intersections

A treatment used for increasing the capacity of intersecting arterials is the implementation of a physical grade separation between the two roadways. In general, arterial grade-separations are considered when arterial traffic from one or more approaches to an intersection can no longer be accommodated by the maximum green time allocated by a traffic signal.

Typical grade-separation designs for arterials are illustrated in Figures 21 and 22 (9). A variation of the diamond interchange design (Figure 21) is to provide flyover ramps for the through movements of one of the arterials.

Costs and Benefits. While the costs associated with arterial grade-separations can vary widely, the implementation of an arterial diamond interchange such as the one shown in Figure 21 would cost approximately $6 million. In general, the cost of implementing flyover ramps is slightly less than that of a diamond interchange (10).

Depending upon the magnitude of the delays that were present prior to an interchange's construction, the benefits can be quite significant (Table 11); the primary benefit being the decreased total delay at the intersection. Data collected for arterial flyover ramps indicate that their implementation can produce increases in capacity of 100% to 300% (4).

Implementation Issues. If the traffic volume on one arterial is significantly higher than the other arterial, a diamond interchange (Figure 21) can ordinarily be designed to

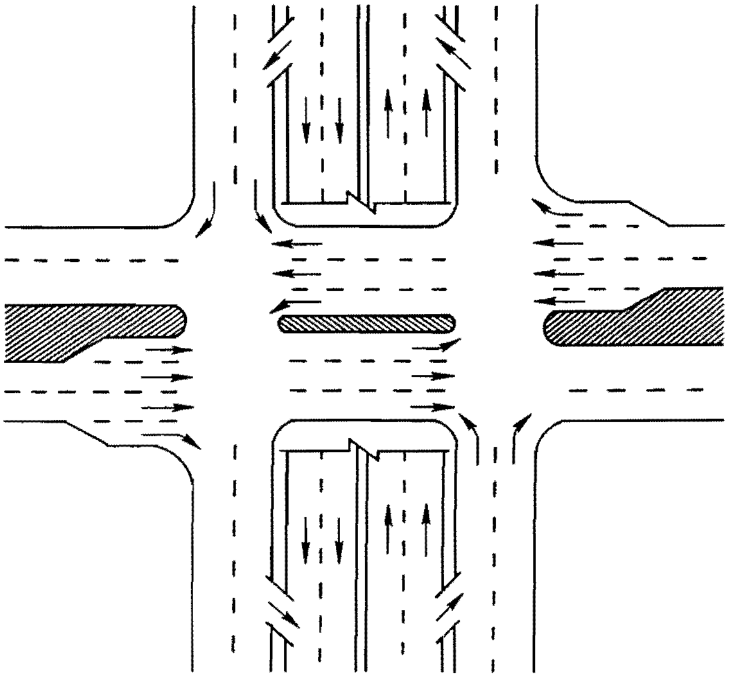


Figure 21. Typical Diamond Interchange Geometrics

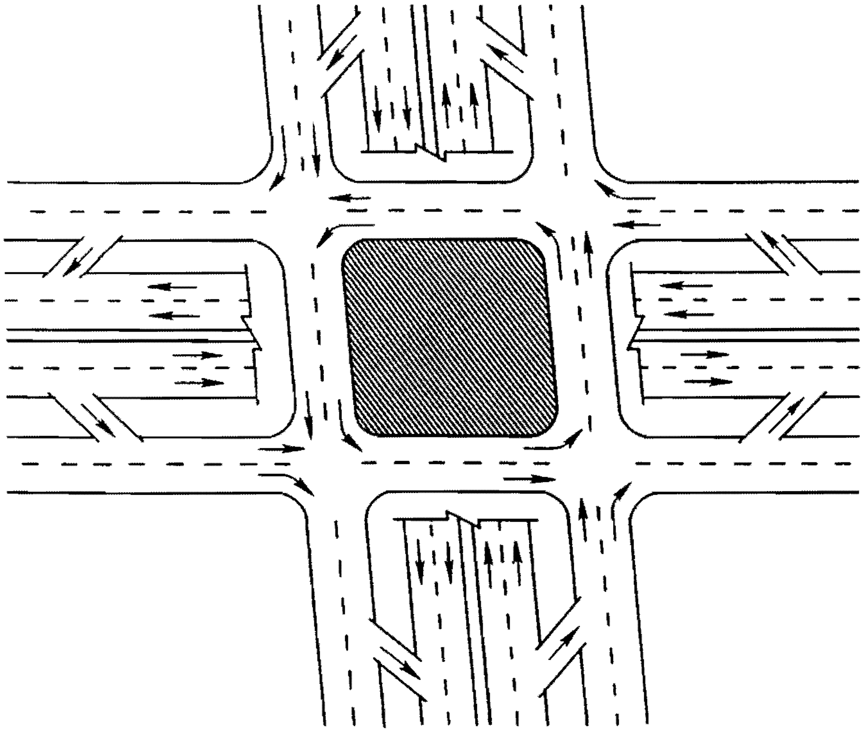


Figure 22. Typical Three-Level Diamond Interchange Geometrics

provide sufficient signal capacity to handle the non-grade separated (at-grade) through movement. However, if the volumes on both arterials are high, and the at-grade through traffic is experiencing significant delays, then a three-level interchange (Figure 22) may be needed.

The following are important criteria that indicate when an arterial grade separation may be warranted (4):

1) The intersection is congested and capacity problems cannot be resolved using conventional traffic engineering methods (i.e., signal-timing improvements, adding turning lanes/bays, etc.).
2) The roadway is at least four lanes wide (both directions combined) and maximum use of the ROW has been made.
3) Obtaining additional ROW is not feasible and a minimum ROW width of 100 feet is available.
4) The accident rate at the candidate intersection is significantly larger than nearby intersections along the same arterial(s).
5) Adjacent property will not be severely impacted.

Operational Improvements

The strategies identified within the category of operational improvements to the transportation system are summarized in Table 12; these strategies range from simple ramp-metering and signal-timing improvements to complex, area-wide surveillance, communication, and control (SC&C) systems.

Table 12. Strategies Included Within the Category of Operational Improvements

Specific Strategies	Cost[1]	Benefit[2]	B/C Ratio[3]
Ramp metering	Low to medium	Increased capacity	
Surveillance, communication and control (SC&C) system	$1 million/mile	Up to 30% increase in capacity	12
Accident investigation sites	Low	Decreased delay	28
Traffic management teams	Low	Coordinated actions	15
Signal-timing optimization	Low	Decreased delay	16
Signal interconnection/ optimization	Medium	Decreased delay	10

[1] Actual cost is shown if available; otherwise, the general magnitude of the cost associated with a strategy is displayed.
[2] One, but not necessarily all of the benefits associated with a strategy.
[3] Benefit-to-cost ratios are listed, if the necessary data are available.

The following discussions highlight the description, costs and benefits, and implementation issues associated with the following individual strategies for alleviating congestion: 1) ramp metering; 2) SC&C systems; 3) accident investigation sites; 4) signal-timing optimization; and 5) signal interconnection and optimization.

Ramp Metering

Ramp metering consists of a modified traffic signal being placed at the end of a freeway entrance ramp. The signal is operated such that it permits traffic to enter the freeway at either pre-timed intervals or times determined by the traffic volume on the ramp and/or freeway (traffic-responsive ramp metering).

Traffic-responsive ramp metering utilizes loop detectors located on the freeway mainlanes and on entrance ramps, in addition to either a local or central computer to determine when vehicles should be allowed to enter the freeway. While ramp metering is normally used for the entrance of general-purpose traffic to the freeway, this approach can also be used in conjunction with an HOV bypass lane at an entrance ramp to provide an incentive for carpool, vanpool, and bus ridership. This approach is illustrated in Figure 23.

Costs and Benefits

Compared to many other strategies for decreasing traffic congestion, ramp metering is relatively low in cost. The typical cost associated with a traffic-responsive ramp meter is approximately $50,000 per unit (11).

Traffic-responsive ramp meters are more expensive than pre-timed ramp meters. Traffic-responsive ramp meters, however, are effective over a wider range of traffic conditions and typically produce benefits that are 5 to 10 percent greater than pre-timed meters (4).

The primary benefits of ramp metering are increased speeds and volumes (capacity) on the freeway mainlanes. Experience in California and Texas indicates that speed increases of up to 30 percent and peak-period volume increases of 10 to 20 percent can result from ramp-metering systems. An additional benefit of ramp metering is a decrease in accident rates; reductions of 20 to 60 percent have been achieved through improved merging operations (4).

Implementation Issues

Ideally, ramp metering should be implemented as part of an areawide freeway management program. However, if this approach is not feasible and ramp meters are planned for installation at selected individual ramps, careful consideration should be given to their location. For instance, if installed in the vicinity of an already congested arterial, a ramp meter could cause traffic to divert from the freeway to the congested arterial. While freeway operations would benefit from the ramp metering, the disbenefits created on the adjacent arterial could be significant enough to negate any benefits gained on the freeway.

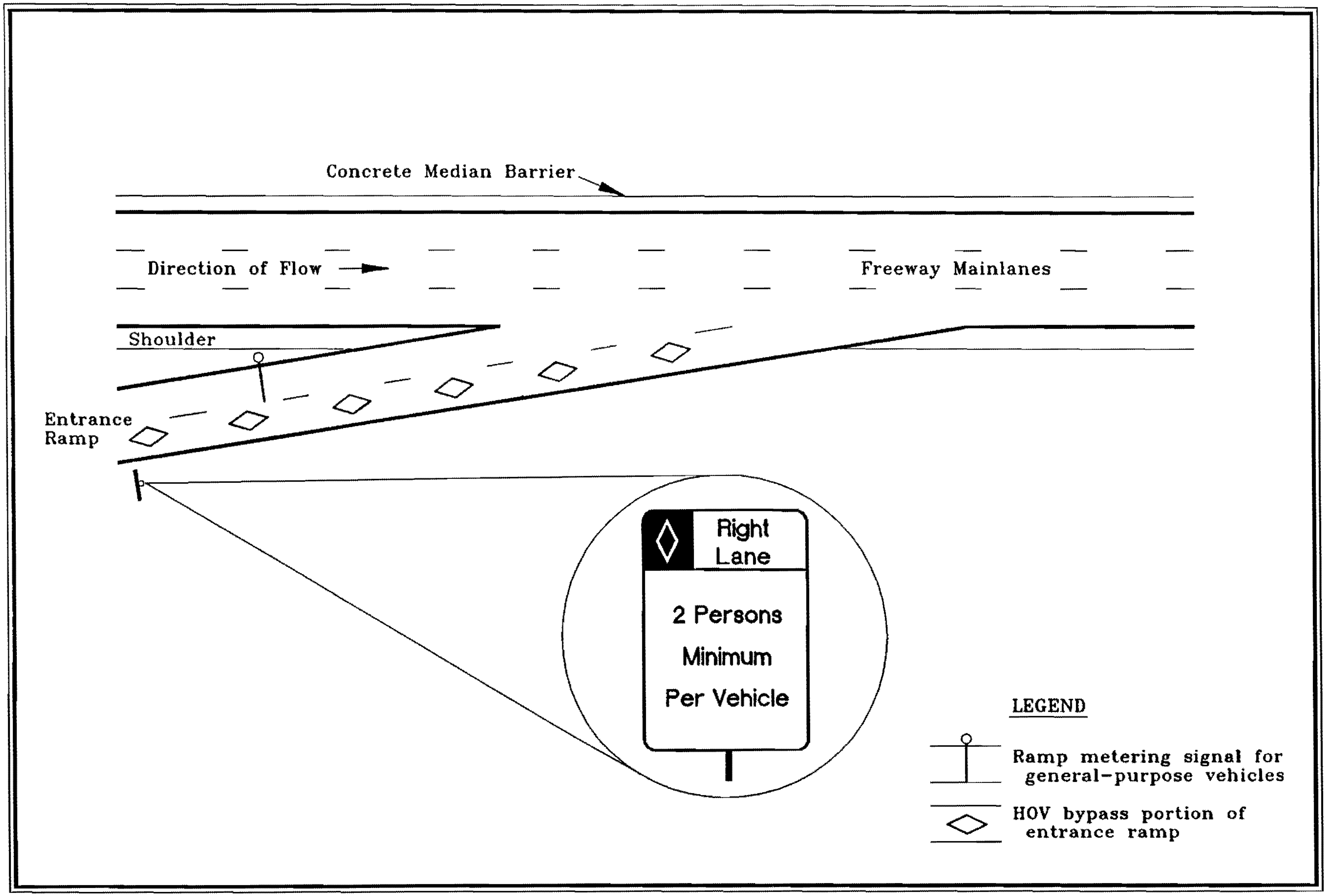


Figure 23. Example of Ramp Metering Applied In Conjunction With An HOV Bypass Lane

It is also possible that the delays created by a ramp meter could create a queue that could adversely impact the operations of a frontage road or nearby signalized intersection. Comprehensive advanced planning is, therefore, recommended prior to implementing ramp meters. Enforcement of ramp metering applications is also typically difficult, thus, requiring special consideration.

Surveillance, Communication, and Control Systems

The goal of surveillance, communication, and control (SC&C) systems is to reduce the detrimental impacts of non-recurring congestion. These systems consist of four major components: 1) a surveillance system to monitor the traffic operations on the freeway(s) and/or arterials and identify when and where problems occur; 2) ramp meters (as described previously) to control the number of vehicles entering the freeway; 3) an incident management program to quickly and effectively respond to, manage the impacts of, and clear major and minor incidents; and 4) an information system to notify motorists of the location and approximate duration of traffic delays and alternate routes to avoid these delays.

Conventional SC&C systems include most, if not all, of the following elements.

1. A system of electronic loop detectors
2. Closed circuit televisions
3. Call boxes
4. Courtesy patrol units
5. Ramp metering equipment
6. An incident management team
7. Accident investigation sites
8. Changeable message signs/lane use signals
9. Highway advisory radio (HAR)
10. Centrally located, computerized control center

Many of these specific elements that constitute SC&C systems can be applied individually (e.g., the ramp metering approaches discussed in the previous section). The following discussion, however, focuses on the costs and benefits of entire SC&C systems.

Costs and Benefits

Experience in areas throughout the nation has indicated that an SC&C system consisting of the elements outlined previously would cost approximately $1 million per lane-mile to implement and $100,000 per year per corridor to maintain and operate (12). In Texas urban areas, SC&C systems are being installed in conjunction with freeway reconstruction/expansion projects. This approach has been shown to reduce the costs of the SC&C systems to approximately $0.5 million per lane-mile.

A benefit of SC&C systems is the reduction in the duration of congestion due to incidents. Accident rates and severity are also typically reduced as a result of SC&C system implementation. These systems are estimated to increase average freeway vehicle throughput by 12 to 20 percent and produce B/C ratios of appoximately 12:1 (13).

Implementation Issues

The primary implementation issues associated with SC&C systems are funding and coordination. While SC&C systems can be expensive to implement on an area or corridor-wide basis, the benefits of these systems far outweigh their cost.

Appoximately 50 percent of all freeway traffic congestion/delay in major urban areas is attributable to non-recurring congestion. If the congestion in an urban area is to be effectively reduced, an SC&C system of some kind should be implemented; otherwise, half of the congestion problem may not be effectively addressed.

Perhaps the most important aspect of any SC&C system is coordination. An SC&C system cannot be expected to operate effectively without the formation of some type of traffic management team. The communication and cooperation between these individuals helps to address an urban area's congestion problems by more effectively responding to incidents and informing motorists of routes with available capacity to make more efficient use of the existing transportation system.

Due to funding limitations, complex, areawide SC&C systems might not always be feasible. As alluded to previously, however, many elements common to SC&C systems can be applied individually as well. For instance, accident investigation sites and traffic management teams are highly cost-effective and can be implemented on an areawide basis at a minimal cost.

Accident Investigation Sites

Accident investigation sites (AISs) are specially designated and signed areas located off the freeway where damaged vehicles can be moved following an accident. These designated areas allow motorists to exchange information and police officers to complete necessary accident forms. These sites are typically located in areas that cannot be seen by freeway drivers; this reduces "rubbernecking" which is a major cause of congestion at freeway accident scenes (14).

Costs and Benefits

Accident investigation sites are typically located in areas that already exist. Therefore, the only costs involved with these sites are those associated with supplemental signing and maintenance. As a result, the cost associated with implementing an AIS is minimal.

The primary benefits of AISs are reductions in delay due to "rubbernecking" and the reduction of secondary accidents. Compared to the cost of AISs, the benefits can be quite significant. Studies in Houston have indicated that B/C ratios of 28:1 can be expected for AISs (14).

Implementation Issues

Key issues associated with the implementation of AISs include: 1) location; 2) design; and 3) public/police awareness. The most desirable location of an AIS is within one block of a freeway exit ramp terminus. Examples of desirable AIS locations are shown in Figures 24 and 25. Basic design requirements of AISs include that they be paved, illuminated, and equipped with some form of telephone communications. In addition, an AIS should have space for parking a minimum of five vehicles (one police car, two damaged vehicles and two wreckers). Additional space is desirable to accommodate multivehicle accidents (14).

Even if designed properly, an AIS will likely be used infrequently unless both the public and local police force are made aware of AISs and their potential benefits. Since freeway patrol officers are essential to the successful use of AISs, local police should be involved in the location and design process. Properly informing the public can be accomplished through supplemental signing and public awareness/advertising campaigns.

Traffic Management Teams

The State of Texas is an example of the success of traffic management teams. Since the inception of the "team" concept in 1975, the popularity of this approach has grown to the point that there are currently 12 "teams" operating in Texas. These "teams" typically bring together professionals from various traffic-related agencies in an urban area and focus on planning to avoid and/or properly react to the following: 1) accidents; 2) chemical spills; 3) special entertainment-related events; 4) weather; 5) construction projects; and 6) maintenance operations. This "team" concept can also be used to produce the organized application of the travel demand management strategies that will be discussed later in this chapter.

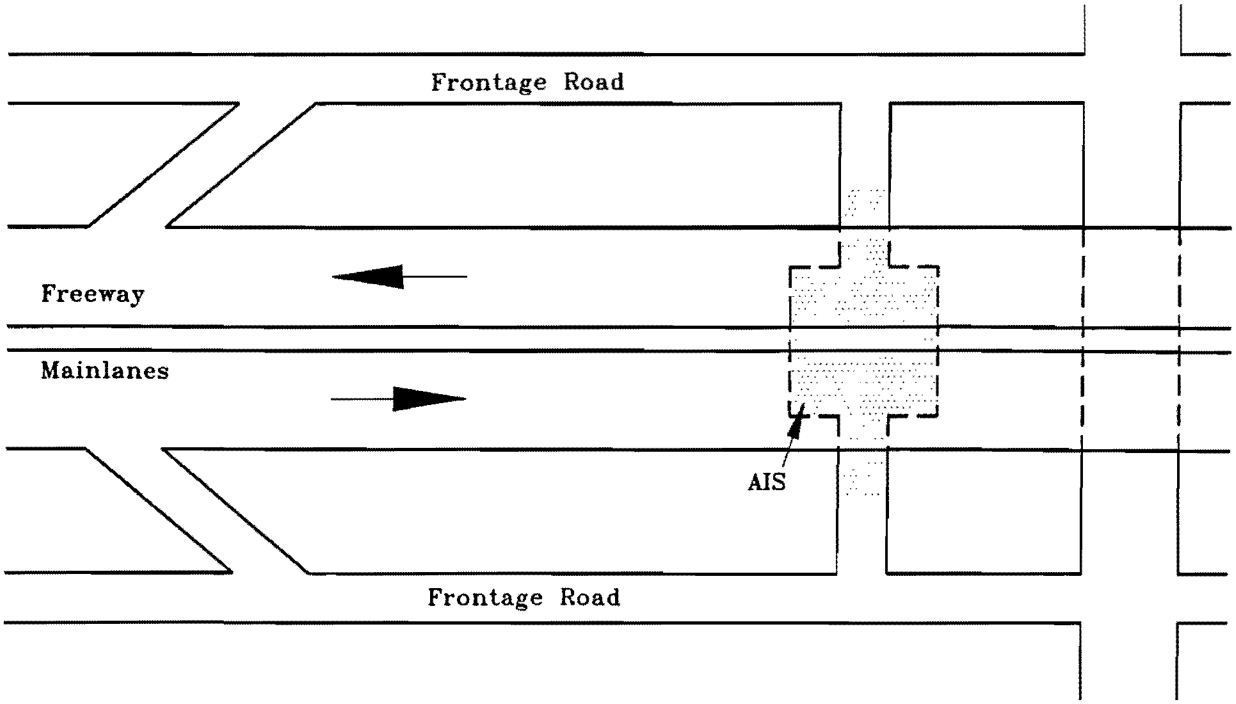


Figure 24. AIS Located Under A Freeway Overpass

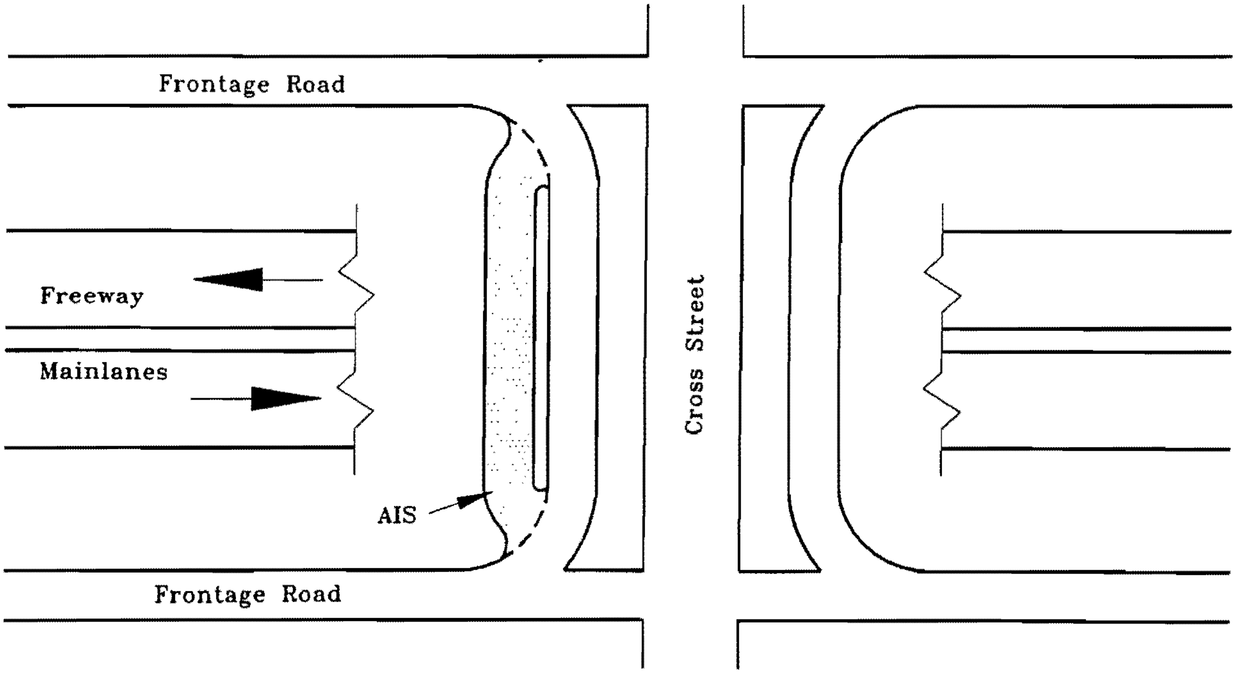


Figure 25. AIS Combined With A U-Turn Roadway

Costs and Benefits

The primary costs of implementing this approach are those associated with the time of key employees to participate in "team" meetings. Benefits can, however, be substantial. A study in Texas has shown that the B/C ratio for "team" activities is commonly in the range of 15:1 (4).

Implementation Issues

The success of a traffic management team depends on having the representation of as many key transportation-related agencies as possible. It is difficult to say specifically which agencies should be represented, since urban areas have varying numbers of transportation agencies. As a minimum, however, most "teams" include representatives from the city and state traffic engineering offices, city and state law enforcement agencies, and the local transit authority.

Signal-Timing Optimization

Signal-timing optimization involves the adjustment of traffic signal timing to more efficiently serve travel demands. Depending upon the approach used, this optimization process can be aimed at minimizing either vehicle delay or the number of stops occurring at an intersection. While the general concept of signal-timing optimization can be applied to all types of traffic signal control, the following discussion focuses on the costs and benefits of optimizing the timing plans for isolated/uncoordinated signalized intersections.

Costs and Benefits

In general, traffic signal system improvements rank as one of the most cost-effective means for decreasing travel delays on a roadway system. Signal-timing plan optimization is the most cost-effective type of traffic signal system improvement. This is primarily due to the fact that the annual costs to optimize isolated/uncoordinated signals are only about

$500 per intersection (15). For minimal additional costs, signal-timing optimization could be used on a series of arterial intersections to create a condition of time-based coordination between the intersections. The costs associated with various signal system improvements are included in Table 13. It should be noted that the costs shown in Table 13 are in 1980 dollars.

Table 13. Summary of Annual Costs of Various Traffic Signal System Improvements[1]

Traffic Control Improvement	Implementation Cost per Signal ($)	Approximate Annual Cost per Signal ($)		
		Equivalent Capital Outlay[1]	Operations and Maintenance[2]	Total
Optimize previously interconnected signals	---	---	300-400	300-400
Interconnect and optimize	2,000-10,000	260-1,300	500-1,400	760-2,700
Advanced computer-based master control (including interconnection and optimization)	5,000-13,000	760-1,800	1,100-2,000	1,860-3,800
Approximate marginal cost of advanced computer-based master control	3,000	500	600	1,100

[1] Equivalent annual capital outlay computed using 10 percent interest and 15 year life for interconnect, 10 year life for marginal costs of advanced master control.

[2] Annual operations and maintenance cost = 10 percent of capital cost for interconnect plus 20 percent of marginal capital costs for advanced control. Optimization cost included in all cases.

Source: Reference 14

Compared to the costs of signal-timing optimization, the benefits are significantly greater in magnitude. In fact, B/C ratios of over 100:1 for congested, uncoordinated intersections are not uncommon. In general, however, B/C ratios are typically in the range of 16:1 (Table 12).

Implementation Issues

As with most transportation system improvements, the possible impacts of latent demand (induced travel) on arterials that have had signal-timing improvements is something to consider. Based on the following considerations, however, it is believed that traffic signal system improvements will not tend to be a significant cause of induced travel:

1. In a comprehensive program, one would not improve a single arterial in a corridor and do nothing with parallel facilities.
2. Signal improvements typically result in only minor capacity improvement on a facility.
3. Signal improvements do not enhance the accessibility of outer suburban reaches dramatically as do some major highway projects.

Signal Interconnection/Optimization

In order to improve traffic operations on major arterials, traffic signals at different intersections are often physically interconnected through the use of fiberoptic cables, etc. This interconnection effectively allows signals to communicate with one another and operate more efficiently as a system of signalized intersections. When a series of intersections along an arterial is interconnected, the intersections are referred to as locally coordinated signals. Likewise, when an entire network of arterials is interconnected and controlled by a master computer, the intersections are said to be centrally coordinated.

Costs and Benefits

While the cost of interconnecting signalized intersections exceeds that of optimizing signal-timing plans, the benefits that can be achieved through this approach are also greater. The B/C ratios of signalized-intersection interconnection projects are typically in the range of 10:1 (Table 12).

The magnitude of the benefits to be achieved are, however, a function of the intersection's existing conditions. For instance, if a series of uncoordinated intersections with old timing plans were interconnected and their timing plans optimized, the benefits would be much greater than had a series of intersections with time-based coordination (no interconnection) and actively updated timing plans been interconnected. Examples of the magnitude of benefits expected for varying degrees of improvement are illustrated in Figure 26 (16).

Implementation Issues

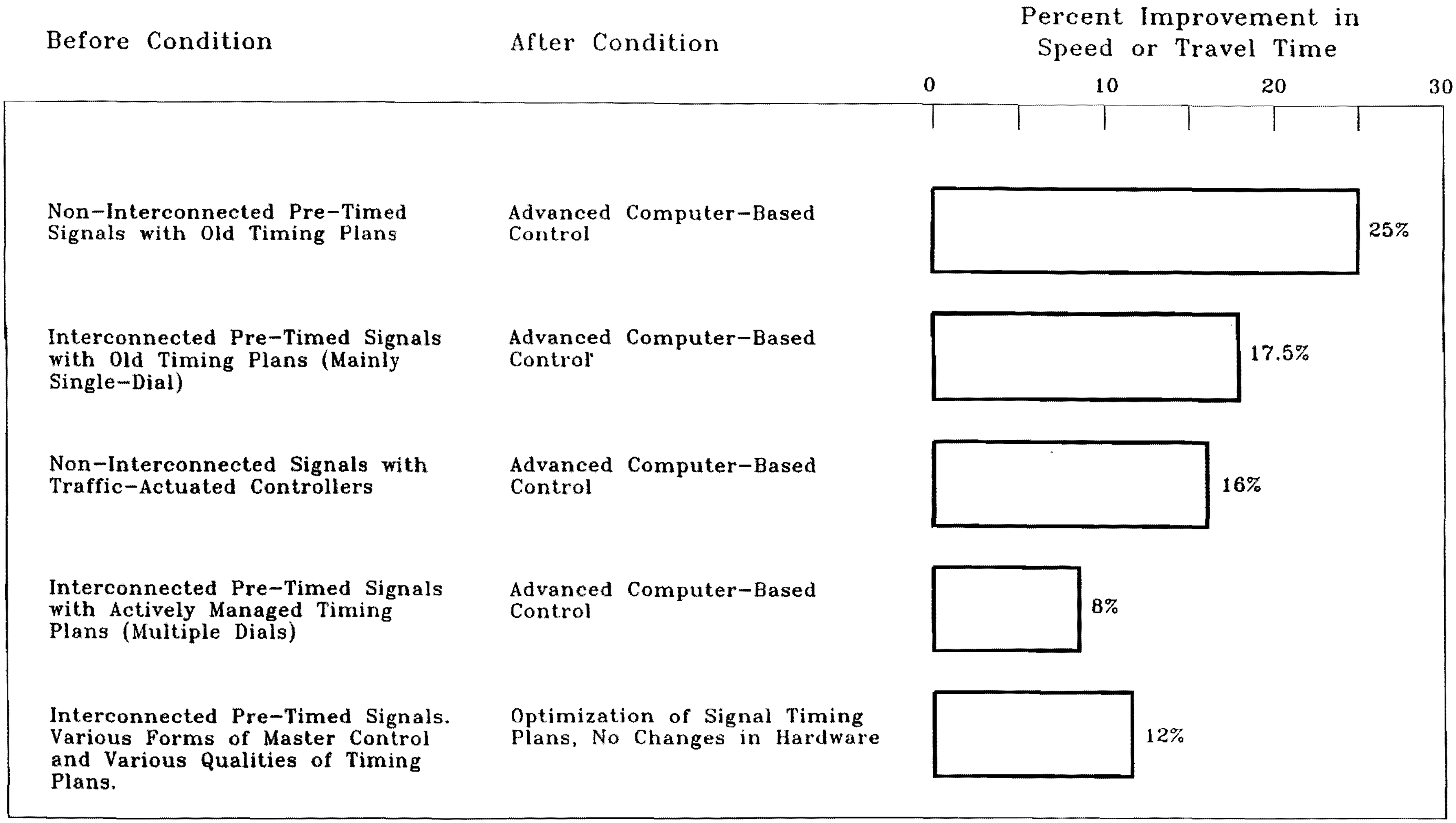
The same implementation issues cited previously for signal-timing optimization apply to signal interconnection/optimization.

Travel Demand Management

Strategies identified within the category of travel demand management (TDM) are summarized in Table 14. The strategies included in this category range from carpool/vanpool programs to telecommunications. The following discussions highlight the description, costs and benefits, and implementation issues associated with the individual strategies included in Table 14.

Carpooling/Vanpooling Programs

Carpool/vanpool programs, generally referred to as ridesharing programs, are a key element of any comprehensive demand management application. This strategy is geared towards increasing average vehicle occupancy during peak travel periods, thereby, decreasing VMT.



Source: Reference 15

Figure 26. Comparative Impacts of Traffic Signal System Improvements

Table 14. Strategies Included in the Category of Travel Demand Management

Specific Strategies	Cost[1]	Benefit[2]	B/C Ratio[3]
Carpooling/Vanpooling programs	Low	Decreased VMT	
Parking management/pricing	Low	Decreased delay	
Alternate work hours	Low	Decreased VMT	
Express bus service	Low to Medium	Added Capacity	
Telecommuting	Low	Decreased VMT	20

[1] General magnitude of the cost associated with a strategy
[2] One, but not necessarily all of the benefits associated with a strategy
[3] Benefit-to-cost ratios are listed, if the necessary data are available

Carpooling normally involves the use of an employee's private vehicle to provide one or more fellow employees with a ride to work. This activity can involve either one driver who is compensated for expenses by riders in the carpool, or individuals in the carpool group taking turns driving so that the expenses of driving are distributed evenly.

There are three basic types of vanpool programs: 1) company-sponsored; 2) third-party; and 3) owner-operated. Company-sponsored programs consist of employers buying or leasing vans and administering the program. With third-party programs, a ridesharing agency provides a vanpool service. Owner-operated programs are the sole responsibility of the owner/driver. As will be discussed in more detail subsequently, owner-operated programs can be supported or subsidized by employers.

Costs and Benefits

The costs of carpool/vanpool programs to the general public are typically non-existent, as comprehensive programs of any size are normally financially supported by employers and/or local ridesharing agencies. The benefits of these programs include reductions in: 1) commuting costs to program participants; 2) energy consumption per passenger; 3) traffic congestion through decreased VMT; 4) parking space demand; and 5) air pollution/vehicle emissions. An example of potential commuting cost savings is shown in Table 15. Assuming an average daily commute of 30 miles, the values shown in Table 15 indicate that a commuter participating in a 3-person carpool could save $1,320 per year.

Table 15. Monthly Commuting Costs for Varying Degrees of Ridesharing and Commuting Distance

Distance of Commute[1]	Total Cost of Commute ($) Based On Indicated Level of Ridesharing		
	Driving Alone	3-Person Carpool	Vanpool (13 Riders)
30 miles	$165	$55	$45
50 miles	231	77	52
70 miles	300	100	60
90 miles	366	122	67

[1] Distance of daily round-trip commute

Source: Reference 4

While the most quantifiable benefits of carpool/vanpool programs are experienced by commuters, employers also achieve benefits by encouraging and/or subsidizing these programs. The most visible benefit to employers is the cost savings due to the reduced need for employee parking spaces. In addition, carpool/vanpool programs have been shown to improve employee morale, reduce absenteeism and tardiness, and improve public image (4).

As has historically been the case with TDM measures in general, the evaluation of carpool/vanpool programs has been limited largely to assessing the impacts of individual programs on local traffic. While many of these localized assessments have indicated significant increases in average vehicle occupancy and other various benefits, a recent study assessing the areawide impacts of comprehensive TDM measures in Southern California indicated that a reduction in areawide VMT of only 3 to 4 percent could be expected (17). Although this particular study suggests that TDM measures will, by no means, single-handedly solve traffic congestion problems, TDM applications can be considered one source of improvement. It should be noted that this same report points out that very little data exist for assessing the areawide impact of TDM applications and more research is needed in this area (16).

Implementation Issues

The key to a successful carpool/vanpool program typically lies in the commitment of an employer to provide ridesharing incentives. These incentives may take the form of subsidies, guaranteed rides home, or preferential parking (i.e. lower parking costs and/or better availablility) for ridesharing-program participants. Regardless of the incentives used to encourage ridesharing, designating a ridesharing coordinator to organize any type of program is recommended.

Examples of subsidies being used as incentives range from actual cash reimbursements to gift certificates and prizes. For example, in some area of California, employees are paid bonuses of up to $80 per month for carpooling.

An important characteristic of most successful ridershare programs is a guaranteed ride home; this involves an employer providing ridesharing employees with daytime transportation service so that employees without their personal vehicles can still leave work in the case of an emergency. In early applications of this concept, employers were worried that providing daytime transportation would be very costly and not encourage employees to participate in ridesharing programs. Experience has, however, indicated that employees rarely need this service (keeping the costs of the service low) and the fact that such a service is available induces many individuals who would not otherwise rideshare to do so.

Preferential parking has also been shown to contribute to the successful implementation of rideshare programs. Examples of parking advantages provided to rideshare program participants include reserved parking spaces located close to office-entry points and reduced or waived parking fees.

Parking Management/Pricing

As mentioned previously, parking management can be a useful tool in encouraging ridesharing. The concept of parking management can, however, be applied both independently and in conjunction with numerous other strategies for alleviating congestion.

Parking management actions can be grouped into the six major categories shown in Table 16. The specific actions included in Table 16 are those which are most useful in reducing traffic congestion.

Costs and Benefits

The costs associated with parking management actions are relatively low. In fact, the implementation of actions such as increasing downtown parking rates and restricting on-street parking during peak periods of travel require virtually no capital investment.

The benefits of parking management programs have been shown to be significant, at least at a local level. For instance, the implementation of structured pricing programs that penalize single-occupant vehicles through higher parking prices commonly results in decreases of 20 to 30 percent in single-occupant vehicle commuting (solo-driving, 4). This tactic is especially successful when applied by employers who have previously provided free parking for their employees. There is, however, very little information available regarding the impact of parking management techniques on areawide congestion.

Table 16. Types of Parking Management Tactics

On-Street Parking Supply	Off-Street Parking Supply in Activity Centers	Fringe and Corridor Parking	Pricing	Enforcement and Adjudication	Marketing
• Remove spaces • Parking restrictions - Peak period restrictions - Off-peak restrictions - Alternate side parking by time of day and/or day of week - Permissible parking durations • Carpool/vanpool Preferential parking - Carpool/vanpool meters - Carpool/vanpool stickers • Loading zone regulations - Bus - Taxi - Delivery	• Restrict off-street supply in central business district (CBD) and activity centers - Zoning requirements • Minimum requirements • Maximum requirements • Joint use - Constrain normal growth in supply • Maximum ceiling (i.e. freeze) on CBD spaces • Reduce minimum parking requirements through HOV and transit incentives • Restrict principal use parking facilities • Restrict parking before or during selected hours of the day • Preferential parking for carpools/ vanpools	• Fringe parking • Park-and-ride parking • Carpool/vanpool parking	• Change parking rates - Increase rates • Parking price increase • Parking rate structure revision • Parking tax • Parking surcharge - Differential pricing programs • Short-term vs. long-term rates • Carpool/vanpool discounts • Vehicle size discounts • Geographically differentiated rates • Monthly contract rates • Merchant shopper discounts - Stamp programs - Token programs • Employer parking subsidies - Reduce subsidies - Transit/HOV subsidies	• Enforcement - Non-police enforcement personnel - Ticketing - Towing - Booting • Adjudication - Administrative - Judicial	• Advertising - Brochures - Maps - Media • Convenience programs (i.e. monthly contracts)

Source: Reference 4.

Implementation Issues

One of the most important issues associated with implementing parking management actions is the provision of an attractive alternative to solo driving. If a reasonable alternative is not provided, motorists and employers will likely show strong opposition to any changes in parking prices and/or availability.

Applying parking management techniques in combination with other strategies not only provides commuters with alternatives but also typically increases the effectiveness of both the parking management tactic used and the strategy(s) with which it is applied. For instance, if an HOV lane was implemented that physically connected major suburban residential areas with an urban area's central business district (CBD) and both park-and-ride lots in the suburbs and increased parking fees and/or decreased parking availability in the CBD were initiated, the benefits associated with these individual strategies would probably be far greater than had the strategies been applied independently.

An additional concern related to parking treatments is the opposition which may arise from businesses. Organizations will often claim that changes in parking policies limit their ability to attract employees and/or customers. Any agency contemplating the implementation of parking management techniques should, therefore, be aware of this potential opposition.

Parking management techniques work well in combination with many strategies. A detailed discussion of the interaction between various strategies is presented in Chapter 4.

Alternate Work Hours

While many of the strategies presented thus far have been directed toward increasing capacity or reducing VMT, alternate work hour programs are designed to spread peak-hour travel demand over a longer time period. The three basic types of alternate work hour programs include: 1) staggered hours; 2) flex-time; and 3) compressed work weeks.

With staggered work hours, different work groups are given different times at which to start and end work. This approach works well for assembly-line operations and similar work arrangements where the commencement and termination of work shifts can easily be controlled.

Flex-time is an approach which allows employees to choose their own schedules within pre-set guidelines. The majority of flex-time programs allow employees to begin work between 7 a.m. and 9:30 a.m., and many programs also allow workers to vary arrival/departure times from day to day. Flex-time approaches work well for offices where employees work independently and can manage their own schedules.

Compressed work weeks typically involve employees working four 10-hour days rather than five 8-hour days. This approach not only requires employees to arrive earlier and leave later, but also eliminates one day of commuting.

Costs and Benefits

Alternate work hour programs require little capital investment to implement. The primary benefit of these programs is decreased traffic congestion due to less demand during the peak hours of travel. By spreading demand out over time, existing transit services and roadway networks can also serve more commuters without any additional investments in peak-hour capacity.

The application of flex-time programs has also been shown to offer the scheduling versatility needed to meet bus schedules and create carpools more conveniently. Flex-time program implementation in Seattle and San Francisco has induced significant decreases in the percentage of individuals driving to work alone (4).

Implementation Issues

An important consideration regarding the implementation of alternate work hour programs is whether or not a significant amount of union workers will be involved in the program. In general, unions oppose longer work days. Any alternate work hour programs should, therefore, take the presence of union workers into consideration.

As mentioned previously, benefits of alternate work programs include increased transit utilization. The flexibility associated with these programs can, however, complicate the provision of public transit service (especially bus service). It is, therefore, important that these programs be implemented in areas or corridors where public transit scheduling can be adjusted.

Express Bus Service

Express bus service consists of a bus route which is operated with a minimal amount of stops to pick up or drop off passengers. As such, express bus service typically operates between park-and-ride lots and major activity centers with no stops between the two.

Costs and Benefits

The costs involved with implementing express bus service can vary, depending upon the amount of service provided and the size of an urban area's bus fleet. If express bus service is provided in only a few select corridors, and the existing bus fleet is fairly large, providing this service may simply be a matter of rescheduling and/or re-routing and, thus, be very inexpensive to implement. If, however, additional buses will be required to provide the service, the costs could be significant.

A major benefit of bus service is its flexibility. Buses can be re-routed and/or rescheduled as ridership warrants; when considering express bus service, this flexibility is especially beneficial.

Express bus service is sometimes used in conjunction with priority bus treatments such as HOV lanes. When used in this capacity, express bus service can also provide travel time savings and a higher level of service to passengers. This type of service strategy is particularly attractive to commuters who live in outlying suburbs and desire a quick and reliable means of travel to and from the downtown portion of an urban area.

Implementation Issues

When implementing express bus service, it is extremely important to provide the public with route and schedule information prior to implementation of the service; this is particularly important if other routes in a corridor are being changed in order to provide the express service.

Telecommuting

In the broadest sense, telecommuting means working at a location other than the central office. This alternate location is typically the home but might also be a satellite office or a neighborhood work center close to an individual's home. The basic concept behind telecommuting is moving the work to the worker rather than moving the worker to work.

Individuals that telecommute typically do so an average of one or two days per week. While many telecommuters require the use of modems and computers, this type of equipment is certainly not a requirement for telecommuting.

Costs and Benefits

The costs associated with telecommuting programs are normally minimal. One factor which decreases telecommuting program costs is the number of individuals who now have their own personal computers at home. The additional costs required for such individuals to telecommute would normally be those associated with the purchase of modems. In addition, many individuals can telecommute without the use of computers, fax machines, etc.

The benefits of telecommuting include: 1) decreases in VMT; 2) reductions in energy consumption; 3) reductions in vehicle emissions; 4) improvements in employee productivity; and 5) decreases in the need for office space (18, 19). While little quantitative data exist regarding the impact of telecommuting on urban area congestion, preliminary findings of a study examining the California Telecommuting Pilot Project indicate that this particular strategy more than pays for itself with B/C ratios in the range of 20:1.

Implementation Issues

As the popularity of telecommuting has increased in recent years, many concerns have been voiced by organizations considering this strategy as a means for reducing traffic congestion. The following beliefs are, however, either not necessarily true or can easily be avoided if a telecommunication program is properly implemented.

1) *Telecommuting leads to abuses by employees.* Organizations implementing this strategy should convey to employees the fact that telecommuting is not a right but rather a privilege that can be taken away if abused. Telecommuting is not for everyone, and potential telecommuters should be carefully selected. If the right individuals are chosen, however, telecommuting can be a win-win situation for both employers and employees.

2) *Telecommuting requires a computer.* While the current trend is directed more towards computer-use in completing work tasks, many individuals need only a pen, paper, and perhaps a telephone to telecommute. Many telecommuters save work that does not require a computer to do at their home or satellite office.

3) *Telecommuters suffer from isolation.* Most telecommuters welcome the quiet of working at home. In fact, most individuals that save paper work (writing, etc.) for

telecommuting days prefer less distractions and are more productive when working alone.

4) *Telecommuting is too informal and unstructured.* Telecommuting is flexible, but not necessarily unstructured. Employers often use a written agreement to formalize exactly what is expected of an employee who is given the privilege to telecommute. The supervisor and telecommuter can also agree in advance on the tasks to be accomplished and delivery dates.

In summary, there appear to be no significant disadvantages to a thoughtfully-administered telecommuting program. Telecommuting is relatively new to most commuters, but it is a manageable, cost-effective strategy for addressing traffic congestion problems.

Land-Use Strategies

The specific applications identified within the category of land-use strategies include: 1) mixed-use zoning and 2) home/neighborhood work centers (Table 18). The following discussions highlight the description, costs and benefits, and implementation issues associated with these strategies.

Table 17. Strategies Included Within the Category of Land-Use Strategies

Specific Strategies	Cost[1]	Benefit[2]
Mixed-use zoning	Low	Decreased VMT
Home/neighborhood work centers	High	Decreased VMT

[1] General magnitude of the cost associated with a strategy

[2] One, but not necessarily all, of the benefits associated with a strategy

Mixed-Use Zoning

Some of the most promising long-term solutions to existing traffic congestion problems are those attainable through land-use applications such as mixed-use zoning. Contrary to existing land-use policies in many urban areas that do nothing to inhibit suburban sprawl, mixed-use zoning allows a variety of land-use activities to take place in close proximity. The purpose of mixed-use zoning, from the standpoint of reducing traffic congestion problems, is to encourage the location of housing, employment, and commercial centers in the same general vicinity, thereby reducing the need for long-haul trips.

These types of development are rapidly gaining popularity. The city of Sacramento, California, recently approved a program coined as a transit-oriented development (TOD). This program represents one of the country's most ambitious attempts to reorient growth toward higher-density housing and neighborhoods serving retail and commercial users. This development is designed to be located along an existing regional transit system (6). The cities of San Francisco and Los Angeles have also recently approved similar mixed-use zones.

Costs and Benefits

While the construction of new housing and employment centers located in mixed-use zoning areas would entail significant investments, the costs associated with simply implementing mixed-use zoning policies are minimal. The cost to the general public would, therefore, be minimal if this approach were applied. The benefits of mixed-use zoning include: 1) reductions in VMT, fuel consumption, and vehicle emissions and 2) a land-use pattern which is more favorable for efficient transit operations. No information exists, beyond that which can merely be speculated, concerning the impact of mixed-use zoning on urban area congestion.

Implementation Issues

When implementing mixed-use zoning policies and encouraging the types of developments described previously, it is important that most, if not all, of the general guidelines included below be followed.

1. Any street system included as part of the development should lend itself to bus transit usage.
2. New developments should be located within areas that have already been established (i.e., in or near downtown, in a CBD, etc.).
3. Sidewalks and walkways, and bikeways should be included to protect pedestrians and encourage walking and/or biking.
4. Automobile parking should be controlled through pricing and/or availability.

Home/Neighborhood Work Centers

Similar to mixed-use zoning developments, home/neighborhood work centers are designed to have housing, employment, and commercial developments in close proximity. The difference in these two approaches is that while mixed-use zoning developments may be spread over an area of several hundred acres, a home/neighborhood work center ideally refers to a huge, concentrated development that is so multi-faceted, an individual residing in it would rarely need to go elsewhere. An example of such a development would be Watergate in Washington, D.C.

Increased attention is also being given to creating these types of developments. The city of Pittsburgh, Pennsylvania, has begun construction of a huge mixed-use development near a downtown light-rail transit station. The size and concentration of the developments involved will make it one of the largest home/neighborhood work centers in the country. Officials close to the project indicate that this development is an excellent example of the economic development generated by investment in public transit.

As mentioned previously, the costs associated with such developments would typically be borne by private investors/businesses. The general public would, therefore, likely incur few costs. The benefits cited previously for mixed-use zoning developments would also apply to home/neighborhood work centers.

Implementation Issues

The general guidelines outlined previously for mixed-use zoning developments would also apply to home/neighborhood work centers.

High-Tech Strategies

The approaches identified within the category of high-tech strategies include: 1) road pricing; 2) pre-trip motorist information; and 3) intelligent vehicle highway systems (IVHS, Table 18). The following discussions highlight the descriptions, costs and benefits, and implementation issues associated with these strategies.

Table 18. Strategies Included Within the Category of High-Tech Strategies

Specific Strategies	Cost[1]	Benefit[2]
Road pricing	Medium	Decreased VMT, self-supporting
Pre-trip info./smart commuter	Medium to high	Decreased delay
Intelligent vehicle highway system (IVHS)	Medium to very high	Decreased delay

[1] General magnitude of the cost associated with a strategy
[2] One, but not necessarily all, of the benefits associated with a strategy

Road Pricing

Roadway, or congestion, pricing consists of charging motorists a fee during periods of congested roadway travel. Unlike tollroads, which are permanent toll-collecting facilities on a 24-hour basis, roadway pricing can be dynamic and can, thus, be applied only when congested travel occurs. During uncongested periods, vehicles utilizing a roadway could be charged no fee.

Advocates of roadway pricing see this approach as a means to address the economically inefficient pricing structure which exists for public roadways. While services such as telephones and electricity are characterized by private ownership and public pricing, most roadways are characterized by public ownership and no pricing.

The concept of roadway pricing has been in existence for some time. Areas currently utilizing this approach to alleviate congestion include Singapore and Norway (18, 20).

Although not such a new, high-tech idea by itself, advances in technology may make road pricing a more feasible and widely used strategy for addressing congestion problems in the near future. For instance, the AVI technology mentioned previously (in association with toll roads) could also be used to charge vehicles utilization fees in a road pricing scheme. Changeable message signs located prior to "priced" sections of roadway could be used to inform motorists of "pricing" periods and any variations in the price to use a facility.

Costs and Benefits

Depending upon the extent to which it is applied, the cost of road pricing can vary significantly. A successful, state-of-the-art road pricing program will, however, require the following as a minimum: 1) the installation of monitoring devices on the road and in vehicles that could conceivably utilize the "priced" roadway and 2) the creation of an administrative/enforcement agency to collect revenues (4).

Roadway pricing theory is based on the concept of user fees. The costs associated with implementing a road pricing program would, therefore, be supported by revenues gained from users of the "priced" facility. Ideally, the general public would not incur tax increases, etc. to support such a program.

The primary benefits of a successful road pricing program would be reduced traffic congestion and the simultaneous attainment of additional revenues with which to further improve a transportation system. Additional benefits might include: 1) encouraging ridesharing and/or the use of public transportation; 2) the diversion of some traffic to less congested roadway facilities; and 3) reductions in both air pollution and fuel consumption.

Implementation Issues

There are many issues which must be considered if a road pricing program is to be successfully implemented. Included among these issues are: 1) the estimated value of time of prospective users; 2) pricing equity; 3) the "big brother" syndrome associated with road pricing system surveillance; 4) financing (who will fund the project and how?); 5) operations and maintenance (who will be responsible for ensuring the safe operation and proper maintenance of the "priced" facility?); and 6) the type(s) of roadway users who will be charged fees (20).

While some of these issues are complicated and most must be addressed on a site-specific basis, solutions do exist. For instance, in the case of pricing equity, lower income travellers can less afford the premium service provided by a "priced" roadway. In order to reduce any political problems arising from this fact, surplus funds gained from a road pricing program could be allocated towards the improvement of "free" parallel roadways or public transportation services.

Similarly, the type of roadway users charged to use the facility could be designated as single-occupant vehicles only. Applying a road pricing scheme in this fashion would also encourage ridesharing and the use of public transportation.

To date, road pricing programs have only been implemented in foreign countries. A road pricing project will, however, be implemented on State Route 91 in California. As the first major road pricing project implemented in the U.S., this project should provide excellent insight to both the general potential of these projects in addressing the urban traffic congestion problem and the issues associated with their implementation in this country.

Pre-Trip Information

High-tech approaches for providing motorists with pre-trip information are receiving increased attention. Programs of this nature that are currently in operation include the InfoBang system in Houston and the Commuter-TV (COM-TV) project in Los Angeles.

InfoBang is an experimental motorist information system which is designed to provide real-time traffic information for pre-trip planning. Information regarding accidents, disabled vehicles, construction, and general traffic congestion is gathered by various commercial, state, and local agencies. These agencies provide this information to a commercial advisory service which, in turn, compiles the information on a computer. This information is then transmitted to computer terminals located throughout the parking areas of buildings in a major activity center. The information displayed on computer screens is updated approximately every five minutes (21). A system similar to InfoBang, that would also provide real-time ridesharing information to commuters, is currently being considered for other travel corridors in Houston (22).

The information provided by the COM-TV system in Los Angeles is similar in content to that provided by InfoBang. The COM-TV system, however, utilizes television screens, as opposed to computer display terminals, to display traffic information. The preliminary results associated with the analyses of both of these systems indicate that these are valuable tools, but improvements such as an increase in the number of terminals/screens and better presentation of traffic information are needed if these systems are to be truly successful.

Costs and Benefits

The California Department of Transportation (Caltrans) indicates that the COM-TV system costs approximately $100,000 per year to operate. The installation of a COM-TV unit (including the television set and hookup) costs approximately $1,000. It, therefore, appears that a system such as COM-TV could be implemented on an extensive basis for a relatively low cost.

Expected benefits of pre-trip motorist information systems include: 1) reductions in congestion due to a more efficient use of available transportation system capacity; 2) reductions in vehicle emissions and fuel consumption; and 3) reductions in secondary accidents. Since both COM-TV and InfoBang were implemented in 1990, few quantitative data are available concerning the benefits of these types of systems.

Implementation Issues

The primary implementation issue associated with these types of systems concerns the extent to which such systems should be applied or, in other words, determining the percentage of individuals who should be provided with real-time traffic information. In theory, this approach should result in a more efficient utilization of existing capacity. In reality, however, if too many individuals divert from a congested route, there exists the possibility that alternate routes with little available capacity could quickly become congested, and the overall system delay could be worse than that which would have resulted had no pre-trip information been provided. Ensuring that alternate routes and/or public transportation with adequate surplus capacity are available is, thus, essential when implementing these types of systems.

Intelligent Vehicle-Highway Systems

Intelligent vehicle-highway systems (IVHS) represent advanced technology to improve traffic flow on highways. Often referred to as "smart cars" and/or "smart highways", these technologies are being designed to make two-way communication between highways and vehicle operators possible. The three components of IVHS that are most directly related to reducing urban area congestion are Advanced Transportation Management Systems (ATMS), Advanced Driver Information Systems (ADIS), and Automated Vehicle Control Systems (AVCS).

There are six primary characteristics that differentiate ATMS from the typical traffic management systems of today (23).

1. An ATMS works in real time.
2. ATMS estimates when and where congestion will take place and take steps to prevent it from occurring.
3. ATMS includes areawide surveillance and detection systems, allowing total system evaluation and/or analysis.
4. ATMS integrates control of various facilities (joint management of freeways and arterials).
5. An ATMS implies collaborative actions; adjacent jurisdictions will work in cooperation with each other.
6. An ATMS includes rapid response incident management strategies (rapid detection, verification and appropriate response plans) and integrated diversion strategies.

Not only will ATMS be able to manage transportation systems, but these systems will also serve as a valuable, comprehensive database.

The implementation of ATMS is the preliminary step towards a comprehensive IVHS. There are currently 29 state-of-the-art systems (ATMSs) in the United States that are either under development or are already partially operational (23).

Advanced Driver Information Systems (ADIS) provide drivers with information on traffic conditions, navigation and location, and alternate routes. Specific types of ADIS technology include: 1) on-board replication of maps and signs; 2) pre-trip electronic route planning; 3) traffic information broadcasting systems; 4) safety warning systems; 5) on-board navigation systems; and 6) electronic route guidance systems.

Technologies that are designed to help the driver perform certain vehicle control functions fall within the category of AVCS. A number of AVCS technologies available or under development include: 1) antilock braking systems; 2) speed control systems; 3) driver warning and/or assist systems; 4) radar braking; 5) automatic headway and lateral control; 6) crash avoidance systems; and 7) automated highway systems.

Costs and Benefits

The ultimate goal of the individual systems discussed previously is to work in combination to form an IVHS. The benefits expected from such an application include decreased urban area congestion, improved highway safety, decreased vehicle emissions, and decreased fuel consumption.

The costs and benefits associated with some of the individual technologies included under the umbrella of IVHS can be assessed. At this time, however, the costs and benefits associated with a full-scale IVHS can only be speculated. Hypothetical analyses indicate that, while being extremely expensive to implement, IVHS can be applied cost-effectively with B/C ratios estimated at approximately 3:1 (24).

Implementation Issues

When considering the implementation of IVHS, it must be realized that many of these technologies will not be available for quite some time. For instance, fully-functional, areawide ATMS and ADIS will probably not materialize until the year 2000 or thereafter. Furthermore, the implementation of fully-automated highways is probably at least 30 years away.

Due to the high financial expense typically associated with state-of-the-art technology, the cost of these systems will likely be the most important implementation issue. Transportation agencies in major urban areas will need to decide whether the benefits associated with IVHS are worth the significant investments required for their implementation. The data necessary to make such detailed decisions are, however, unavailable at this time.

Summary

The strategies discussed in this chapter represent the most promising techniques by which urban area traffic congestion can be alleviated both at present and in the foreseeable future (Table 19). In addition, these strategies, while varying widely in terms of their cost, are those which appear to be most applicable on an area-or corridor-wide basis. General cost figures (low, medium, high, etc.) are provided in the absence of detailed cost data. As a point of reference, ramp metering could be considered "medium-to-low" and the construction of a freeway considered "high" in terms of relative costs.

Among the discussions presented in this chapter have been the general costs and benefits associated with the implementation of the strategies summarized in Table 19. The data necessary to perform a more detailed assessment of HOV lanes, SC&C systems, and signal system improvements were, however, available. A more detailed discussion of the potential impacts these particular strategies might have on congestion is presented in Chapter 4. Furthermore, while the discussions presented in this chapter focused on a variety of strategies (Table 19) applied independently, the issue of simultaneously applying various strategies (i.e., the interaction between strategies) will be addressed in the following chapter.

Table 19. Summary of Congestion-Alleviating Strategies

General Category	Specific Strategies	Cost[1]	Benefit[2]	B/C Ratio[3]
Construction/ expansion of system	Construction of: - Principal arterials	$1.5 million/lane-mile	Added lane-miles	2-4
	- Super arterials	$3-4 million/lane-mile	30-70% more capacity than normal arterial	2-4
	- Freeways	$4.5 million/lane-mile	Added lane-miles	2-4
	- Toll roads	High	Self-supporting	
	- HOV facilities:			
	- Barrier-separated	$4-10 million/lane-mile	Added capacity	2-6
	- Concurrent/ contraflow lanes	$0.5-2 million/lane-mile	Added capacity	2-10
	- Arterial HOV lanes	$0.5-2 million/lane-mile	Added capacity	
	- Commuter rail	$5-10 million/mile	Added capacity	
	- Light rail transit	$10-30 million/mile	Added capacity	
	- Heavy rail transit	$40-100 million/mile	Added capacity	
	Addition of: - Principal arterial lane	$0.5-1 million/lane-mile	Added lane-miles	9
	- Freeway lane	$2.5 million/lane-mile	Added lane-miles	3
	Reducing lane width/using shoulder as a lane	$0.5 million/lane-mile	Added lane-miles	7
	Grade-separated arterial intersections	$6 million/intersection	Increased capacity	
Operational improvements	Ramp metering	$50,000/unit	Increased capacity	
	Surveillance, communication and control (SC&C) system	$1 million/mile	Up to 30% increase in capacity	12
	Traffic management teams	Low	Coordinated actions	15
	Accident investigation sites	Low	Decreased delay	28
	Signal-timing optimization	Low	Decreased delay	16
	Signal interconnection/ optimization	Medium	Decreased delay	10
Travel demand management	Carpooling/vanpooling programs	Low	Decreased VMT	
	Parking management/pricing	Low	Decreased VMT	
	Alternate work hours	Low	Decreased delay	
	Express bus service	Low to medium	Added capacity	
	Telecommuting	Low	Decreased VMT	20
Land-use strategies	Mixed-use zoning	Low	Decreased VMT	
	Home/neighborhood work centers	High	Decreased VMT	
High-tech strategies	Road pricing	Medium	Decreased VMT; self-supporting	
	Motorist information systems: Pre-trip information	Medium to high	Decreased delay	
	Intelligent veh. highway system (IVHS)	Medium to very high	Decreased delay	

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[1] Actual cost is shown if available; otherwise, the general magnitude of the cost associated with a strategy is displayed

[2] At least one, but not necessarily all of the benefits associated with a strategy

[3] Benefit-to-cost ratios are listed, if the necessary data are available

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IV. APPLICATION OF STRATEGIES

In identifying the costs and benefits associated with the strategies discussed in Chapter 3, the data necessary to perform a detailed assessment of several strategies were identified; these strategies included HOV lanes, SC&C systems and signal system improvements. The subsequent section presents a more detailed assessment of the potential of these approaches for alleviating urban traffic congestion in major Texas urban areas.

Impact of Individual Strategies on Congestion

HOV Lanes

Accompanying the implementation of HOV lanes in Houston has been an extensive evaluation effort. This evaluation has resulted in the assembly of a significant amount of data related to the operational aspects of the Houston HOV lane system. Utilizing these data, a methodology was developed in this study to assess the impact of HOV lanes on urban area congestion.

This methodology is based on the supply and demand characteristics of HOV lanes expressed in terms consistent with those of the RCI mentioned previously (Equation 1). For instance, this methodology produces an estimate of the effective additional freeway lane-miles provided by an HOV lane, taking into account the greater number of persons that can be moved on an HOV lane (with respect to a typical general-purpose lane). This methodology also estimates the effective DVMT on the HOV lane, taking into account the improved travel speeds that can occur on these lanes. Adding these two HOV lane components (effective lane-miles and DVMT) to the existing freeway system characteristics produces a modified RCI that considers the impacts of HOV lanes on urban area congestion.

Applying this methodology to the Houston HOV lane system in 1989, it can be shown that the HOV lanes effectively reduce the 1989 RCI from 1.13 to 1.10 -- a reduction in urban area congestion of approximately 3 percent. Considering the fact that the Houston HOV lane system is responsible for providing mobility (at a relatively high level of service) to approximately 4 percent of all persons travelling during the peak periods of weekday travel, this estimated reduction in congestion appears reasonable.

Assuming that the components of the Houston HOV lane system that remain to be constructed will exhibit operating characteristics similar to those of the existing portion of the system, it can be estimated that the eventual 95.5 lane-miles of HOV facilities could effectively reduce congestion in Houston by approximately 7 to 10 percent. Similar reductions in congestion could also be expected in conjunction with of HOV facilities currently being planned for implementation in the Dallas urban area. A detailed explanation of the methodology described previously and specific examples illustrating its application are included in Appendix B.

SC&C Systems

The implementation of SC&C systems on congested freeways is generally believed to increase the throughput of vehicles by 12 to 20 percent (1). While not actually increasing the physical capacity of a freeway, the benefits provided by an SC&C system (e.g., decreased reaction time to incidents) can be shown to effectively increase a congested freeway's capacity by approximately 15 percent.

The percentage of congested freeway lane-miles in major Texas urban areas during 1989 was identified in previous TTI research. Utilizing these data and the assumption that an SC&C system can effectively increase a congested freeway's capacity by 15 percent, estimates of the potential impact of SC&C systems on urban area congestion were developed; these estimates were specifically developed for the seven largest urban areas in Texas.

The results of this hypothetical analysis indicate that SC&C systems implemented on an areawide basis in the seven largest Texas urban areas could have a significant impact on congestion. As indicated in Table 20, the effective reductions in congestion estimated through this analysis range from 2 percent in Corpus Christi and El Paso to over 8 percent in Houston.

Areawide SC&C systems will not likely be operational in any major Texas urban areas for at least a few years. During this time, traffic congestion on most major urban area freeways is predicted to worsen. The potential benefits of SC&C systems illustrated previously can, therefore, be considered a conservative estimate of the positive impacts these systems can have on urban area traffic congestion in Texas.

Signal System Improvements

While the benefits of HOV lanes and SC&C systems are directed toward the freeway system, the impact of signal system improvements on principal arterial system congestion can also be significant. The potential benefits of signal system improvements, however, depend upon the existing signal timing system. The status of the existing signal systems on principal arterials in the seven largest Texas urban areas was, therefore, determined through the use of a survey.

In this survey, city traffic engineers were asked to identify the percentage of principal arterial signalized intersections falling into the following four general categories: 1) isolated/uncoordinated signals; 2) signals having local coordination either through time-based coordination or hardwire interconnections; 3) monitored/coordinated signals (local coordinated signals that can be monitored such that pre-determined signal timing plans can be down-loaded to the signals if the need arises); and 4) central coordinated signals (signals for which timing is continually optimized by computers using real-time data).

Table 20. Potential Impact of Freeway Surveillance, Communication and Control (SC&C) Systems on Urban Traffic Congestion in Texas

Urban Area	Freeway Lane-Miles, 1989	Congested Freeway Lane-Miles, 1989	% Congested Freeway Lane-Miles, 1989	Freeway Lane-Miles with SC&C[1]	Freeway		Principal Arterial		Congestion Index[3]		
					DVMT (1000)	DVMT/ Ln-Mile[2]	DVMT (1000)	DVMT/ Ln-Mile	No SC&C[4]	with SC&C[5]	% Decrease in Congestion
AUSTIN	430	237	55	466	5300	11384	2050	4820	0.95	0.89	6.6
CORPUS CHRISTI	190	19	10	193	1520	7882	1450	4530	0.70	0.69	1.9
DALLAS	1690	930	55	1830	22650	12380	8230	4860	1.02	0.95	6.7
EL PASO	350	70	20	361	3300	9154	3180	3830	0.74	0.72	2.1
FT. WORTH	1020	408	40	1081	11280	10433	4220	4880	0.87	0.82	4.9
HOUSTON	1860	1302	70	2055	27640	13448	10210	5080	1.13	1.03	8.4
SAN ANTONIO	830	332	40	880	9180	10434	5210	4820	0.87	0.83	4.5

[1] The effective freeway lane-miles in an urban area with an SC&C system in place; assuming SC&C system effectively increases capacity by 15% on congested freeways

[2] Daily vehicle-miles of travel per lane-mile with an SC&C system in place

[3] Roadway congestion index

[4] The roadway congestion index for the urban area roadway system in 1989; at that point in time there were no areawide SC&C systems in place

[5] The roadway congestion index for the urban area roadway system assuming an areawide SC&C system were in place

Using the data obtained from this survey, several scenarios of signal timing improvements and their respective impacts on urban area traffic congestion were examined.

As shown in Table 21, the results of this analysis indicate that the impact of signal system improvements can be fairly significant. For instance, signal system upgrades that are feasibly implementable within the next 5 to 10 years could decrease congestion by approximately 1 to 2 percent in major Texas urban areas. Similarly, by upgrading the majority of principal arterial signals to central coordinated control, a reduction in congestion of 1.5 to 3 percent could be achieved.

Table 21. Potential Impact of Principal Arterial Signal System Improvements on Urban Traffic Congestion in Texas

Urban Area	Type of Signal System Improvement	Implementation Time Frame[1]	Estimated Decrease in Congestion, %[2]
Austin	Upgrading all isolated/uncoordinated to local coordinated[3]	1992-1995	0.2
	75% monitored/coordinated, 25% central coordinated[4]	1995-2000	0.7
	25% monitored/coordinated, 75% central coordinated[5]	2000-2010	1.3
Corpus Christi	Upgrading all isolated/uncoordinated to local coordinated[3]	1992-1995	0.1
	75% monitored/coordinated, 25% central coordinated[4]	1995-2000	1.3
	25% monitored/coordinated, 75% central coordinated[5]	2000-2010	2.7
Dallas	Upgrading all isolated/uncoordinated to local coordinated[3]	1992-1995	0.1
	75% monitored/coordinated, 25% central coordinated[4]	1995-2000	0.9
	25% monitored/coordinated, 75% central coordinated[5]	2000-2010	1.3
El Paso	Upgrading all isolated/uncoordinated to local coordinated[3]	1992-1995	0.3
	75% monitored/coordinated, 25% central coordinated[4]	1995-2000	0.8
	25% monitored/coordinated, 75% central coordinated[5]	2000-2010	1.9
Fort Worth	Upgrading all isolated/uncoordinated to local coordinated[3]	1992-1995	0.5
	75% monitored/coordinated, 25% central coordinated[4]	1995-2000	0.9
	25% monitored/coordinated, 75% central coordinated[5]	2000-2010	1.5
Houston	Upgrading all isolated/uncoordinated to local coordinated[3]	1992-1995	0.1
	75% monitored/coordinated, 25% central coordinated[4]	1995-2000	0.7
	25% monitored/coordinated, 75% central coordinated[5]	2000-2010	1.2
San Antonio	Upgrading all isolated/uncoordinated to local coordinated[3]	1992-1995	0.6
	75% monitored/coordinated, 25% central coordinated[4]	1995-2000	1.8
	25% monitored/coordinated, 75% central coordinated[5]	2000-2010	2.7

[1] The time period during which the respective signal system improvement would most likely take place

[2] The estimated percentage decrease in the roadway congestion index (RCI) due to the respective signal system improvements

[3] Upgrading all isolated/uncoordinated signalized intersections on principal arterials to local coordinated control

[4] Upgrading the principal arterial signal system such that 75% is monitored/coordinated and 25% is central coordinated

[5] Upgrading the principal arterial signal system such that 25% is monitored/coordinated and 75% is central coordinated

Naturally, many other scenarios could be examined. The scenarios examined in this study should, however, provide one with a general idea of the magnitude of benefits achievable through the implementation of signal system improvements. A detailed explanation of the analysis used to produce the estimates shown in Table 21 is included in Appendix B.

All of the strategies discussed to this point can reduce peak period traffic congestion when applied properly. However, their impact on traffic congestion is contingent on many factors such as urban area size, existing levels of traffic congestion, and individual traffic characteristics of a corridor or subarea. The goal is to choose strategies for implementation that maximize the reduction in traffic congestion for a given level of expenditure.

Effectiveness of Strategies Based on Urban Area Size and Severity of Congestion

One factor which influences the effectiveness of a strategy is the overall size of an urban area. Due to factors such as typical length of trips, population, and funding availability, certain strategies are more appropriate in larger urban areas. Table 22 shows the categories of urban area population that will be used for the purposes of discussion in this report. These classifications of urban size are important in targeting specific strategies to alleviate traffic congestion.

Table 22. Categories of Urban Area Size

Urban Area Size	Population
Small	less than 300,000
Medium	300,000 - 750,000
Large	750,001 - 1,250,000
Very Large	greater than 1,250,000

Another factor influencing the effectiveness of strategies to reduce traffic congestion is the existing level of congestion in the urban area. The categories identified for varying levels of congestion (described by the RCI) are given in Table 23. The classification of congestion level is important because some strategies are effective under severe congestion but may not be effective under moderate congestion levels.

Table 23. Categories for Level of Congestion

Level of Congestion	Urban Area Congestion Index (RCI)
Slight	≤ 0.70
Moderate	0.71 - 0.89
Heavy	0.90 - 1.09
Severe	≥ 1.10

The following Texas cities are used to give an example of cities that fall into these urban area size and congestion level categories:

Small Urban Area with Slight Congestion:	Corpus Christi
Medium Urban Area with Moderate Congestion:	El Paso
Medium Urban Area with Heavy Congestion:	Austin
Large Urban Area with Moderate Congestion:	Fort Worth, San Antonio
Very Large Urban Area with Heavy Congestion:	Dallas
Very Large Urban Area with Severe Congestion:	Houston

Interaction Between Strategies

One key to maximizing the reduction in traffic congestion is choosing a combination of two or more strategies that will obtain greater combined effectiveness than if the strategies were applied individually.

The general strategies considered in this report are listed in Table 24, with a definition of the specific actions to be implemented under each strategy. While the primary scope of this study is the urban area, a thorough evaluation of the interaction between various strategies for alleviating urban traffic congestion can best be conducted by considering their simultaneous application at the corridor or sub-area level. The subsequent discussions should, therefore, be viewed within this context.

In order to describe how each of the strategies influence each other, matrices were developed. These matrices are shown in Figures 27 through 34 and are categorized by urban area size and severity of congestion. Included in each of these matrices is a designation for the effectiveness of a combination of two strategies. These designations are limited to the three following possibilities: 1) a "+" sign means that the simultaneous application of two strategies will have a synergistic impact on congestion (the total effect of the two strategies applied concurrently is greater than the sum of the individual effects); 2) a "-" sign means that the simultaneous application of two strategies will produce less benefits than had the two approaches been applied independently; and 3) no designation means that the concurrent application of two strategies has no significant impact on their individual effects.

For example, in a very large urban area with severe congestion (Figure 27), automated vehicle control would complement an advanced information management system and create a smart-car/smart-highway system. On the other hand, in a large urban area with heavy congestion (Figure 29), mixed-use zoning would have a detrimental impact on express bus service by decreasing the need for long-haul trips.

Table 24. Glossary for Strategy Matrices

Term	Definition
New Transit	The construction of commuter, light, or heavy rail.
IVHS (Automated Vehicle Control)	The Automated Vehicle Control Systems (AVCS) aspect of Intelligent Vehicle Highway Systems (IVHS). This specifically refers to the design of systems that will help drivers perform certain vehicle control functions.
IVHS (Advance Information/Management)	The Advance Driver Information System (ADIS) aspect of IVHS. This specifically refers to pre-trip/in-vehicle information systems and advanced two-way communications between vehicles and remote/central control centers.
Home/Neighborhood Work Centers	Large developments that contain most, but not necessarily all of the following within the same building or groups of buildings: family housing, business offices, retail shops, and health care/professional services.
New Facility Construction	The construction of new freeway, arterial, or toll road facilities.
Freeway HOV Facilities	The implementation/construction of the following reversible or two-way high-occupancy vehicle (HOV) facilities in separate or within freeway right-of-way (barrier separated lanes located in the freeway median), concurrent flow HOV lanes (one lane is taken from the off-peak direction of flow is designated for HOVs only), or contraflow HOV lanes (one lane is taken from the off-peak direction of flow and designated for HOVs traveling in the peak direction).
Additional Lane Construction	The addition of roadway lane-miles to existing freeways and/or arterials.
SC&C	Surveillance, communication, and control systems utilizing existing technology; this refers specifically to systems providing monitoring capabilities through the presence of loop detectors and/or closed circuit television in freeway corridors.
Arterial HOV Facilities	Arterial street lanes designated for use by HOVs only. These lanes may be restricted to HOVs by time of day (i.e. HOVs only during peak hour or peak period).
Traffic Engineering (TSM)	Low-to-medium cost traffic engineering applications such as: signal timing optimization, signal systems interconnection, ramp metering, HOV bypass lanes, accident investigation sites, and the addition of turning lanes (storage capacity) at arterial street intersections.
Express Bus Service	The provision of bus service/routes that pick persons up at suburban locations (e.g. park-and-ride lots) and provide non-stop transportation service to large activity/employment centers.
Mixed-Use Zoning	A policy decision allowing and/or encouraging various types of land use to take place within close proximity to one another.
Car/Vanpool Programs	The organization of ride-share programs aimed at matching up individuals or groups of persons so that carpooling and vanpooling are made more convenient for commuters.
Parking Management	The management of parking facilities either through decreased parking availability (fewer spaces) or increased parking fees.
Telecommuting	The partial or total substitution of telecommunications (transporting information and ideas using telecommunication technology), with or without the assistance of computers, for the daily commute to and from work.
Alternate Work Hours	Any number of approaches involving the shift in time of a commuting trip. Examples of this approach include staggered work hours (departing earlier/later than usual for work) and shortened work weeks (four 10-hour days instead of five 8-hour days).

Code	Strategy/Category	Cost[1]	VH1 New Transit	VH2 IVHS (Automated Veh Control)	H1 IVHS (Advanced Info/Mgmt)	H2 Home/Neighborhood Work Centers	H3 New Facility Construction	H4 Freeway HOV Facilities	M1 Additional Lane Construction	M2 SC&C	M3 Arterial HOV Facilities	M4 Traffic Engineering (TSM)	L1 Express Bus Service	L2 Mixed-Use Zoning	L3 Car/Vanpool Program	L4 Parking Management	L5 Telecommuting	L6 Alternate Work Hours
VH1	New Transit[2]	v.high																
VH2	IVHS (Automated Veh Control)[3]	v.high																
H1	IVHS (Advanced Info/Mgmt)[4]	high		+														
H2	Home/Neighborhood Work Centers	high																
H3	New Facility Construction[5]	high		+	+													
H4	Freeway HOV Facilities[6]	high	+	+	+													
M1	Additional Lane Construction[7]	med		+	+													
M2	SC&C[8]	med		-	-		+	+	+									
M3	Arterial HOV Facilities	med			+			+										
M4	Traffic Engineering (TSM)[9]	med					+	+	+	+	+							
L1	Express Bus Service	low	+		+			+			+	+						
L2	Mixed-Use Zoning	low					+		+									
L3	Car/Vanpool Program	low			+			+			+	+						
L4	Parking Management	low	+			+		+			+		+		+			
L5	Telecommuting	low			+	+										+		
L6	Alternate Work Hours	low			+		+		+			+				+	+	

Note: Very large urban area with severe congestion defined as an area with a population of >1,300,000 persons and Roadway Congestion Index of ≥1.1

[1] Refers to the general magnitude of financial commitment required to implement various strategies; these costs are not necessarily categorized by the cost to the average taxpayer

[2] Construction of commuter rail, light rail, or heavy rail

[3] Refers to Automated Vehicle Control Systems (AVCS) that are being designed to help drivers perform certain vehicle control functions

[4] Refers to an increased communicating capacity between vehicles and highways/centralized control systems

[5] Construction of freeway, arterials, or toll roads

[6] Exclusive median HOV, Concurrent Flow HOV, or Contraflow HOV lanes

[7] Addition of roadway lane-miles to existing facilities

[8] Surveillance, communication, and control systems (existing technology)

[9] Signal timing optimization; signal system interconnect; ramp metering; accident investigation sites; turn lanes at intersections; shoulder conversion

Figure 27. Strategy Matrix for a Very Large Urban Area With Severe Congestion

Code	Strategy/Category	Cost[1]	VH1 New Transit	VH2 IVHS (Automated Veh Control)	H1 IVHS (Advanced Info/Mgmt)	H2 Home/Neighborhood Work Centers	H3 New Facility Construction	H4 Freeway HOV Facilities	M1 Additional Lane Construction	M2 SC&C	M3 Arterial HOV Facilities	M4 Traffic Engineering (TSM)	L1 Express Bus Service	L2 Mixed-Use Zoning	L3 Car/Vanpool Program	L4 Parking Management	L5 Telecommuting	L6 Alternate Work Hours
VH1	New Transit[2]	v.high																
VH2	IVHS (Automated Veh Control)[3]	v.high																
H1	IVHS (Advanced Info/Mgmt)[4]	high		+														
H2	Home/Neighborhood Work Centers	high																
H3	New Facility Construction[5]	high		+	+													
H4	Freeway HOV Facilities[6]	high		+	+													
M1	Additional Lane Construction[7]	med		+	+													
M2	SC&C[8]	med		-	-		+	+	+									
M3	Arterial HOV Facilities	med			+			+										
M4	Traffic Engineering (TSM)[9]	med					+	+	+	+	+							
L1	Express Bus Service	low	+		+			+			+	+						
L2	Mixed-Use Zoning	low					+		+									
L3	Car/Vanpool Program	low			+	-		+			+	+						
L4	Parking Management	low	+			+		+			+		+		+			
L5	Telecommuting	low			+	+										+		
L6	Alternate Work Hours	low			+		+		+			+				+	+	

Note: Very large urban area with heavy congestion defined as an area with a population of >1,300,000 persons and Roadway Congestion Index of 0.9–1.09

[1] Refers to the general magnitude of financial commitment required to implement various strategies; these costs are not necessarily categorized by the cost to the average taxpayer

[2] Construction of commuter rail, light rail, or heavy rail

[3] Refers to Automated Vehicle Control Systems (AVCS) that are being designed to help drivers perform certain vehicle control functions

[4] Refers to an increased communicating capacity between vehicles and highways/centralized control systems

[5] Construction of freeway, arterials, or toll roads

[6] Exclusive median HOV, Concurrent Flow HOV, or Contraflow HOV lanes

[7] Addition of roadway lane-miles to existing facilities

[8] Surveillance, communication, and control systems (existing technology)

[9] Signal timing optimization; signal system interconnect; ramp metering; accident investigation sites; turn lanes at intersections; shoulder conversion

Figure 28. Strategy Matrix for a Very Large Urban Area With Heavy Congestion

Code	Strategy/Category	Cost[1]	H1 IVHS (Advanced Info/Mgmt)	H2 Home/Neighborhood Work Centers	H3 New Facility Construction	H4 Freeway HOV Facilities	M1 Additional Lane Construction	M2 SC&C	M3 Arterial HOV Facilities	M4 Traffic Engineering (TSM)	L1 Express Bus Service	L2 Mixed-Use Zoning	L3 Carpool/Vanpool Program	L4 Parking Management	L5 Telecommuting	L6 Alternate Work Hours
H1	IVHS (Advanced Info/Mgmt)[2]	high														
H2	Home/Neighborhood Work Centers	high														
H3	New Facility Construction[3]	high	+													
H4	Freeway HOV Facilities[4]	high	+	-	-											
M1	Additional Lane Construction[5]	med	+													
M2	SC&C[6]	med	-		+	+	+									
M3	Arterial HOV Facilities	med	+			+										
M4	Traffic Engineering (TSM)[7]	med			+	+	+	+	+							
L1	Express Bus Service	low	+			+			+	+						
L2	Mixed-Use Zoning	low			+		+				-					
L3	Carpool/Vanpool Program	low	+	-		+			+	+		-				
L4	Parking Management	low		+		+			+		+		+			
L5	Telecommuting	low	+	+										+		
L6	Alternate Work Hours	low	+		+	-	+		-	+	-		-	+	+	

Note: Large urban area with heavy congestion defined as an area with a population of 700,001–1,300,000 persons and a Roadway Congestion Index of 0.9–1.09

[1] Refers to the general magnitude of financial commitment required to implement various strategies; these costs are not necessarily categorized by the cost to the average taxpayer

[2] Refers to an increased communicating capacity between vehicles and highways/centralized control systems

[3] Construction of freeway, arterials, or toll roads

[4] Exclusive median HOV, Concurrent flow HOV, or Contraflow HOV lanes

[5] Addition of roadway lane–miles to existing facilities

[6] Surveillance, communication, and control systems (existing technology)

[7] Signal timing optimization; signal system interconnect; ramp metering; accident investigation sites; turn lanes at intersections; shoulder conversion

Figure 29. Strategy Matrix for a Large Urban Area With Heavy Congestion

Code	Strategy/Category	Cost[1]	H2 Home/Neighborhood Work Centers	H3 New Facility Construction	H4 Freeway HOV Facilities	M1 Additional Lane Construction	M2 SC&C	M3 Arterial HOV Facilities	M4 Traffic Engineering (TSM)	L1 Express Bus Service	L2 Mixed-Use Zoning	L3 Carpool/Vanpool Program	L4 Parking Management	L5 Telecommuting	L6 Alternate Work Hours
H2	Home/Neighborhood Work Centers	high													
H3	New Facility Construction[2]	high													
H4	Freeway HOV Facilities[3]	high	-	-											
M1	Additional Lane Construction[4]	med													
M2	SC&C[5]	med		+	+	+									
M3	Arterial HOV Facilities	med			+										
M4	Traffic Engineering (TSM)[6]	med		+	+	+	+	+							
L1	Express Bus Service	low			+			+	+						
L2	Mixed-Use Zoning	low		+		+				-					
L3	Carpool/Vanpool Program	low	-		+			+	+		-				
L4	Parking Management	low	+	-	+	-		+		+		+			
L5	Telecommuting	low	+	-		-							+		
L6	Alternate Work Hours	low		+	-	+		-	+	-		-	+	+	

Note: Large urban area with moderate congestion defined as an area with a population of 700,001–1,300,000 persons and a Roadway Congestion Index of 0.71–0.89

[1] Refers to the general magnitude of financial commitment required to implement various strategies; these costs are not necessarily categorized by the cost to the average taxpayer

[2] Construction of freeway, arterials, or toll roads

[3] Exclusive median HOV, Concurrent flow HOV, or Contraflow HOV lanes

[4] Addition of roadway lane-miles to existing facilities

[5] Surveillance, communication, and control systems (existing technology)

[6] Signal timing optimization; signal system interconnect; ramp metering; accident investigation sites; turn lanes at intersections; shoulder conversion

Figure 30. Strategy Matrix for a Large Urban Area With Moderate Congestion

Code	Strategy/Category	Cost[1]	H3 New Facility Construction	H4 Freeway HOV Facilities	M1 Additional Lane Construction	M2 SC&C	M3 Arterial HOV Facilities	M4 Traffic Engineering (TSM)	L1 Express Bus Service	L2 Mixed-Use Zoning	L3 Carpool/Vanpool Program	L4 Parking Management	L5 Telecommuting	L6 Alternate Work Hours
H3	New Facility Construction[2]	high												
H4	Freeway HOV Facilities[3]	high	-											
M1	Additional Lane Construction[4]	med												
M2	SC&C[5]	med	+	+	+									
M3	Arterial HOV Facilities	med		+										
M4	Traffic Engineering (TSM)[6]	med	+	+	+	+	+							
L1	Express Bus Service	low		+			+	+						
L2	Mixed-Use Zoning	low	+		+				-					
L3	Carpool/Vanpool Program	low		+			+	+		-				
L4	Parking Management	low		+			+		+		+			
L5	Telecommuting	low	-	-	-		-		-		-	+		
L6	Alternate Work Hours	low	+	-	+		-	+	-		-	+	+	

Note: Medium-sized urban area with heavy congestion defined as an area with a population of 300,001-700,000 persons and a Roadway Congestion Index of 0.9-1.09

[1] Refers to the general magnitude of financial commitment required to implement various strategies; these costs are not necessarily categorized by the cost to the average taxpayer
[2] Construction of freeway, arterials, or toll roads
[3] Exclusive median HOV, Concurrent flow HOV, or Contraflow HOV lanes
[4] Addition of roadway lane-miles to existing facilities
[5] Surveillance, communication, and control systems (existing technology)
[6] Signal timing optimization; signal system interconnect; ramp metering; accident investigation sites; turn lanes at intersections; shoulder conversion

Figure 31. Strategy Matrix for a Medium-Sized Urban Area With Heavy Congestion

Code	Strategy/Category	Cost[1]	H3 New Facility Construction	M1 Additional Lane Construction	M2 SC&C	M3 Arterial HOV Facilities	M4 Traffic Engineering (TSM)	L1 Express Bus Service	L2 Mixed-Use Zoning	L3 Carpool/Vanpool Program	L4 Parking Management	L5 Telecommuting	L6 Alternate Work Hours
H3	New Facility Construction[2]	high											
M1	Additional Lane Construction[3]	med											
M2	SC&C[4]	med	+	+									
M3	Arterial HOV Facilities	med											
M4	Traffic Engineering (TSM)[5]	med	+	+	+	+							
L1	Express Bus Service	low	-	-		+							
L2	Mixed-Use Zoning	low	+	+				-					
L3	Carpool/Vanpool Program	low				+							
L4	Parking Management	low	-	-		+		+		+			
L5	Telecommuting	low	-	-		-		-		-	+		
L6	Alternate Work Hours	low				-	+	-		-	+	+	

Note: Medium-sized urban area with moderate congestion defined as an area with a population of 300,001-700,000 persons and a Roadway Congestion Index of 0.71-0.89

[1] Refers to the general magnitude of financial commitment required to implement various strategies; these costs are not necessarily categorized by the cost to the average taxpayer

[2] Construction of freeway, arterials, or toll roads

[3] Addition of roadway lane-miles to existing facilities

[4] Surveillance, communication, and control systems (existing technology)

[5] Signal timing optimization; signal system interconnect; ramp metering; accident investigation sites; turn lanes at intersections; shoulder conversion

Figure 32. Strategy Matrix for a Medium-Sized Urban Area With Moderate Congestion

Code	Strategy/Category	Cost[1]	H3 New Facility Construction	M1 Additional Lane Construction	M2 SC&C	M3 Arterial HOV Facilities	M4 Traffic Engineering (TSM)	L1 Express Bus Service	L3 Carpool/Vanpool Program	L4 Parking Management	L6 Alternate Work Hours
H3	New Facility Construction[2]	high									
M1	Additional Lane Construction[3]	med									
M2	SC&C[4]	med									
M3	Arterial HOV Facilities	med									
M4	Traffic Engineering (TSM)[5]	med	+	+	+	+					
L1	Express Bus Service	low	-	-		+					
L3	Carpool/Vanpool Program	low				+		-			
L4	Parking Management	low				+		+	+		
L6	Alternate Work Hours	low	-	-		-	+	-	-	+	

Note: Small urban area with moderate congestion defined as an area with a population of <300,000 persons and a Roadway Congestion Index of 0.71–0.89

[1] Refers to the general magnitude of financial commitment required to implement various strategies; these costs are not necessarily categorized by the cost to the average taxpayer

[2] Construction of freeways, arterials, or toll roads

[3] Addition of roadway lane–miles to existing facilities

[4] Surveillance, communication, and control systems

[5] Signal timing optimization; signal system interconnect; ramp metering; accident investigation sites; turn lanes at intersections; shoulder conversion

Figure 33. Strategy Matrix for a Small Urban Area With Moderate Congestion

Code	Strategy/Category	Cost[1]	H3 New Facility Construction	M1 Additional Lane Construction	M2 SC&C	M4 Traffic Engineering (TSM)	L3 Carpool/Vanpool Program	L4 Parking Management	L6 Alternate Work Hours
H3	New Facility Construction[2]	high							
M1	Additional Lane Construction[3]	med							
M2	SC&C[4]	med							
M4	Traffic Engineering (TSM)[5]	med	+	+	+				
L3	Carpool/Vanpool Program	low				+			
L4	Parking Management	low					+		
L6	Alternate Work Hours	low	-	-		+	-	+	

Note: Small urban area with slight congestion defined as an area with a population of <300,000 persons and a Roadway Congestion Index of ≤0.70

[1] Refers to the general magnitude of financial commitment required to implement various strategies; these costs are not necessarily categorized by the cost to the average taxpayer
[2] Construction of freeways, arterials, or toll roads
[3] Addition of roadway lane-miles to existing facilities
[4] Surveillance, communication, and control systems
[5] Signal timing optimization; signal system interconnect; ramp metering; accident investigation sites; turn lanes at intersections; shoulder conversion

Figure 34. Strategy Matrix for a Small Urban Area With Slight Congestion

The strategies included in these matrices (Figures 27 through 34) are coded according to implementation costs. For example, new transit is coded VH1 (Figure 27) since it is the first strategy listed in the very high category. These codes remain constant between matrices.

Descriptions of how the strategies impact each other are outlined in Tables 25 through 28. Explanations of why an interaction between two strategies is designated with a '+' or '-' are given in Table 25 for very large urban area matrices. The remaining tables (Tables 26 through 28) provide explanations of interactions between strategies that change due to urban area size and/or the degree of traffic congestion. For instance, while new roadway facilities and/or additional roadway lane-miles (H3 and M1) could effectively be simultaneously implemented with a telecommuting program (L5) in a very large urban area with severe congestion (Figure 27 and Table 25), the simultaneous application of these strategies within the same corridor/sub-area in a large urban area with moderate congestion (Figure 30 and Table 26) would likely detract from the effectiveness of a telecommuting program. The explanations provided in Tables 26 through 28 are based on previous research as well as observations of projects that have been implemented (2, 3).

Packages of Strategies

As traffic congestion continues to worsen in most urban areas, it is becoming increasingly apparent that no one strategy will solve the mobility problems we now face. The primary purpose of these matrices is to illustrate which strategies can be applied most effectively in combination. The matrices should also serve to illustrate which strategies are not recommended for simultaneous application within the same corridor/subarea.

Based on how the individual strategies related to one another in the matrices, the strategies were grouped into packages. These packages are designed to combine strategies that should work especially well together in reducing traffic congestion. Twelve packages are shown in Table 29. Each of the packages is constructed to treat a different size urban

Table 25. Explanations for Very Large Urban Area Matrices

Status of Congestion	Combination(s)[1]	Explanation[2]
Severe	VH2-H1	Automated vehicle control would complement an advanced info./mgmt. system and create a smart-highway/smart-vehicle system.
	VH2-H3, VH2-H4, VH2-M1	Implementation of automated vehicle control would improve the operating efficiency and safety of new and existing roadways (freeways) and freeway HOV facilities.
	H3-H1, M1-H1	Implementation of advanced info./mgmt. systems, in conjunction with new/additional roadway capacity, would result in improved efficiency for new and existing roadways.
	VH1-H4	Severe congestion might produce enough ridership for both new transit (rail) and a freeway HOV facility to operate efficiently within the same corridor/subarea.
	H1-H4, H1-M3, H1-L1, H1-L3, H1-L5, H1-L6	An advanced info./mgmt. system would enhance the efficiency and general attractiveness of HOV facilities. This would be accomplished by providing commuters with real-time bus service info. and improved ride-matching capabilities (smart commuting). This type of system would also enable commuters to make more educated decisions about telecommuting (on what days congestion could be avoided) and alternate work hours (what time periods are congested).
	M2-VH2, M2-H1	If a traffic mgmt. system were to be put in place in the future, it would be either SC&C (existing technology) or IVHS; both strategies would not be implemented within the same corridor.
	M2-H3, M2-H4, M2-M1	An SC&C system would improve the efficiency of new/expanded roadways and HOV facilities.
	M3-H4	Arterial HOV facilities would work well with freeway HOV facilities by providing a continuum of benefits to HOVs making typical commuter-type trips.
	M4-H3, M4-M1, M4-M2	TSM applications would improve the efficiency of new/additional roadway capacity and complement the usually broad scope of an SC&C system.
	M4-H4, M4-L1, M4-L3, M4-L6	Signal-timing optimization would improve arterial HOV operations, while HOV bypass lanes would improve the efficiency of express transit, car/vanpool programs, and freeway HOV facilities.
	L1-VH1, L1-H4, L1-M3	Express bus service would enhance the attractiveness of HOV facilities and could be used as a link between home and the rail station so as to improve ridership of a rail line.
	L2-H3, L2-M1	Mixed-use zoning, applied as a policy, would provide for better use of new and existing roadway supply by decreasing the demand for long-haul (home-to-work, etc.) trips.
	L3-H4, L3-M3	Car/vanpool programs would improve the effectiveness of HOV facilities.
	L4-VH1, L4-H4, L4-M3, L4-L1, L4-L3	Parking mgmt. would provide an incentive to change modes of travel (i.e., promote use of rail or HOV facilities). In the case of HOV facilities, this would entail increased utilization of express transit and car/vanpool programs.
	L4-H2, L5-H2	Parking mgmt. and telecommuting would complement the effects of home/neighborhood work centers by further discouraging the use of the automobile.
	L5-L4	Parking mgmt. would encourage telecommuting.
	L6-H3, L6-M1	Alternate work hours would help optimize the utilization of new and existing roadway capacity by spreading demand out over a longer period of time.

Table 25. Explanations for Very Large Urban Area Matrices (continued)

Status of Congestion	Combination(s)1	Explanation[2]
Severe	L4-L6	Parking mgmt. (decreased parking availability) would further encourage persons to commute at an earlier/later time.
	L6-L5	Alternate work hours would provide flexibility for persons wishing to telecommute on days of their choice.
Heavy[3]	H2-L3	A home/neighborhood work center implemented within the same corridor as a car/vanpool program would detract from the effectiveness of the latter.
	VH1-H4	Traffic congestion would likely not be of enough magnitude to enable a freeway HOV facility and new transit (rail) to operate in a synergistic fashion within the same corridor/subarea.

[1] Combinations corresponding to the codes for strategies included in Figures 15 through 22 (matrices)

[2] One, but not necessarily the only, explanation for either a '+' or '-' designation having been given to a combination of strategies

[3] The only changes in '+' or '-' designations for a very large urban area with heavy congestion, in comparison to a very large urban area with severe congestion, are for combinations H2-L3 and VH1-H4. All other designations and explanations remain the same.

Table 26. Explanations for Large Urban Area Matrices.

Status of Congestion	Combination(s)[1]	Explanation[2]
Heavy	H4-H2	A home/neighborhood work center implemented within the same corridor as a car/vanpool program would detract from the effectiveness of the latter.
	H4-H3	HOV not compatible with new freeway construction.
	L2-L1	Mixed-use zoning would have a detrimental impact on express bus services by decreasing the need for long-haul trips.
	L6-H4, L6-L1, L6-L3, L6-M3	Alternate work hours would complicate the formation of car/vanpool programs (i.e., ride-share matching) and operate in competition with express transit service; it would, thus, adversely impact the effectiveness of HOV facilities.
Moderate[3]	L5-H3, L5-M1	New roadway facilities and/or additional roadway lane-miles would be a disincentive to telecommute.

Notes: In the case of a large urban area with heavy congestion, new transit (rail) and IVHS (automated vehicle control) would typically not be appropriate/economically feasible strategies; for large urban areas with only moderate congestion, IVHS (advanced info./mgmt.) would probably be inappropriate

[1] Combinations corresponding to the codes for strategies included in Figures 15 through 22 (matrices)

[2] One, but not necessarily the only, explanation for either a '+' or '-' designation having been given to a combination of strategies

[3] The only change in '+' or '-' designations for a large urban area with moderate congestion, in comparison to a large urban area with heavy congestion, are for combinations L5-H3 and L5-M1. All other designations and explanations remain the same.

Table 27. Explanations for Medium-Sized Urban Area Matrices.

Status of Congestion	Combination(s)[1]	Explanation[2]
Heavy	L5-H4, L5-L1, L5-L3	A large-scale telecommuting program implemented within a medium-sized urban area would probably detract from the success of car/vanpool programs and express; this would, in turn, have an adverse impact on the effectiveness of freeway and arterial HOV lanes.
Moderate[3]	L1-H3, L1-M1	Additional lane-miles of capacity would be a disincentive to use express transit.

Notes: In the case of a medium-sized urban area with heavy congestion, home/neighborhood work centers would likely be inappropriate; for medium-sized urban areas with only moderate congestion, freeway HOV facilities would also typically be unwarranted.

[1] Combinations corresponding to the codes for strategies included in Figures 15 through 22 (matrices)

[2] One, but not necessarily the only, explanation for either a '+' or '-' designation having been given to a combination of strategies

[3] The only changes in '+' or'-' designations for a medium-sized urban area with moderate congestion, in comparison to a medium-sized urban area with heavy congestion, are for combinations L1-H3, L1-M1, L1-M4, L3-M4, L6-H3, and L6-M1. All other designations and explanations remain the same.

Table 28. Explanations for Small Urban Area Matrices.

Status of Congestion	Combination(s)[1]	Explanation[2]
Moderate	L6-H3, L6-M1	Additional roadway capacity would be a disincentive to shift to alternate work hours.
	L3-L1	Simultaneous implementation of car/vanpool programs and express bus service would cause these two strategies to compete for the same ridership in a small urban area, to the point that neither would probably be effective if examined individually.
Slight	None	There were no changes in designations/explanations for those strategies common to the small urban area matrices.

Notes: In the case of a small urban area with moderate congestion, mixed-use zoning and telecommuting would probably not be warranted; for a small urban area with only slight congestion, arterial HOV facilities and express bus service would likely become inappropriate.

[1] Combinations corresponding to the codes for strategies included in Figure 15 through 22 (matrices)

[2] One, but not necessarily the only, explanation for either '+' or '-' designation having been given to a combination of strategies

area and level of congestion. The appropriate packages for a given urban area size and level of congestion are shown in Table 30.

Many of the packages shown in Table 29 include individual strategies that may not necessarily be implemented all at once in the same subarea. A number of other combinations could easily be designed. The combinations shown in Table 29 should, therefore, be viewed as general groups of strategies that would work well together in addressing typical, urban area traffic congestion problems.

Summary

Faced with the fact that traffic congestion problems in major urban areas can no longer be adequately addressed by simply constructing additional roadway lane-miles of supply, information is needed regarding the interaction between various congestion-reducing strategies when being applied simultaneously. The information included in this chapter addresses this need.

The material presented in this chapter should be considered useful in making a preliminary assessment of the general applicability of certain strategies and possible packages of strategies for urban areas of varying population and severity of congestion. While this chapter has addressed the general applicability of various combinations of strategies on a corridor/subarea basis, the following chapter will provide a quantitative assessment of the costs and effectiveness of selected strategy combinations on an urban area basis.

Table 29. Packages of Strategies to Alleviate Congestion

Code	Strategy/Category	Cost	Packages											
			1	2	3	4	5	6	7	8	9	10	11	12
VH1	New Transit	v.high												
VH2	IVHS (Automated Veh Control)	v.high												X
H1	IVHS (Advanced Info/Mgmt)	high										X		X
H2	Home/Neighborhood Work Centers	high											X	
H3	New Facility Construction	high	X		X				X		X			
H4	Freeway HOV Facilities	high							X	X		X		
M1	Additional Lane Construction	med	X		X				X		X			
M2	SC&C	med	X		X				X	X	X			
M3	Arterial HOV Facilities	med			X	X	X		X	X		X		
M4	Traffic Engineering (TSM)	med	X	X	X	X	X		X	X	X	X		
L1	Express Bus Service	low					X			X				
L2	Mixed-Use Zoning	low												
L3	Car/Vanpool Program	low		X		X	X			X				
L4	Parking Management	low		X		X	X	X		X			X	
L5	Telecommuting	low						X					X	
L6	Alternate Work Hours	low						X					X	

Table 30. Implementation of Corridor/Subarea Congestion Reduction Strategies

Urban Area Size	Congestion Level	Packages											
		1	2	3	4	5	6	7	8	9	10	11	12
Small	Slight	X	X										
Small	Moderate			X	X								
Medium	Moderate			X		X	X						
Medium	Heavy					X	X	X					
Large	Heavy					X	X			X			
Large	Severe					X			X	X	X	X	X
Very Large	Heavy					X			X	X	X	X	X
Very Large	Severe					X			X	X	X	X	X

References

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V. RELATIONSHIP BETWEEN LEVEL OF EXPENDITURE AND REDUCTION IN URBAN AREA CONGESTION

The final objective of this study was to identify general levels of expenditure required to bring about varying reductions in urban area congestion. Utilizing data identified in previous tasks of this research study, macroscopic assessments of the costs and reductions in congestion associated with the implementation of certain strategies were, therefore, developed.

This study was not intended to supersede any existing plans for urban area transportation system improvements. Since signal system upgrades and SC&C systems are planned for eventual implementation in the major Texas urban areas, these two strategies were chosen for this particular analysis. As discussed in Chapter 4, in addition to HOV lanes, these two strategies also represent means by which to alleviate congestion for which the most comprehensive databases exist.

The following discussions provide an assessment of the costs and reductions in congestion associated with implementing signal system upgrades and SC&C systems in the urban areas of Corpus Christi, San Antonio, and Houston. These three urban areas were chosen for this analysis to provide a comparison between areas of varying size and severity of congestion.

In particular, these analyses will examine the upgrade of the principal arterial signal systems in these urban areas from their existing status to the condition of being 25% monitored/coordinated and 75% central coordinated. In addition, these analyses will examine the implementation of SC&C capabilities for all congested freeway lane-miles within the respective urban areas.

The costs associated with implementing, operating, and maintaining an SC&C system are assumed to be approximately $1 million per freeway center-mile. The cost figures used in the signal system upgrade analyses are shown in Table 31; these costs are represented as annual costs and include maintenance and operational expenses (1, 2).

Table 31. Costs Associated With Implementing Signal System Upgrades

Status of Existing Intersection	Final Status of Intersection	Annual Cost Per Intersection ($)[1]
Isolated Uncoordinated	Monitored/Coordinated	$2,000
Local Coordinated	Monitored/Coordinated	$ 800
Isolated Uncoordinated	Central Coordinated	$5,200
Local Coordinated	Central Coordinated	$1,600
Monitored Coordinated	Central Coordinated	$ 500

Source: References 1 and 2

[1] The annual cost per intersection including maintenance and operational costs

Corpus Christi

Corpus Christi represents a small urban area with slight congestion. Assuming a 10-year life for the upgraded signal system, the net present value (NPV) of the costs required to implement such a system in Corpus Christi is estimated to be $4 million. While this cost estimate may seem low, it should be noted that there are only about 200 principal arterial intersections in Corpus Christi that are located in areas other than the central business district (CBD). According to the results of the signal system survey discussed earlier in this report, the majority of the signalized intersections in the CBD are already operated under central coordinated control.

The estimated decrease in urban area congestion for this hypothetical signal system upgrade is approximately 3 percent. Using the relationship illustrated previously in Figure 18, the benefits associated with this decrease in congestion can be estimated. Comparing these benefits to the costs results in a B/C of approximately 20:1.

The cost associated with implementing an SC&C system for congested freeways in Corpus Christi is estimated to be $5 million. Again, while this estimate may seem low, it should be noted that there are few lane-miles of freeway in Corpus Christi that are currently considered to be congested. This SC&C system would, therefore, be very small. Comparing the benefits associated with an estimated 2 percent decrease in urban area congestion to this cost results in a B/C of approximately 8:1.

In summary, it appears that a level of expenditure in the range of $8 to $10 million could reduce congestion in a Corpus Christi-type urban area by approximately 5 percent. It should, however, be noted that this 5 percent decrease in congestion represents only a small change in the RCI (from 0.70 to 0.67).

San Antonio

San Antonio represents a large urban area with moderate congestion. The estimated cost of upgrading the principal arterial signal system in San Antonio to 25% monitored/coordinated and 75% central coordinated is $20 million. The estimated decrease in urban area congestion associated with this improvement is approximately 3 percent. Comparing the cost to the monetary value of this benefit results in a B/C of approximately 18:1.

The cost associated with implementing an SC&C system for congested freeways in San Antonio is estimated to be $55 million. The estimated decrease in urban area congestion associated with this improvement is approximately 5 percent; the resulting B/C is approximately 11:1.

In summary, it appears that a level of expenditure in the range of $70 to $75 million could reduce congestion in a San Antonio-type urban area by approximately 7 percent. This estimated 7 precent decrease in urban area congestion corresponds with a change in the RCI from an existing level of 0.87 to 0.81.

Houston

Houston represents a very large urban area with severe congestion. The estimated cost of upgrading Houston's principal arterial signal system to the status outlined previously is $40 million. The decrease in urban area congestion that could be expected in association with this improvement is approximately 2 percent. Comparing the benefits and costs of this upgrade results in a B/C of approximately 25:1.

It is estimated that implementing an SC&C system for congested freeways in Houston would cost $205 million and would decrease urban area congestion by approximately 7 percent. These costs and benefits result in a B/C of approximately 15:1.

As discussed previously, Houston has already implemented a significant system of HOV lanes. Utilizing data for the existing HOV lane system, it can be shown that, to date, the system has cost $130 million, has effectively decreased urban area congestion by 3 percent and is characterized by a B/C of approximately 10:1.

It, therefore, appears that a level of expenditure of approximately $225 million (if spent on signal system upgrades and an SC&C system) could reduce congestion in a Houston-type urban area by approximately 9 percent (a reduction from the existing RCI of 1.13 to 1.03). Furthermore, if one also considers the HOV lane system characteristics cited previously, it can be shown that a total expenditure of approximately $375 million could reduce congestion in a Houston-type urban area by approximately 12 percent (a reduction from the existing RCI of 1.13 to 0.99).

Summary

The results of the analyses discussed in this chapter are summarized in Table 32. Principal arterial signal system upgrades and freeway SC&C systems are designed to decrease congestion on two different components of an urban area roadway system. The impacts of these two strategies on urban area congestion can, therefore, be considered to be additive. As indicated in Table 32, the strategies examined in these analyses can be implemented on a very cost effective basis.

Table 32. Summary of Costs and Benefits Associated with the Implementation of Signal System Upgrades, SC&C Systems, and HOV Lane Systems

Urban Area	Type of Improvement	Level of Expenditure ($ millions)		Congestion Index					B/C[7]
					After Improvements		Percent Decrease		
		Individual[1]	Total[2]	Existing	Individual[3]	Total[4]	Individual[5]	Total[6]	
Corpus Christi	Signal system upgrade	4	9	0.70	0.67	0.67	2.7	4.6	20
	SC&C system	5		0.70	0.69		1.9		7
San Antonio	Signal system upgrade	20	75	0.87	0.85	0.81	2.7	7.2	18
	SC&C system	55		0.87	0.83		4.5		11
Houston	Signal system upgrade	40	375	1.13	1.11	0.99	1.8	12.4	25
	SC&C system	205		1.13	1.03		7.1		15
	HOV lane system	130		1.13	1.10		3.0		10

[1] The level of expenditure associated with respective individual improvements
[2] The total expenditure associated with implementing signal system upgrades and an SC&C system; in the case of Houston, this total cost also includes expenditures related to the Houston HOV lane system
[3] The roadway congestion index (RCI) reflecting the impacts of respective strategies applied individually
[4] The RCI reflecting the total impact of the strategies applied simultaneously
[5] The percent decrease in the RCI corresponding to respective strategies applied individually
[6] The total percent decrease in the RCI corresponding to the strategies being applied simultaneously
[7] The estimated B/C associated with respective improvements

While the material presented in this chapter relates to only a few strategies for alleviating urban congestion, these discussions should serve to illustrate the general level of expenditure required to bring about varying reductions in urban area traffic congestion.

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APPENDIX A

URBANIZED AREAWIDE CONGESTION MEASUREMENT METHODOLOGY DEVELOPMENT

APPENDIX A
URBANIZED AREAWIDE CONGESTION MEASUREMENT METHODOLOGY DEVELOPMENT

Previous research (1,2,3,4) on areawide mobility levels in Texas resulted in a methodology to compare urban roadway congestion levels. This section summarizes the purpose, data base, analysis procedure and major findings of that research effort and an FHWA research report on urban freeway congestion.

Purpose of Congestion Measurement Techniques

Transportation professionals and the general public are increasingly aware of the traffic congestion levels experienced in major cities. This interest resulted in research to develop a procedure that would allow quantitative comparisons of urbanized areawide traffic volumes and roadway mileage. Obviously, a procedure that utilizes generally available data would be more desirable than one which required new or more extensive data collection.

Previous Urban Mobility Comparison Studies

Lack of comparable and significant urban travel data has hampered the analysis of congestion levels on a national basis. The amount of roadway system performance statistics collected and reported by local and state agencies varies significantly across the nation. Differences in roadway functional classification terminology have resulted in significant variations between major and minor arterial street mileage. The Highway Performance Monitoring System (HPMS) data base (5) compiled by FHWA since 1980 was used as the basic source of data for this analysis. Local planning and transportation agencies, and state departments of transportation (DOT) were also contacted to obtain relevant data and provide local review.

HPMS data is submitted to FHWA by state DOTs and includes information on state and locally maintained roadway systems. This should give a more accurate representation of the urbanized area roadway condition than information that could be developed from a single organization. The differences in functional classification and the amount of data used to update the database each year varies in each state. Locally developed planning data were, therefore, used to provide another source of information concerning the urban roadway system.

The boundary chosen for inclusion in a mobility analysis is also significant. City or county jurisdictions vary in the percentage of urbanized area included and the density of development. State laws pertaining to municipal incorporation, and the time and manner in which the area developed, also have a substantial impact on land use patterns.

In conducting the initial relative mobility studies, data availability proved to be the largest problem. Consistent data that allowed an accurate comparative assessment of urban congestion are not available from any agency or group of agencies. Data collected in several ways by many sources were acquired. In the opinion of the research staff and reviewers of the research report, however, the quantitative measures used in the studies (1,2,3,4) did provide a reasonably accurate measure of overall urban mobility. The general nature of the mobility assessment and the variety of data sources, as well as the experience of the reviewing agencies, combined to provide analysis results consistent with the accuracy level desired.

Comparability of the measures was achieved using several estimates of both travel and area statistics. For example, in defining urbanized area, it was not always possible to use jurisdictional limits as the defining boundaries due to either lack of data on related travel measures or non-comparability of information. County boundaries may appear to provide consistency, but variations in county size, as well as percentage of urbanization, significantly impaired the utility of county-based data. This study uses a population density of more than 1,000 persons per square mile as the criterion for urbanized area delineation.

A 1986 FHWA research report entitled, "Quantification of Urban Freeway Congestion and Analysis of Remedial Measures" (11) utilized the HPMS data base to develop detailed estimates of congestion due to recurring delay (usual, high traffic volumes) and incident delay. Freeway systems in the 37 Metropolitan Statistical Areas (MSAs) with populations greater than one million were analyzed for travel delay and excess fuel consumption. The study ranked the urbanized areas according to a congestion severity index (total delay per million vehicle-miles of travel) for 1984 and 2005. The future values were derived from the traffic volume growth estimates in HPMS and applied to the existing roadway system to illustrate the effect a construction moratorium would have on the systems.

The 1984 FHWA rankings are compared to those developed within this report. It should be noted that the FHWA report (11) focused on relatively detailed estimates of urbanized area freeway delay for large MSAs, while this project analyzed planning level estimates of delay, fuel and insurance costs for freeways and principal arterial streets. While not directly comparable, these studies should illustrate areas of concern to transportation planners.

Study Design

The urbanized area traffic volume level that was consistent with desirable overall mobility was determined using data derived from the Houston area. During the late 1960s and early 1970s, citizens in Houston enjoyed one of the best transportation systems in the nation. Peak-hour speed on most facilities was reasonable, and congestion did not extend for a significant period beyond either peak hour. By 1980, however, Houston had acquired, and probably deserved, a reputation as one of the most congested cities in the country. At some point, transportation mobility had declined from desirable to undesirable.

The initial focus of the 1982 research effort (2) was to develop an estimate of the initial point at which mobility levels could be described as undesirable. Having estimated this point, the measures of mobility levels associated with that time could be assumed to be representative of undesirable congestion levels.

Houston's Experience with Declining Mobility

The Houston data detailing the increase in congestion were analyzed to provide a basis for quantitative indicators of mobility decline. The rapid increase in congestion on Houston area freeways and arterial streets during the 1970s emphasized the need for actions to restore and maintain good mobility.

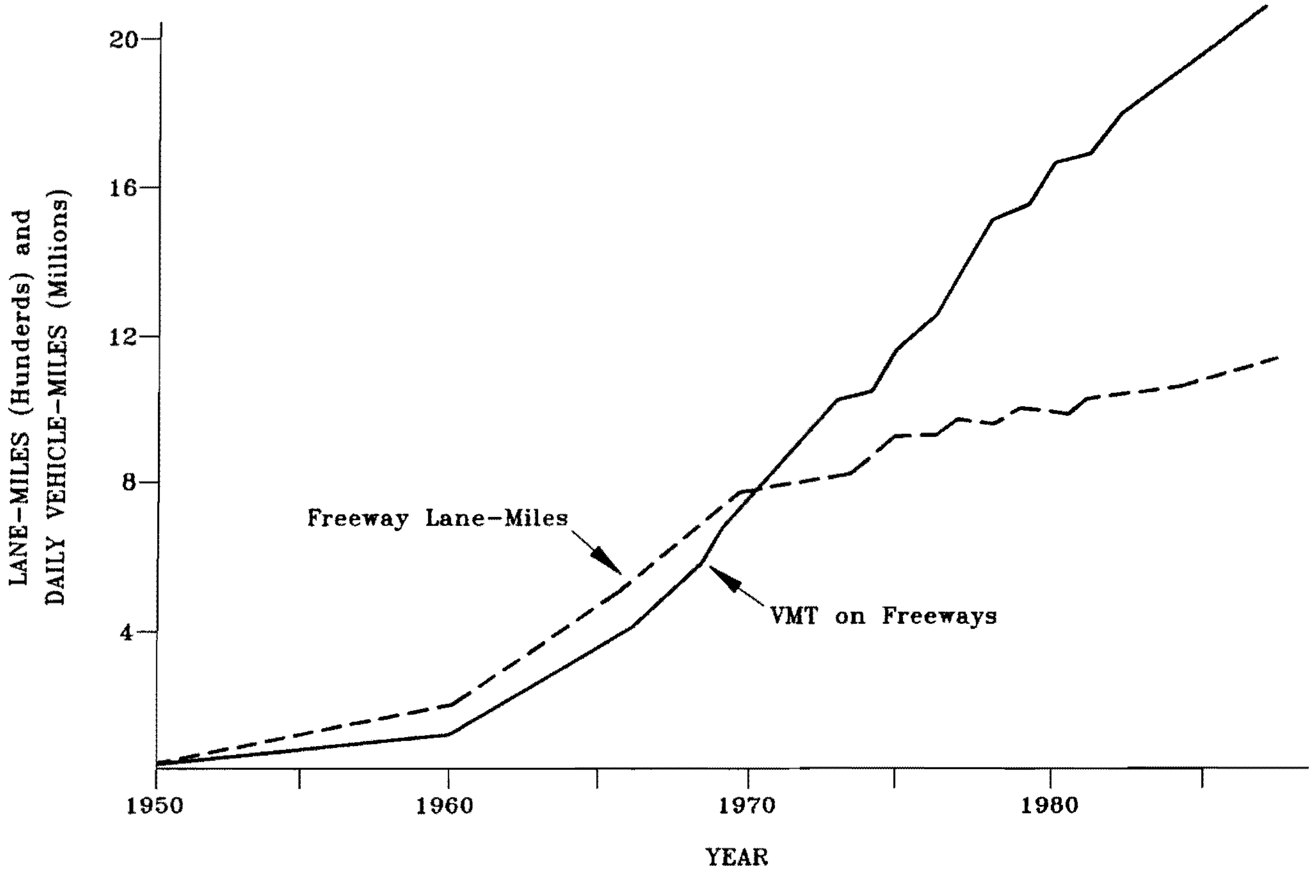
The disparity between increases in freeway lane-miles and freeway travel during the 1970s in Houston is quantified in Table A-1 and Figure A-1. The rate of new freeway construction in the 1970s was one-sixth that of the 1960s, while daily freeway VMT increased at approximately the same rate throughout the 20-year period (2). Vehicle registration, population, and traffic volume counts were thoroughly analyzed and also indicated the shift from relatively good mobility to relatively poor mobility in only a few years.

Table A-1. City of Houston Growth Trends, 1950 to 1985

Year	Annual Average Population (1000)	Annual Average Vehicles (1000)	Freeway Travel in VMT Per Day[1] (1000)	Freeway Capacity (Lane-Miles)	Daily VMT Per Freeway Lane-Mile
1950	595[2]	240	200	25	8,400
1955	690[2]	375	620	100	6,200
1960	940[2]	480	1,045	185	5,600
1965	1,085	625	3,425	455	7,500
1970	1,235	775	7,320	760	9,600
1975	1,440	1,000	11,365	900	12,700
1980	1,610	1,270	16,310	960	17,000
1985	1,730	1,450	20,600	1,100	18,700
Percent Increase Per Year					
1960-70	2.8	4.9	19.6	15.1	5.5
1970-80	2.6	5.1	8.4	2.4	5.9

Notes: [1] VMT--Vehicle-Miles of Travel
[2] As of April 1

Source: References 2, 3, 5, 9



Note: The values presented are averages of the six freeways studied (I-10W, I-10E, US 59S, US 59N, I-45S, I-45N).

Source: References 2,3.

Figure A-1. Freeway Capacity and Travel in Houston, 1950 to 1986

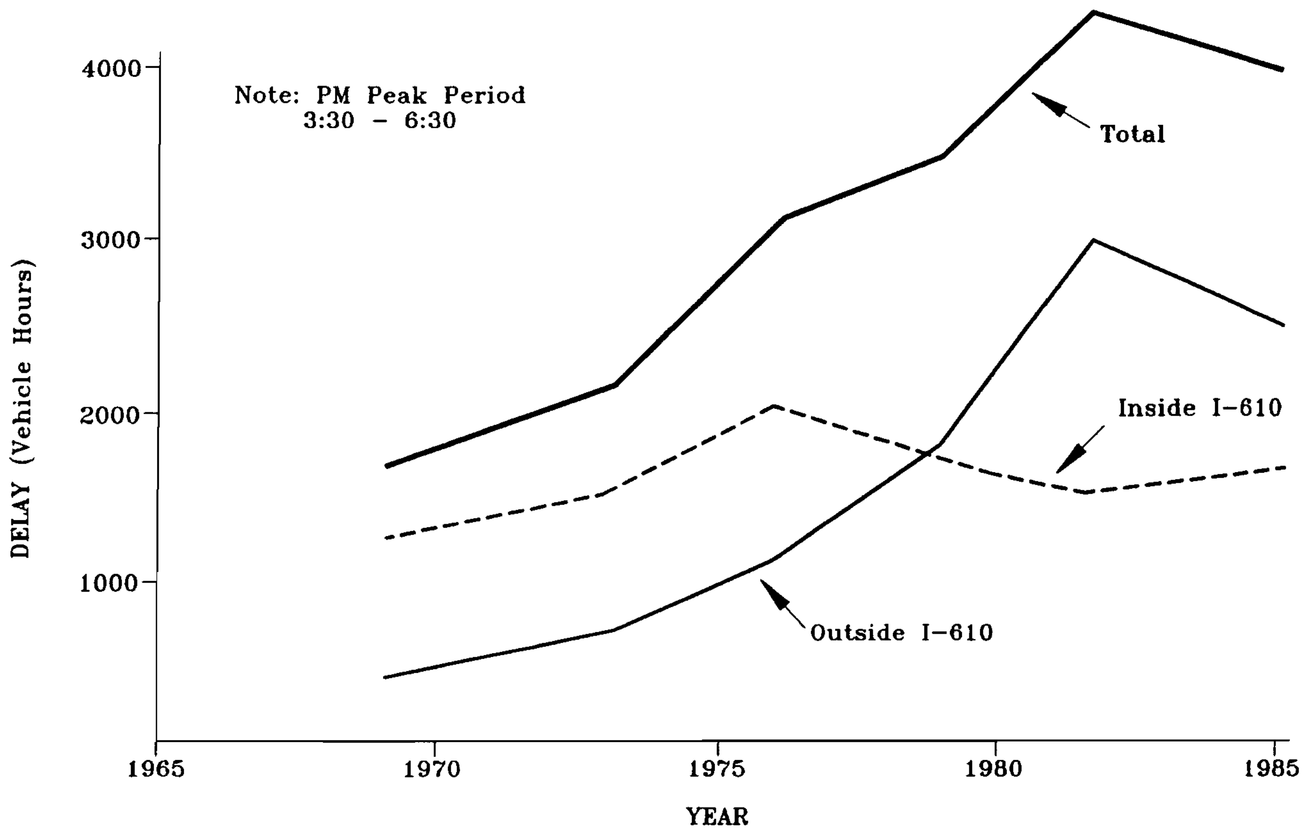
Congestion increases were also apparent in the travel delay estimates. Peak-period volume and travel time information were utilized to generate the data in Table A-2 and Figure A-2. Six major radial freeways were evaluated in each of four travel studies conducted by the Houston-Galveston Regional Transportation Study (HGRTS) (6). The dramatic (380 percent) increase in delay between I-610 and Beltway 8 (Figure A-2) from 1969 to 1979 indicates the decline in mobility outside the central city area. The decrease in delay inside I-610 (a major circumferential freeway approximately five miles from downtown) may be attributable to several factors, including the completion of certain freeway sections and the traffic metering effect of I-610. On most radial freeways the number of lanes outside Loop 610 is less than that inside the Loop. Volumes, however, are not significantly lower, resulting in greater congestion outside I-610.

Table A-2. Average Evening Peak-Period Delay by Freeway Segment Per Major Radial Freeway

Year	Inside I-610 (Veh-Hours)	I-610 to Beltway 8 (Veh-Hours)	Total (Veh-Hours)
1969	1,315	390	1,705
1973	1,560	685	2,245
1976	2,110	1,165	3,275
1979	1,830	1,860	3,690
1982	1,480	3,000	4,480
1985	1,615	2,565	4,180

Source: References 1, 2, 7, 8, 9

Note: Evening peak period used for analysis was 3:30 to 6:30 p.m.



Note: The values presented are averages of the six freeways studied (I-10W, I-10E, US 59S, US 59N, I-45S, I-45N).

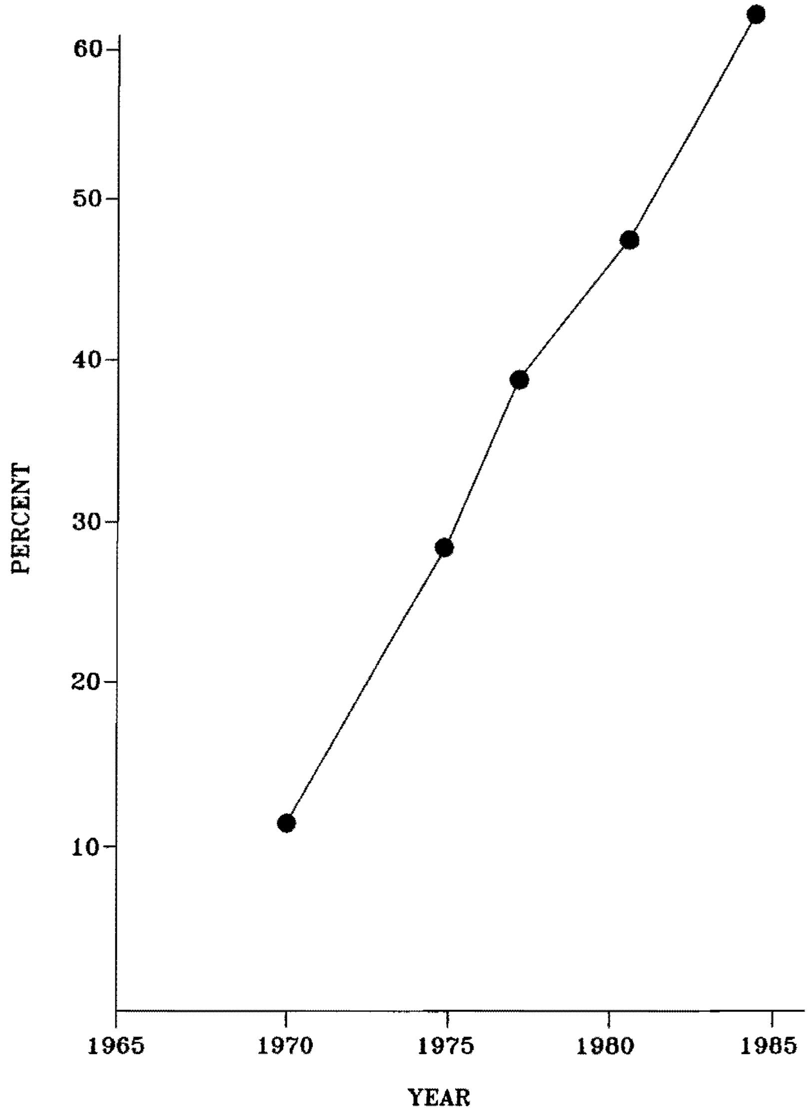
Source: References 1, 2, 8, 9, 10

Figure A-2. Delay by Segments for Houston Freeways, P.M. Peak Period

The maximum freeway service flow rate for level-of-service C (LOS C) is 1,550 passenger cars per lane per hour (volume/capacity ratio equal to 0.77) for a 70 mph design speed facility (12). Using average values for k-factor (the percentage of daily traffic volume during the peak hour) and directional distribution, and including some adjustment for trucks, these values can be interpreted to indicate that 15,000 vehicles per lane per day is an estimate of the beginning of level-of-service D operation. (The development of this value is consistent with the planning level analysis methodology presented in this report.)

The use of the boundary between level-of-service C and D as the beginning of congestion is consistent with reports by the Department of Transportation to Congress on the status of highways in the United States (13) (congestion begins at a volume/capacity ratio of 0.8) and the AASHTO Policy on Geometric Design of Highways and Streets (13) (urban freeways and streets should be designed for level-of-service C). While the use of a single number tends to mask the myriad of factors used in roadway capacity analyses, the level of accuracy of the data base and the planning nature of the ultimate use of the results of this methodology are compatible with this approach.

Figure A-3 quantifies the increase in congested freeway lane-miles in Harris County between 1965 and 1985. Although it is not known what percentage of the freeway system exceeding 15,000 vehicles per lane per day (operating at LOS D or worse in the peak hour) is an "acceptable" measure, it can be assumed that the 10 percent value in 1970 did not suggest county-wide deficiencies; however, the 45 percent in 1980 would appear to suggest such deficiencies did exist.



Source: 1, 2, 6

Figure A-3. Percent of Freeway Lane-Miles with more than 15,000 ADT for Harris County (Houston), 1970 to 1985

The data available to the study team did not allow the determination of a specific date at which Houston's traffic problems became critical. For purposes of the overall analysis, however, this was not required. Prior to 1975, mobility in Houston could be characterized as "reasonably good." Peak-period speeds on freeways and major arterials were fairly high, and traffic delay was not a major concern. By the late 1970s, however, peak-period travel delay had doubled from 1970 levels, and volume per lane values reflected two or more hours of congested operation during both the morning and evening peak periods. Congested freeway lane-miles in Harris County (Figure A-2) increased from 10 percent in 1970 to 40 percent in 1978. When rural areas of Harris County were subtracted from the analysis, the 1978 congested urban freeway mileage approached 50 percent.

Congestion Indicator Determination

The data on mobility decline for Houston indicated that an "unacceptable" level of transportation service was reached somewhere in the 1975-1976 time frame. That assumption allowed quantitative measures of impending congestion problems to be developed and compared for the major urbanized areas of Texas. The following factors, listed in apparent order of reliability and usefulness, represent guidelines that can be used to determine if congestion in an urbanized area is becoming critical.

Traffic Per Lane

As shown previously, 15,000 vehicles per lane per day for freeways can be interpreted to represent the beginning of LOS D operation. Once traffic volume has entered that range, congestion is becoming critical. As a measure of approaching congestion, the 13,000 vehicles per lane per day value used by the Federal Highway Administration in the highway needs estimate (15) and by the Texas Department of Highways and Public Transportation in their Project Development Process (16) would appear to represent a more appropriate value. That standard also was attained on an average urbanized area basis in Houston during the period (1975-76) when mobility was becoming unacceptable.

The corresponding measure for urban arterial streets would appear to be approximately 5,000 vehicles per lane per day. This value was not reached in Houston until 1979-80, but the design of the Houston area principal arterial street system would not accommodate traffic volumes representative of congestion in other urbanized areas. An inconsistent arterial system with respect to both the number of lanes and continuous roadway length, reduced the levels of traffic volume necessary to cause undesirable congestion. This value is also in general agreement with values presented in the Highway Capacity Manual (11).

- Urbanized Area Average Traffic Volume
  - Freeway: 13,000 daily vehicle-miles of travel per lane-mile
  - Principal Arterial Street: 5,000 daily vehicle-miles of travel per lane-mile

Roadway Congestion Index

Combining the freeway and principal arterial street traffic volume per lane values into one indicator (Equation A-1) generates a value to compare the major mobility providing roadways of each urbanized area. Weighing the vehicle-miles of travel (VMT) per lane values by the amount of VMT in each functional class provides flexibility in applying the formula to areas with very different freeway and street travel characteristics. The congestion levels are normalized, with a value of 1.0 representing the beginning of undesirable mobility levels.

$$\text{Roadway Congestion Index} = \frac{\text{Freeway VMT/Lane-mile} \times \text{Freeway VMT} + \text{Prin. Art. Str. VMT/Lane-Mile} \times \text{Prin. Art. Str. VMT}}{13{,}000 \times \text{Freeway VMT} + 5{,}000 \times \text{Prin. Art. Str. VMT}} \qquad \text{Eq. A-1}$$

Percentage of Congested Freeway

The percentage of the freeway system operating under congested conditions (15,000 vehicles per lane per day or more) was determined to be another description of congestion and mobility levels. Those data for the Houston area were presented previously (Figure A-3). From that information, using the 1975-76 time frame, it appears that once 30 percent of the lane-miles are operating at or above 15,000 vehicles per day, mobility has become significantly impaired.

- Percentage of Freeway System with ADT Greater than 15,000 Per Lane: 30 percent.

Summary

These measures are only some of the variables examined during the assessment of possible mobility indicators (2). While all of the measures have limitations due to the reliability and accuracy of the data base, the three indicators below are illustrative of urban travel conditions.

- Urbanized Area traffic volumes
- Roadway Congestion Index
- Percentage of freeway system with ADT per lane greater than 15,000

These factors are also available without any new data collection requirements, which allows the use of historical traffic data collected during the usual urban planning process. A single variable may not be indicative of the traffic congestion in an urbanized area, but if all of the measures are examined, the relative mobility levels should become apparent. The analysis in the following section used the indicators to assess relative mobility levels in the study areas.

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APPENDIX B

METHODOLOGIES UTILIZED IN QUANTIFYING IMPACT OF STRATEGIES IN TERMS OF THE ROADWAY CONGESTION INDEX (RCI)

APPENDIX B

METHODOLOGIES UTILIZED IN QUANTIFYING IMPACT OF STRATEGIES IN TERMS OF THE ROADWAY CONGESTION INDEX (RCI)

The methodologies described subsequently were utilized in this study to estimate the impacts of HOV lanes and signal system improvements on urban area congestion. These methodologies were designed to express any impacts these strategies might have on congestion in terms of the RCI described previously (Equation 1 and Appendix A). For the purposes of this study, the RCI is considered to be the most appropriate means by which to quantify urban area congestion.

HOV Lane Methodology

The primary operational benefits of HOV lanes (compared to congested general-purpose freeway lanes) are higher travel speeds and average vehicle occupancy (i.e., the ability to move a greater number of persons). Any methodology designed to estimate the impacts of HOV lanes on congestion should, therefore, include these operational characteristics as analytical components.

The vehicular capacity of an HOV lane and a general-purpose freeway lane are fairly similar. As alluded to previously, however, the person-moving capacity of an HOV lane is significantly greater than that of a general-purpose freeway lane.

A significant percentage of HOV lane patrons are typically individuals who travelled adjacent, general-purpose freeway lanes in single occupant vehicles prior to HOV lane implementation. The superior person-moving efficiency of HOV lanes can, therefore, be considered to decrease congestion by effectively removing at least a portion of single occupant vehicles from the general-purpose freeway lanes.

The supply component of the methodology developed to estimate the impact of HOV lanes on congestion takes this potential operational characteristic into account. As is shown in Equation B-1, the average number of persons utilizing the HOV facility is divided by the average vehicle occupancy level for the general-purpose freeway lanes. This value is then divided by the theoretical vehicular capacity (under ideal conditions) of a freeway lane; the resulting number effectively estimates the number of general-purpose freeway lanes than would be required to serve the persons utilizing the HOV lane. In the case of a reversible facility, this value is then multiplied by two (since the HOV lane serves the peak direction of flow during both the morning and evening peak hours) and subsequently multiplied by the length of the HOV facility (in miles). The final product of this equation is an estimate of the effective additional general-purpose freeway lane-miles provided by an HOV facility (i.e., the number of general-purpose freeway lanes required to move the same amount of people as the HOV lane).

$$\begin{array}{c} \text{Avg. no. of} \\ \text{HOV persons} \\ \text{(peak hour)} \end{array} \div \begin{array}{c} \text{1.2 persons} \\ \text{per vehicle} \end{array} \div \begin{array}{c} \text{2,000 veh/} \\ \text{lane} \end{array} * 2 * \begin{array}{c} \text{Length of} \\ \text{HOV facility} \end{array} = \begin{array}{c} \text{Effective additional general-purpose} \\ \text{freeway lane-miles provided by HOV lane} \end{array} \tag{Eq. B-1}$$

An example illustrating the application of this methodology utilizing data from the Katy HOV lane in Houston is included below.

Example 1. An average of approximately 4,000 persons utilized the 11.9-mile Katy HOV lane during both the morning and evening peak hours in 1988.

$$4{,}000 \text{ persons} \div 1.2 \text{ persons/veh} \div 2{,}000 \text{ veh/lane} * 2 * 11.9 \text{ miles} \approx 40 \text{ lane-miles}$$

The results of this example indicate that, during 1988, the 11.9-mile Katy HOV lane effectively served as 40 general-purpose freeway lane-miles.

While the superior person-moving capacity and, thus, the potential supply-side benefits of HOV lanes are apparent, it would be incorrect to only account for the effective increase in supply to the urban area freeway system; HOV lanes also have travel demands associated with them. Logic would dictate that the demand component of an HOV lane analysis should include a means by which to assess the level of service (LOS) being provided by the priority facility. The peak-hour per-lane vehicle volume on an HOV facility was used for this purpose. As illustrated in Equation B-2, the peak hour volume on the HOV facility is gauged by a value that represent the beginning of LOS D operations on the facility. This ratio is multiplied by 15,000 DVMT/ln-mi, which represents the beginning of LOS D operations on a daily basis for an individual facility. The values included in the demand component are arranged to assess the general level of congestion on the HOV facility. It should be noted that the use of the peak-hour per-lane HOV volume as a LOS indicator is based on the assumption that an HOV facility will always be properly managed and a high LOS always maintained (i.e., HOV facility operations will never be allowed to deteriorate to the extent that there are low volumes and low speeds on the facility for any significant length of time).

$$\frac{\text{Peak-hour per-lane HOV volume}}{\text{1,500 veh.}} * \text{15,000 DVMT/ln-mi.} * \text{Lane-miles} = \begin{array}{c}\text{Effective DVMT}\\ \text{on the HOV lane}\end{array} \qquad \text{Eq. B-2}$$

An example illustrating the application of this methodology utilizing data from the Katy HOV lane in Houston is included below.

Example 2. The average peak hour volume on the 11.9-mile, single-lane reversible Katy HOV facility was 1,335 vehicles during 1988.

$$\frac{\text{1,335 veh.}}{\text{1,500 veh.}} * \text{15,000 DVMT} * \text{11.9 Lane-miles} \approx \text{158,865 DVMT}$$

The results of this example indicate that, during 1988, the Katy HOV lane effectively served a demand of 158,865 general-purpose freeway DVMT.

The values produced by applying Equations B-1 and B-2 can be added directly to freeway lane-mile and DVMT data for a roadway system (i.e., data such as that included in Table 1 of Chapter 2). If these calculations were carried out for the entire Houston HOV lane system in 1989, (43.5 lane-miles of HOV facilities) the RCI for the Houston urban area would be shown to decrease from 1.13 to 1.10 (approximately a 3 percent reduction in congestion). Considering the fact that the HOV lane system in Houston provides mobility (at a relatively high LOS) to approximately 4 percent of all persons travelling during the peak periods of weekday travel, this estimated reduction in congestion appears reasonable.

It is important to note that, while utilizing DVMT and total roadway (freeway and principal arterial) lane-miles of supply as a basis for assessing urban area congestion, the RCI is designed to reflect the peak hour operations of a roadway system. In order to maintain consistency while working within the context of the RCI, the methodology described previously (Equations B-1 and B-2) utilizes peak hour data to assess the impacts of HOV facilities on urban area congestion. These data are, however ultimately expressed in terms that are consistent with the RCI (i.e., DVMT and lane-miles).

Signal System Improvement Methodology

As described previously in Chapter 4, the potential benefits of signal system improvements depend upon the status of the existing signal timing system. For instance, if a system comprised primarily of isolated/uncoordinated signals were upgraded to central coordinated control, the benefits would be greater than had a system comprised primarily of local coordinated signals been upgraded to central coordinated control. The status of the existing principal arterial signal systems in the seven largest urban areas in Texas was, therefore, determined through the use of a survey.

In this survey, city traffic engineers were asked to identify the percentage of their signalized principal arterial intersections falling into the following four general categories: 1) isolated/uncoordinated signals; 2) local coordinated signals either through time-based coordination or hardwire interconnection; 3) monitored/coordinated signals (local coordinated signals that can be monitored such that pre-determined signal timing plans can be down-loaded to the signals if the need arises; and 4) central coordinated signals (signals for which timing is continually optimized by computers using real-time data).

The results of this survey are summarized in Table B-1. As indicated in this table, significant portions of the principal arterial signal systems in several major urban areas in Texas are still operated under isolated/uncoordinated control. An example survey and cover letter are included at the end of this section.

As discussed previously in Appendix A, the RCI is an empirically developed equation based on the travel conditions in Houston during the late 1970s. If pinpointed to a specific year, it appears that urban area travel conditions reached the undesirable level during 1977. If, therefore, improvements to the signal systems shown in Table B-1 were to be correctly assessed in terms of the RCI, the existing (1989) congestion indices should be adjusted to reflect any changes in these systems relative to the Houston principal arterial signal system in 1977.

Table B-1. Existing Status of Texas Urban Area Principal Arterial Signal Systems

Urban Area	Principal Arterial Lane-Miles in System, 1989	Category By % of System			
		Isolated/ Uncoordinated[1]	Local Coordinated[2]	Monitored/ Coordinated[3]	Central Coordinated[4]
Austin	425	21	10	69	0
Corpus Christi	320	4	55	27	15
Dallas	1,695	11	82	5	1
El Paso	830	14	51	0	35
Fort Worth	865	41	34	0	25
Houston	2,010	7	75	13	5
San Antonio	1,080	33	58	9	0

[1] Includes pre-timed signals without any type of interconnection with other signals

[2] Includes signals coordinated either through hard-wire interconnection or time-based coordination

[3] Includes signals that are able to be monitored such that a library of timing plans developed off-line can be downloaded to the signal if needed

[4] Includes UTCS control; signals that are monitored by computers with the capability to implement timing plans developed on-line; virtual real-time, traffic responsive timing capabilities

Based on previous research by Wagner (referenced earlier in the body of this report), it appears that the effective increases in principal arterial capacity shown in Table B-2 are appropriate for assessing the impact of signal system improvements on urban area congestion.

While benefits associated with signal system improvements are typically expressed in terms of delay, the benefits in Table B-2 are expressed in lanes-miles of supply so that the impacts can be expressed in terms consistent with the RCI.

Table B-2. Estimated Impacts of Various Levels of Signal System Improvement on Principal Arterial Congestion

Before Condition[1]	After Condition[2]	Effective Increase In Supply, %[3]
Isolated/uncoordinated	Local coordinated	10%
Isolated/uncoordinated	Monitored/coordinated	15%
Isolated/uncoordinated	Central coordinated	25%
Local coordinated	Monitored/coordinated	5%
Local coordinated	Central coordinated	15%
Monitored/coordinated	Central coordinated	10%

[1] The status of a signalized principal arterial intersection prior to being upgraded
[2] The status of a signalized principal arterial intersection after being upgraded
[3] The effective percentage increase in capacity due to respective signal system improvements

The effective increases included in Table B-2 were used in conjunction with data relative to the Houston principal arterial signal system in 1977 to produce adjusted congestion indices for the seven major Texas urban areas (Table B-3). As indicated in Table B-3, with the exception of Corpus Christi and El Paso, the effective reductions in congestion were minimal.

Table B-3. Adjusted Existing Status of Texas Urban Area Principal Arterial Signal Systems

Urban Area	Principal Arterial Lane-Miles in System, 1989	Category By % of System				Effective Increase in Supply[5]		Roadway Congestion Index (RCI)		
		Isolated/ Uncoordinated[1]	Local Coordinated[2]	Monitored/ Coordinated[3]	Central Coordinated[4]	Lane-Miles	%	Before[6]	After[7]	% Reduction
Austin	425	21	10	69	0	17	4.1	0.96	0.96	0.5
Corpus Christi	320	4	55	27	15	19	5.9	0.71	0.69	2.0
Dallas	1,695	11	82	5	1	35	2.1	1.02	1.02	0.2
El Paso	830	14	51	0	35	55	6.6	0.74	0.72	1.8
Fort Worth	865	41	34	0	25	21	2.4	0.87	0.87	0.3
Houston, 1977	1,450	30	65	5	0	0	0.0	1.01	1.01	0.0
Houston, 1989	2,010	7	75	13	5	68	3.4	1.13	1.13	0.4
San Antonio	1,080	33	58	9	0	0	0.0	0.87	0.87	0.0

[1] Includes pre-timed signals without any type of interconnection with other signals

[2] Includes signals coordinated either through hard-wire interconnection or time-based coordination

[3] Includes signals that are able to be monitored such that a library of timing plans developed off-line can be down-loaded to the signal if needed

[4] Includes UTCS control; signals that are monitored by computers with the capability to implement timing plans developed on-line; virtual real-time, traffic responsive timing capabilities

[5] The effective increase in supply/capacity due to signal-timing improvements relative to the Houston system in 1977

[6] Existing (1989) roadway congestion index (RCI) prior to being adjusted for signal-system timing improvements

[7] RCI after being adjusted for signal-system timing improvements; these adjustments are relative to the condition of the Houston principal arterial signal system in 1977 (the point at which congestion in Houston is estimated to have reached the undesirable level; also the point in time to which the RCI is gauged)

Once the congestion indices had been adjusted to reflect existing signal system characteristics, the following three scenarios of signal system improvements were examined: 1) upgrading all isolated/uncoordinated signals to local coordinated control; 2) upgrading the signal systems to 75% monitored/coordinated and 25% central coordinated; and 3) upgrading the signal systems to 25% monitored/coordinated and 75% central coordinated. The same relationships between respective upgrades indicated in Table B-2 were used to assess the impact of these three scenarios of signal system improvements on urban area congestion.

The results of these analyses are summarized in Tables B-4 through B-6. As indicated in these tables, the estimated reductions in congestion from upgrading the principal arterial signal systems to the latter two scenarios range from approximately 1 to 3 percent.

Table B-4. Adjusted Existing Status of Texas Urban Area Principal Arterial Signal Systems

Urban Area	Principal Arterial Lane-Miles in System, 1989	Category By % of System				Effective Increase in Supply[5]		Roadway Congestion Index (RCI)		
		Isolated/ Uncoordinated[1]	Local Coordinated[2]	Monitored/ Coordinated[3]	Central Coordinated[4]	Lane-Miles	%	Before[6]	After[7]	% Reduction
Austin	425	0	30	70	0	10	2.4	0.96	0.96	0.2
Corpus Christi	320	0	58	27	15	1	0.3	0.69	0.69	0.1
Dallas	1,695	0	94	5	1	18	1.1	1.02	1.02	0.1
El Paso	830	0	65	0	35	11	1.3	0.72	0.72	0.3
Fort Worth	865	0	75	0	25	35	4.0	0.87	0.86	0.5
Houston	2,010	0	82	13	5	15	0.7	1.13	1.12	0.1
San Antonio	1,080	0	91	9	0	34	3.1	0.87	0.87	0.6

[1] Includes pre-timed signals without any type of interconnection with other signals

[2] Includes signals coordinated either through hard-wire interconnection or time-based coordination

[3] Includes signals that are able to be monitored such that a library of timing plans developed off-line can be down-loaded to the signal if needed

[4] Includes UTCS control; signals that are monitored by computers with the capability to implement timing plans developed on-line; virtual real-time, traffic responsive timing capabilities

[5] The effective increase in supply/capacity due to signal-timing improvements relative to the Houston system in 1977

[6] Existing (1989) roadway congestion index (RCI) prior to being adjusted for signal-system timing improvements

[7] RCI after being adjusted for signal-system timing improvements; these adjustments are relative to the condition of the Houston principal arterial signal system in 1977 (the point at which congestion in Houston is estimated to have reached the undesirable level; also the point in time to which the RCI is gauged)

Table B-5. Adjusted Existing Status of Texas Urban Area Principal Arterial Signal Systems

Urban Area	Principal Arterial Lane-Miles in System, 1989	Category By % of System				Effective Increase in Supply[5]		Roadway Congestion Index (RCI)		
		Isolated/ Uncoordinated[1]	Local Coordinated[2]	Monitored/ Coordinated[3]	Central Coordinated[4]	Lane-Miles	%	Before[6]	After[7]	% Reduction
Austin	425	0	0	75	25	27	6.4	0.96	0.95	0.7
Corpus Christi	320	0	0	75	25	14	4.4	0.69	0.68	1.3
Dallas	1,695	0	0	75	25	139	8.2	1.02	1.01	0.9
El Paso	830	0	0	75	25	30	3.6	0.72	0.72	0.8
Fort Worth	865	0	0	75	25	68	7.9	0.87	0.86	0.9
Houston	2,010	0	0	75	25	138	6.9	1.13	1.12	0.7
San Antonio	1,080	0	0	75	25	111	10.3	0.87	0.86	1.8

[1] Includes pre-timed signals without any type of interconnection with other signals

[2] Includes signals coordinated either through hard-wire interconnection or time-based coordination

[3] Includes signals that are able to be monitored such that a library of timing plans developed off-line can be down-loaded to the signal if needed

[4] Includes UTCS control; signals that are monitored by computers with the capability to implement timing plans developed on-line; virtual real-time, traffic responsive timing capabilities

[5] The effective increase in supply/capacity due to signal-timing improvements relative to the Houston system in 1977

[6] Existing (1989) roadway congestion index (RCI) prior to being adjusted for signal-system timing improvements

[7] RCI after being adjusted for signal-system timing improvements; these adjustments are relative to the condition of the Houston principal arterial signal system in 1977 (the point at which congestion in Houston is estimated to have reached the undesirable level; also the point in time to which the RCI is gauged)

Table B-6. Adjusted Existing Status of Texas Urban Area Principal Arterial Signal Systems

Urban Area	Principal Arterial Lane-Miles in System, 1989	Category By % of System				Effective Increase in Supply[5]		Roadway Congestion Index (RCI)		
		Isolated/ Uncoordinated[1]	Local Coordinated[2]	Monitored/ Coordinated[3]	Central Coordinated[4]	Lane-Miles	%	Before[6]	After[7]	% Reduction
Austin	425	0	0	25	75	48	11.3	0.96	0.94	1.3
Corpus Christi	320	0	0	25	75	30	9.4	0.69	0.67	2.7
Dallas	1,695	0	0	25	75	223	13.2	1.02	1.01	1.3
El Paso	830	0	0	25	75	72	8.7	0.72	0.71	1.9
Fort Worth	865	0	0	25	75	111	12.8	0.87	0.85	1.5
Houston	2,010	0	0	25	75	238	11.8	1.13	1.11	1.2
San Antonio	1,080	0	0	25	75	165	15.3	0.87	0.85	2.7

[1] Includes pre-timed signals without any type of interconnection with other signals

[2] Includes signals coordinated either through hard-wire interconnection or time-based coordination

[3] Includes signals that are able to be monitored such that a library of timing plans developed off-line can be down-loaded to the signal if needed

[4] Includes UTCS control; signals that are monitored by computers with the capability to implement timing plans developed on-line; virtual real-time, traffic responsive timing capabilities

[5] The effective increase in supply/capacity due to signal-timing improvements relative to the Houston system in 1977

[6] Existing (1989) roadway congestion index (RCI) prior to being adjusted for signal-system timing improvements

[7] RCI after being adjusted for signal-system timing improvements; these adjustments are relative to the condition of the Houston principal arterial signal system in 1977 (the point at which congestion in Houston is estimated to have reached the undesirable level; also the point in time to which the RCI is gauged)