TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-90-1131-2		

4. Title and Subtitle Roadway Congestion in Major Urban Areas 1982 to 1987	5. Report Date October 1989 6. Performing Organization Code
7. Author(s) James W. Hanks, Jr. and Timothy J. Lomax	8. Performing Organization Report No. Research Report 1131-2
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. 11. Contract or Grant No. Study 2-10-90-1131
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Interim: September 1987 February 1990 14. Sponsoring Agency Code

15. Supplementary Notes
Research performed in cooperation with DOT, FHWA.
Research Study Title: Roadway Congestion in Major Urban Areas 1982 to 1987

16. Abstract

This research report is an update and expansion of "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," Research Report no. 431-1F. This study expanded the number of urban areas studied to 39, to better represent a geographical cross-section of urban areas throughout the country. An assessment of the freeway and major street operating conditions was performed in seven Texas and 32 other urban areas in the continental United States. In addition, the analyses from 1982 to 1986 were updated to include 1987 urban area data. Vehicle-miles of travel and lane-miles of roadway data were collected from a variety of sources to estimate congestion on the freeway/expressway and principal arterial street systems. The values for each system were combined into a roadway congestion index used to rank mobility in each urban area on a relative scale.

An analysis of the cost of this congestion was performed using travel delay, increased fuel consumption and increased auto insurance premiums as the economic analysis factors. The economic cost to the urban area, and to the individual resident, was estimated.

17. Key Words	18. Distribution Statement
Mobility, Congestion, Economic Analysis, Transportation Planning	No restrictions. This document is available to the public through the: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of the report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	104	

Form DOT F 1700.7 (8-69)

ROADWAY CONGESTION IN MAJOR URBAN AREAS 1982 TO 1987

James W. Hanks, Jr.
Assistant Research Engineer

and

Timothy J. Lomax
Associate Research Engineer

Research Report 1131-2

Research Study Number 2-10-88-1131

Sponsored By

State Department of Highways
and Public Transportation
in Cooperation with the
U.S. Department of Transportation
U.S. Federal Highway Administration

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843

October 1989

METRIC (SI*) CONVERSION FACTORS

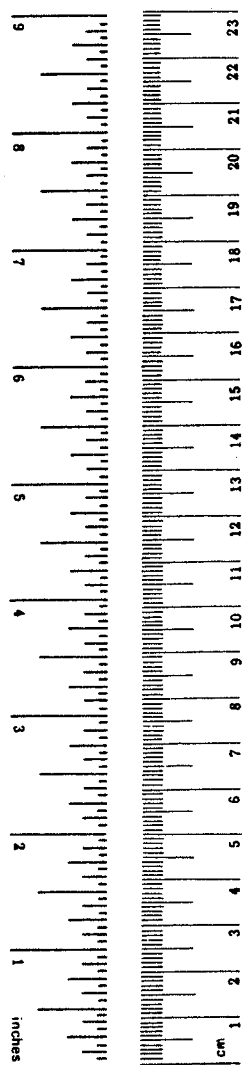
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

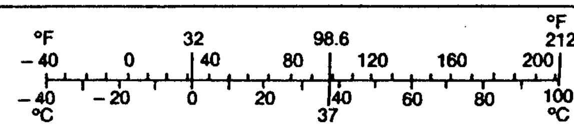


APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

This research report is an update and expansion of "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," Research Report No. 431-1F. This study expanded the number of urban areas studied to 39, to better represent a geographical cross-section of urban areas throughout the country. An assessment of the freeway and major street operating conditions was performed in seven Texas and 32 other urban areas in the continental United States. In addition, the analyses from 1982 to 1986 were updated to include 1987 urban area data. Vehicle-miles of travel and lane-miles of roadway data were collected from a variety of sources to estimate congestion on the freeway/expressway and principal arterial street systems. The values for each system were combined into a roadway congestion index used to rank mobility in each urban area on a relative scale.

An analysis of the cost of this congestion was performed using travel delay, increased fuel consumption, and increased auto insurance premiums as the economic analysis factors. The economic cost to the urban area, and to the individual resident, was estimated.

Key Words: Mobility, Congestion, Economic Analysis, Transportation Planning

IMPLEMENTATION STATEMENT

As a means of assisting the Texas Department of Highways and Public Transportation in planning future highway needs and identifying funding requirements, it is desirable to have a measure of the seriousness of the congestion and mobility problem in major Texas cities and how those cities compare with other major U.S. cities. This report provides a quantification of those mobility levels and the economic impact of congested roadways on urban motorists. A survey of the business community estimated the role of transportation in business planning and decision-making activities. The information in this report should be of value in identifying and prioritizing transportation facility and program needs.

DISCLAIMER

SUMMARY

Roadway system congestion has increased over the past decade in most large U.S. urban areas as transportation facility construction and expansion did not keep pace with the growth of travel demands. Urban areas with low to moderate population densities largely depend on freeway and principal arterial street systems to provide the majority of travel demand requirements. Texas cities have demonstrated a heavy reliance on these systems to provide the person movement required within the urban areas.

This report expands and updates a previous research effort entitled "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," Research Report No. 431-1F. The 431-1F report was expanded, in this study, to include ten additional urban areas located in the Northeast/Midwest region of the country. Overall, this report estimates the congestion level in seven large Texas urban areas and 32 other large U.S. urban areas. Estimates of urban congestion were updated to represent 1987 conditions and trends presented for 82-87. The economic impact of urban roadway congestion on travel time, fuel consumption, and automobile insurance premiums was also estimated to determine the cost of adverse travel conditions.

Freeway and Principal Arterial Street Traffic Congestion

Table S-1 presents the 1987 estimates of daily vehicle-miles of travel (DVMT) per lane-mile of freeway and principal arterial. The roadway congestion index (RCI) value for each urban area was developed by combining the DVMT per lane-mile data for each roadway type in a ratio defined by the amount of daily vehicle-miles of travel. Equation S-1 illustrates how these DVMT per lane-mile values were combined to calculate the urban area congestion index. RCI values greater than 1.0 indicate undesirable mobility levels within the urban area. Urban areas with RCI values less than 1.0 may have roadway sections which experience intense traffic congestion, but the average mobility level within the urban area may be described as good.

$$\text{Roadway Congestion Index} = \frac{\text{Freeway VMT/Ln-Mi} \times \text{Freeway VMT} + \text{Prin. Art. Strs. VMT/Ln-Mi} \times \text{Prin. Art. Strs. VMT}}{13{,}000 \times \text{Freeway VMT} + 5{,}000 \times \text{Prin. Art. Strs. VMT}} \qquad \text{Eq. S-1}$$

Table S-1. 1987 Congestion Index Value

Urban Area	Freeway/Expway DVMT[1] (1000)	Freeway/Expway DVMT[2] Ln-Mile	Principal Arterial Street DVMT[1] (1000)	Principal Arterial Street DVMT[2] Ln-Mile	Congestion[3] Index	Rank
Western & Southern Cities						
Phoenix AZ	4,580	295	16,475	2,610	1.23	4
Los Angeles CA	96,890	4,880	73,810	11,780	1.47	1
Sacramento CA	8,055	660	6,135	1,000	1.00	17
San Diego CA	23,155	1,640	8,180	1,560	1.08	12
San Fran-Oak CA	39,580	2,305	12,670	2,005	1.31	2
Denver CO	9,550	830	10,600	1,930	0.95	22
Miami FL	7,420	555	13,000	2,000	1.14	7
Tampa FL	3,300	280	3,880	610	1.02	16
Atlanta GA	23,940	1,600	9,350	1,500	1.16	6
Indianapolis IN	7,640	710	4,100	835	0.85	32
Louisville KY	5,380	515	2,975	520	0.86	30
Kansas City MO	11,920	1,410	4,350	910	0.69	39
St. Louis MO	16,290	1,430	11,215	1,745	0.96	20
Albuquerque NM	2,025	200	3,550	650	0.91	26
Oklahoma City OK	6,330	700	3,465	655	0.76	36
Portland OR	6,700	540	3,200	525	1.00	17
Memphis TN	3,730	375	3,930	760	0.84	34
Nashville TN	5,000	430	4,915	905	0.95	22
Salt Lake City UT	3,810	410	1,865	340	0.78	35
Seattle-Everett WA	16,600	1,140	8,950	1,475	1.14	7
Northeast & Midwest Cities						
Washington DC	22,910	1,555	18,400	2,240	1.25	3
Chicago IL	30,945	2,260	24,965	3,870	1.11	9
Baltimore MD	13,735	1,200	9,020	1,680	0.92	25
Boston MA	20,205	1,490	13,700	2,675	1.04	14
Detroit MI	21,800	1,610	21,545	3,450	1.10	11
Minn-St. Paul MN	15,620	1,230	5,200	1,160	0.97	19
New York NY	73,615	5,385	46,490	6,930	1.11	9
Cincinnati OH	9,560	845	3,315	790	0.87	29
Cleveland OH	11,185	960	4,840	1,100	0.89	27
Philadelphia PA	15,125	1,370	22,550	3,150	1.06	13
Pittsburgh PA	7,190	925	9,905	1,510	0.85	32
Milwaukee WI	6,820	570	4,640	930	0.94	24
Major Texas Cities						
Austin TX	5,150	420	2,150	415	0.96	20
Corpus Christi TX	1,500	180	1,490	320	0.72	37
Dallas TX	22,100	1,640	8,200	1,690	1.03	15
El Paso TX	3,200	345	3,000	805	0.72	37
Fort Worth TX	11,000	990	4,250	840	0.88	28
Houston Tx	25,800	1,640	10,500	1,970	1.19	5
San Antonio TX	8,800	810	4,800	1,050	0.86	30
West/South Avg	15,095	1,045	9,750	1,715	1.01	
North/Midwest Avg	20,725	1,615	15,380	2,455	1.01	
Outside Texas Avg	17,205	1,260	11,860	1,995	1.01	
Texas Avg	11,080	860	4,910	1,015	0.91	
Congested Texas Avg	14,570	1,100	5,980	1,195	0.98	
Total Avg	16,105	1,190	10,610	1,820	0.99	
Maximum Value	96,890	5,385	73,810	11,780	1.47	
Minimum Value	1,500	180	1,490	320	0.69	

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston and San Antonio

[1]Daily vehicle-miles of travel
[2]Daily vehicle-miles of travel per lane-mile
[3]See Equation S-1

Source: TTI Analysis

The average RCI value for the five most congested Texas cities was three percent lower than the average of cities outside Texas, with Houston being the only Texas city ranked in the ten most congested cities. Figure S-1 presents the relationship of the average congestion index value by region from 1982 to 1987. This Figure shows that both Texas averages experience a consistent increase from 1982 to 1986, however, the average values for 1987 indicate RCI values may have begun to decline.

Cost of Congestion on Urban Roadway Systems

The economic effect of traffic congestion was estimated in the cost of travel delay, excess fuel consumed and higher automobile insurance premiums paid by residents of large, congested urban areas. Table S-2 illustrates the 1987 estimated component and total congestion costs for each urban area. The effects of urban area size and population are normalized in Table S-3 by providing congestion costs on a per capita basis. This table (Table S-3) also separates the direct effects of congestion (delay and fuel) from the less direct (insurance premiums). The per capita cost values and rankings are the most comparable to the congestion index indicators.

Twelve urban areas were estimated to have total 1987 congestion costs in excess of $1 billion. The total estimated impact of congestion on the 39 urban areas studied was approximately $41 billion, or slightly more than $1 billion per city. The 39 cities per capita congestion cost was approximately $360.

The seven Texas cities studied were estimated to have approximately $3.5 billion associated with the adverse impacts of congestion, or $330 per capita. Dallas and Houston have estimated congestion costs in excess of $1 billion with Houston being the only Texas city ranked among the ten highest. On a cost per capita basis Dallas and Houston are ranked in the top ten of the 39 cities studied.

Table S-4 presents the comparison between urban area ranks based on both estimated Congestion Index and congestion cost per capita. This Table shows that normalizing the impact of congestion by population does have an effect on urban area ranking. Normalizing

Table S-2. Component and Total Congestion Costs By Urban Area

Urban Area	Annual Cost Due to Congestion (Millions of $'s) Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Insurance	Total	Delay/Fuel Cost (Millions)
Western & Southern Cities							
Phoenix AZ	390	390	60	60	40	930	890
Los Angeles CA	2,510	2,900	400	460	1,660	7,940	6,280
Sacramento CA	130	120	20	20	80	360	290
San Diego CA	250	190	40	30	60	580	510
San Fran-Oakland CA	770	960	130	160	350	2,370	2,015
Denver CO	240	250	40	40	70	630	560
Miami FL	330	380	50	60	380	1,200	810
Tampa FL	80	100	10	10	20	220	210
Atlanta GA	390	420	60	60	210	1,140	930
Indianapolis IN	20	30	3	4	20	90	60
Louisville KY	50	60	6	7	20	140	120
Kansas City MO	40	60	4	7	40	140	110
St Louis MO	270	300	40	40	90	730	640
Albuquerque NM	40	50	5	6	10	120	100
Oklahoma City OK	40	40	5	5	30	130	100
Portland OR	100	140	10	20	50	310	270
Memphis TN	50	50	6	6	60	170	110
Nashville TN	70	80	10	10	20	200	180
Salt Lake City UT	30	30	4	4	20	90	70
Seattle-Everett WA	330	420	50	70	60	930	870
Northeast & Midwest Cities							
Washington DC	710	1,050	110	160	190	2,220	2,030
Chicago IL	800	910	120	140	500	2,470	1,970
Baltimore MD	150	240	20	50	190	640	440
Boston MA	280	630	40	90	100	1,140	1,040
Detroit MI	520	730	80	110	420	1,870	1,440
Minn-St Paul MN	170	170	30	30	70	450	380
New York NY	1,720	2,830	250	400	1,600	6,800	5,200
Cincinnati OH	70	60	10	10	10	160	150
Cleveland OH	80	70	10	10	130	310	180
Philadelphia PA	550	660	70	90	750	2,120	1,370
Pittsburgh PA	200	260	30	30	230	740	510
Milwaukee WI	80	90	10	10	30	230	200
Major Texas Cities							
Austin TX	80	90	10	10	10	200	190
Corpus Christi TX	10	10	0	0	5	25	20
Dallas TX	280	460	50	70	150	1,010	860
El Paso TX	20	20	0	0	20	60	40
Fort Worth TX	110	180	20	30	70	410	340
Houston TX	470	610	70	100	300	1,540	1,240
San Antonio TX	90	100	10	20	50	270	220
West/South Avg.	310	350	50	50	160	920	760
North/Midwest Avg.	440	640	60	90	350	1,600	1,240
Outside Texas Avg.	360	460	50	70	230	1,170	940
Texas Avg.	150	210	20	30	90	500	410
Congested Texas Avg.	210	290	30	50	120	690	570
Total Avg.	320	410	50	60	210	1,050	840
Maximum Value	2,510	2,900	400	460	1,660	7,940	6,280
Minimum Value	10	10	0	0	5	25	20

Note: Congested Texas cities average includes Austin, Dallas, Fort Worth, Houston, and San Antonio

Source: TTI Analysis and Local Transportation Agency References

Table S-3. Estimated Economic Impact of Congestion

Urban Area	Congestion Cost Per Capita (Dollars)	Delay/Fuel Cost Per Capita (Dollars)	Total Congestion Cost Per Reg. Veh. (Dollars)	Delay/Fuel Cost Per Reg. Veh. (Dollars)
Western & Southern Cities				
Phoenix AZ	510	490	800	765
Los Angeles CA	730	580	1,040	820
Sacramento CA	360	290	300	240
San Diego CA	280	250	440	390
San Fran-Oakland CA	670	570	805	685
Denver CO	420	370	480	425
Miami FL	670	450	895	610
Tampa FL	340	320	380	355
Atlanta GA	650	530	750	610
Indianapolis IN	100	70	160	115
Louisville KY	180	160	320	270
Kansas City MO	130	90	220	165
St Louis MO	380	330	780	680
Albuquerque NM	250	230	315	290
Oklahoma City OK	170	130	270	205
Portland OR	300	260	510	440
Memphis TN	210	130	290	185
Nashville TN	380	340	410	370
Salt Lake City UT	120	90	145	110
Seattle-Everett WA	580	550	810	760
Northeast & Midwest Cities				
Washington DC	740	680	1,380	1,260
Chicago IL	340	270	625	500
Baltimore MD	340	240	645	445
Boston MA	400	370	755	690
Detroit MI	480	370	650	500
Minn-St Paul MN	240	200	285	245
New York NY	430	330	1,190	910
Cincinnati OH	170	160	180	165
Cleveland OH	180	100	215	125
Philadelphia PA	520	340	790	510
Pittsburgh PA	410	280	625	430
Milwaukee WI	190	160	430	375
Major Texas Cities				
Austin TX	420	390	430	405
Corpus Christi TX	80	60	95	75
Dallas TX	530	450	645	550
El Paso TX	110	80	155	110
Fort Worth TX	360	300	410	340
Houston TX	550	440	695	560
San Antonio TX	260	210	325	270
West/South Avg.	370	310	505	425
North/Midwest Avg.	370	290	645	510
Outside Texas Avg.	370	300	560	460
Texas Avg.	330	280	395	330
Congested Texas Avg.	420	360	500	425
Total Avg.	360	300	530	435
Maximum Value	740	680	1,380	1,260
Minimum Value	80	60	95	75

Source: TTI Analysis and Local Transportation Agency References

Table S-4. 1987 Urban Area Rankings By Congestion Index and Cost Per Capita

Urban Area	Congestion Index		Congestion Cost Per Capita	
	Value	Rank	Value (Dollars)	Rank
Western & Southern Cities				
Phoenix AZ	1.23	4	510	10
Los Angeles CA	1.47	1	730	2
Sacramento CA	1.00	17	360	19
San Diego CA	1.08	12	280	25
San Fran-Oakland CA	1.31	2	670	3
Denver CO	.95	22	420	13
Miami FL	1.14	7	670	3
Tampa FL	1.02	16	340	21
Atlanta GA	1.16	6	650	5
Indianapolis IN	.85	32	100	38
Louisville KY	.86	30	180	31
Kansas City MO	.69	39	130	35
St Louis MO	.96	20	380	17
Albuquerque NM	.91	26	250	27
Oklahoma City OK	.76	36	170	33
Portland OR	1.00	17	300	24
Memphis TN	.84	34	210	29
Nashville TN	.95	22	380	17
Salt Lake City UT	.78	35	120	36
Seattle-Everett WA	1.14	7	580	6
Northeast & Midwest Cities				
Washington DC	1.25	3	740	1
Chicago IL	1.11	9	340	21
Baltimore MD	.92	25	340	21
Boston MA	1.04	14	400	16
Detroit MI	1.10	11	480	11
Minn-St Paul MN	.97	19	240	28
New York NY	1.11	9	430	12
Cincinnati OH	.87	29	170	32
Cleveland OH	.89	27	180	31
Philadelphia PA	1.06	13	520	9
Pittsburgh PA	.85	32	410	15
Milwaukee WI	.94	24	190	30
Major Texas Cities				
Austin TX	.96	20	420	13
Corpus Christi TX	.72	37	80	39
Dallas TX	1.03	15	530	8
El Paso TX	.72	37	110	37
Fort Worth TX	.88	28	360	19
Houston TX	1.19	5	550	7
San Antonio TX	.86	30	260	26

Note: [1]Rankings based on rounded values
Source: TTI Analysis

congestion impact using cost per capita, four urban areas move in and out of the ten highest ranked. The four urban areas affected consist of Chicago (9th to 21st) and New York (9th to 12th) being excluded and Philadelphia (13th to 9th) and Dallas (15th to 8th) being included. It should be noted that the other cities do change their ranked position but remain within the highest ten ranked areas.

Undetermined Impacts of Congestion

The expected outcome of this analysis would intuitively be that urban areas with larger populations, area size, or densities, experience higher roadway congestion index values than smaller urban areas. However, this study indicates while these factors may indeed influence the roadway congestion index, one cannot assume these factors dictate the RCI value magnitude. Many larger Northeastern/Midwestern cities, such as New York City, Chicago, Detroit, and Washington, D.C., typify this paradox. New York City has the largest population and urban area, and is the second most densely populated area included in this study. Roadway congestion index calculations, however, rank New York City 9th with respect to urban area congestion. Intuitively, this conclusion seems unrealistic and becomes more confusing considering general public opinion of traffic conditions in New York City.

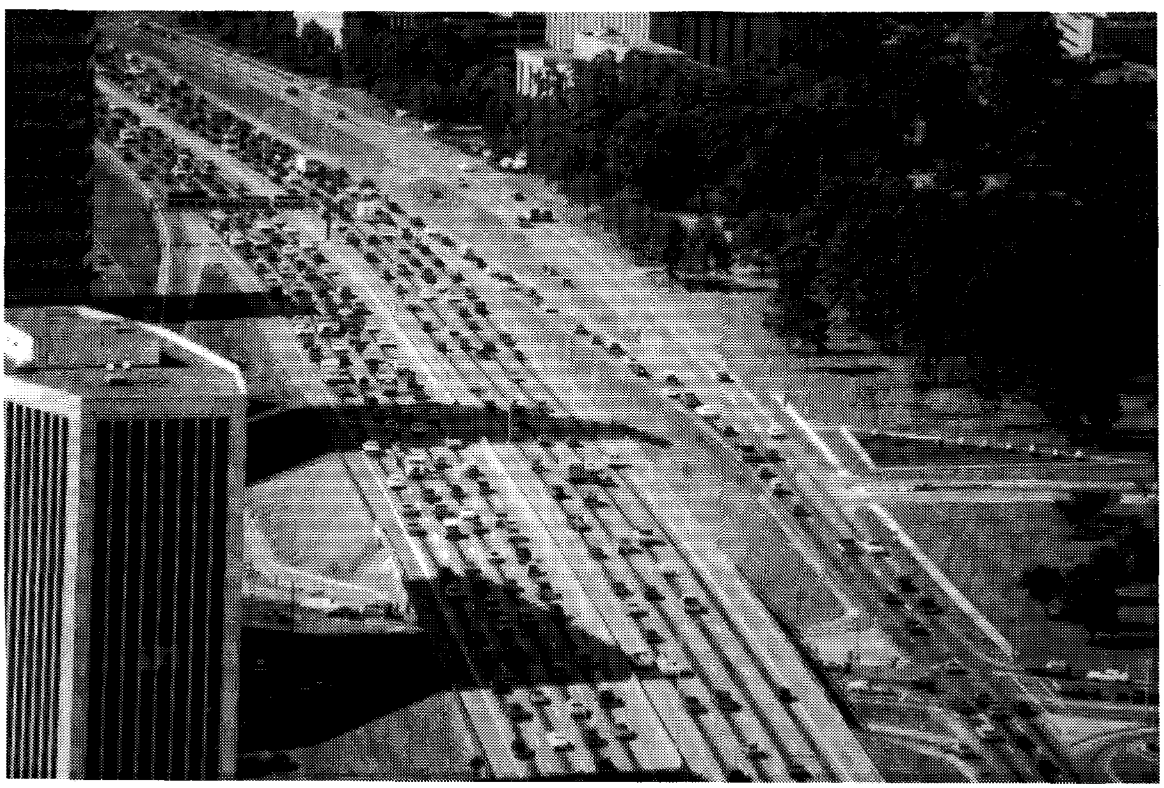
The roadway congestion index, as stated in this report, is intended to be an urban area value, representing the entire area and not site specific locations, i.e. bridges, tunnels, or other point sites of congestion. Secondly, the roadway congestion index is based on areawide freeway and principal arterial street travel. Therefore, if a large percentage of the freeways or principal arterial street systems have "good" operational characteristics, the effects of bottlenecks and other sites of point congestion may be underestimated or "washed-out" with this analysis. It should also be noted that the RCI and its methodology were developed for urban areas in the Southern/Western portion of the country. Urban areas in the Northeastern/Midwestern states have different roadway and development patterns. In addition, freeway systems in many Northeastern/Midwestern cities have older designs including narrower lanes and shoulders than systems prevalent in the South and West.

Other caveats pertaining to the interpretation of the roadway congestion index, as intended by this study, include traffic signal system operation and the role of transit. Neither of these were included in the RCI methodology. While it is agreed that these factors affect urban mobility, their effects are more complex than could be included in an areawide analysis technique.

TABLE OF CONTENTS

INTRODUCTION

Since the mid-1970s, the general public and businesses alike have become increasingly aware of the effects of congestion on urban mobility. The existing freeway system, in most cities, is the result of the 42,000 mile National System of Interstate and Defense Highways approved by Congress in 1956. The first major expenditures toward improving urban systems through new construction and rehabilitation were implemented by the Federal Aid Highway Act of 1970. This act was redefined by the Federal Aid Highway Act of 1973. The system, defined by those two acts, serves major centers of activity within urban areas. However, the relative slowdown in roadway construction during the mid-1970s allowed the level of urban mobility to deteriorate. Urban areas with low to moderate population densities like those in Texas, depend on the freeway and major street systems to provide almost all person movement throughout the urban area; roadway system congestion has increased over the past ten years. The importance of traffic congestion measurement methodologies is related to the reliance on transportation infrastructure, and the support of economic growth.



The most noticeable effect of congestion on urban mobility from the public's perspective is the increased traffic delay. Traffic congestion directly affects the travel time motorists incur during their daily travels. "Rush-hour" traffic, in most larger cities, no longer occurs only during the traditional morning and evening peak-periods, but rather extends into much of a normal day.

A recent study (1)[1] indicates that most businesses consider the roadway network serving their firm severely congested during weekday peak travel hours. Table 1 illustrates factors that businesses consider important in deciding where to locate.

Table 1. Relative Importance of Various Factors in Company's Decision to Locate at Present Site

Factor	Rating[1] Mean Total Sample	Significance Level[2] Total Sample
Land ownership or leasing costs	4.02	Most Significant
Convenient access to highway facilities	3.90	
Physical environment	3.88	
Proximity to markets	3.81	
Availability of parking	3.74	
Uncongested highway facilities	3.53	Intermediate Significance
Availability of trained labor force	3.30	
Convenient access to airport	3.13	
Local government attitudes or incentives	3.09	
Existing residential location of professional/managerial staff	2.95	Least Significant
Local taxes	2.92	
Existing residential locations of support/technical staff	2.92	
Proximity to public transportation	2.87	
Cost of living	2.84	
Availability of good housing nearby	2.80	

[1]Each factor was rated on a scale of one (not important) to five (very important).
[2]To assess statistically significant differences in the responses, a Duncan's multiple range test for variable rank was performed.

Source: TTI. "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," Research Report 431-1F, 1989.

Table 1 cites transportation factors as being significant in the location of a business. The quality of transportation, (Table 2), is also extremely important to business activities.

---

[1]Numbers in parentheses denote references listed at the end of the report.

Table 2. Relative Importance of Various Factors to Current Business Activities of Firm

Factor	Rating[1] Mean Total Sample	Significance Level[2] Total Sample
The quality of transportation facilities and services in making your city a pleasant place to live and work	3.86	Most Significant
Access for your personnel to others in your industry	3.63	Intermediate Significance
Transportation of materials and products to and from markets and suppliers	3.04	Least Significant

[1]Each factor was rated on a scale of one (not important) to five (very important).
[2]To assess statistically significant differences in the responses, a Duncan's multiple range test for variable rank was performed.

Source: TTI. "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," Research Report 431-1F, 1989.

The current perception of transportation mobility levels in many major cities is negative. This perception has resulted in an increase of roadway construction in urban areas by federal, state, and local agencies. Limited funds available for construction make urban mobility an important issue in urban planning. This reconstruction is necessary so that the transportation infrastructure can keep pace with increasing demands of the urban area.

Relative Mobility Levels

Recent research (1, 2, 3) has resulted in the development of a methodology to provide quantitative estimates of a city's mobility level. This methodology uses several data bases and a methodology which analyze the impact of traffic congestion, traffic volume growth, and facility construction on mobility. This allows comparisons to be made between various transportation systems, with respect to the mobility level being provided by existing facilities. This research report uses existing data from federal, state, and local agencies to develop planning level estimates of traffic conditions on freeways and principal arterial streets in 39 urban areas, between 1982 and 1987. The seven largest urban areas in Texas (population greater than 250,000) are included in the urban areas studied.

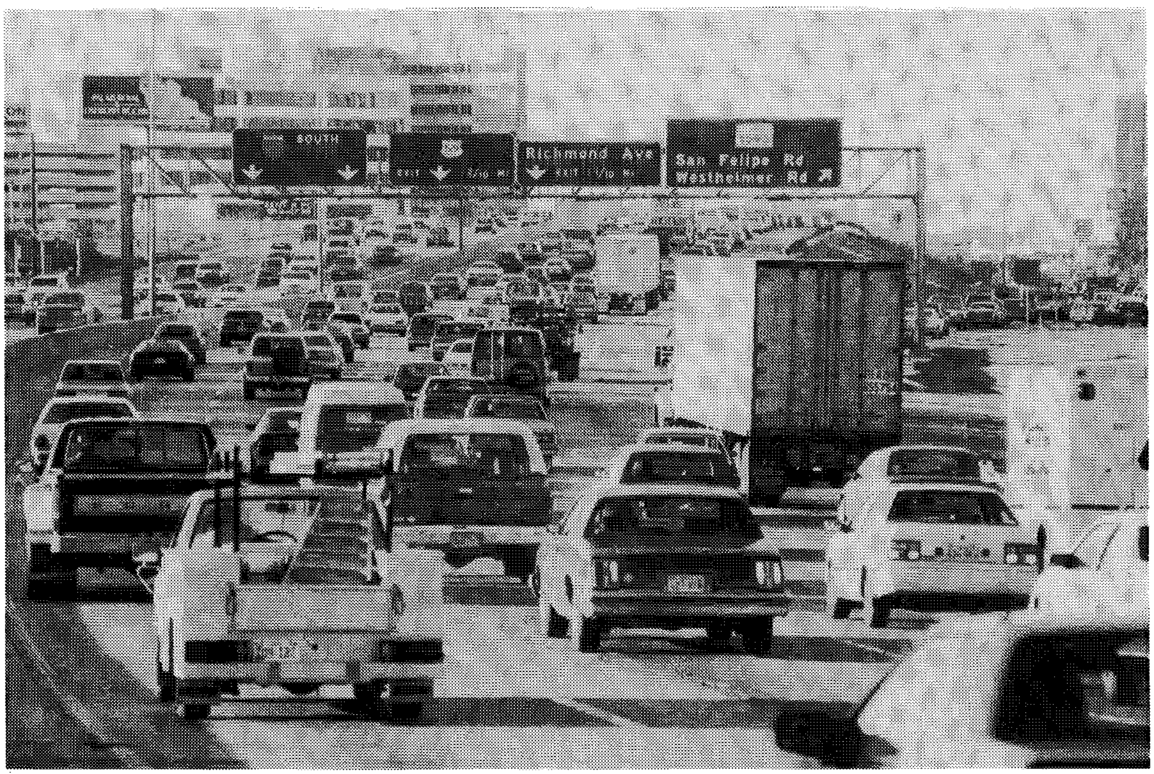
The urban areas included in this research have varying population densities, development, and land use patterns. For this reason, a limited level of comparability exists between Texas and Northeastern/Midwestern urban areas. The development of roadway system, in those two regions, also differs a great deal. Northeastern/Midwestern cities tend to be older and have roadway systems consisting of more principal arterial streets. Older freeway design are prevalent in these cities. These designs, are often typified by the absence of shoulders and narrow lane widths. The methodology used in this study was developed for urban areas in the Western/Southern region of the country. Most of these cities have low to moderate population density and rely on street and highway systems for urban mobility. Urban areas in the region have a more automobile-oriented society than the Northeastern/Midwestern urban areas.

Economic Impact

This research study estimates the costs associated with traffic congestion in large urban areas. There are three factors which were analyzed to quantify the economic impact of traffic congestion. Travel delay is a major element of the congestion cost associated with a transportation system. Traffic congestion also results in increased fuel consumption. The third element of congestion cost estimated in this study was higher insurance rates paid by urban residents when compared to rates paid by persons living in less urbanized areas. Combining the effects of these three factors, congestion costs are estimated on an areawide, per registered vehicle, and per capita basis.

URBAN AREA RELATIVE MOBILITY LEVEL

This section summarizes urban area travel volume and capacity statistics. The statistics, in this section, were developed for the 39 study areas from federal, state, and local sources. This study uses the major indicators of daily vehicle-miles of travel (DVMT) per lane-mile for freeways and principal arterial streets combined in a congestion index to rank the relative mobility of an urban area. Comparing urban area relative mobility was facilitated by the use of frequency and density ratios. These ratios are the result of combining travel volume and facility demand with urban area population and size.



Methodology

The congestion indicators and indices used in this study are the result of research conducted by the Texas Transportation Institute (TTI) (1, 2, 3). The most important indicators of congestion are freeway and principal arterial street daily vehicle-miles of travel per lane-mile. When areawide freeway travel volumes reach 13,000 daily vehicle-miles of travel per lane-mile, congested conditions (level of service D) are estimated to occur. For principal arterial streets, the corresponding level of service is represented by a system average of 5,000 daily vehicle-miles of travel per lane-mile. These values were combined with the existing freeway and principal arterial street DVMT per lane-mile values to estimate one indicator of relative mobility in urban areas. Equation 1 illustrates how these values were combined to calculate the roadway congestion index.

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

A detailed discussion of this methodology is contained in Appendix A of this report.

Freeway/Expressway Travel and Mileage Statistics

Freeway operating conditions in 1987 are summarized in Table 3. Table 3 illustrates the daily vehicle-miles of travel (DVMT), lane-miles of urban freeway system, average number of lanes in the system and DVMT per lane-mile. DVMT per lane-mile is the basis of the ranking reported in Table 3. At the bottom of the Table are the summary statistics for the freeway system travel and mileage. This summary compares the freeway systems of urban areas in several geographical regions.

Of the 39 urban areas included in this study, 14 have DVMT per lane-mile values exceeding the desirable areawide average of 13,000 DVMT per lane-mile. Los Angeles, San Francisco, Houston, Phoenix, Atlanta, Washington D.C., Seattle-Everett, San Diego, New York, and Chicago were estimated to have the ten most congested urban freeway systems. Of the ten most congested cities, Phoenix (300 lane-miles) has the only freeway system of less than 1,000 lane-miles. This system also has the smallest average systemwide number of lanes (4.8) of the top ten. Congestion on the Phoenix freeway system may be attributed to inadequate freeway system length and cross-section. The remaining nine freeway systems have an average cross-section of 6.3 lanes. Congestion in these urban areas appears to be caused by high traffic demand (DVMT) on the freeway system.

Table 3. 1987 Freeway Mileage and Travel Volume

Urban Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Rank[3] DVMT/LM
Western & Southern Cities					
Phoenix AZ	4,580	300	4.8	15,530	4
Los Angeles CA	96,890	4,880	8.2	19,860	1
Sacramento CA	8,060	660	6.9	12,210	18
San Diego CA	23,160	1,640	7.4	14,120	8
San Fran-Oak CA	39,580	2,310	6.8	17,170	2
Denver CO	9,550	830	5.2	11,510	23
Miami FL	7,420	560	5.4	13,370	14
Tampa FL	3,300	280	4.9	11,790	20
Atlanta GA	23,940	1,600	6.1	14,960	5
Indianapolis IN	7,640	710	5.0	10,760	30
Louisville KY	5,380	520	4.4	10,450	31
Kansas City MO	11,920	1,410	4.6	8,450	37
St. Louis MO	16,290	1,430	5.5	11,390	25
Albuquerque NM	2,030	200	5.0	10,130	32
Oklahoma City OK	6,330	700	5.0	9,040	36
Portland OR	6,700	540	5.0	12,410	16
Memphis TN	3,730	380	5.1	9,950	33
Nashville TN	5,000	430	4.4	11,630	22
Salt Lake City UT	3,810	410	5.5	9,290	34
Seattle-Everett WA	16,600	1,140	5.8	14,560	7
Northeast & Midwest Cities					
Washington DC	22,910	1,560	5.6	14,730	6
Chicago IL	30,950	2,260	5.8	13,690	10
Baltimore MD	13,740	1,200	5.2	11,450	24
Boston MA	20,210	1,490	5.6	13,560	11
Detroit MI	21,800	1,610	5.8	13,540	12
Minn-St. Paul MN	15,620	1,230	4.8	12,700	15
New York NY	73,620	5,390	5.2	13,760	9
Cincinnati OH	9,560	850	5.3	11,310	26
Cleveland OH	11,190	960	4.6	11,650	21
Philadelphia PA	15,130	1,370	5.3	11,040	28
Pittsburgh PA	7,190	930	4.1	7,770	39
Milwaukee WI	6,820	570	5.1	11,970	19
Major Texas Cities					
Austin TX	5,150	420	5.5	12,260	17
Corpus Christi TX	1,500	180	5.3	8,330	38
Dallas TX	22,100	1,640	5.4	13,480	13
El Paso TX	3,200	350	5.0	9,280	35
Fort Worth TX	11,000	990	5.1	11,110	27
Houston Tx	25,800	1,640	6.2	15,730	3
San Antonio TX	8,800	810	5.0	10,860	29
West/South Avg.	15,100	1,050	5.6	12,430	
North/Midwest Avg.	20,730	1,620	5.2	12,260	
Outside Texas Avg.	17,210	1,260	5.4	12,370	
Texas Avg.	11,080	860	5.3	11,580	
Congested Texas Avg.	14,570	1,100	5.4	12,690	
Total Avg.	16,110	1,190	5.4	12,230	
Maximum Value	96,890	5,390	8.2	19,860	
Minimum Value	1,500	180	4.1	7,770	

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston and San Antonio

[1] Daily vehicle-miles of travel
[2] Daily vehicle-miles of travel per lane-mile of freeway
[3] Rank value of 1 associated with most congested condition

Source: TTI Analysis and Local Transportation Agency References

Seven Texas urban areas were included in this study. Of those seven areas, only the Dallas and Houston freeway systems experience DVMT per lane-mile values exceeding the undesirable level. Houston is the only urban area in Texas ranked in the ten most congested freeway systems. The Houston freeway system has an average cross-section of 6.2 lanes, while the statewide average is 5.3 lanes.

The summary statistics at the bottom of Table 3 show that all geographic areas (Southern/Western, Northeastern/Midwestern, and Texas) have average DVMT values slightly lower than the undesirable 13,000 DVMT per lane-mile value. The statewide Texas average is the lowest, approximately six percent less than the other two geographic regions considered in this study. The congested urban areas of Texas have a DVMT per lane-mile value slightly higher than the other regional averages.

Table 4 presents freeway system statistics in relation with the 1987 urban area size and population estimates. Of the 39 study areas, ten have population densities of over 3,000 persons per square mile. Overall, urban areas outside Texas have population densities over 50 percent more dense than the urban areas located in Texas. If the ten more densely populated cities were removed from this average, Texas urban areas are approximately 25 percent less dense.

The urban areas in Texas have the highest average levels of freeway travel per capita. This statistic illustrates the reliance of an urban area on the freeway system. Western/Southern cities were found to have higher levels of freeway travel per capita than Northeastern/Midwestern cities. The five most congested Texas cities have the highest average of freeway travel per capita (almost 10.0).

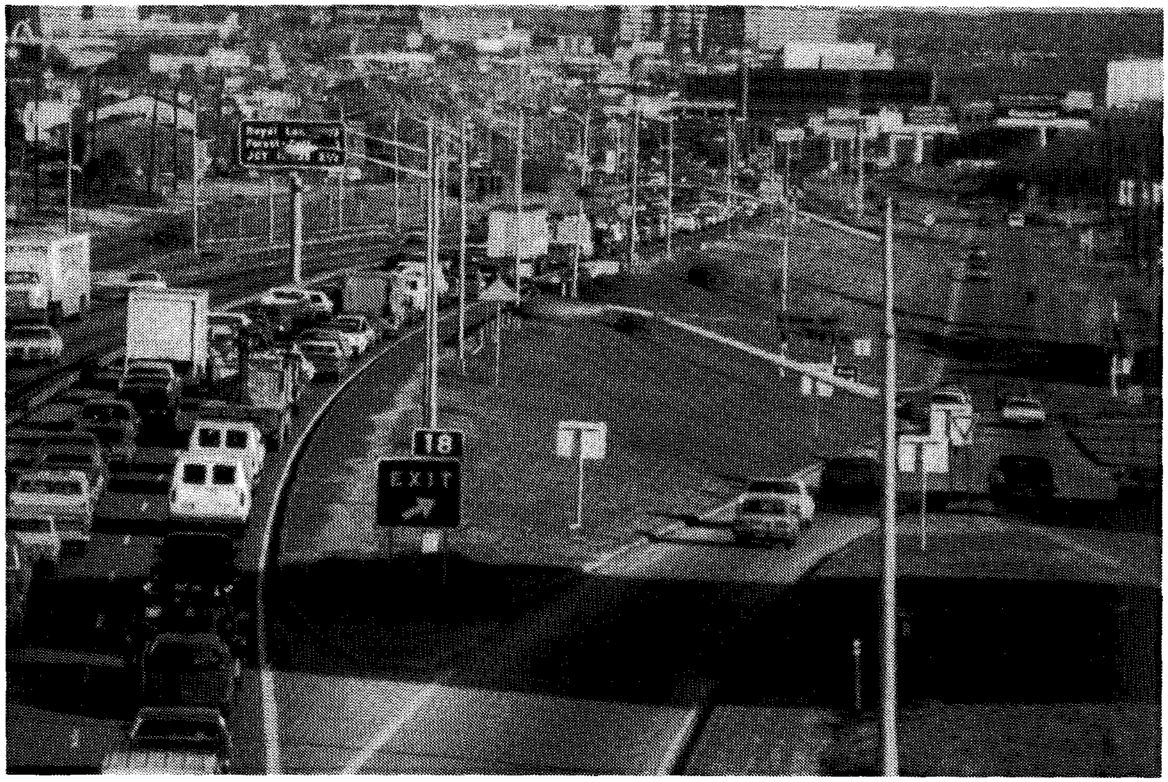
Table 4. Summary of Freeway Travel Frequency and Density Statistics for 1987

Urban Area	1987 Popn. (1000)	Urban Area (Sq. Mi)	Popn. Density Per/Sq Mi	DVMT[1] Per Person	Rank[5]	DVMT[2] Per Sq Mi	Rank[5]	Ln Mi[3] Per 1000 Pers	Rank[5]	Ln Mi[4] Per Sq Mi	Rank[5]
Western & Southern Cities											
Phoenix AZ	1,820	890	2,050	2.52	39	5,150	39	0.16	39	0.33	39
Los Angeles CA	10,920	2,100	5,200	8.87	12	46,140	2	0.45	31	2.32	4
Sacramento CA	1,000	340	2,930	8.10	18	23,690	6	0.66	15	1.94	8
San Diego CA	2,070	680	3,040	11.19	4	34,050	3	0.79	9	2.41	2
San Fran-Oak CA	3,520	820	4,290	11.24	3	48,270	1	0.65	16	2.81	1
Denver CO	1,510	880	1,730	6.32	26	10,910	31	0.55	22	0.95	34
Miami FL	1,790	460	3,880	4.16	36	16,130	18	0.31	37	1.21	25
Tampa FL	650	430	1,520	5.12	30	7,770	38	0.43	33	0.66	38
Atlanta GA	1,770	1,500	1,180	13.53	1	15,960	21	0.90	4	1.07	30
Indianapolis IN	930	430	2,150	8.26	17	17,770	14	0.77	10	1.65	13
Louisville KY	790	360	2,190	6.81	22	14,940	26	0.65	16	1.43	17
Kansas City MO	1,140	590	1,950	10.46	6	20,380	11	1.24	1	2.41	2
St. Louis MO	1,940	710	2,730	8.40	14	22,940	9	0.74	12	2.01	6
Albuquerque NM	460	250	1,820	4.45	34	8,100	37	0.44	32	0.80	37
Oklahoma City OK	730	500	1,460	8.67	13	12,660	29	0.96	2	1.40	18
Portland OR	1,050	410	2,550	6.41	23	16,340	17	0.52	25	1.32	19
Memphis TN	820	400	2,040	4.58	33	9,330	35	0.46	30	0.94	35
Nashville TN	520	470	1,110	9.62	10	10,640	32	0.83	8	0.91	36
Salt Lake City UT	770	380	2,010	5.00	31	10,030	34	0.54	24	1.08	29
Seattle-Everett WA	1,600	710	2,260	10.41	7	23,550	7	0.71	13	1.62	14
Northeast & Midwest Cities											
Washington DC	2,980	820	3,630	7.69	19	27,940	4	0.52	25	1.90	9
Chicago IL	7,200	1,960	3,670	4.30	35	15,790	22	0.31	37	1.15	27
Baltimore MD	1,880	530	3,570	7.33	20	26,160	5	0.64	20	2.29	5
Boston MA	2,850	1,040	2,750	7.09	21	19,520	12	0.52	25	1.44	16
Detroit MI	3,890	1,250	3,120	5.61	28	17,510	16	0.41	34	1.29	20
Minn-St. Paul MN	1,890	1,000	1,890	8.29	16	15,700	23	0.65	16	1.24	22
New York NY	16,000	3,160	5,060	4.60	32	23,300	8	0.34	35	1.70	12
Cincinnati OH	930	420	2,210	10.28	8	22,760	10	0.91	3	2.01	6
Cleveland OH	1,750	630	2,780	6.39	25	17,750	15	0.55	22	1.52	15
Philadelphia PA	4,090	1,120	3,660	3.70	38	13,570	27	0.34	35	1.23	24
Pittsburgh PA	1,810	720	2,530	3.97	37	10,060	33	0.51	28	1.29	20
Milwaukee WI	1,210	550	2,200	5.64	27	12,400	30	0.47	29	1.04	31
Major Texas Cities											
Austin TX	480	340	1,410	10.73	5	15,150	25	0.88	5	1.24	22
Corpus Christi TX	280	180	1,570	5.45	29	8,570	36	0.65	16	1.03	32
Dallas TX	1,910	1,420	1,350	11.57	2	15,560	24	0.86	7	1.15	27
El Paso TX	500	200	2,500	6.40	24	16,000	20	0.69	14	1.73	10
Fort Worth TX	1,130	830	1,360	9.73	9	13,250	28	0.88	5	1.19	26
Houston Tx	2,820	1,610	1,750	9.15	11	16,030	19	0.58	21	1.02	33
San Antonio TX	1,050	470	2,230	8.38	15	18,720	13	0.77	10	1.72	11
West/South Avg.	1,790	660	2,400	7.71		18,740		0.64		1.46	
North/Midwest Avg.	3,870	1,100	3,090	6.24		18,540		0.51		1.50	
Outside Texas Avg.	2,570	830	2,660	7.16		18,660		0.59		1.48	
Texas Avg.	1,170	720	1,740	8.77		14,760		0.76		1.30	
Congested Texas Avg.	1,480	930	1,620	9.91		15,740		0.79		1.26	
Total Avg.	2,320	810	2,500	7.45		17,960		0.62		1.45	
Maximum Value	16,000	3160	5,200	13.53		48,270		1.24		2.81	
Minimum Value	280	180	1,110	2.52		5,150		0.16		0.33	

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston and San Antonio

[1]Daily vehicle-miles of travel per person
[2]Daily vehicle-miles of travel per square mile of urban area
[3]Lane-miles per 1000 persons
[4]Lane-miles per square mile of urban area
[5]Rank value of 1 associated with most congested condition

Source: TTI Analysis and Local Transportation Agency References



The freeway travel per square mile of urban area is a statistic describing the density of development within the area. A large freeway travel per square mile value indicates either a dense development and/or heavier than average dependance on the freeway system. Los Angeles, San Diego, and San Francisco-Oakland are the only areas having freeway travel per square mile estimates greater than 30,000.

Table B-1 in Appendix B illustrates the effects of normalizing Table 4 freeway statistics for population density. Dividing the freeway statistics by population density controls for the variability due to development patterns. The higher density cities (Los Angeles and New York) are ranked significantly lower in all four ratios once normalized in this manner. The largest effect on ranking is in urban areas with more dense populations. This may be the result of less dependance on the freeway system and more dependance on other systems for urban mobility, i.e. buses, rail, transit.

Principal Arterial Street Travel and Mileage Statistics

Table 5 presents the 1987 estimate of principal arterial street travel and mileage. Table 5 has a format identical to that of Table 3. The interpretation of results in this table

Table 5. 1987 Principal Arterial Street Mileage Travel Volume

Urban Area	DVMT[1] (1000)	Lane-Miles	Avg No. Lanes	DVMT/[2] Lane-Mile	Rank[3] DVMT/LM
Western & Southern Cities					
Phoenix AZ	16,480	2,610	3.3	6,310	10
Los Angeles CA	73,810	11,780	4.0	6,270	11
Sacramento CA	6,140	1,000	4.0	6,140	14
San Diego CA	8,180	1,560	3.4	5,240	25
San Fran-Oak CA	12,670	2,010	3.9	6,320	9
Denver CO	10,600	1,930	3.8	5,490	18
Miami FL	13,000	2,000	4.3	6,500	5
Tampa FL	3,880	610	3.8	6,360	8
Atlanta GA	9,350	1,500	3.7	6,230	13
Indianapolis IN	4,100	840	3.7	4,910	31
Louisville KY	2,980	520	3.6	5,720	17
Kansas City MO	4,350	910	3.4	4,780	33
St. Louis MO	11,220	1,750	3.2	6,430	7
Albuquerque NM	3,550	650	3.5	5,460	20
Oklahoma City OK	3,470	660	3.1	5,290	24
Portland OR	3,200	530	3.3	6,100	15
Memphis TN	3,930	760	4.0	5,170	27
Nashville TN	4,920	910	3.4	5,430	21
Salt Lake City UT	1,870	340	3.4	5,490	18
Seattle-Everett WA	8,950	1,480	3.3	6,070	16
Northeast & Midwest Cities					
Washington DC	18,400	2,240	3.8	8,210	1
Chicago IL	24,970	3,870	3.6	6,450	6
Baltimore MD	9,020	1,680	4.0	5,370	22
Boston MA	13,700	2,680	3.4	5,120	28
Detroit MI	21,550	3,450	4.4	6,250	12
Minn-St. Paul MN	5,200	1,160	3.5	4,480	36
New York NY	46,490	6,930	3.4	6,710	3
Cincinnati OH	3,320	790	3.3	4,200	38
Cleveland OH	4,840	1,100	2.9	4,400	37
Philadelphia PA	22,550	3,150	3.0	7,160	2
Pittsburgh PA	9,910	1,510	2.7	6,560	4
Milwaukee WI	4,640	930	3.0	4,990	30
Major Texas Cities					
Austin TX	2,150	420	4.1	5,180	26
Corpus Christi TX	1,490	320	3.5	4,660	34
Dallas TX	8,200	1,690	4.5	4,850	32
El Paso TX	3,000	810	3.6	3,730	39
Fort Worth TX	4,250	840	3.9	5,060	29
Houston Tx	10,500	1,970	3.9	5,330	23
San Antonio TX	4,800	1,050	3.3	4,570	35
West/South Avg.	9,750	1,190	3.6	5,760	
North/Midwest Avg.	15,380	2,050	3.4	5,740	
Outside Texas Avg.	11,860	1,990	3.5	5,800	
Texas Avg.	4,910	1,010	3.8	4,770	
Congested Texas Avg.	5,980	1,190	3.9	5,000	
Total Avg.	10,610	1,820	3.6	5,620	
Maximum Value	73,810	11,780	4.5	8,210	
Minimum Value	1,490	320	2.7	3,730	

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston and San Antonio

[1]Daily vehicle-miles of travel
[2]Daily vehicle-miles of travel per lane-mile of principal arterial
[3]Rank value of 1 associated with most congested condition

Source: TTI Analysis and Local Transportation Agency References

are based on a desirable systemwide level of 5,000 DVMT per lane-mile for principal arterial streets. Only ten cities shown in Table 5 have DVMT per lane-mile levels lower than the desirable level of 5,000. More than one-third of the areas studied had DVMT per lane-mile values in excess of 6,000. Summary statistics show Texas cities having the lowest average DVMT per lane-mile value of the regions summarized, approximately 20 percent lower than urban areas outside Texas. The congested Texas cities have an average of 5,000 DVMT per lane-mile, the desirable limit. Austin, Fort Worth, and Houston are the only Texas cities with values exceeding the desirable level of DVMT per lane-mile.

The average principal arterial street in Texas cities is approximately four lanes. Facilities located outside Texas average 3.5 lanes. These values seem to indicate that Texas has fewer two-lane streets designated as principal arterials than the other U.S. cities studied.

Table 6 presents the volume and principal arterial street system mileage values on a per capita and square mile basis. This Table has the same format as Table 4. Table B-2 in Appendix B presents the four ratios in Table 6 divided by the population density for each urban area.

Comparing results from Tables 4 and 6, illustrated which roadway system (freeway or principal arterial street) provides the most mobility. For example, Texas cities had the highest average DVMT per capita values for freeway travel and the lowest on principal arterial streets. These statistics indicate that Texas cities are the most dependent on the freeway system for mobility. Phoenix exhibits the reverse, with most of the mobility within the urban area being provided by the principal arterial street system.

1987 Roadway Congestion Index Values

Freeway and principal arterial street system travel statistics are summarized in Table 7. Roadway congestion index (RCI) values for 1987 were calculated using systemwide DVMT per lane-mile values and Equation 1. A RCI value equal to or greater than 1.0 indicates an undesirable level of congestion.

Table 6. Principal Arterial Street Travel Frequency and Density Statistics for 1987

Urban Area	1987 Popn. (1000)	Urban Area (Sq. Mi)	Popn. Density Per/Sq Mi	DVMT[1] Per Person	Rank[5]	DVMT[2] Per Sq Mi	Rank[5]	Ln Mi[3] Per 1000 Pers	Rank[5]	Ln Mi[4] Per Sq Mi	Rank[5]
Western & Southern Cities											
Phoenix AZ	1,820	890	2,050	9.05	2	18,510	5	1.43	3	2.93	6
Los Angeles CA	10,920	2,100	5,200	6.76	6	35,150	1	1.08	8	5.61	1
Sacramento CA	1,000	340	2,930	6.17	7	18,040	6	1.01	9	2.94	5
San Diego CA	2,070	680	3,040	3.95	26	12,030	19	0.75	28	2.29	14
San Fran-Oak CA	3,520	820	4,290	3.60	32	15,450	10	0.57	35	2.45	13
Denver CO	1,510	880	1,730	7.02	5	12,115	18	1.28	5	2.21	16
Miami FL	1,790	460	3,880	7.28	4	28,260	2	1.12	7	4.35	2
Tampa FL	650	430	1,520	6.02	9	9,130	24	0.95	11	1.44	29
Atlanta GA	1,770	1,500	1,180	5.28	17	6,230	35	0.85	22	1.00	38
Indianapolis IN	930	430	2,150	4.43	24	9,540	23	0.90	15	1.94	21
Louisville KY	790	360	2,190	3.77	29	8,260	27	0.66	32	1.44	29
Kansas City MO	1,140	590	1,950	3.82	28	7,440	31	0.80	25	1.56	28
St. Louis MO	1,940	710	2,730	5.78	11	15,800	9	0.90	15	2.46	12
Albuquerque NM	460	250	1,820	7.80	3	14,200	13	1.43	3	2.60	10
Oklahoma City OK	730	500	1,460	4.75	21	6,930	32	0.90	15	1.31	31
Portland OR	1,050	410	2,550	3.06	35	7,810	29	0.50	37	1.28	32
Memphis TN	820	400	2,040	4.82	18	9,830	22	0.93	13	1.90	23
Nashville TN	520	470	1,110	9.45	1	10,460	20	1.74	1	1.93	22
Salt Lake City UT	770	380	2,010	2.44	39	4,910	39	0.44	38	0.89	39
Seattle-Everett WA	1,600	710	2,260	5.61	12	12,700	17	0.92	14	2.09	19
Northeast & Midwest Cities											
Washington DC	2,980	820	3,630	6.17	7	22,440	3	0.75	28	2.73	9
Chicago IL	7,200	1,960	3,670	3.47	34	12,740	16	0.54	36	1.97	20
Baltimore MD	1,880	530	3,570	4.81	19	17,180	8	0.90	15	3.20	4
Boston MA	2,850	1,040	2,750	4.81	19	13,240	15	0.94	12	2.58	11
Detroit MI	3,890	1,250	3,120	5.55	13	17,310	7	0.89	19	2.77	8
Minn-St. Paul MN	1,890	1,000	1,890	2.76	38	5,230	37	0.62	34	1.17	36
New York NY	16,000	3,160	5,060	2.91	36	14,710	12	0.43	39	2.19	17
Cincinnati OH	930	420	2,210	3.56	33	7,890	28	0.85	22	1.88	24
Cleveland OH	1,750	630	2,780	2.77	37	7,680	30	0.63	33	1.75	26
Philadelphia PA	4,090	1,120	3,660	5.52	14	20,220	4	0.77	26	2.83	7
Pittsburgh PA	1,810	720	2,530	5.47	15	13,850	14	0.83	24	2.11	18
Milwaukee WI	1,210	550	2,200	3.83	27	8,440	26	0.77	26	1.69	27
Major Texas Cities											
Austin TX	480	340	1,410	4.48	23	6,320	34	0.86	21	1.22	33
Corpus Christi TX	280	180	1,570	5.42	16	8,510	25	1.16	6	1.83	25
Dallas TX	1,910	1,420	1,350	4.29	25	5,780	36	0.88	20	1.19	35
El Paso TX	500	200	2,500	6.00	10	15,000	11	1.61	2	4.03	3
Fort Worth TX	1,130	830	1,360	3.76	30	5,120	38	0.74	30	1.01	37
Houston Tx	2,820	1,610	1,750	3.72	31	6,520	33	0.70	31	1.22	33
San Antonio TX	1,050	470	2,230	4.57	22	10,210	21	1.00	10	2.23	15
West/South Avg.	1,790	670	2,400	5.54		13,140		0.96		2.23	
North/Midwest Avg.	3,870	1,100	3,090	4.30		13,410		0.74		2.24	
Outside Texas Avg.	2,570	830	2,660	5.08		13,240		0.88		2.23	
Texas Avg.	1,170	720	1,740	4.61		8,210		0.99		1.82	
Congested Texas Avg.	1,480	930	1,620	4.16		6,790		0.84		1.37	
Total Avg.	2,320	808	2,500	4.99		12,340		0.90		2.16	
Maximum Value	16,000	3160	5,200	9.45		35,150		1.74		5.61	
Minimum Value	280	180	1,110	2.44		4,910		0.43		0.89	

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston and San Antonio

[1] Daily vehicle-miles of travel per person
[2] Daily vehicle-miles of travel per square mile of urban area
[3] Lane-miles per 1000 persons
[4] Lane-miles per square mile of urban area
[5] Rank value of 1 associated with most congested condition

Source: TTI Analysis and Local Transportation Agency References

The ten highest RCI values were equal to or greater than 1.1. Overall 18 of the 39 urban areas studied had RCI values greater than 1.0. Eight other urban areas have congestion indices greater than 0.9 indicating that these systems could become congested in the near future. Houston, ranked 5th, was the only urban area in Texas among the ten most congested. The only other Texas city with a RCI value greater than 1.0 was Dallas (1.03).

Summary statistics (Table 7) show that Texas urban areas have a lower average congestion index (0.91) than the other two geographic regions (1.01). The five Texas congested cities have approximately the same average congestion index as the average of all 39 study areas.

Traffic Congestion Growth, 1982 to 1987

The congestion indices for each study area between 1982 and 1987 are presented in Table 8. Tables B-3 to B-7 in Appendix B provide more detailed information for each study area. San Diego, San Francisco-Oakland, Atlanta, and Washington, D.C. were estimated to have the fastest congestion growth rate. The average RCI values increased in excess of five percent per year. Congested Texas cities averaged an annual growth of approximately three percent which is slightly higher than experienced by areas outside the state.

The congestion levels for Texas cities exhibit an increasing trend from 1982 to 1986 for both the statewide and congested categories. However, 1987 data indicates a slight decrease in the Texas roadway congestion index values while Western/Southern and Northeastern/Midwestern averages continued to increase. Corpus Christi and Fort Worth were the only two Texas urban areas that had estimated 1987 RCI values higher than 1986 values. Overall, the statewide and congested cities values were two percent lower than the estimated 1986 values.

Table 7. 1987 Congestion Index Value

Urban Area	Freeway/Expway DVMT[1] (1000)	Freeway/Expway DVMT[2]/ Ln-Mile	Principal Arterial Street DVMT[1] (1000)	Principal Arterial Street DVMT[2]/ Ln-Mile	Congestion[3] Index	Rank
Western & Southern Cities						
Phoenix AZ	4,580	15,525	16,475	6,310	1.23	4
Los Angeles CA	96,890	19,855	73,810	6,265	1.47	1
Sacramento CA	8,055	12,205	6,135	6,135	1.00	17
San Diego CA	23,155	14,120	8,180	5,245	1.08	12
San Fran-Oak CA	39,580	17,170	12,670	6,320	1.31	2
Denver CO	9,550	11,505	10,600	5,490	0.95	22
Miami FL	7,420	13,370	13,000	6,500	1.14	7
Tampa FL	3,300	11,785	3,880	6,360	1.02	16
Atlanta GA	23,940	14,965	9,350	6,235	1.16	6
Indianapolis IN	7,640	10,760	4,100	4,910	0.85	32
Louisville KY	5,380	10,445	2,975	5,720	0.86	30
Kansas City MO	11,920	8,455	4,350	4,780	0.69	39
St. Louis MO	16,290	11,390	11,215	6,425	0.96	20
Albuquerque NM	2,025	10,125	3,550	5,460	0.91	26
Oklahoma City OK	6,330	9,045	3,465	5,290	0.76	36
Portland OR	6,700	12,405	3,200	6,095	1.00	17
Memphis TN	3,730	9,945	3,930	5,170	0.84	34
Nashville TN	5,000	11,630	4,915	5,430	0.95	22
Salt Lake City UT	3,810	9,295	1,865	5,485	0.78	35
Seattle-Everett WA	16,600	14,560	8,950	6,070	1.14	7
Northeast & Midwest Cities						
Washington DC	22,910	14,735	18,400	8,215	1.25	3
Chicago IL	30,945	13,690	24,965	6,450	1.11	9
Baltimore MD	13,735	11,445	9,020	5,370	0.92	25
Boston MA	20,205	13,560	13,700	5,120	1.04	14
Detroit MI	21,800	13,540	21,545	6,245	1.10	11
Minn-St. Paul MN	15,620	12,700	5,200	4,485	0.97	19
New York NY	73,615	13,670	46,490	6,710	1.11	9
Cincinnati OH	9,560	11,315	3,315	4,195	0.87	29
Cleveland OH	11,185	11,650	4,840	4,400	0.89	27
Philadelphia PA	15,125	11,040	22,550	7,160	1.06	13
Pittsburgh PA	7,190	7,775	9,905	6,560	0.85	32
Milwaukee WI	6,820	11,965	4,640	4,990	0.94	24
Major Texas Cities						
Austin TX	5,150	12,260	2,150	5,180	0.96	20
Corpus Christi TX	1,500	8,335	1,490	4,655	0.72	37
Dallas TX	22,100	13,475	8,200	4,850	1.03	15
El Paso TX	3,200	9,275	3,000	3,725	0.72	37
Fort Worth TX	11,000	11,110	4,250	5,060	0.88	28
Houston Tx	25,800	15,730	10,500	5,330	1.19	5
San Antonio TX	8,800	10,865	4,800	4,570	0.86	30
West/South Avg	15,095	12,430	9,750	5,785	1.01	
North/Midwest Avg	20,725	12,255	15,380	5,825	1.01	
Outside Texas Avg	17,205	12,365	11,860	5,800	1.01	
Texas Avg	11,080	11,580	4,910	4,770	0.91	
Congested Texas Avg	14,570	12,690	5,980	5,000	0.98	
Total Avg	16,105	12,225	10,610	5,615	0.99	
Maximum Value	96,890	19,855	73,810	8,215	1.47	
Minimum Value	1,500	7,775	1,490	3,725	0.69	

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston and San Antonio

[1]Daily vehicle-miles of travel
[2]Daily vehicle-miles of travel per lane-mile
[3]See Equation 1

Source: Equation 1 and Tables 3 and 5

Table 8. Congestion Index Values, 1982 to 1987

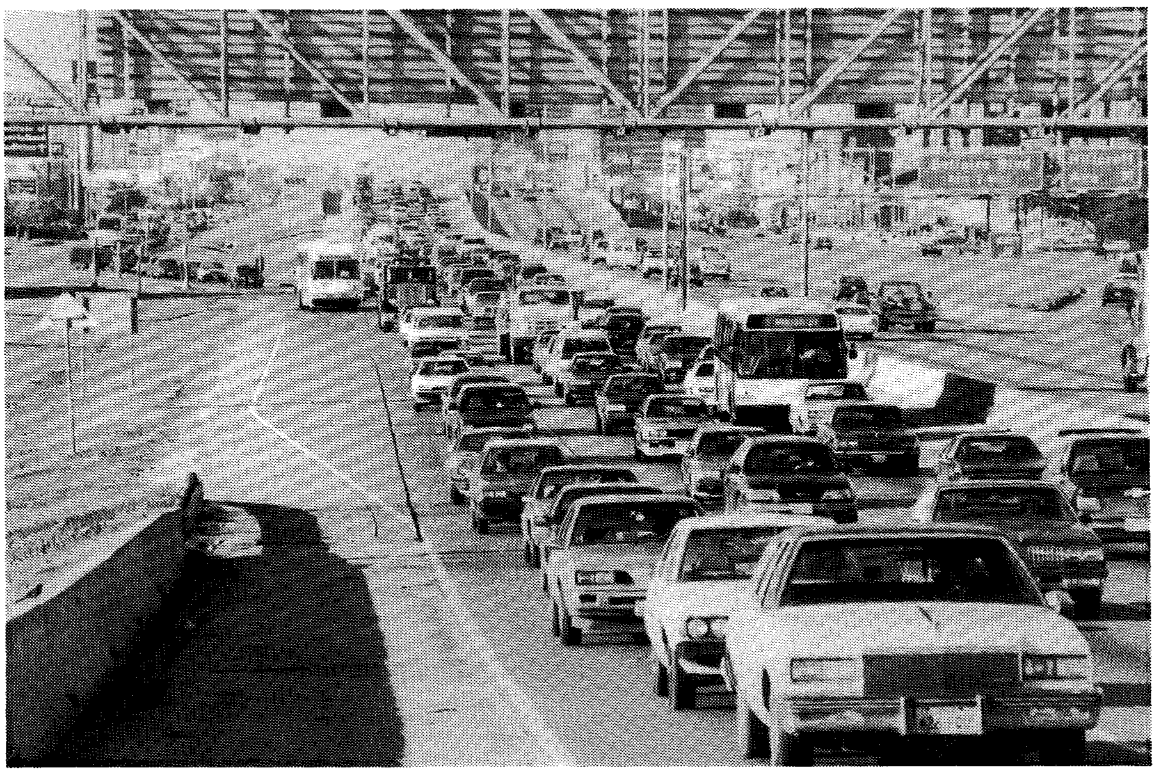
Urban Area	Year						Percent Change
	1982	1983	1984	1985	1986	1987	
Western & Southern Cities							
Phoenix AZ	1.16	1.15	1.17	1.20	1.18	1.23	6
Los Angeles CA	1.22	1.27	1.32	1.36	1.42	1.47	20
Sacramento CA	0.80	0.84	0.88	0.92	0.95	1.00	25
San Diego CA	0.78	0.83	0.91	0.95	1.00	1.08	38
San Fran-Oak CA	1.01	1.05	1.12	1.17	1.24	1.31	29
Denver CO	0.88	0.90	0.96	0.99	1.01	0.95	8
Miami FL	1.05	1.09	1.07	1.13	1.10	1.14	8
Tampa FL	0.94	0.91	1.03	1.00	0.96	1.02	8
Atlanta GA	0.89	0.94	0.99	1.05	1.15	1.16	30
Indianapolis IN	0.73	0.69	0.74	0.76	0.80	0.85	16
Louisville KY	0.85	0.83	0.83	0.82	0.80	0.86	1
Kansas City MO	0.55	0.56	0.58	0.62	0.64	0.69	25
St. Louis MO	0.83	0.87	0.90	0.91	0.95	0.96	15
Albuquerque NM	0.87	0.81	0.87	0.92	0.87	0.91	4
Oklahoma City OK	0.72	0.72	0.75	0.74	0.71	0.76	5
Portland OR	0.87	0.86	0.88	0.93	0.97	1.00	14
Memphis TN	0.76	0.74	0.72	0.73	0.77	0.84	10
Nashville TN	0.75	0.77	0.85	0.86	0.89	0.95	26
Salt Lake City UT	0.73	0.73	0.75	0.76	0.77	0.78	6
Seattle-Everett WA	0.95	0.99	1.02	1.05	1.09	1.14	20
Northeast & Midwest Cities							
Washington DC	0.95	0.98	1.06	1.13	1.21	1.25	31
Chicago IL	1.00	1.01	1.02	1.06	1.11	1.11	11
Baltimore MD	0.86	0.87	0.87	0.89	0.91	0.92	7
Boston MA	0.90	0.93	0.95	0.98	1.05	1.04	15
Detroit MI	1.13	1.10	1.13	1.12	1.11	1.10	-2
Minn-St. Paul MN	0.78	0.82	0.86	0.88	0.93	0.97	24
New York NY	1.06	1.06	1.05	1.05	1.09	1.11	4
Cincinnati OH	0.86	0.83	0.82	0.83	0.84	0.87	1
Cleveland OH	0.80	0.82	0.83	0.81	0.86	0.89	11
Philadelphia PA	0.90	0.97	0.98	1.01	1.06	1.06	17
Pittsburgh PA	0.81	0.81	0.81	0.84	0.86	0.85	4
Milwaukee WI	0.85	0.86	0.89	0.90	0.91	0.94	10
Major Texas Cities							
Austin TX	0.77	0.84	0.89	0.91	0.98	0.96	24
Corpus Christi TX	0.67	0.69	0.69	0.71	0.71	0.72	7
Dallas TX	0.84	0.89	0.94	0.98	1.05	1.03	22
El Paso TX	0.63	0.64	0.65	0.70	0.75	0.72	14
Fort Worth TX	0.76	0.79	0.80	0.82	0.87	0.88	15
Houston Tx	1.17	1.21	1.25	1.23	1.21	1.19	1
San Antonio TX	0.77	0.79	0.82	0.88	0.91	0.86	11
West/South Avg.	0.87	0.88	0.92	0.94	0.96	1.00	16
North/Midwest Avg.	0.91	0.92	0.94	0.96	1.00	1.00	11
Outside Texas Avg.	0.88	0.89	0.93	0.95	0.98	1.01	14
Texas Avg.	0.80	0.84	0.86	0.89	0.93	0.91	13
Congested Texas Avg.	0.86	0.90	0.94	0.96	1.00	0.98	14
Total Avg.	0.87	0.88	0.91	0.94	0.97	0.99	13
Maximum Value	1.22	1.27	1.32	1.36	1.42	1.47	20
Minimum Value	0.55	0.56	0.58	0.62	0.64	0.69	25

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston and San Antonio

Source: Equation 1 and Tables 3, 5, and B-3 to B-6

ECONOMIC IMPACT OF CONGESTION IN URBAN AREAS

The economic impact of congestion was analyzed in the 39 urban areas in 25 states included in this study. The study includes seven urban areas within Texas: Austin, Corpus Christi, Dallas, El Paso, Fort Worth, Houston, and San Antonio. This section will be devoted to the analysis and discussion of the economic impact of congestion. The analysis procedure was based on a methodology developed for the Houston Regional Mobility Plan (4) and is further documented in Appendix C.



Daily Vehicle-Miles of Travel and Population Estimates

The basic unit of input used in the congestion cost estimates was daily vehicle-miles of travel (DVMT). Population provided a base on which to evaluate cost of congestion in the areas studied. Table 9 is a summary of DVMT and population in the cities selected for study.

Table 9. **Summary of DVMT Values and Population for Congestion Cost Estimates**

Urban Area	Daily Vehicle-Miles of Travel (1000s)			1987 Population (1000s)
	Freeway/ Expressway	Principal Arterial Street	Freeway and Arterial	
Western & Southern Cities				
Phoenix AZ	4,580	16,480	21,060	1,820
Los Angeles CA	96,890	73,810	170,700	10,920
Sacramento CA	8,060	6,140	14,190	1,000
San Diego CA	23,160	8,180	31,340	2,070
San Fran-Oak CA	39,580	12,670	52,250	3,520
Denver CO	9,550	10,600	20,150	1,510
Miami FL	7,420	13,000	20,420	1,790
Tampa FL	3,300	3,880	7,180	650
Atlanta GA	23,940	9,350	33,290	1,770
Indianapolis IN	7,640	4,100	11,740	930
Louisville KY	5,380	2,980	8,360	790
Kansas City MO	11,920	4,350	16,270	1,140
St. Louis MO	16,290	11,220	27,510	1,940
Albuquerque NM	2,030	3,550	5,580	460
Oklahoma City OK	6,330	3,470	9,800	730
Portland OR	6,700	3,200	9,900	1,050
Memphis TN	3,730	3,930	7,660	820
Nashville TN	5,000	4,920	9,920	520
Salt Lake City UT	3,810	1,870	5,680	770
Seattle-Everett WA	16,600	8,950	25,550	1,600
Northeast & Midwest Cities				
Washington DC	22,910	18,400	41,310	2,980
Chicago IL	30,950	24,970	55,910	7,200
Baltimore MD	13,740	9,020	22,760	1,880
Boston MA	20,210	13,700	33,910	2,850
Detroit MI	21,800	21,550	43,350	3,890
Minn-St. Paul MN	15,620	5,200	20,820	1,890
New York NY	73,620	46,490	120,110	16,000
Cincinnati OH	9,560	3,320	12,880	930
Cleveland OH	11,190	4,840	16,030	1,750
Philadelphia PA	15,130	22,550	37,680	4,090
Pittsburgh PA	7,190	9,910	17,100	1,810
Milwaukee WI	6,820	4,640	11,460	1,210
Major Texas Cities				
Austin TX	5,150	2,150	7,300	480
Corpus Christi TX	1,500	1,490	2,990	280
Dallas TX	22,100	8,200	30,300	1,910
El Paso TX	3,200	3,000	6,200	500
Fort Worth TX	11,000	4,250	15,250	1,130
Houston TX	25,800	10,500	36,300	2,820
San Antonio TX	8,800	99,800	108,600	1,050
West/South Avg.	14,600	10,330	29,830	1,790
North/Midwest Avg.	20,730	15,380	36,110	3,870
Outside Texas Avg.	17,210	12,230	29,430	2,570
Texas Avg.	11,080	18,480	29,560	1,170
Congested Texas Avg.	14,570	24,980	39,550	1,480
Total Avg.	16,110	13,350	29,460	2,320
Maximum Value	96,890	99,800	170,700	16,000
Minimum Value	1,500	1,490	2,990	280

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston, and San Antonio

Source: TTI Analysis and Local Transportation Agency References

The DVMT values (Table 9) used throughout this study were obtained from a combination of sources. Primarily this data was obtained from the Federal Highway Administration's Highway Performance Monitoring System (HPMS) (5) and various local and state transportation planning agencies, are illustrated in Table C-1. The 1987 population values were estimated using U.S. Census Bureau and HPMS data.

Definition of Congestion for Individual Roadway Sections

Prior to calculating congestion cost, the congested peak-period VMT for both freeways/expressways and principal arterial streets within the study areas was estimated. The congested peak-period VMT consists of the percentage of total vehicle travel operating in congested conditions during the morning and evening peak periods. For this study, congested conditions were estimated to begin at the transition from level-of-service (LOS) C to D (as discussed in Appendix A in the section titled, "Houston's Experience With Declining Mobility"). Traffic volume representative of the beginning of congestion on an individual section of freeway was estimated as 15,000 daily vehicles per lane per day.

Developing a similar level for principal arterial streets, however, was not as straightforward. Principal arterial street operational analyses consider the volume of traffic and intersection signal timings. Therefore, a range of cycle lengths from 60 to 120 seconds was considered, with the principal arterial street receiving 50 percent of the green signal time. (The limiting condition for principal arterial street condition would be at the intersection of two principal arterial streets). These calculations resulted in an estimate of 5,750 vehicles per day per lane as the beginning of LOS D on a section of principal arterial street. This volume is also in general agreement with a value that could be derived by applying the ratio of undesirable urban area traffic volume per lane (5,000 for principal arterial streets and 13,000 for freeways/expressways) to the value for congestion on an individual section of freeway (15,000 vehicles per lane per day).

HPMS sample data were utilized to estimate the percentage of urban area DVMT occurring on facilities with traffic volume per lane values in excess of the congestion levels (15,000 vehicles per day per lane for freeways/expressways and 5,750 vehicles per day per lane for principal arterial streets). Congested urban area VMT estimates are presented in Appendix B.

Economic Impact Estimate

The methodology used in this study includes traffic delay and excess fuel cost caused by both incident and recurring type events encountered by the motorist. Recurring congestion results from normal daily facility operations, while incident congestion occurs as a result of an accident or vehicle breakdown. The calculations also identify additional insurance premium cost within an urban area. The congestion cost calculations are discussed in detail in Appendix C of this report. Therefore, this section only briefly covers the constants, variables, and measures of effectiveness (MOEs) used in this portion of the analysis.

Study Constants

The methodology of the congestion cost analysis utilized six independent variables. These constant values were applied to the calculations for each study area considered.

1. Average vehicle occupancy -- 1.25 persons.
2. Working days per year -- 250.
3. Average cost of time (6) -- $8.50 per person-hour.[1]
4. Commercial vehicle operating cost (7) -- $1.65 per mile.
5. Vehicle mix -- 95 percent passenger and 5 percent commercial.
6. Vehicular speeds: (8)

   Freeway/Expressway peak: 35mph, off-peak: 55mph

   Principal Arterial Street peak: 20mph, off-peak: 35mph

[1]The referenced value of $8.00 per hour in 1985 was adjusted using the 1987 Consumer Price Index (CPI).

Urban Area Travel Variables

The congestion cost estimates also included five site-specific variables which were dependent on the urban area being analyzed. These variables are discussed in detail in Appendix C of this report; this section briefly describes each variable used in the calculations. The five dependent variables include:

1. Daily vehicle-miles of travel (DVMT) -- the average daily traffic of a section of roadway multiplied by the length (in miles) of that section of roadway.
2. Insurance rates -- the state average and specific urban area insurance rates for the state-required minimum coverage.
3. Fuel cost -- the state average fuel cost per gallon for 1987.
4. Registered vehicles -- the number of registered vehicles as reported by county tax offices.
5. Population -- estimated by 1985 U.S. Census Bureau and 1987 HPMS data.

Measures of Effectiveness

The economic impact of congestion resulting from the calculations detailed in Appendix B were stated in terms of annual urban area congestion cost and cost per capita. This study utilized these cost values (delay, fuel, and insurance) to analyze the effect of congestion within each study area.

Estimates of traffic delay and fuel cost were calculated for both incident and recurring events. The excess insurance premium cost for each area was also determined. The total cost (delay, fuel, and insurance) for each study area was then tabulated.

Delay due to congested traffic operation is the most expensive type of congestion related cost. As estimated in this study, delay is defined as the total vehicle-hours per day spent by motorists operating vehicles on facilities under congested conditions. Delay is the most noticeable impact of congestion to motorists because it directly impacts the travel time of their commute.

Fuel cost represents the excess fuel consumed by vehicles operating in congested conditions. This type of congestion related cost is relatively small when compared to delay. However, should fuel be in short supply, excess fuel consumption could become a substantial commuter issue.

Another congestion related cost estimated in this study was increased insurance premiums. Vehicles operating in congested conditions generally have a greater risk of being involved in an accident. Higher urban area accident rates usually equate to higher insurance premiums for motorists operating vehicles in this urban area. For this reason, 70 percent of the insurance premiums were estimated to be the result of claims and the remaining 30 percent to be overhead and expense of the carrier. Insurance premiums are not only affected by accident rates, however, these premiums are also affected by the crime rates within each urban area. Therefore, results of the analyses are presented including and excluding this factor.

Presenting cost values on a per capita basis allowed traffic congestion to be evaluated for individual residents of an urban area. The congestion cost per capita was also calculated with and without the estimated urban area insurance cost.

Results of Economic Analysis

Congestion costs shown in Tables 10 and 11 are the result of converting the congested peak-period VMT into vehicle-hours of delay for congestion resulting from recurring and non-recurring (incident) events using the procedure outlined in Appendix C.

Both fuel and delay costs were, in general, greater for incidents than for recurring events. Incident events resulted in varying amounts of increased delay than events that are recurring in nature. These incident delay values were determined by reviewing data presented in the report by Lindley ["Quantification of Urban Freeway Congestion and Analysis of Remedial Measures" (9)], for urban areas included in this study. This increase in delay may be a result of the timing of incidents; many occur during congested operations and are more likely to result in the closing of one or more lanes of traffic. The closing of traffic lanes further intensifies the congested situation and causes greater delay and higher fuel consumption.

Table 10 presents the 1987 component and total congestion costs for each urban area studied. Reviewing the component costs of congestion, it is shown that delay (recurring and incidental) accounts for the majority of annual congestion cost. Delay costs contribute a maximum of 83 percent (Phoenix) and a minimum of 50 percent (Cleveland) of the annual urban area congestion cost. Overall, delay costs represent an average of 71 percent of the annual cost. Fuel costs had a maximum effect of 13 percent (Phoenix, Seattle-Everett, and Austin) and a minimum of seven percent (Philadelphia) on urban area congestion cost. The factor that had the largest variation from urban area to urban area was insurance costs. These values ranged from a maximum of 42 percent (Cleveland) to a minimum of four percent (Phoenix), with a study-wide average of 19 percent.

The estimated economic impact of congestion on a per capita and per registered vehicle basis is illustrated in Table 11. In all four categories, Texas has a marginally lower statewide average and higher average in congested Texas cities when compared to regional or studywide averages.

Geographic Impact on Congestion Values

The summary information in Table 11 illustrates that urban areas located within Texas tend to have lower average values in all annual congestion cost categories than urban areas outside Texas. The per capita congestion cost values for congested Texas urban areas, however, exceeds those outside Texas by 13 percent, Texas statewide by 30 percent, and the total urban area average by 17 percent. Evaluating cost per capita excluding additional insurance premiums also indicates that congested Texas areas were the most impacted by congestion; the average cost per capita was 30 percent higher than the study areas outside Texas. Excluding insurance premiums lowered the average per capita cost by approximately 22 percent for all geographic areas, while reducing per capita cost 18 percent statewide in Texas and 17 percent for congested Texas areas.

Table 10. Component and Total Congestion Costs By Urban Area

Urban Area	Annual Cost Due to Congestion (Millions of $'s) Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Insurance	Total	Delay/Fuel Cost (Millions)
Western & Southern Cities							
Phoenix AZ	390	390	60	60	40	930	890
Los Angeles CA	2,510	2,900	400	460	1,660	7,940	6,280
Sacramento CA	130	120	20	20	80	360	290
San Diego CA	250	190	40	30	60	580	510
San Fran-Oakland CA	770	960	130	160	350	2,370	2,015
Denver CO	240	250	40	40	70	630	560
Miami FL	330	380	50	60	380	1,200	810
Tampa FL	80	100	10	10	20	220	210
Atlanta GA	390	420	60	60	210	1,140	930
Indianapolis IN	20	30	3	4	20	90	60
Louisville KY	50	60	6	7	20	140	120
Kansas City MO	40	60	4	7	40	140	110
St Louis MO	270	300	40	40	90	730	640
Albuquerque NM	40	50	5	6	10	120	100
Oklahoma City OK	40	40	5	5	30	130	100
Portland OR	100	140	10	20	50	310	270
Memphis TN	50	50	6	6	60	170	110
Nashville TN	70	80	10	10	20	200	180
Salt Lake City UT	30	30	4	4	20	90	70
Seattle-Everett WA	330	420	50	70	60	930	870
Northeast & Midwest Cities							
Washington DC	710	1,050	110	160	190	2,220	2,030
Chicago IL	800	910	120	140	500	2,470	1,970
Baltimore MD	150	240	20	50	190	640	440
Boston MA	280	630	40	90	100	1,140	1,040
Detroit MI	520	730	80	110	420	1,870	1,440
Minn-St Paul MN	170	170	30	30	70	450	380
New York NY	1,720	2,830	250	400	1,600	6,800	5,200
Cincinnati OH	70	60	10	10	10	160	150
Cleveland OH	80	70	10	10	130	310	180
Philadelphia PA	550	660	70	90	750	2,120	1,370
Pittsburgh PA	200	260	30	30	230	740	510
Milwaukee WI	80	90	10	10	30	230	200
Major Texas Cities							
Austin TX	80	90	10	10	10	200	190
Corpus Christi TX	10	10	0	0	5	25	25
Dallas TX	280	460	50	70	150	1,010	860
El Paso TX	20	20	2	2	20	60	40
Fort Worth TX	110	180	20	30	70	410	340
Houston TX	470	610	70	100	300	1,540	1,240
San Antonio TX	90	100	10	20	50	260	220
West/South Avg.	310	350	50	50	160	920	760
North/Midwest Avg.	440	640	60	90	350	1,600	1,240
Outside Texas Avg.	360	460	50	70	230	1,170	940
Texas Avg.	150	210	20	30	90	500	410
Congested Texas Avg.	210	290	30	50	120	690	570
Total Avg.	320	410	50	60	210	1,050	840
Maximum Value	2,510	2,900	400	460	1,660	7,940	6,280
Minimum Value	10	10	0	0	5	25	25

Note: Congested Texas cities average includes Austin, Dallas, Fort Worth, Houston, and San Antonio

Source: TTI Analysis and Local Transportation Agency References

Table 11. Estimated Economic Impact of Congestion

Urban Area	Congestion Cost Per Capita (Dollars)	Delay/Fuel Cost Per Capita (Dollars)	Total Congestion Cost Per Reg. Veh. (Dollars)	Delay/Fuel Cost Per Reg. Veh. (Dollars)
Western & Southern Cities				
Phoenix AZ	510	490	800	765
Los Angeles CA	730	580	1,040	820
Sacramento CA	360	290	300	240
San Diego CA	280	250	440	390
San Fran-Oakland CA	670	570	805	685
Denver CO	420	370	480	425
Miami FL	670	450	895	610
Tampa FL	340	320	380	355
Atlanta GA	650	530	750	610
Indianapolis IN	100	70	160	115
Louisville KY	180	160	320	270
Kansas City MO	130	90	220	165
St Louis MO	380	330	780	680
Albuquerque NM	250	230	315	290
Oklahoma City OK	170	130	270	205
Portland OR	300	260	510	440
Memphis TN	210	130	290	185
Nashville TN	380	340	410	370
Salt Lake City UT	120	90	145	110
Seattle-Everett WA	580	550	810	760
Northeast & Midwest Cities				
Washington DC	740	680	1,380	1,260
Chicago IL	340	270	625	500
Baltimore MD	340	240	645	445
Boston MA	400	370	755	690
Detroit MI	480	370	649	500
Minn-St Paul MN	240	200	285	245
New York NY	430	330	1,190	910
Cincinnati OH	170	160	180	165
Cleveland OH	180	100	215	125
Philadelphia PA	520	340	790	510
Pittsburgh PA	410	280	625	430
Milwaukee WI	190	160	430	375
Major Texas Cities				
Austin TX	420	390	430	405
Corpus Christi TX	80	60	95	75
Dallas TX	530	450	645	550
El Paso TX	110	80	155	110
Fort Worth TX	360	300	410	340
Houston TX	550	440	695	560
San Antonio TX	260	210	325	270
West/South Avg.	370	310	505	425
North/Midwest Avg.	370	290	645	510
Outside Texas Avg.	370	300	560	460
Texas Avg.	330	280	395	330
Congested Texas Avg.	420	360	500	425
Total Avg.	360	300	530	435
Maximum Value	740	680	1,380	1,260
Minimum Value	80	60	95	75

Source: TTI Analysis and Local Transportation Agency References

Urban Area Ranking

Table 12 presents the ranking of the urban areas for annual and per capita congestion cost, including and excluding excess insurance premiums, for 1987. The overall rank of urban areas, with few exceptions, does not seem to be affected by either normalizing with population or by insurance premiums.

The urban area rankings for total congestion cost and congestion cost per capita generally concur with one another, but there are some significant changes between annual and per capita rankings. Examples of these variations include Austin and New York. Austin ranks in the lower half of urban areas (28th and 27th) when analyzed with respect to annual estimated congestion cost; however, Austin ranks 13th and 10th with the per capita analyses. The change in ranking of New York is the reverse that of Austin. New York ranks 2nd in annual impact (including and excluding insurance premiums) and 12th and 17th in cost per capita categories.

Comparison of Urban Mobility Levels

A relatively good correlation exists between the ranking of urban areas based on estimated economic impact of congestion (Table 12) and the rankings based on congestion index values (Table 7). All of the top ten ranked urban areas by congestion index (Table 7) are included in the top ten of one or more categories illustrated in Table 12. Overall, variations between the ranking systems are relatively minor.

It should be noted that the basic input for all ranking schemes mentioned is daily vehicle-miles of travel. While the focus of the economic and congestion index analyses differ, the same sources of data were used in both analyses. The rankings (Tables 7 and 12) may represent some repetition and/or contradictory information, but traffic congestion and economic impact are different concepts.

Table 12. 1987 Rankings of Urban Area by Estimated Economic Impact of Congestion

Urban Area	Total Congestion Cost	Total Delay/Fuel Cost	Congestion Cost Per Capita	Delay/Fuel Cost Per Capita	Congestion Cost Per Reg. Veh.	Delay/Fuel Cost Per Reg. Veh.
Western & Southern Cities						
Phoenix AZ	13	11	10	6	7	4
Los Angeles CA	1	1	2	2	3	3
Sacramento CA	22	22	19	20	29	30
San Diego CA	19	17	25	24	20	21
San Fran-Oakland CA	4	4	3	3	6	7
Denver CO	18	16	13	11	19	19
Miami FL	9	14	3	7	4	10
Tampa FL	27	25	21	18	25	24
Atlanta GA	10	10	5	5	11	9
Indianapolis IN	37	37	38	38	36	36
Louisville KY	32	31	31	31	27	27
Kansas City MO	32	33	35	35	33	33
St Louis MO	16	15	17	16	9	8
Albuquerque NM	35	33	27	26	28	26
Oklahoma City OK	34	35	33	33	32	31
Portland OR	23	23	24	23	18	17
Memphis TN	30	32	29	32	30	32
Nashville TN	29	29	17	14	23	23
Salt Lake City UT	36	36	36	36	38	37
Seattle-Everett WA	14	12	6	4	5	5
Northeast & Midwest Cities						
Washington DC	5	3	1	1	1	1
Chicago IL	3	5	21	22	16	14
Baltimore MD	17	19	21	25	14	16
Boston MA	10	9	16	13	10	6
Detroit MI	7	6	11	12	13	14
Minn-St Paul MN	20	21	28	28	31	29
New York NY	2	2	12	17	2	2
Cincinnati OH	31	30	33	30	35	33
Cleveland OH	23	28	31	34	34	35
Philadelphia PA	6	7	9	15	8	13
Pittsburgh PA	15	18	15	21	17	18
Milwaukee WI	26	26	30	29	21	22
Major Texas Cities						
Austin TX	28	27	13	10	21	20
Corpus Christi TX	39	39	39	39	39	39
Dallas TX	12	13	8	8	14	12
El Paso TX	38	38	37	37	37	38
Fort Worth TX	21	21	19	19	23	25
Houston TX	8	8	7	9	12	11
San Antonio TX	25	24	27	27	26	28

Source: TTI Analysis and Local Transportation Agency References

Conclusions

The economic analysis presented in this section estimated costs due to congestion (time, fuel, and insurance) in an urban area. In general, the less congested urban areas with larger populations exhibit higher total congestion costs than smaller urban areas. Estimating the severity of traffic congestion, however, requires that some normalizing device be used to distinguish between large areas and severely congested areas. The cost per capita values represent a better tool for comparison with the congestion index estimated in the previous section, and urban mobility studies performed by FHWA and others. Total urban area congestion cost estimates are important in developing support for transportation system improvement programs requiring increased state and local funding.

Of the three types of cost considered to be affected by congestion (time, fuel, and insurance), insurance premiums are the most difficult to apply to congestion cost estimates and not as closely associated with congestion as delay and fuel. The excess insurance premium cost represents a widely varying portion of the total congestion cost, but only small differences were found in rankings including and excluding insurance cost.

Table 13 summarizes the daily vehicle-miles of travel, congestion index value, 1986 and 1987 RCI rankings, and 1986 and 1987 congestion cost per capita. Overall, urban areas located in Texas seem to have a general decrease in congestion cost per capita while Western/Southern cities exhibit a general increase. Comparisons of these values in the future may clarify these trends.

Table 13. Preliminary 1987 Congestion Index Values

Urban Area	DVMT/Ln-Mile		Congestion Index			Congestion Costs Per Capita	
	Frwy	Prin. Art	1987 Value	Rank 1986	Rank 1987	1986	1987
Western & Southern Cities							
Phoenix AZ	15,530	6,310	1.23	5	4	550	510
Los Angeles CA	19,860	6,270	1.47	1	1	880	730
Sacramento CA	12,210	6,140	1.00	20	17	400	360
San Diego CA	14,120	5,240	1.08	16	12	300	280
San Fran-Oak CA	17,170	6,320	1.31	2	2	780	670
Denver CO	11,510	5,490	0.95	15	22	380	420
Miami FL	13,370	6,500	1.14	9	7	730	670
Tampa FL	11,790	6,360	1.02	19	16	380	340
Atlanta GA	14,960	6,230	1.16	6	6	530	650
Indianapolis IN	10,760	4,910	0.85	32	32	70	90
Louisville KY	10,450	5,720	0.86	32	30	140	180
Kansas City MO	8,450	4,780	0.69	39	39	185	130
St. Louis MO	11,390	6,430	0.96	20	20	420	380
Albuquerque NM	10,130	5,460	0.91	27	26	230	250
Oklahoma City OK	9,040	5,290	0.76	37	36	165	170
Portland OR	12,410	6,100	1.00	18	17	325	300
Memphis TN	9,950	5,170	0.84	34	34	160	210
Nashville TN	11,630	5,430	0.95	26	22	295	380
Salt Lake City UT	9,290	5,490	0.78	34	35	95	120
Seattle-Everett WA	14,560	6,070	1.14	10	7	500	580
Northeast & Midwest Cities							
Washington DC	14,730	8,210	1.25	3	3	-[1]	740
Chicago IL	13,690	6,450	1.11	7	9	-	340
Baltimore MD	11,450	5,370	0.92	23	25	-	340
Boston MA	13,560	5,120	1.04	13	14	-	400
Detroit MI	13,540	6,250	1.10	7	11	-	480
Minn-St. Paul MN	12,700	4,480	0.97	22	19	170	240
New York NY	13,760	6,710	1.11	10	9	-	430
Cincinnati OH	11,310	4,200	0.87	31	29	-	170
Cleveland OH	11,650	4,400	0.89	29	27	-	180
Philadelphia PA	11,040	7,160	1.06	12	13	-	520
Pittsburgh PA	7,770	6,560	0.85	29	32	-	410
Milwaukee WI	11,970	4,990	0.94	23	24	190	190
Major Texas Cities							
Austin TX	12,260	5,180	0.96	17	20	450	420
Corpus Christi TX	8,330	4,660	0.72	37	37	70	80
Dallas TX	13,480	4,850	1.03	13	15	590	530
El Paso TX	9,280	3,730	0.72	36	37	90	110
Fort Worth TX	11,110	5,060	0.88	27	28	370	360
Houston TX	15,730	5,330	1.19	3	5	600	550
San Antonio TX	10,860	4,570	0.86	23	30	230	250

[1]Denotes urban areas not included in 1986 analysis

Source: TTI Analysis and Local Transportation References

CONCLUSIONS

This report examined the relative mobility on both freeway and principal arterial street systems in 39 large urban areas. Seven of those urban areas are the largest cities in Texas. The 32 urban areas located outside Texas have a variety of travel and development patterns some significantly different than the Texas cities studied. The urban areas studied also represent a cross-section of urban development with various population densities and modal travel percentages for peak period and daily person-trips.

Undetermined Impacts of Congestion

The expected outcome of this analysis would intuitively be that urban areas with larger populations, area size, or densities, experience higher roadway congestion index values than smaller urban areas. However, this study indicates while these factors may indeed influence the roadway congestion index, one cannot assume these factors dictate the RCI value magnitude. Many larger Northeastern/Midwestern cities, such as New York City, Chicago, Detroit, and Washington, D.C., typify this paradox. New York City has the largest population and urban area, and is the second most densely populated area included in this study. Roadway congestion index calculations, however, rank New York City 9th with respect to urban area congestion. Intuitively, this conclusion seems unrealistic and becomes more confusing considering general public opinion of traffic conditions in New York City.

The roadway congestion index, as stated in this report, is intended to be an urban area value, representing the entire area and not site specific locations, i.e. bridges, tunnels, or other point sites of congestion. Secondly, the roadway congestion index is based on areawide freeway and principal arterial street travel. Therefore, if a large percentage of the freeways or principal arterial street systems have "good" operational characteristics, the effects of bottlenecks and other sites of point congestion may be underestimated or "washed-out" with this analysis. It should also be noted that the RCI and its methodology were developed for urban areas in the Southern/Western portion of the country. Urban areas in the Northeastern/Midwestern states have different roadway and development patterns. In addition, freeway systems in many Northeastern/Midwestern cities have older designs including narrower lanes and shoulders than systems prevalent in the South and West.

Other caveats pertaining to the interpretation of the roadway congestion index, as intended by this study, include traffic signal system operation and the role of transit. Neither of these were included in the RCI methodology. While it is agreed that these factors affect urban mobility, their effects are more complex than could be included in an areawide analysis technique.

Urban Area Roadway Congestion

A comparison of Tables 3 and 5 indicates that Texas cities rely more on the freeway system for mobility than other urban areas. The five most congested Texas cities have daily vehicle-miles of travel per lane-mile two percent higher than Southern/Western urban areas, and three percent higher than urban areas located in the Northeastern/Midwestern region. Tables 3 and 5 also indicate that the congested Texas cities have an average of three percent more freeway vehicle-miles of travel per lane-mile (DVMT/LM) and 16 percent less principal arterial street DVMT/LM than the cities located outside Texas. The 1986 estimates placed these values at ten and eight percent, respectively.

Data collected from 1982 through 1987 (Table 8) indicate that urban roadway congestion in congested Texas cities increased by approximately three percent, while areas outside Texas increase marginally less (2.5 percent). Historically, the congestion in Texas has increased much faster than in other areas. However, the average RCI values for Texas decreased from 1986 to 1987, while the average for cities outside Texas rose slightly. Overall, the Texas statewide and congested cities values were two percent lower than the RCI values estimated in 1986.

Economic Impact of Urban Roadway Congestion

Three factors were used to estimate the cost of congestion to urban residents in the 39 study areas.

- Travel delay due to congested peak-period roadways and due to incidents which temporarily reduce capacity
- Increased fuel consumption due to traffic operating in congested conditions
- Increased insurance premiums paid by motorists in urban areas due to increased accident rates associated with congested roadways.

For comparative purposes, the annual estimated congestion cost represents the economic impact on society of an inadequate roadway system. Large urban areas will have significant congestion cost values by virtue of their size. Normalizing the areawide economic impact with urban population estimates, however, provides a comparison of the congestion experienced by individual motorists in different urban areas.

Twelve urban areas were estimated to have total 1987 congestion cost values in excess of $1 billion. The total estimated congestion cost value in the 39 study cities was approximately $41 billion, or slightly more than $1 billion per study area (Table 10). The

39 city average congestion cost was approximately $360 per capita (Table 11). If the insurance premium cost calculation is eliminated (high premiums may be related to factors other than traffic congestion) the delay and fuel cost were estimated at $300 per capita. Eliminating the per capita insurance calculation results in seven urban areas in the top ten changing rank (Table 12). Of those seven, Philadelphia (9th - total congestion per capita) drops out of the top ten (to 15th) and Austin (13th - total congestion per capita) is added (10th).

The seven Texas cities were estimated to have approximately $3.5 billion associated with the adverse impacts of congestion. Dallas and Houston both have estimated congestion costs in excess of $1 billion (Table 10), however, Houston (8th) is the only Texas city ranked in the top ten (Table 12) for total congestion costs. On a cost per capita basis Dallas and Houston are ranked in the top ten of the 39 cities studied. When congestion costs are expressed in terms of registered vehicles, none of the sites studied in Texas are in the ten highest ranked areas. While the Texas (statewide and congested) average number of registered vehicles per person are the lowest in this study, Dallas and Houston both have in excess of 1.5 million registered vehicles. Urban areas relying primarily on personal automobiles for mobility will generally be ranked lower in congestion cost per registered vehicles than shown on a per capita basis.

Table 14 presents the comparison between ranking urban areas by congestion index and cost per capita. Only four cities "shift" places out of the top ten congested cities between these two ranking techniques. These cities are Chicago, New York, Philadelphia, and Dallas.

Table 14. 1987 Urban Area Rankings By Congestion Index and Cost Per Capita

Urban Area	1987 Congestion Index	Rank	Congestion Cost Per Capita (Dollars)	Rank
Western & Southern Cities				
Phoenix AZ	1.23	4	510	10
Los Angeles CA	1.47	1	730	2
Sacramento CA	1.00	17	360	19
San Diego CA	1.08	12	280	25
San Fran-Oakland CA	1.31	2	670	3
Denver CO	.95	22	420	13
Miami FL	1.14	7	670	3
Tampa FL	1.02	16	340	21
Atlanta GA	1.16	6	650	5
Indianapolis IN	.85	32	100	38
Louisville KY	.86	30	180	31
Kansas City MO	.69	39	130	35
St Louis MO	.96	20	380	17
Albuquerque NM	.91	26	250	27
Oklahoma City OK	.76	36	170	33
Portland OR	1.00	17	300	24
Memphis TN	.84	34	210	29
Nashville TN	.95	22	380	18
Salt Lake City UT	.78	35	120	36
Seattle-Everett WA	1.14	7	580	6
Northeast & Midwest Cities				
Washington DC	1.25	3	740	1
Chicago IL	1.11	9	340	21
Baltimore MD	.92	25	340	21
Boston MA	1.04	14	400	16
Detroit MI	1.10	11	480	11
Minn-St Paul MN	.97	19	240	28
New York NY	1.11	9	430	12
Cincinnati OH	.87	29	170	33
Cleveland OH	.89	27	180	31
Philadelphia PA	1.06	13	520	9
Pittsburgh PA	.85	32	410	15
Milwaukee WI	.94	24	190	30
Major Texas Cities				
Austin TX	.96	20	420	13
Corpus Christi TX	.72	37	80	39
Dallas TX	1.03	15	530	8
El Paso TX	.72	38	110	37
Fort Worth TX	.88	28	360	19
Houston TX	1.19	5	550	7
San Antonio TX	.86	30	260	26

Source: TTI Analysis

REFERENCES

1. Texas Transportation Institute. "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," Research Report 431-1F, 1988.
2. Texas Transportation Institute. "Estimates of Relative Mobility in Major Texas Cities," Research Report 323-1F, 1982.
3. Texas Transportation Institute. "Relative Mobility in Texas Cities, 1975 to 1984," Research Report 339-8, 1986.
4. Houston Chamber of Commerce. "Houston Regional Mobility Plan," 1982.
5. United States Department of Transportation, Federal Highway Administration. "Highway Performance Monitoring System." 1982 to 1987 Data.
6. Chui, Margaret K. and McFarland, William F., "The Value of Travel Time: New Estimates Developed Using a Speed Choice Model," Texas Transportation Institute, January 1987.
7. "Private Truck Counsel of America Cost Index Survey," Houston Post, July 6, 1987.
8. Houston-Galveston Regional Transportation Study Office. "Travel Time and Speed Survey -- 1969, 1973, 1976 and 1979."
9. Lindley, Jeffery A. "Quantification of Urban Freeway Congestion and Analysis of Remedial Measures," Federal Highway Administration, FHWA/RD-87/052. October 1986.
10. Transportation Research Board. Special Report 209, "Highway Capacity Manual," 1985.
11. Report of the Secretary of Transportation to the United States Congress. "The Status of the Nation's Highways: Condition and Performance," June 1985.
12. American Association of State Highway and Transportation Officials. <u>A Policy on Geometric Design of Highways and Streets</u>," 1984.
13. United States Department of Transportation, Federal Highway Administration. "1980-3R Study."
14. Texas Department of Highways and Public Transportation. "Ten-Year Project Development Plan Documentation and Support Data," 1986.
15. American Automobile Association, "Fuel Gauge Report", April 2, July 2, November 26, and December 19, 1985.

16. State Department of Highways and Public Transportation. "Permanent Automatic Traffic Recorder Data -- 1950 - 1984."
17. Raus, J., "A Method for Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks," Report No. FHWA-TS-81-210, April 1981.
18. U.S. Department of Commerce, Bureau of the Census. <u>State and Metropolitan Area Data Book</u>, 1986.

APPENDIX A

DEVELOPMENT OF URBAN AREAWIDE CONGESTION MEASUREMENT METHODOLOGY

APPENDIX A
URBAN AREAWIDE CONGESTION MEASUREMENT METHODOLOGY DEVELOPMENT

Previous research (1,2,3) 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 urban 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 urban 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 urban 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 (2,3) 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 urban 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 urban area delineation.

A 1986 FHWA research report entitled, "Quantification of Urban Freeway Congestion and Analysis of Remedial Measures" (9) 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 urban 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 (9) focused on relatively detailed estimates of urban 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 urban 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

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

Source: References 2, 3, 5, 9

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

Table A-2. Summary of Normalized Principal Arterial Travel and Mileage Statistics for 1986 Normalized For Population Density[1]

Urban Area	VMT Per Person	Rank	VMT Per Sq Mi	Rank	Ln Mi Per 1000 Pers	Rank	Ln Mi Per Sq Mi	Rank
Phoenix AZ	4.80	2	9,455	1	.79	2	1.55	3
Los Angeles CA	1.13	28	5,795	8	.20	27	1.04	8
Sacramento CA	1.82	20	5,130	12	.34	21	.96	11
San Diego CA	1.31	24	3,860	23	.26	25	.77	21
San Fran-Oak CA	.72	29	3,040	26	.12	29	.53	27
Denver CO	4.14	4	7,190	3	.74	4	1.29	5
Miami FL	1.68	22	6,850	5	.27	23	1.10	7
Tampa FL	4.16	3	6,085	6	.68	6	1.00	9
Atlanta GA	4.03	5	4,880	13	.66	7	.80	20
Indianapolis IN	2.06	17	4,165	19	.45	14	.92	13
Louisville KY	1.60	23	3,485	25	.28	22	.61	25
Minn-St Paul MN	1.21	25	2,615	28	.27	23	.59	26
Kansas City MO	1.94	19	3,880	21	.40	17	.81	19
St. Louis MO	2.18	15	5,590	9	.35	19	.90	14
Albuquerque NM	3.92	6	7,140	4	.74	4	1.35	4
Oklahoma City OK	3.11	10	4,535	15	.61	11	.88	16
Portland OR	1.16	27	3,020	27	.19	28	.50	28
Memphis TN	2.08	16	4,425	16	.42	15	.88	16
Nashville TN	7.47	1	8,735	2	1.40	1	1.64	1
Salt Lake City UT	1.20	26	2,400	29	.22	26	.43	29
Seattle-Everett WA	2.38	12	5,320	10	.41	16	.93	12
Milwaukee WI	1.77	21	3,885	20	.35	19	.77	21
Austin TX	3.32	8	4,660	14	.62	10	.87	18
Corpus Christi TX	3.36	7	5,185	11	.77	3	1.19	6
Dallas TX	3.23	9	4,345	18	.66	7	.89	15
El Paso TX	2.31	13	5,950	7	.64	9	1.64	1
Fort Worth TX	2.81	11	3,795	24	.56	12	.75	23
Houston TX	2.21	14	3,860	22	.40	17	.70	24
San Antonio TX	2.04	18	4,365	17	.46	13	.98	10
Outside Texas Avg	2.54		5,070		.46		.92	
Texas Avg	2.75		4,595		.59		1.00	
Congested Texas Avg	2.72		4,205		.54		.84	
Total Avg	2.59		4,955		.49		.94	
Maximum Value	7.47		9,460		1.40		1.64	
Minimum Value	.72		2,400		.12		.43	

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston and San Antonio

[1]Ratio values in Table 6 divided by population density

Source: TTI Analysis and Local Transportation Agency References

conducted by the Houston-Galveston Regional Transportation Study (HGRTS) (8). 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.

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 (10). 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 (11) (congestion begins at a volume/capacity ratio of 0.8) and the AASHTO Policy on Geometric Design of Highways and Streets (12) (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.

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.

Table A-3. Summary of Relative Mobility Values For 1982

Urban Area	Freeway/Expressway				Principal Arterial Street				Congestion
	DVMT[1] (1000)	Lane-Miles	Avg No. Lanes	DVMT/[2] Ln-Mile	DVMT[1] (1000)	Lane-Miles	Avg No. Lanes	DVMT/[2] Ln-Mile	Index
Phoenix AZ	2,850	210	4.9	13,570	14,930	2,460	3.1	6,070	1.16
Los Angeles CA	72,905	4,350	7.8	16,760	55,050	10,185	3.6	5,405	1.24
Sacramento CA	5,300	630	7.0	8,415	4,995	830	3.6	6,015	.80
San Diego CA	15,075	1,520	7.0	9,915	6,130	1,430	3.0	4,285	.78
San Fran-Oak CA	28,865	2,105	6.3	13,715	9,685	1,725	3.5	5,615	1.06
Denver CO	7,900	745	4.9	10,605	9,160	1,800	3.6	5,090	.88
Miami FL	5,950	515	5.2	11,555	11,870	1,875	4.2	6,330	1.05
Tampa FL	1,980	190	4.7	10,420	3,190	545	3.8	5,855	.94
Atlanta GA	15,765	1,365	5.6	11,550	5,740	1,320	3.6	4,350	.89
Indianapolis IN	5,730	650	5.0	8,815	3,770	795	3.6	4,740	.73
Louisville KY	3,915	410	4.3	9,550	2,925	465	3.6	6,290	.85
Minn-St Paul MN	11,200	1,100	4.8	10,180	4,300	1,110	3.3	3,875	.78
Kansas City MO	8,900	1,350	4.5	6,590	3,805	940	3.4	4,050	.55
St. Louis MO	12,035	1,210	5.3	9,945	8,955	1,670	3.1	5,360	.83
Albuquerque NM	1,535	200	5.0	7,675	2,860	570	3.4	5,020	.76
Oklahoma City OK	5,825	665	4.9	8,760	2,750	575	3.0	4,785	.72
Portland OR	4,740	440	4.9	10,770	2,775	515	3.1	5,390	.87
Memphis TN	3,050	355	5.0	8,590	3,500	720	4.0	4,860	.76
Nashville TN	3,250	345	4.3	9,420	3,250	790	3.3	4,115	.75
Salt Lake City UT	2,870	325	5.4	8,830	1,455	300	3.4	4,850	.73
Seattle-Everett WA	12,270	1,005	5.7	12,210	6,835	1,340	3.2	5,100	.95
Milwaukee WI	5,600	525	4.9	10,665	4,290	915	2.9	4,690	.85
Austin TX	2,530	265	5.3	9,545	1,595	340	4.3	4,690	.77
Corpus Christi TX	1,300	160	5.2	8,125	1,250	310	3.5	4,030	.67
Dallas TX	16,870	1,550	6.1	10,885	6,440	1,555	4.4	4,140	.84
El Paso TX	2,560	325	5.0	7,875	2,600	760	3.5	3,420	.63
Fort Worth TX	8,625	905	5.3	9,530	3,660	785	4.0	4,660	.76
Houston TX	21,080	1,375	6.1	15,330	9,725	1,785	4.0	5,450	1.17
San Antonio TX	7,600	760	4.9	10,000	3,525	940	3.4	3,750	.77
Outside Texas Avg	10,795	920	5.3	10,385	7,830	1,495	3.4	5,095	.86
Texas Avg	8,650	760	5.4	10,185	4,114	925	3.9	4,305	.80
Congested Texas Avg	11,340	970	5.5	11,060	4,990	1,080	4.0	4,540	.86
Total Avg	10,275	880	5.4	10,340	6,930	1,355	3.5	4,905	.85
Maximum Value	72,905	4,350	7.8	16,760	55,050	10,185	4.4	6,330	1.24
Minimum Value	1,300	160	4.3	6,595	1,250	300	2.9	3,280	.55

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston and San Antonio

[1]Daily vehicle-miles of travel
[2]Daily vehicle-miles of travel per lane-mile of roadway

Source: TTI Analysis and Local Transportation Agency References

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 urban 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 urban 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 (13) and by the Texas Department of Highways and Public Transportation in their Project Development Process (14) would appear to represent a more appropriate value. That standard also was attained on an average urban area basis in Houston during the period (1976-77) 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 urban 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 (8).

- Urban 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 urban 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 1976-77 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.

- Urban 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 urban 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.

APPENDIX B

FREEWAY AND PRINCIPAL ARTERIAL STREET TRAVEL AND MILEAGE STATISTICS 1982 TO 1987

Table B-1. Summary of Normalized Freeway Travel and Mileage Statistics for 1987

Urban Area	Normalized for Population Density[1]							
	VMT Per Person	Rank	VMT Per Sq Mi	Rank	Ln Mi Per 1000 Pers	Rank	Ln Mi Per Sq Mi	Rank
Western & Southern Cities								
Phoenix AZ	1.23	35	2,520	39	0.08	38	0.16	39
Los Angeles CA	1.71	33	8,870	12	0.09	35	0.45	31
Sacramento CA	2.77	20	8,100	18	0.23	23	0.66	15
San Diego CA	3.68	14	11,190	4	0.26	21	0.79	9
San Fran-Oak CA	2.62	21	11,240	3	0.15	31	0.65	18
Denver CO	3.66	15	6,320	26	0.32	14	0.55	22
Miami FL	1.07	37	4,160	36	0.08	37	0.31	38
Tampa FL	3.37	17	5,120	30	0.29	17	0.43	33
Atlanta GA	11.47	1	13,530	1	0.77	1	0.91	4
Indianapolis IN	3.84	12	8,260	17	0.36	10	0.77	11
Louisville KY	3.10	18	6,810	22	0.30	16	0.65	19
Kansas City MO	5.37	7	10,460	6	0.63	6	1.24	1
St. Louis MO	3.07	19	8,400	14	0.27	19	0.74	12
Albuquerque NM	2.45	27	4,450	34	0.24	22	0.44	32
Oklahoma City OK	5.94	6	8,670	13	0.66	3	0.96	2
Portland OR	2.51	25	6,410	23	0.20	26	0.52	27
Memphis TN	2.25	29	4,580	33	0.23	24	0.46	30
Nashville TN	8.70	2	9,620	10	0.75	2	0.82	8
Salt Lake City UT	2.48	26	4,980	31	0.27	20	0.54	24
Seattle-Everett WA	4.60	10	10,410	7	0.32	15	0.72	13
Northeast & Midwest Cities								
Washington DC	2.12	30	7,690	19	0.14	32	0.52	26
Chicago IL	1.17	36	4,300	35	0.09	36	0.31	37
Baltimore MD	2.05	31	7,330	20	0.18	30	0.64	20
Boston MA	2.57	22	7,090	21	0.19	29	0.52	25
Detroit MI	1.80	32	5,610	28	0.13	33	0.41	34
Minn-St. Paul MN	4.38	11	8,290	16	0.34	12	0.65	17
New York NY	0.91	39	4,600	32	0.07	39	0.34	35
Cincinnati OH	4.64	9	10,280	8	0.41	9	0.91	3
Cleveland OH	2.30	28	6,390	25	0.20	28	0.55	23
Philadelphia PA	1.01	38	3,700	38	0.09	34	0.34	36
Pittsburgh PA	1.57	34	3,970	37	0.20	27	0.51	28
Milwaukee WI	2.56	23	5,640	27	0.21	25	0.47	29
Major Texas Cities								
Austin TX	7.60	4	10,730	5	0.62	7	0.88	5
Corpus Christi TX	3.47	16	5,460	29	0.42	8	0.66	16
Dallas TX	8.60	3	11,570	2	0.64	5	0.86	7
El Paso TX	2.56	24	6,400	24	0.28	18	0.69	14
Fort Worth TX	7.15	5	9,740	9	0.64	4	0.87	6
Houston Tx	5.22	8	9,150	11	0.33	13	0.58	21
San Antonio TX	3.75	13	8,380	15	0.35	11	0.77	10
West/South avg.	3.79		7,700		0.32		0.64	
North/Midwest Avg.	2.26		6,240		0.19		0.51	
Outside Texas Avg.	3.22		7,160		0.27		0.59	
Texas Avg.	5.48		8,770		0.47		0.76	
Congested Texas Avg.	6.46		9,910		0.52		0.79	
Total Avg.	3.62		7,450		0.31		0.62	
Maximum Value	11.47		13,530		0.77		1.24	
Minimum Value	0.91		2,520		0.07		0.16	

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston, and San Antontio.

[1]Ratio values in Table 4 divided by population density.

Source: TTI Analysis and Local Transportation Agency References.

Table B-2. Summary of Normalized Principal Arterial Street Travel and Mileage Statistics (1987)

Urban Area	Normalized for Population Density[1]							
	VMT Per Person	Rank	VMT Per Sq Mi	Rank	Ln Mi Per 1000 Pers	Rank	Ln Mi Per Sq Mi	Rank
Western & Southern Cities								
Phoenix AZ	4.43	3	9,050	2	0.70	6	1.43	3
Los Angeles CA	1.30	32	6,760	6	0.21	34	1.08	8
Sacramento CA	2.11	18	6,170	8	0.34	21	1.00	9
San Diego CA	1.30	33	3,950	26	0.25	30	0.75	28
San Fran-Oak CA	0.84	38	3,600	32	0.13	38	0.57	35
Denver CO	4.07	5	7,020	5	0.74	4	1.28	5
Miami FL	1.88	22	7,280	4	0.29	27	1.12	7
Tampa FL	3.97	6	6,010	9	0.62	9	0.95	11
Atlanta GA	4.47	2	5,280	17	0.72	5	0.85	23
Indianapolis IN	2.06	19	4,430	24	0.42	15	0.90	15
Louisville KY	1.72	26	3,770	29	0.30	26	0.66	32
Kansas City MO	1.96	21	3,820	28	0.41	16	0.80	25
St. Louis MO	2.12	17	5,780	11	0.33	24	0.90	16
Albuquerque NM	4.29	4	7,800	3	0.78	2	1.43	4
Oklahoma City OK	3.25	8	4,750	21	0.61	10	0.90	17
Portland OR	1.20	35	3,060	35	0.20	36	0.50	37
Memphis TN	2.37	14	4,820	18	0.46	13	0.93	13
Nashville TN	8.54	1	9,460	1	1.57	1	1.75	1
Salt Lake City UT	1.21	34	2,440	39	0.22	32	0.44	38
Seattle-Everett WA	2.48	12	5,610	12	0.41	17	0.92	14
Northeast & Midwest Cities								
Washington DC	1.70	27	6,180	7	0.21	35	0.75	29
Chicago IL	0.94	37	3,470	34	0.15	37	0.54	36
Baltimore MD	1.35	31	4,810	19	0.25	29	0.90	18
Boston MA	1.75	24	4,810	20	0.34	22	0.94	12
Detroit MI	1.78	23	5,550	13	0.28	28	0.89	19
Minn-St. Paul MN	1.46	30	2,760	38	0.32	25	0.62	34
New York NY	0.57	39	2,910	36	0.09	39	0.43	39
Cincinnati OH	1.61	28	3,570	33	0.38	19	0.85	22
Cleveland OH	1.00	36	2,770	37	0.23	31	0.63	33
Philadelphia PA	1.51	29	5,520	14	0.21	33	0.77	26
Pittsburgh PA	2.16	15	5,470	15	0.33	23	0.83	24
Milwaukee WI	1.74	25	3,840	27	0.35	20	0.77	27
Major Texas Cities								
Austin TX	3.17	10	4,480	23	0.61	11	0.86	21
Corpus Christi TX	3.45	7	5,420	16	0.74	3	1.16	6
Dallas TX	3.19	9	4,290	25	0.66	7	0.88	20
El Paso TX	2.40	13	6,000	10	0.64	8	1.61	2
Fort Worth TX	2.76	11	3,760	30	0.55	12	0.74	30
Houston Tx	2.12	16	3,720	31	0.40	18	0.70	31
San Antonio TX	2.05	20	4,570	22	0.45	14	1.00	10
West/South Avg.	2.78		5,540		0.49		0.96	
North/Midwest Avg.	1.46		4,300		0.26		0.74	
Outside Texas Avg.	2.28		5,080		0.40		0.88	
Texas Avg.	2.73		4,610		0.58		0.99	
Congested Texas Avg.	2.66		4,170		0.53		0.84	
Total Avg.	2.37		5,000		0.43		0.90	
Maximum Value	8.54		9,460		1.57		1.75	
Minimum Value	0.57		2,440		0.09		0.43	

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston, and San Antontio.

[1]Ratio values in Table 4 divided by population density.

Source: TTI Analysis and Local Transportation Agency References.

Table B-3. Summary of Relative Mobility Values For 1982

Urban Area	Freeway/Expressway				Principal Arterial Street				Congestion Index
	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	
Western & Southern Cities									
Phoenix AZ	2,850	210	4.9	13,570	14,930	2,460	3.1	6,070	1.16
Los Angeles CA	75,490	4,550	8.1	16,590	57,150	10,960	3.9	5,220	1.22
Sacramento CA	5,300	630	6.8	8,410	5,000	830	3.9	6,020	0.80
San Diego CA	15,080	1,520	7.3	9,920	6,130	1,430	3.3	4,290	0.78
San Fran-Oak CA	28,870	2,200	6.7	13,120	9,690	1,840	3.7	5,280	1.01
Denver CO	7,900	750	4.9	10,610	9,160	1,800	3.6	5,090	0.88
Miami FL	5,950	520	5.2	11,550	11,870	1,880	4.2	6,330	1.05
Tampa FL	1,980	190	4.7	10,420	3,190	550	3.8	5,850	0.94
Atlanta GA	15,770	1,370	5.6	11,550	5,740	1,320	3.6	4,350	0.89
Indianapolis IN	5,730	650	5.0	8,820	3,770	800	3.6	4,740	0.73
Louisville KY	3,920	410	4.3	9,550	2,930	470	3.6	6,290	0.85
Kansas City MO	8,900	1,350	4.5	6,590	3,810	900	3.4	4,230	0.55
St. Louis MO	12,040	1,210	5.3	9,950	8,960	1,670	3.1	5,360	0.83
Albuquerque NM	1,710	200	5.0	8,550	3,370	590	3.5	5,760	0.87
Oklahoma City OK	5,830	670	4.9	8,760	2,750	580	3.0	4,780	0.72
Portland OR	4,740	440	4.9	10,770	2,780	520	3.1	5,390	0.87
Memphis TN	3,050	360	5.0	8,590	3,500	720	4.0	4,860	0.76
Nashville TN	3,250	350	4.3	9,420	3,250	790	3.3	4,120	0.75
Salt Lake City UT	2,870	330	5.4	8,830	1,460	300	3.4	4,850	0.73
Seattle-Everett WA	12,270	1,010	5.7	12,210	6,840	1,340	3.2	5,100	0.95
Northeast & Midwest Cities									
Washington DC	16,090	1,440	5.7	11,170	12,600	2,040	3.6	6,180	0.95
Chicago IL	25,460	2,120	5.6	12,040	20,910	3,410	3.5	6,130	1.00
Baltimore MD	10,240	950	5.3	10,780	7,480	1,540	3.9	4,860	0.86
Boston MA	15,910	1,400	5.5	11,360	12,760	2,580	3.3	4,950	0.90
Detroit MI	20,200	1,480	5.7	13,650	21,330	3,250	4.3	6,560	1.13
Minn-St. Paul MN	11,200	1,100	4.8	10,180	4,300	1,110	3.3	3,880	0.78
New York NY	63,170	4,950	5.1	12,760	44,340	6,550	3.3	6,770	1.06
Cincinnati OH	8,490	750	5.2	11,310	3,020	780	3.3	3,900	0.86
Cleveland OH	10,000	960	4.6	10,420	4,500	1,100	2.9	4,090	0.80
Philadelphia PA	12,380	1,270	5.2	9,750	17,550	2,990	2.9	5,880	0.90
Pittsburgh PA	5,520	780	4.1	7,120	8,860	1,440	2.7	6,150	0.81
Milwaukee WI	5,600	530	4.9	10,670	4,290	920	2.9	4,690	0.85
Major Texas Cities									
Austin TX	2,530	270	5.3	9,550	1,600	340	4.3	4,690	0.77
Corpus Christi TX	1,300	160	5.2	8,130	1,250	310	3.5	4,030	0.67
Dallas TX	16,870	1,550	5.4	10,890	6,440	1,560	4.4	4,140	0.84
El Paso TX	2,560	330	5.0	7,880	2,600	760	3.5	3,420	0.63
Fort Worth TX	8,630	910	4.8	9,530	3,660	790	4.0	4,660	0.76
Houston Tx	21,080	1,380	6.1	15,330	9,730	1,790	4.0	5,450	1.17
San Antonio TX	7,600	760	4.9	10,000	3,530	940	3.4	3,750	0.77
West/South Avg.	11,180	950	5.4	10,390	8,310	1,590	3.5	5,200	0.87
North/Midwest Avg.	17,020	1,480	5.1	10,940	13,500	2,310	3.3	5,340	0.91
Outside Texas Avg.	13,370	1,150	5.3	10,600	10,260	1,860	3.4	5,250	0.88
Texas Avg.	8,650	770	5.2	10,190	4,120	930	3.9	4,310	0.80
Congested Texas Avg.	11,340	970	5.3	11,060	4,990	1,080	4.0	4,540	0.86
Total Avg.	12,520	1,080	5.3	10,520	9,160	1,690	3.5	5,080	0.87
Maximum Value	75,490	4,950	8.1	16,590	57,150	10,960	4.4	6,770	1.22
Minimum Value	1,300	160	4.1	6,590	1,250	300	2.7	3,420	0.55

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston, and San Antontio.

[1]Daily vehicle-miles of travel.
[2]Daily vehicle-miles of travel per lane-mile of roadway.

Source: TTI Analysis and Local Transportation Agency References.

Table B-4. Summary of Relative Mobility Values For 1983

Urban Area	Freeway/Expressway				Principal Arterial Street				Congestion Index
	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	
Western & Southern Cities									
Phoenix AZ	2,910	220	4.9	13,540	14,970	2,490	3.2	6,010	1.15
Los Angeles CA	79,340	4,630	5.1	17,140	60,210	11,100	3.9	5,420	1.27
Sacramento CA	5,800	630	6.8	9,210	5,200	850	3.9	6,120	0.84
San Diego CA	16,480	1,550	7.3	10,630	6,490	1,450	3.3	4,480	0.83
San Fran-Oak CA	30,000	2,210	6.7	13,580	10,230	1,850	3.7	5,530	1.05
Denver CO	8,240	750	5.0	11,060	9,400	1,830	3.7	5,140	0.90
Miami FL	6,270	520	5.2	12,170	12,300	1,900	4.2	6,470	1.09
Tampa FL	1,950	190	4.7	10,240	3,070	550	3.8	5,620	0.91
Atlanta GA	17,010	1,400	5.6	12,150	6,540	1,380	3.6	4,760	0.94
Indianapolis IN	5,260	650	5.0	8,090	3,720	810	3.6	4,590	0.69
Louisville KY	4,440	450	4.4	9,860	2,720	470	3.6	5,790	0.83
Kansas City MO	8,990	1,350	4.5	6,660	3,860	900	3.4	4,280	0.56
St. Louis MO	13,040	1,250	5.3	10,470	9,290	1,680	3.1	5,530	0.87
Albuquerque NM	1,620	200	5.0	8,080	3,080	580	3.5	5,360	0.81
Oklahoma City OK	5,940	680	4.9	8,800	2,900	610	3.0	4,790	0.72
Portland OR	5,380	500	4.9	10,750	2,730	520	3.1	5,290	0.86
Memphis TN	3,000	360	5.1	8,450	3,400	720	4.0	4,720	0.74
Nashville TN	3,300	340	4.3	9,710	3,400	810	3.3	4,190	0.77
Seattle-Everett WA	13,100	1,040	5.7	12,650	7,320	1,370	3.2	5,360	0.99
Northeast & Midwest Cities									
Washington DC	16,150	1,440	5.7	11,220	13,600	2,050	3.6	6,630	0.98
Chicago IL	25,840	2,150	5.6	12,020	21,600	3,440	3.5	6,280	1.01
Baltimore MD	10,550	970	5.3	10,880	7,780	1,570	3.9	4,960	0.87
Boston MA	16,820	1,420	5.5	11,880	12,990	2,600	3.3	5,000	0.93
Detroit MI	19,660	1,480	5.7	13,280	20,910	3,270	4.3	6,390	1.10
Minn-St. Paul MN	12,170	1,130	4.8	10,770	4,450	1,120	3.4	3,970	0.82
New York NY	62,250	4,980	5.1	12,510	46,050	6,600	3.3	6,980	1.06
Cincinnati OH	8,490	790	5.2	10,740	3,170	780	3.3	4,080	0.83
Cleveland OH	10,220	960	4.6	10,650	4,530	1,100	2.9	4,110	0.82
Philadelphia PA	13,450	1,320	5.2	10,190	19,520	2,990	2.9	6,540	0.97
Pittsburgh PA	6,120	840	4.1	7,290	8,940	140	2.7	6,210	0.81
Milwaukee WI	5,800	530	4.9	10,940	4,280	920	2.9	4,650	0.86
Major Texas Cities									
Austin TX	2,970	280	5.4	10,610	1,710	360	4.2	4,750	0.84
Corpus Christi TX	1,370	170	5.2	8,300	1,300	320	3.5	4,130	0.69
Dallas TX	18,400	1,580	5.4	11,650	7,040	1,600	4.4	4,410	0.89
El Paso TX	2,690	340	5.0	8,030	2,710	780	3.5	3,470	0.64
Fort Worth TX	9,230	940	4.9	9,870	3,850	800	3.9	4,810	0.79
Houston Tx	22,560	1,410	6.1	16,000	10,350	1,850	3.9	5,610	1.21
San Antonio TX	7,970	780	4.9	10,280	3,690	970	3.3	3,820	0.79
West/South Avg.	11,750	960	5.4	10,600	8,620	1,610	3.5	5,230	0.88
North/Midwest Avg.	17,290	1,500	5.1	11,030	13,980	2,210	3.3	5,480	0.92
Outside Texas Avg.	13,830	1,160	5.3	10,760	10,630	1,840	3.5	5,320	0.89
Texas Avg.	9,310	780	5.3	10,680	4,380	950	3.8	4,430	0.84
Congested Texas Avg.	12,220	1,000	5.3	11,680	5,330	1,110	3.9	4,680	0.90
Total Avg.	13,020	1,100	5.3	10,740	9,510	1,680	3.5	5,160	0.88
Maximum Value	79,340	4,980	8.1	17,140	60,210	11,100	4.4	6,980	1.27
Minimum Value	1,370	170	4.1	6,660	1,300	140	2.7	3,470	0.56

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston, and San Antontio.

[1] Daily vehicle-miles of travel.
[2] Daily vehicle-miles of travel per lane-mile of roadway.

Source: TTI Analysis and Local Transportation Agency References.

Table B-5. Summary of Relative Mobility Values For 1984

Urban Area	Freeway/Expressway				Principal Arterial Street				Congestion Index
	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	
Western & Southern Cities									
Phoenix AZ	3,150	220	4.9	14,320	15,310	2,530	3.2	6,050	1.17
Los Angeles CA	83,390	4,680	8.2	17,820	63,430	11,250	4.0	5,640	1.32
Sacramento CA	6,480	640	6.9	10,130	5,420	900	4.0	6,020	0.88
San Diego CA	18,480	1,580	7.3	11,730	7,090	1,480	3.4	4,790	0.91
San Fran-Oak CA	32,220	2,210	6.8	14,580	10,790	1,900	3.8	5,680	1.12
Denver CO	8,740	750	5.0	11,730	10,110	1,860	3.8	5,430	0.96
Miami FL	6,470	530	5.3	12,320	12,000	1,930	4.3	6,230	1.07
Tampa FL	2,540	220	4.7	11,550	3,660	570	3.7	6,410	1.03
Atlanta GA	18,110	1,430	5.7	12,660	7,460	1,410	3.6	5,310	0.99
Indianapolis IN	6,090	690	5.0	8,830	4,060	830	3.6	4,920	0.74
Louisville KY	4,600	460	4.4	10,000	2,650	480	3.6	5,510	0.83
Kansas City MO	9,380	1,360	4.5	6,900	3,910	910	3.4	4,300	0.58
St. Louis MO	14,410	1,320	5.4	10,960	9,750	1,710	3.2	5,700	0.90
Albuquerque NM	1,710	200	5.0	8,550	3,370	590	3.5	5,760	0.87
Oklahoma City OK	6,060	680	5.0	8,910	3,330	630	3.0	5,290	0.75
Portland OR	5,570	510	4.9	10,920	2,800	520	3.2	5,430	0.88
Memphis TN	3,020	360	5.1	8,380	3,320	730	4.0	4,540	0.72
Nashville TN	3,650	360	4.3	10,130	4,300	850	3.4	5,050	0.85
Salt Lake City UT	3,020	340	5.5	8,880	1,680	310	3.4	5,400	0.75
Seattle-Everett WA	13,920	1,070	5.8	13,070	7,790	1,410	3.3	5,530	1.02
Northeast & Midwest Cities									
Washington DC	18,070	1,480	5.7	12,250	14,800	2,070	3.6	7,150	1.06
Chicago IL	26,770	2,150	5.7	12,450	22,560	3,750	3.5	6,020	1.02
Baltimore MD	10,880	1,020	5.3	10,670	7,780	1,570	3.9	4,960	0.87
Boston MA	17,300	1,430	5.5	12,140	13,150	2,600	3.4	5,060	0.95
Detroit MI	20,760	1,490	5.7	13,930	21,130	3,300	4.3	6,400	1.13
Minn-St. Paul MN	13,000	1,160	4.8	11,260	4,650	1,130	3.4	4,120	0.86
New York NY	65,320	5,230	5.1	12,490	45,390	6,650	3.3	6,830	1.05
Cincinnati OH	8,660	810	5.3	10,690	3,230	780	3.3	4,160	0.82
Cleveland OH	10,410	960	4.6	10,840	4,550	1,100	2.9	4,130	0.83
Philadelphia PA	13,640	1,320	5.2	10,330	19,810	3,000	2.9	6,600	0.98
Pittsburgh PA	6,460	860	4.1	7,510	9,080	1,470	2.7	6,180	0.81
Milwaukee WI	5,880	530	5.0	11,100	4,660	930	2.9	5,010	0.89
Major Texas Cities									
Austin TX	3,300	290	5.4	11,380	1,825	380	4.1	4,800	0.89
Corpus Christi TX	1,360	170	5.2	8,240	1,350	320	3.5	4,220	0.69
Dallas TX	19,930	1,620	5.3	12,300	7,640	1,650	4.5	4,630	0.94
El Paso TX	2,800	350	5.0	8,120	2,820	800	3.5	3,530	0.65
Fort Worth TX	9,690	970	4.9	10,040	4,015	825	3.9	4,870	0.80
Houston Tx	24,380	1,480	6.1	16,470	10,860	1,920	3.9	5,660	1.25
San Antonio TX	8,450	790	4.9	10,760	3,920	980	3.3	4,000	0.82
West/South Avg.	12,550	980	5.5	11,120	9,110	1,640	3.6	5,450	0.92
North/Midwest Avg.	18,090	1,540	5.2	11,300	14,230	2,360	3.3	5,550	0.94
Outside Texas Avg.	14,630	1,190	5.4	11,190	11,030	1,910	3.5	5,490	0.93
Texas Avg.	9,990	810	5.3	11,040	4,630	980	3.8	4,530	0.86
Congested Texas Avg.	13,150	1,030	5.3	12,190	5,650	1,150	3.9	4,790	0.94
Total Avg.	13,800	1,120	5.3	11,160	9,880	1,740	3.5	5,320	0.91
Maximum Value	83,390	5,230	8.2	17,820	63,430	11,250	4.5	7,150	1.32
Minimum Value	1,360	170	4.1	6,900	1,350	310	2.7	3,530	0.58

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston, and San Antontio.

[1]Daily vehicle-miles of travel.
[2]Daily vehicle-miles of travel per lane-mile of roadway.

Source: TTI Analysis and Local Transportation Agency References.

Table B-6. Summary of Relative Mobility Values For 1985

Urban Area	Freeway/Expressway DVMT[1] (1000)	Freeway/Expressway Lane-Miles	Freeway/Expressway Avg. No. Lanes	Freeway/Expressway DVMT/[2] Ln-Mile	Principal Arterial Street DVMT[1] (1000)	Principal Arterial Street Lane-Miles	Principal Arterial Street Avg. No. Lanes	Principal Arterial Street DVMT/[2] Ln-Mile	Congestion Index
Western & Southern Cities									
Phoenix AZ	3,530	240	4.8	15,020	15,710	2,570	3.2	6,110	1.20
Los Angeles CA	87,640	4,750	8.2	18,450	66,830	11,400	4.0	5,860	1.36
Sacramento CA	6,900	640	6.9	10,780	5,650	940	4.0	6,010	0.92
San Diego CA	19,650	1,600	7.4	12,320	7,500	1,500	3.4	5,000	0.95
San Fran-Oak CA	34,670	2,270	6.8	15,270	11,380	1,940	3.8	5,870	1.17
Denver CO	9,050	750	5.0	12,150	10,470	1,890	3.8	5,540	0.99
Miami FL	7,110	540	5.3	13,170	12,700	1,960	4.3	6,480	1.13
Tampa FL	2,850	260	4.9	10,940	3,840	600	3.8	6,450	1.00
Atlanta GA	19,430	1,460	5.8	13,350	8,370	1,440	3.6	5,810	1.05
Indianapolis IN	6,280	690	5.0	9,100	4,100	840	3.7	4,910	0.76
Louisville KY	4,450	460	4.4	9,670	2,760	480	3.6	5,740	0.82
Kansas City MO	10,190	1,380	4.6	7,380	4,250	910	3.4	4,670	0.62
St. Louis MO	14,820	1,360	5.4	10,930	10,260	1,730	3.2	5,930	0.91
Albuquerque NM	1,820	200	5.0	9,100	3,600	600	3.5	6,000	0.92
Oklahoma City OK	5,980	690	5.0	8,720	3,350	650	3.0	5,190	0.74
Portland OR	5,930	520	4.9	11,500	2,970	520	3.3	5,700	0.93
Memphis TN	3,050	370	5.1	8,360	3,520	750	4.0	4,690	0.73
Nashville TN	3,920	390	4.4	10,170	4,590	880	3.4	5,210	0.86
Salt Lake City UT	3,220	360	5.5	8,940	1,800	330	3.3	5,440	0.76
Seattle-Everett WA	14,850	1,100	5.8	13,500	8,060	1,440	3.3	5,600	1.05
Northeast & Midwest Cities									
Washington DC	19,890	1,500	5.6	13,260	15,900	2,110	3.7	7,540	1.13
Chicago IL	28,670	2,180	5.7	13,150	22,870	3,780	3.6	6,050	1.06
Baltimore MD	12,170	1,110	5.2	10,960	8,620	1,620	4.0	5,340	0.89
Boston MA	18,200	1,440	5.6	12,640	13,490	2,620	3.4	5,150	0.98
Detroit MI	21,460	1,550	5.7	13,840	21,240	3,340	4.4	6,360	1.12
Minn-St. Paul MN	13,690	1,190	4.8	11,500	4,890	1,140	3.5	4,310	0.88
New York NY	66,060	5,270	5.2	12,530	46,700	6,800	3.4	6,870	1.05
Cincinnati OH	8,850	820	5.3	10,790	3,290	780	3.3	4,220	0.83
Cleveland OH	10,060	960	4.6	10,470	4,640	1,100	2.9	4,210	0.81
Philadelphia PA	13,110	1,240	5.2	10,570	20,410	3,050	2.9	6,690	1.01
Pittsburgh PA	6,660	860	4.1	7,740	9,450	1,470	2.7	6,430	0.84
Milwaukee WI	6,070	540	5.1	11,230	4,820	930	3.0	5,180	0.90
Major Texas Cities									
Austin TX	4,890	420	5.5	11,640	2,000	400	4.1	5,000	0.91
Corpus Christi TX	1,400	170	5.2	8,490	1,370	320	3.5	4,280	0.71
Dallas TX	21,100	1,640	5.3	12,870	7,950	1,675	4.5	4,750	0.98
El Paso TX	3,120	350	5.0	9,040	2,880	800	3.6	3,600	0.70
Fort Worth TX	10,070	980	5.0	10,330	4,140	840	3.9	4,930	0.82
Houston Tx	24,120	1,480	6.1	16,290	10,850	1,930	3.9	5,620	1.23
San Antonio TX	9,080	800	5.0	11,350	4,280	1,020	3.3	4,200	0.88
West/South Avg.	13,270	1,000	5.5	11,440	9,580	1,670	3.6	5,610	0.94
North/Midwest Avg.	18,740	1,560	5.2	11,560	14,690	2,390	3.4	5,700	0.96
Outside Texas Avg.	15,320	1,210	5.4	11,490	11,500	1,940	3.5	5,640	0.95
Texas Avg.	10,540	830	5.3	11,430	4,780	1,000	3.8	4,620	0.89
Congested Texas Avg.	13,850	1,060	5.4	12,500	5,850	1,170	3.9	4,900	0.96
Total Avg.	14,460	1,140	5.4	11,480	10,290	1,770	3.6	5,460	0.94
Maximum Value	87,640	5,270	8.2	18,450	66,830	11,400	4.5	7,540	1.36
Minimum Value	1,400	170	4.1	7,380	1,370	320	2.7	3,600	0.62

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston, and San Antontio.

[1]Daily vehicle-miles of travel.
[2]Daily vehicle-miles of travel per lane-mile of roadway.

Source: TTI Analysis and Local Transportation Agency References.

Table B-7. Summary of Relative Mobility Values For 1986

Urban Area	Freeway/Expressway DVMT[1] (1000)	Freeway/Expressway Lane-Miles	Freeway/Expressway Avg. No. Lanes	Freeway/Expressway DVMT/[2] Ln-Mile	Principal Arterial Street DVMT[1] (1000)	Principal Arterial Street Lane-Miles	Principal Arterial Street Avg. No. Lanes	Principal Arterial Street DVMT/[2] Ln-Mile	Congestion Index
Western & Southern Cities									
Phoenix AZ	4,620	320	4.8	14,670	15,840	2,600	3.2	6,100	1.18
Los Angeles CA	92,110	4,800	8.2	19,190	70,410	11,610	4.0	6,070	1.42
Sacramento CA	7,400	650	6.9	11,390	5,890	970	4.0	6,070	0.95
San Diego CA	21,020	1,630	7.4	12,940	7,850	1,530	3.4	5,130	1.00
San Fran-Oak CA	36,930	2,290	6.8	16,160	12,000	1,980	3.8	6,080	1.24
Denver CO	9,290	750	5.0	12,470	10,680	1,920	3.8	5,560	1.01
Miami FL	6,980	540	5.3	12,920	12,300	1,980	4.3	6,230	1.10
Tampa FL	2,940	270	4.9	10,890	3,650	600	3.8	6,080	0.96
Atlanta GA	21,530	1,460	5.8	14,800	9,060	1,480	3.6	6,120	1.15
Indianapolis IN	6,910	690	5.0	10,010	3,950	840	3.7	4,730	0.80
Louisville KY	4,790	510	4.4	9,480	2,740	480	3.6	5,700	0.80
Kansas City MO	10,910	1,410	4.6	7,730	4,390	910	3.4	4,820	0.64
St. Louis MO	15,620	1,380	5.5	11,320	10,770	1,730	3.2	6,220	0.95
Albuquerque NM	1,930	200	5.0	9,650	3,250	620	3.5	5,290	0.87
Oklahoma City OK	5,780	690	5.0	8,380	3,310	650	3.1	5,130	0.71
Portland OR	6,330	530	5.0	12,050	3,140	530	3.3	5,980	0.97
Memphis TN	3,110	370	5.1	8,520	3,760	750	4.0	5,010	0.77
Nashville TN	4,250	400	4.4	10,630	4,810	900	3.4	5,340	0.89
Salt Lake City UT	3,450	380	5.5	9,080	1,830	330	3.3	5,530	0.77
Seattle-Everett WA	15,500	1,110	5.8	13,960	8,330	1,450	3.3	5,740	1.09
Northeast & Midwest Cities									
Washington DC	22,410	1,560	5.6	14,410	17,400	2,220	3.7	7,840	1.21
Chicago IL	30,950	2,260	5.8	13,720	24,980	3,840	3.6	6,510	1.11
Baltimore MD	13,020	1,160	5.2	11,220	8,930	1,650	4.0	5,430	0.91
Boston MA	20,060	1,460	5.6	13,740	13,410	2,640	3.4	5,090	1.05
Detroit MI	21,670	1,580	5.8	13,720	21,450	3,400	4.4	6,310	1.11
Minn-St. Paul MN	14,560	1,190	4.8	12,240	5,100	1,150	3.5	4,440	0.93
New York NY	71,600	5,360	5.2	13,360	46,460	6,860	3.4	6,780	1.09
Cincinnati OH	8,910	820	5.3	10,890	3,240	780	3.3	4,150	0.84
Cleveland OH	10,710	960	4.6	11,150	4,730	1,100	2.9	4,300	0.86
Philadelphia PA	13,810	1,250	5.2	11,040	21,430	3,050	2.9	7,030	1.06
Pittsburgh PA	6,900	860	4.1	8,020	9,810	1,490	2.7	6,580	0.86
Milwaukee WI	6,320	560	5.1	11,380	4,700	930	3.0	5,050	0.91
Major Texas Cities									
Austin TX	5,300	420	5.5	12,620	2,190	410	4.1	5,340	0.98
Corpus Christi TX	1,420	170	5.2	8,370	1,400	320	3.5	4,380	0.71
Dallas TX	22,580	1,640	5.3	13,770	8,230	1,680	4.5	4,900	1.05
El Paso TX	3,420	350	5.0	9,910	2,920	805	3.6	3,620	0.75
Fort Worth TX	10,750	980	5.0	11,000	4,250	840	3.9	5,060	0.87
Houston Tx	24,120	1,510	6.1	15,970	10,810	1,960	3.9	5,530	1.21
San Antonio TX	9,450	810	5.0	11,350	4,290	1,030	3.3	4,450	0.91
West/South Avg.	14,070	1,020	5.5	11,810	9,900	1,690	3.6	5,650	0.96
North/Midwest Avg.	20,070	1,580	5.2	12,070	15,140	2,430	3.4	5,790	1.00
Outside Texas Avg.	16,320	1,230	5.4	11,910	11,860	1,970	3.5	5,700	0.98
Texas Avg.	11,000	840	5.3	11,850	4,870	1,010	3.8	4,750	0.93
Congested Texas Avg.	14,440	1,070	5.4	12,940	5,950	1,180	3.9	5,060	1.00
Total Avg.	15,370	1,160	5.4	11,900	10,610	1,790	3.6	5,530	0.97
Maximum Value	92,110	5,360	8.2	19,190	70,410	11,610	4.5	7,840	1.42
Minimum Value	1,420	170	4.1	7,730	1,400	320	2.7	3,620	0.64

Note: Congested Texas Cities average includes Austin, Dallas, Fort Worth, Houston, and San Antonio.

[1]Daily vehicle-miles of travel.
[2]Daily vehicle-miles of travel per lane-mile of roadway.

Source: TTI Analysis and Local Transportation Agency References.

APPENDIX C
CONGESTION COST ESTIMATE

APPENDIX C
CONGESTION COST ESTIMATE

Delay in travel time represents a significant cost to the motoring public. This Appendix attempts to quantify these costs to the drivers in terms of time, fuel, and increased insurance rates. The delay calculations are affected by a number of constants and urban area/state specific variables that will be discussed in the following sections.

Cost Estimate Constants

The congestion cost estimate calculations utilized the following derived constant values.

1. Occupancy -- 1.25 persons per vehicle.
2. 250 working days per year.
3. Average cost of time (6) -- \$8.50 per person hour[1].
4. Commercial vehicle operating cost (7) -- \$1.65 per mile.
5. Vehicle mix -- 95 percent passenger and 5 percent commercial.
6. Vehicular speeds (8):

Freeway/Expressway -- peak: 35 mph, off-peak: 55 mph.
Principal Arterial Street -- peak: 20 mph, off-peak: 35 mph.

These constants were applied to all study areas consistently for the cost estimate calculations.

[1]Referenced value of \$8.00/hr in 1985 adjusted with the Consumer Price Index to value used for 1987 wage rate.

Table C-1. 1987 Congestion Cost Estimate Variables

Urban Area	Daily Vehicle-Miles of Travel Frwy (1000)	Prin.Art.Str (1000)	Total (1000)	Auto Insurance Rates (Dollars)	Annual Insurance Difference (Dollars)	1987 State Avg Fuel Cost (Dollars)	1987 Registered Auto's	Population (1000)	Popn. Per Reg. Veh.
Western & Southern Cities									
Phoenix AZ	4,580	16,480	21,060	620	50	1.14	1,166,900	1,820	1.56
Los Angeles CA	96,890	73,810	170,700	800	310	1.09	7,652,770	10,920	1.43
Sacramento CA	8,060	6,140	14,190	580	90		1,198,570	1,000	.83
San Diego CA	23,160	8,180	31,340	560	70		1,318,170	2,070	1.57
San Fran-Oakland CA	39,580	12,670	52,250	660	170		2,942,880	3,520	1.20
Denver CO	9,480	10,600	20,080	525	75	1.11	1,323,710	1,510	1.14
Miami FL	7,420	13,000	20,420	960	410	1.08	1,336,090	1,790	1.34
Tampa FL	3,300	3,880	7,180	590	40		583,110	650	1.11
Atlanta GA	23,940	9,350	33,290	610	200	1.01	1,522,280	1,770	1.16
Indianapolis IN	7,640	4,100	11,740	380	65	1.06	544,300	930	1.70
Louisville KY	5,380	2,980	8,360	400	70	1.03	450,000	790	1.76
Kansas City MO	11,920	4,350	16,270	430	80	.98	644,690	1,140	1.77
St Louis MO	16,290	11,220	27,510	490	140		939,480	1,940	2.06
Albuquerque NM	2,030	3,550	5,580	400	40	1.05	364,110	460	1.25
Oklahoma City OK	6,330	3,470	9,800	450	90	1.02	467,910	730	1.56
Portland OR	6,700	3,200	9,900	450	100	.97	615,540	1,050	1.70
Memphis TN	3,730	3,930	7,660	520	150	1.04	596,800	820	1.37
Nashville TN	5,000	4,920	9,920	430	60		479,090	520	1.09
Salt Lake City UT	3,810	1,870	5,680	370	50	1.08	653,020	770	1.17
Seattle-Everett WA	16,600	8,950	25,550	455	70	1.07	1,145,370	1,600	1.39
Northeast & Midwest Cities									
Washington DC	22,910	18,400	41,310	745	165	1.06	1,609,070	2,980	1.85
Chicago IL	30,950	24,970	55,910	630	180	1.07	3,960,000	7,200	1.82
Baltimore MD	13,740	9,020	22,760	850	280	1.06	993,750	1,880	1.89
Boston MA	20,210	13,700	33,910	770	90	.98	1,510,560	2,850	1.89
Detroit MI	21,800	21,550	43,350	690	210	1.05	2,872,930	3,890	1.35
Minn-St Paul MN	15,620	5,200	20,820	480	60	1.09	1,574,410	1,890	1.20
New York NY	73,610	46,490	120,110	830	400	1.00	5,727,060	16,000	2.79
Cincinnati OH	9,560	3,320	12,880	370	20	1.04	888,750	930	1.05
Cleveland OH	11,190	4,840	16,030	480	130		1,444,390	1,750	1.21
Philadelphia PA	15,130	22,550	37,680	800	400	.99	2,687,670	4,090	1.52
Pittsburgh PA	7,190	9,910	17,100	680	280		1,192,230	1,810	1.52
Milwaukee WI	6,820	4,640	11,460	400	80	1.04	521,260	1,210	2.32
Major Texas Cities									
Austin TX	5,150	2,150	7,300	460	40	1.06	468,310	480	1.02
Corpus Christi TX	1,500	1,490	2,990	450	30		224,250	280	1.23
Dallas TX	22,100	8,200	30,300	560	140		1,569,870	1,910	1.22
El Paso TX	3,200	3,000	6,200	490	70		352,390	500	1.42
Fort Worth TX	11,000	4,250	15,250	520	100		1,000,330	1,130	1.13
Houston TX	25,800	10,500	36,300	610	190		2,220,530	2,820	1.27
San Antonio TX	8,800	4,800	13,600	500	80		808,810	1,050	1.30
West/South Avg.	15,090	10,330	25,420	530	115	1.05	1,297,240	1,790	1.41
North/Midwest Avg.	20,730	15,380	36,110	640	190	1.04	2,081,840	3,870	1.70
Outside Texas Avg.	17,200	12,230	29,430	575	145	1.05	1,591,460	2,570	1.52
Texas Avg.	11,080	4,910	15,990	510	95	1.06	949,210	1,170	1.23
Congested Texas Avg.	14,570	5,980	20,550	530	110		1,213,570	1,480	1.19
Total Avg.	16,110	10,910	27,020	565	135	1.05	1,476,190	2,320	1.46
Maximum Value	96,890	73,810	170,700	960	410	1.14	7,652,770	16,000	2.79
Minimum Value	1,500	1,490	2,990	370	20	.97	224,250	280	.83

Source: TTI Analysis and Local Transportation Agency References

Cost Estimate Variables

In addition to the derived constants, five urban area/state specific variables were identified and used in the congestion cost estimate calculations. These variables are illustrated in Table C-1.

Daily Vehicle-Miles Of Travel

The daily vehicle-miles of travel (DVMT) is the average daily traffic (ADT) of a section of roadway multiplied by the length (in miles) of that section of roadway. This allows the daily volume of all urban facilities to be represented in terms that can be quantified and utilized in cost calculations. DVMT was estimated for the freeways and principal arterial streets located in each study urban area. These estimates originate from the HPMS data base and other local transportation data sources, and are presented in a previous section of this report.

Insurance Rates

Auto insurance rates reported in Table C-1 represent the state and urban area averages. These rates were compiled by averaging the rates for minimum required automobile coverage in the various areas and states as quoted by three major insurance carriers. The statewide rate is the average state rate excluding the study areas and other large urban areas. This allowed the calculation of the additional insurance premiums paid by motorists operating vehicles in large urban areas.

Fuel Costs

Statewide average fuel cost estimates were obtained from 1987 data published by the American Automobile Association (AAA) (15). These data represent the average reported fuel cost for 1987. Values for different fuel types used in motor vehicles, i.e., diesel and gasoline, did not vary enough to be reported separately. Therefore, an average rate for fuel was used in cost estimate calculations.

Registered Vehicles

The registered vehicle data was obtained from the county Tax Assessor's office in each study area. These data represent the passenger automobiles and light trucks (pick-ups) registered within the study area in 1987.

Population

Population data were obtained from the combination of 1986 U.S. Census Bureau estimates and 1987 population estimates reported in the Federal Highway Administration's Highway Performance Monitoring System (HPMS).

Cost Estimate Calculations

The first step in the cost estimate procedure was to convert DVMT into vehicle-hours of delay. Vehicle-hours of delay is the basis for the delay and fuel cost calculations. To obtain vehicle-hours of delay, vehicle-miles of travel on congested roadways during each peak period was estimated. This was accomplished by the use of two factors.

Highway Performance Monitoring System (HPMS) data were used to determine the percentage of urban area DVMT occurring on congested facilities. Two functional classes, freeways/expressways and principal arterial streets, were considered in the calculation of this factor. Congested conditions for these facilities were defined by the following ADT per lane values.

- Freeways/Expressways-------ADT per lane greater than 15,000
- Principal Arterial Streets--------ADT per lane greater than 5,750

Using these values, the percent DVMT operating in congested conditions could be calculated by functional class. This percentage adjusts DVMT to congested DVMT, the first step in the process to obtain travel volume that occurs during congested conditions.

The congested DVMT values were adjusted by a factor to represent the percentage occurring in the peak period. This factor was calculated using Texas Department of Highways and Public Transportation (TDHPT) 1986 Automatic Traffic Recorder Data (16) for the study areas in Texas. Using these data, the percentage of ADT occurring during the morning and evening peak periods could be determined. These data indicated that a relatively consistent value of 45 percent of total daily traffic occurred during the peak periods. This factor was applied to all the study areas.

Once the DVMT was converted to peak-period congested vehicle-miles of travel (Table C-2), the recurring vehicle-hours of delay were computed (Equation C-1). Recurring delay is caused by the peak facility conditions during normal operations. This value does not include delay resulting from accidents, construction or maintenance operations.

$$\text{Recurring Vehicle-Hour Delay Per Day} = \frac{\text{Peak-Period Congested DVMT}}{\text{Avg. Peak-Period Speed}} - \frac{\text{Peak-Period Congested DVMT}}{\text{Avg. Off-Peak Speed}} \qquad \text{Eq. C-1}$$

This calculation was performed for both freeways and principal arterial streets in a study area; the total recurring vehicle-hours of delay is the sum of the two. The result of these calculations is shown in Table C-3.

Another type of delay encountered by vehicles is incident delay. This is the delay that results from an accident or disabled vehicles. Incident vehicle-hours of delay vary for each area by facility type, i.e., freeway/expressway or arterial street. For the freeway system in individual study areas the ratio of recurring to incident delay reported by Lindley [9] were used. The resulting incident delay was calculated using Equation C-2.

$$\text{Frwy Incident Vehicle-Hours of Delay Per Day} = \text{Peak-Period Frwy Vehicle-Hours of Delay Per Day} \times \text{Frwy Incident/Recurring Ratio} \qquad \text{Eq. C-2}$$

An incident will have varying effects on different types of facilities; for the purpose of this study, incident delay for arterial streets is defined as 110 percent of arterial street recurring delay. This incident delay factor was calculated using Equation C-3.

$$\text{Principal Arterial Street Incident Vehicle-Hour Delay Per Day} = \text{Principal Arterial Street Recurring Vehicle-Hour Delay Per Day} \times 1.1 \qquad \text{Eq.C-3}$$

Table C-2. 1987 Congested Daily Vehicle-Miles of Travel

Urban Area	Daily Vehicle-Miles of Travel			Congested DVMT[1,2]		Peak Period Congested[1,3]		DVMT
	Frwy (1000)	Prin.Art.Str. (1000)	Total (1000)	Frwy (%)	Prin.Art.Str. (%)	Frwy (1000)	Prin.Art.Str. (1000)	Totals (1000)
Western & Southern Cities								
Phoenix AZ	4,580	16,480	21,060	.70	.70	1,440	5,190	6,630
Los Angeles CA	96,890	73,810	170,700	.85	.50	37,060	16,610	53,670
Sacramento CA	8,060	6,140	14,190	.35	.45	1,270	1,240	2,510
San Diego CA	23,160	8,180	31,340	.45	.30	4,690	1,100	5,790
San Fran-Oakland CA	39,580	12,670	52,250	.80	.60	14,250	3,420	17,670
Denver CO	9,480	10,600	20,080	.50	.50	2,130	2,390	4,520
Miami FL	7,420	13,000	20,420	.50	.70	1,670	4,100	5,770
Tampa FL	3,300	3,880	7,180	.20	.65	300	1,140	1,430
Atlanta GA	23,940	9,350	33,290	.50	.65	5,390	2,740	8,120
Indianapolis IN	7,640	4,100	11,740	.05	.15	170	280	450
Louisville KY	5,380	2,980	8,360	.05	.55	120	740	860
Kansas City MO	11,920	4,350	16,270	.05	.20	270	390	660
St Louis MO	16,290	11,220	27,510	.20	.65	1,470	3,280	4,750
Albuquerque NM	2,030	3,550	5,580	.10	.40	90	640	730
Oklahoma City OK	6,330	3,470	9,800	.05	.35	140	550	690
Portland OR	6,700	3,200	9,900	.35	.60	1,060	860	1,920
Memphis TN	3,730	3,930	7,660	.10	.35	170	620	790
Nashville TN	5,000	4,920	9,920	.20	.40	450	890	1,340
Salt Lake City UT	3,810	1,870	5,680	.15	.40	260	340	590
Seattle-Everett WA	16,600	8,950	25,550	.65	.55	4,860	2,220	7,070
Northeast & Midwest Cities								
Washington DC	22,910	18,400	41,310	.65	.85	6,700	7,040	13,740
Chicago IL	30,950	24,970	55,910	.55	.70	7,660	7,860	15,520
Baltimore MD	13,740	9,020	22,760	.25	.35	1,550	1,420	2,970
Boston MA	20,210	13,700	33,910	.40	.35	3,640	2,160	5,800
Detroit MI	21,800	21,550	43,350	.40	.60	3,920	5,820	9,740
Minn-St Paul MN	15,620	5,200	20,820	.30	.55	2,110	1,290	3,400
New York NY	73,620	46,490	120,110	.55	.75	18,220	15,690	33,910
Cincinnati OH	9,560	3,320	12,880	.25	.25	1,080	370	1,450
Cleveland OH	11,190	4,840	16,030	.25	.25	1,260	550	1,800
Philadelphia PA	15,130	22,550	37,680	.25	.75	1,700	7,610	9,310
Pittsburgh PA	7,190	9,910	17,100	.20	.60	650	2,670	3,320
Milwaukee WI	6,820	4,640	11,460	.30	.35	920	730	1,650
Major Texas Cities								
Austin TX	5,150	2,150	7,300	.55	.45	1,270	440	1,710
Corpus Christi TX	1,500	1,490	2,990	.10	.10	70	70	140
Dallas TX	22,100	8,200	30,300	.55	.30	5,470	1,110	6,580
El Paso TX	3,200	3,000	6,200	.20	.05	290	70	360
Fort Worth TX	11,000	4,250	15,250	.40	.30	1,980	570	2,550
Houston TX	25,800	10,500	36,300	.70	.50	8,130	2,360	10,490
San Antonio TX	8,800	4,800	13,600	.40	.20	1,580	430	2,020
West/South Avg.	15,090	10,330	25,420	.34	.48	3,860	2,440	6,300
North/Midwest Avg.	20,730	15,380	36,110	.36	.53	4,120	4,430	8,550
Outside Texas Avg.	17,200	12,230	29,430	.35	.50	3,960	3,190	7,140
Texas Avg.	11,080	4,910	15,990	.41	.27	2,680	720	3,410
Congested Texas Avg.	14,570	5,980	20,550	.52	.35	3,690	980	4,670
Total Avg.	16,110	10,910	27,020	.36	.46	3,730	2,740	6,470
Maximum Value	96,890	73,810	170,700	.85	.85	37,060	16,610	53,670
Minimum Value	1,500	1,490	2,990	.05	.05	70	70	140

[1] Daily vehicle-miles of travel
[2] Represents the percentage of daily vehicle-miles of travel on each roadway system during the peak period operating in congested conditions
[3] Daily vehicle-miles of travel multiplied by peak-period vehicle travel and percent of congested DVMT

Source: TTI Analysis and Local Transportation Agency References

Table C-3. Recurring and Incident Delay Relationships

Urban Area	1987 Peak Period Congested DVMT[1,2] Frwy (1000)	Prin.Art.Str. (1000)	Total (1000)	Incident/Recurring[3] Ratio Frwy	Prin.Art. Street	Recurring Vehicle-Hours[4] of Delay Total (Daily)	Frwy	Prin.Art. Street	Incident Vehicle-Hours[4] of Delay Total (Daily)	Frwy	Prin.Art. Street
Western & Southern Cities											
Phoenix AZ	1,440	5,190	6,630	.40	1.10	128,380	17,175	111,220	129,200	6,870	122,330
Los Angeles CA	37,060	16,610	53,670	1.20	1.10	797,070	441,200	335,870	920,890	529,430	391,460
Sacramento CA	1,270	1,240	2,510	.60	1.10	41,730	15,100	26,620	38,350	9,060	29,280
San Diego CA	4,690	1,100	5,790	.60	1.10	79,480	55,820	23,660	59,520	33,490	26,030
San Fran-Oakland CA	14,250	3,420	17,670	1.30	1.10	242,930	169,630	73,310	301,150	220,520	80,640
Denver CO	2,130	2,390	4,520	1.00	1.10	76,500	25,390	51,110	81,610	25,390	56,220
Miami FL	1,670	4,100	5,770	1.50	1.10	107,630	19,880	87,750	126,340	29,810	96,530
Tampa FL	300	1,140	1,440	1.50	1.10	27,860	3,540	24,320	32,050	5,300	26,750
Atlanta GA	5,390	2,740	8,130	1.10	1.10	122,730	64,130	58,600	135,000	70,540	64,470
Indianapolis IN	170	280	450	1.50	1.10	7,980	2,050	5,930	9,590	3,070	6,520
Louisville KY	120	740	860	1.10	1.10	17,220	1,440	15,780	18,940	1,590	17,360
Kansas City MO	270	390	660	3.10	1.10	11,580	2,190	8,390	19,130	9,900	9,230
St Louis MO	1,470	3,280	4,750	1.20	1.10	87,750	17,450	70,290	98,270	20,940	77,320
Albuquerque NM	90	640	730	1.10	1.10	14,780	1,080	13,690	16,260	1,190	15,060
Oklahoma City OK	140	550	690	1.10	1.10	13,390	1,700	11,690	14,730	1,870	12,860
Portland OR	1,060	860	1,920	2.00	1.10	31,080	12,560	18,510	45,490	25,130	20,370
Memphis TN	170	620	790	1.10	1.10	15,260	1,200	13,260	16,790	2,200	14,590
Nashville TN	450	890	1,340	1.10	1.10	24,320	5,360	18,960	26,750	5,890	20,850
Salt Lake City UT	260	340	600	.60	1.10	10,260	3,060	7,190	9,750	1,840	7,910
Seattle-Everett WA	4,860	2,220	7,080	1.40	1.10	105,270	57,800	47,470	133,140	80,930	52,210
Northeast & Midwest Cities											
Washington DC	6,700	7,040	13,740	2.20	1.10	230,590	79,780	150,810	341,200	175,510	165,900
Chicago IL	7,660	7,860	15,520	1.20	1.10	259,690	91,180	168,510	294,780	109,410	185,370
Baltimore MD	1,550	1,420	2,970	2.30	1.10	48,840	18,400	30,440	75,800	42,310	33,490
Boston MA	3,640	2,160	5,800	3.50	1.10	89,530	43,300	46,240	202,400	151,540	50,860
Detroit MI	3,920	5,820	9,740	2.20	1.10	171,370	46,710	124,650	239,890	102,770	137,120
Minn-St Paul MN	2,110	1,290	3,400	.90	1.10	52,680	25,100	27,580	52,930	22,600	30,340
New York NY	18,220	15,690	33,910	2.50	1.10	553,120	216,900	336,220	912,100	542,250	369,850
Cincinnati OH	1,080	370	1,450	.80	1.10	20,800	12,800	7,990	19,030	10,240	8,790
Cleveland OH	1,260	550	1,810	.70	1.10	26,650	14,980	11,670	23,320	10,490	12,840
Philadelphia PA	1,700	7,610	9,310	2.10	1.10	183,340	20,260	163,080	221,930	42,540	179,390
Pittsburgh PA	650	2,670	3,320	2.90	1.10	65,010	7,700	57,310	85,380	22,340	63,040
Milwaukee WI	920	730	1,650	1.00	1.10	26,620	10,960	15,660	28,190	10,960	17,230
Major Texas Cities											
Austin TX	1,275	470	1,710	1.10	1.10	24,500	15,170	9,330	26,950	16,690	10,260
Corpus Christi TX	70	65	140	1.10	1.10	2,240	800	1,440	2,460	880	1,580
Dallas TX	5,470	1,107	6,580	1.80	1.10	88,840	65,120	23,720	143,300	117,210	26,090
El Paso TX	290	70	360	1.10	1.10	4,880	3,430	1,450	5,360	3,770	1,590
Fort Worth TX	1,980	575	2,560	1.80	1.10	35,870	23,570	12,290	55,950	42,430	13,520
Houston TX	8,130	2,365	10,490	1.40	1.10	147,380	96,750	50,630	191,140	135,450	55,690
San Antonio TX	1,585	430	2,020	1.10	1.10	28,110	18,860	9,260	30,930	20,740	10,180
West/South Avg.	3,860	2,435	6,300	1.23	1.10	98,160	45,980	52,180	111,650	54,250	57,400
North/Midwest Avg.	4,115	4,435	8,550	1.86	1.10	144,020	49,010	95,010	208,100	103,580	104,520
Outside Texas Avg.	3,955	3,185	7,140	1.46	1.10	115,360	47,110	68,240	147,820	72,750	75,070
Texas Avg.	2,685	720	3,410	1.34	1.10	47,400	31,960	15,440	65,160	48,170	17,000
Congested Texas Avg.	3,685	980	4,670	1.44	1.10	64,940	43,890	21,050	89,650	66,500	23,150
Total Avg.	3,730	2,740	6,470	1.44	1.10	103,160	44,390	58,770	132,980	68,340	64,640
Maximum Value	37,060	16,605	53,670	3.50	1.10	797,070	441,200	355,870	920,890	542,250	391,460
Minimum Value	70	65	140	.40	1.10	2,240	800	1,440	2,460	880	1,580

[1] Daily vehicle-miles of travel
[2] Represents the percentage of Daily Vehicle-Miles of Travel on each roadway system during the peak period operating in congested conditions
[3] Percentage of Incident Delay related to Recurring Delay
[4] Facility delays as calculated by type and urban area

Note: Congested Texas cities average includes Austin, Dallas, Fort Worth, Houston, and San Antonio

Source: TTI Analysis and Local Transportation Agency References

The factor of 1.1 is based on the following assumptions as they relate to delay:

1. Arterial street systems designs are more consistent from city to city than freeway design.

2. The side streets, drives, median openings, and other appurtenances associated with arterial streets allow numerous opportunities to remove incidents from the travelled way.

3. Historical data shows the accident rate on arterial streets to be approximately twice that of freeways but, as stated in the second assumption, there is a greater opportunity to remove the incident from the roadway.

Table C-3 shows the results of the freeway and principal arterial street recurring and incident delay calculations.

Prior to calculating the congestion costs, two other variables were calculated to simplify the cost equations. These variables are the average vehicular speed and the average fuel mileage for the vehicles operating in congested conditions. The average vehicular speed is a weighted average of the operating speeds on the facility under consideration, and is defined by Equation C-4.

$$\text{Avg. Speed (mph)} = \frac{(35\text{ mph} \times \text{Peak-Period Frwy VMT}) + (20\text{ mph} \times \text{Peak-Period Prin. Art. Str. VMT})}{\text{Total Peak-Period VMT}} \qquad \text{Eq. C-4}$$

Congestion Cost

Three cost components can be associated with congestion: 1) delay cost, 2) fuel cost, and 3) insurance cost. These costs can be directly related to the vehicle-hours of delay, with the exception of the insurance cost. Table C-4 is a summary of the cost calculations for the component congestion cost per each urban area.

Table C-4. Component and Total Congestion Costs By Urban Area

Urban Area	Annual Cost Due to Congestion (Millions of $'s)						Delay/Fuel Cost (Millions)
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Insurance	Total	
Western & Southern Cities							
Phoenix AZ	390	390	60	60	40	930	890
Los Angeles CA	2,510	2,900	400	460	1,660	7,940	6,280
Sacramento CA	130	120	20	20	80	360	290
San Diego CA	250	190	40	30	60	580	510
San Fran-Oakland CA	770	960	130	160	350	2,370	2,015
Denver CO	240	250	40	40	70	630	560
Miami FL	330	380	50	60	380	1,200	810
Tampa FL	80	100	10	10	20	220	210
Atlanta GA	390	420	60	60	210	1,140	930
Indianapolis IN	20	30	3	4	20	90	60
Louisville KY	50	60	6	7	20	140	120
Kansas City MO	40	60	4	7	40	140	110
St Louis MO	270	300	40	40	90	730	640
Albuquerque NM	40	50	5	6	10	120	100
Oklahoma City OK	40	40	5	5	30	130	100
Portland OR	100	140	10	20	50	310	270
Memphis TN	50	50	6	6	60	170	110
Nashville TN	70	80	10	10	20	200	180
Salt Lake City UT	30	30	4	4	20	90	70
Seattle-Everett WA	330	420	50	70	60	930	870
Northeast & Midwest Cities							
Washington DC	710	1,050	110	160	190	2,220	2,030
Chicago IL	800	910	120	140	500	2,470	1,970
Baltimore MD	150	240	20	50	190	640	440
Boston MA	280	630	40	90	100	1,140	1,040
Detroit MI	520	730	80	110	420	1,870	1,440
Minn-St Paul MN	170	170	30	30	70	450	380
New York NY	1,720	2,830	250	400	1,600	6,800	5,200
Cincinnati OH	70	60	10	10	10	160	150
Cleveland OH	80	70	10	10	130	310	180
Philadelphia PA	550	660	70	90	750	2,120	1,370
Pittsburgh PA	200	260	30	30	230	740	510
Milwaukee WI	80	90	10	10	30	230	200
Major Texas Cities							
Austin TX	80	90	10	10	10	200	190
Corpus Christi TX	10	10	0	0	5	25	20
Dallas TX	280	460	50	70	150	1,010	860
El Paso TX	20	20	2	2	20	60	40
Fort Worth TX	110	180	20	30	70	410	340
Houston TX	470	610	70	100	300	1,540	1,240
San Antonio TX	90	100	10	20	50	260	220
West/South Avg.	310	350	50	50	160	920	760
North/Midwest Avg.	440	640	60	90	350	1,600	1,240
Outside Texas Avg.	360	460	50	70	230	1,170	940
Texas Avg.	150	210	20	30	90	500	410
Congested Texas Avg.	210	290	30	50	120	690	570
Total Avg.	320	410	50	60	210	1,050	840
Maximum Value	2,510	2,900	400	460	1,660	7,940	6,280
Minimum Value	10	10	0	0	5	25	20

Note: Congested Texas cities average includes Austin, Dallas, Fort Worth, Houston, and San Antonio

Source: TTI Analysis and Local Transportation Agency References

The average fuel mileage represents the fuel consumption of the vehicles operating in congested conditions. The equation (Equation C-5) is a linear regression applied to a modified version of fuel consumption reported by Raus (17).

$$\text{Average Fuel Mileage (mpg)} = 8.8 + 0.25\ (\text{Average Vehicular Speed}) \qquad \text{Eq. C-5}$$

Delay Cost - The delay cost is the cost of lost time due to congested roadways. This cost was calculated by Equation C-6.

$$\frac{\text{Annual}}{\text{Delay Cost}} = \frac{\text{Vehicle-Hrs. of Delay}}{\text{Day}} \times \frac{1.25\ \text{person}}{\text{Vehicle}} \times \frac{\$8.50}{\text{Hour}} \times \frac{250\ \text{Workdays}}{\text{Year}} \qquad \text{Eq. C-6}$$

where: vehicle-hours of delay/day is the combined freeway and principal arterial street representing the city's recurring or incident delay.

This equation is used to separately calculate delay costs resulting from both incident and recurring delays.

Fuel Cost - Fuel cost was also related to vehicle-hours of delay per day and speed by Equation C-7 for passenger vehicles and Equation C-8 for commercial vehicles.

$$\text{Passenger Fuel Cost} = \frac{\frac{\text{Vehicle-Hrs. of Delay}}{\text{Day}} \times 95\% \times \text{Avg. Speed}}{\text{Avg. Fuel Mileage}} \qquad \text{Eq. C-7}$$

$$\text{Commercial Fuel Cost} = \frac{\frac{\text{Vehicle-Hrs. of Delay}}{\text{Day}} \times 5\% \times \text{Avg. Speed}}{\text{Avg. Fuel Mileage}} \qquad \text{Eq. C-8}$$

where: vehicle-hours of delay is the combined value for freeways and principal arterial streets representing either recurring or incident delay

These calculations were completed for both incident and recurring delay. The respective portions, i.e., incident and recurring, were combined in Equation C-9 to determine the yearly fuel cost due to congestion resulting from incident and recurring delay.

$$\text{Average Urban Area Fuel Cost} = (\text{Passenger Fuel Cost} + \text{Commercial Fuel Cost}) \times \frac{250 \text{ Days}}{\text{Year}} \qquad \text{Eq. C-9}$$

This calculation was done for each study area using the specific area/state fuel cost, peak-period congested VMT, and vehicle-hours of recurring and incident delay per day.

Insurance Cost - Insurance cost was calculated by multiplying the insurance rate differential by the number of registered vehicles within the area (Equation C-10). The factor of 0.70, represents the approximate percentage of an insurance premium used to provide insurance coverage for the vehicle. Thirty percent of the premium was estimated to be used for the overhead period coverage.

$$\text{"Excess" Insurance Cost per year} = (\text{Study Area Rate} - \text{Average State Rate}) \times 0.70 \times \text{Number of Registered Vehicles} \qquad \text{Eq. C-10}$$

The 70/30 ratio was a factor generally agreed upon after several interviews with insurance carriers. The insurance costs do not include commercial vehicles because of the wide variance in rates and the difficulty in identifying the registered commercial vehicles actually operating within a particular area.

Results of Cost Estimate Calculations

Using the methods and equations discussed in the previous sections, the annual cost for each urban area was calculated (Table C-4). Reviewing the component costs of delay, fuel, and insurance, it is shown that congestion costs associated with delay make up the majority of annual congestion cost. Delay costs including both recurring and incident account for a minimum 50 percent (Cleveland) to a maximum of 83 percent (Phoenix) of the annual cost. The delay costs represent an average of 71 percent including all urban areas. Delay is responsible for 73 percent of the five congested Texas cities and 71 percent for all seven Texas study cities total annual cost due to congestion. The congested Texas cities include Austin, Dallas, Fort Worth, Houston, and San Antonio. Urban areas in the west and south have 72 percent of the total annual cost attributed to delay, while locations in the northeast and midwest averaged 68 percent.

Fuel costs had a much smaller impact on an urban area's total annual congestion cost than insurance. This factor had a maximum of 13 percent (Phoenix, Seattle-Everett, and Austin) with a minimum of seven percent (Philadelphia).

The Texas statewide and study average impact of fuel costs was 11 percent. Urban areas included in the congested Texas average were affected the most, with fuel cost averaging 12 percent of the total cost. Fuel costs in the western and southern urban areas were 11 percent of total congestion cost with the northeast and midwest being the lowest at ten percent.

Insurance costs, account for a minimum of four percent (Phoenix) to a maximum of 42 percent (Cleveland) of the annual congestion cost. The average insurance percentage of total cost for all study areas is 19 percent. Texas has a statewide average of 18 percent, with the congested Texas cities average (15 percent) being three percent age points lower. Northeast and midwest urban areas experience the highest percent of 22, with the west and south having 17 percent of total congested being attributed to insurance costs.

Table C-5 illustrates the impacts of the component and total congestion cost in terms of per capita and per registered vehicle.

Table C-6 illustrates the categorical ranking of the urban study areas by annual congestion cost, annual cost per capita, and annual cost per registered vehicle including and excluding insurance costs. It is shown that the elimination of insurance costs from the annual congestion cost did marginally affect the ranking of the top ten urban areas. The top 25 urban areas, however, were not affected by exclusion of the insurance cost.

The effects of omitting insurance cost seem to be the least prevalent in the annual congestion cost category. In this category, the average rank change due to omitting insurance costs was approximately two, with an extreme in rank change of five positions, e.g. Miami from 9th to 14th.

The annual cost per capita and registered vehicle categories also experienced an average change in rank of the positions if insurance costs were dropped from consideration. The extremes, for these two categories were six and five, respectively. In both cases, Philadelphia was the urban area involved in the extreme change in ranking.

Table C-5. Estimated Economic Impact of Congestion in 1987

Urban Area	Total Congestion Cost Per Capita (Dollars)	Delay/Fuel Cost Per Capita (Dollars)	Total Congestion Cost Per Reg. Veh. (Dollars)	Delay/Fuel Cost Per Reg. Veh. (Dollars)
Western & Southern Cities				
Phoenix AZ	510	490	800	765
Los Angeles CA	730	580	1,040	820
Sacramento CA	360	290	300	240
San Diego CA	280	250	440	390
San Fran-Oakland CA	670	570	805	685
Denver CO	420	370	480	425
Miami FL	670	450	895	610
Tampa FL	340	320	380	355
Atlanta GA	650	530	750	610
Indianapolis IN	100	70	160	115
Louisville KY	180	160	320	270
Kansas City MO	130	90	220	165
St Louis MO	380	330	780	680
Albuquerque NM	250	230	315	290
Oklahoma City OK	170	130	270	205
Portland OR	300	260	510	440
Memphis TN	210	130	290	185
Nashville TN	380	340	410	370
Salt Lake City UT	120	90	145	110
Seattle-Everett WA	580	550	810	760
Northeast & Midwest Cities				
Washington DC	740	680	1,380	1,260
Chicago IL	340	270	625	500
Baltimore MD	340	240	645	445
Boston MA	400	370	755	690
Detroit MI	480	370	649	500
Minn-St Paul MN	240	200	285	245
New York NY	430	330	1,190	910
Cincinnati OH	170	160	180	165
Cleveland OH	180	100	215	125
Philadelphia PA	520	340	790	510
Pittsburgh PA	410	280	625	430
Milwaukee WI	190	160	430	375
Major Texas Cities				
Austin TX	420	390	430	405
Corpus Christi TX	80	60	95	75
Dallas TX	530	450	645	550
El Paso TX	110	80	155	110
Fort Worth TX	360	300	410	340
Houston TX	550	440	695	560
San Antonio TX	260	210	325	270
West/South Avg.	370	310	505	425
North/Midwest Avg.	370	290	645	510
Outside Texas Avg.	370	300	560	460
Texas Avg.	330	280	395	330
Congested Texas Avg.	420	360	500	425
Total Avg.	360	300	530	435
Maximum Value	740	680	1,380	1,260
Minimum Value	80	60	95	75

Source: TTI Analysis and Local Transportation Agency References

Table C-6. 1987 Rankings of Urban Area by Estimated Economic Impact of Congestion

Urban Area	Total Congestion Cost	Total Delay/Fuel Cost	Congestion Cost Per Capita	Delay/Fuel Cost Per Captia	Congestion Cost Per Reg. Veh.	Delay/Fuel Cost Per Reg. Veh.
Western & Southern Cities						
Phoenix AZ	13	11	10	6	7	4
Los Angeles CA	1	1	2	2	3	3
Sacramento CA	22	22	19	20	29	30
San Diego CA	19	17	25	24	20	21
San Fran-Oakland CA	4	4	3	3	6	7
Denver CO	18	16	13	11	19	19
Miami FL	9	14	3	7	4	10
Tampa FL	27	25	21	18	25	24
Atlanta GA	10	10	5	5	11	9
Indianapolis IN	37	37	38	38	36	36
Louisville KY	32	31	31	31	27	27
Kansas City MO	32	33	35	35	33	33
St Louis MO	16	15	17	16	9	8
Albuquerque NM	35	33	27	26	28	26
Oklahoma City OK	34	35	33	33	32	31
Portland OR	23	23	24	23	18	17
Memphis TN	30	32	29	32	30	32
Nashville TN	29	29	17	14	23	23
Salt Lake City UT	36	36	36	36	38	37
Seattle-Everett WA	14	12	6	4	5	5
Northeast & Midwest Cities						
Washington DC	5	3	1	1	1	1
Chicago IL	3	5	21	22	16	14
Baltimore MD	17	19	21	25	14	16
Boston MA	10	9	16	13	10	6
Detroit MI	7	6	11	12	13	14
Minn-St Paul MN	20	21	28	28	31	29
New York NY	2	2	12	17	2	2
Cincinnati OH	31	30	33	30	35	33
Cleveland OH	23	28	31	34	34	35
Philadelphia PA	6	7	9	15	8	13
Pittsburgh PA	15	18	15	21	17	18
Milwaukee WI	26	26	30	29	21	22
Major Texas Cities						
Austin TX	28	27	13	10	21	20
Corpus Christi TX	39	39	39	39	39	39
Dallas TX	12	13	8	8	14	12
El Paso TX	38	38	37	37	37	38
Fort Worth TX	21	21	19	19	23	25
Houston TX	8	8	7	9	12	11
San Antonio TX	25	24	27	27	26	28

Source: TTI Analysis and Local Transportation Agency References

APPENDIX D

POPULATION, LAND AREA, AND DENSITY ESTIMATES

APPENDIX D
POPULATION, LAND AREA, AND DENSITY ESTIMATES

Population, land area, and density serve as a basis of comparison for both congestion indices and rankings. This Appendix offers an explanation and definition of how the population, land area, and subsequent density were derived for each urban area analyzed in this study. The population and land area are the urban area variables based on HPMS (5) data from which density is calculated.

Population and Land Area

The most recent HPMS data base currently includes population and land area data from 1982 to 1987. These values are contained in the areawide data within the areawide summary tables. Table D-1 summarizes those data for the 39 urban areas considered in this study.

The population and land area, reported in HPMS, are determined by the latest official census (1980) [18] adjusted to current federal-aid urban area boundaries. While the HPMS data is updated on an annual basis, Table D-1 indicates that population and land area are not regularly updated. For this reason, the HPMS values were adjusted to reflect urban growth where appropriate.

Adjustments to HPMS Data

HPMS data from 1982 was used as the base year for population and land area adjustments. This was the first year which had data comparable to census estimates. In reviewing the HPMS data (Table D-1) most population and land area values do not change until 1985 or 1987. Using trends set by the 1980 census data and subsequent census estimates, 1985 and 1987 HPMS values were adjusted. The same trends were used to derive estimates for the years, primarily between 1982 and 1985, when no change was indicated in the HPMS data base.

The HPMS population and land area data were adjusted by the percent increase of these two variables as indicated by census estimates. Using the 1980 census as a base, the increase was calculated as were age and annual rate. The average annual rate was applied to 1982 data to estimate the population and land area for subsequent years.

Population and Land Area Estimates

Table D-2 illustrates the adjusted population and land area values used in this study. Density values shown in this table were calculated values using the adjusted population and land area values.

Table D-1. HPMS Population and Land Area Summary Data 1982-1987

Urban Area	HPMS (1982)		HPMS (1983)		HPMS (1984)		HPMS (1985)		HPMS (1986)		HPMS (1987)	
	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)
Western & Southern Cities												
Phoenix AZ	1,410	550	1,410	550	1,410	550	1,560	730	1,670	850	1,820	890
Los Angeles CA	9,900	1,830	9,900	1,830	9,900	1,830	9,480	1,830	10,730	2,100	10,920	2,100
Sacramento CA	830	280	830	280	830	280	800	280	960	340	1,000	340
San Diego CA	1,780	610	1,780	610	1,780	610	1,710	610	2,000	680	2,070	680
San Fran-Oak CA	3,330	800	3,330	800	3,330	800	3,190	800	3,470	820	3,520	820
Denver CO	1,350	430	1,350	430	0	0	0	0	0	0	1,350	430
Miami FL	1,730	410	1,720	410	1,750	440	1,770	440	1,800	440	1,780	440
Tampa FL	540	350	560	350	570	390	580	390	600	390	650	390
Atlanta GA	1,610	630	1,610	-	1,610	-	1,610	0	1,610	1,530	1,770	1530
Indianapolis IN	860	420	860	420	860	420	860	420	860	420	870	420
Louisville KY	770	360	780	360	780	360	780	360	1,180	360	780	360
Kansas City MO	1,100	610	1,100	610	1,100	610	1,130	610	1,140	610	1,140	610
St. Louis MO	1,850	650	1,850	700	1,850	700	1,910	690	1,930	690	1,930	700
Albuquerque NM	450	210	420	210	420	210	420	210	420	0	370	170
Oklahoma City OK	640	400	640	400	640	400	640	400	640	400	640	400
Portland OR	1,010	350	1,000	350	1,010	350	1,030	350	1,040	350	920	350
Memphis TN	810	350	770	30	770	30	770	30	770	390	770	390
Nashville TN	560	330	520	-	520	-	520	0	520	470	520	470
Salt Lake City UT	680	360	680	360	680	360	750	360	760	360	760	360
Seattle-Everett WA	1,440	650	1,480	650	1,520	650	1,540	650	1,560	650	1,590	645
Northeast & Midwest Cities												
Washington DC	3,440	820	2,780	740	2,810	740	2,860	740	2,920	820	2,980	820
Chicago IL	7,080	1900	7,100	1,960	7,100	1,960	7,100	1,960	7,160	1,960	7,160	1,960
Baltimore MD	1,230	410	1,820	490	1,820	520	1,940	520	1,860	520	1,870	520
Boston MA	2,850	910	2,760	1,030	2,760	1030	2,760	1,030	2,760	1,030	2,760	1,030
Detroit MI	3,810	1,090	3,810	1,090	3,810	1090	3,890	1,240	3,890	1,240	3,890	1,240
Minn-St. Paul MN	1,750	800	1,750	800	1,750	800	1,750	800	1,750	80	1,890	1,000
New York NY	16,660	3,180	16,660	3,150	15,340	3,160	15,340	3,160	15,340	3,160	15,340	3160
Cincinnati OH	1,230	610	1,130	560	1,130	560	1,130	560	1,130	560	1,130	560
Cleveland OH	1,980	780	1,750	630	1,750	630	1,750	630	1,750	630	1,750	630
Philadelphia PA	4,070	970	4,070	970	4,070	1,100	4,070	1,100	4,070	1,100	4,080	1,110
Pittsburgh PA	1,810	980	1,810	980	1,810	710	1,810	710	1,810	710	1,810	710
Milwaukee WI	1,210	550	1,210	550	1,210	550	1,210	550	1,180	550	1,180	550
Major Texas Cities												
Austin TX	380	200	380	120	380	120	380	120	380	120	380	120
Corpus Christi TX	250	100	250	400	250	400	250	400	250	400	250	400
Dallas-Ft. Worth TX	2,450	1,390	2,450	1,400	2,450	1,400	20,450	1,400	2,450	1,400	2,450	1,400
El Paso TX	450	150	450	190	450	180	450	180	450	190	450	190
Houston TX	2,410	1,310	2,410	1,550	2,410	1,550	20,410	1,550	2,410	1,550	2,410	1,550
San Antonio TX	950	350	950	440	950	440	950	440	950	440	950	440

Source: FHWA-Highway Performance Monitoring System 1982-1987 Data.

Table D-2. 1987 Urban Area Population, Area and Density

Urban Area	Population (1000)	Land Area (sq. mi.)	Population Density Persons/sq. mi.
Western & Southern Cities			
Phoenix AZ	1,820	890	2,045
Los Angeles CA	10,920	2,100	5,200
Sacramento CA	955	340	2,295
San Diego CA	2,070	680	3,045
San Fran-Oak CA	3,520	820	4,295
Denver CO	1,510	875	1,725
Miami FL	1,785	460	3,880
Tampa FL	645	425	1,520
Atlanta GA	1,770	1,500	1,180
Indianapolis IN	925	430	2,150
Louisville KY	790	360	2,195
Kansas City MO	1,140	585	1,950
St. Louis MO	1,940	710	2,730
Albuquerque NM	455	250	1,820
Oklahoma City OK	730	500	1,460
Portland OR	1,045	410	2,550
Memphis TN	815	400	2,040
Nashville TN	520	470	1,105
Salt Lake City UT	765	380	2,015
Seattle-Everett WA	1,595	705	2,260
Northeast & Midwest Cities			
Washington DC	2,980	820	3,635
Chicago IL	7,200	1,960	3,675
Baltimore MD	1,875	525	3,570
Boston MA	2,850	1,035	2,755
Detroit MI	3,885	1,245	3,120
Minn-St. Paul MN	1,885	995	1,895
New York NY	16,000	3,160	5,365
Cincinnati OH	930	420	2,215
Cleveland OH	1,750	630	2,780
Philadelphia PA	4,085	1,115	3,665
Pittsburgh PA	1,810	715	2,530
Milwaukee WI	1,210	550	2,200
Major Texas Cities			
Austin TX	480	340	1,410
Corpus Christi TX	275	175	1,570
Dallas-Ft. Worth TX	1,910	1,420	1,345
El Paso TX	500	200	2,500
Fort Worth, TX	1,130	830	1,360
Houston TX	2,820	1,610	1,750
San Antonio TX	1,050	470	2,235

Source: TTI Analysis and 1987 Highway Performance Measuring System