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16. Abstract
This research report is the fourth year continuation of a six year research effort focused on quantifying urban mobility. This study contain the facility information for 50 urban areas throughout the country. The data base used for this research contains vehicle-miles of travel, urban area information, facility mileage, and facility lane-mile data from 1982 to 1989. Various federal, state, and local agencies provided the information used to update and verify the primary data base. The primary data base and source of information is the Federal Highway Administration's Highway Performance Monitoring System (HPMS).

Vehicle-miles of travel and lane-mile data were combined to develop Roadway Congestion Index (RCI) values for 50 urban areas including the seven largest in Texas. These RCI values provide an indicator of the relative mobility level within an urban area.

An analysis of the impacts and cost of congestion were also performed using travel delay, increased fuel consumption, and additional facility lane-miles as measures of urban mobility. Congestion costs were estimated on an areawide, per registered vehicle, and per capita basis.

17. Key Words
Mobility, Congestion, Economic Analysis, Transportation Planning, Travel Delay

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	centimetres squared	cm^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)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

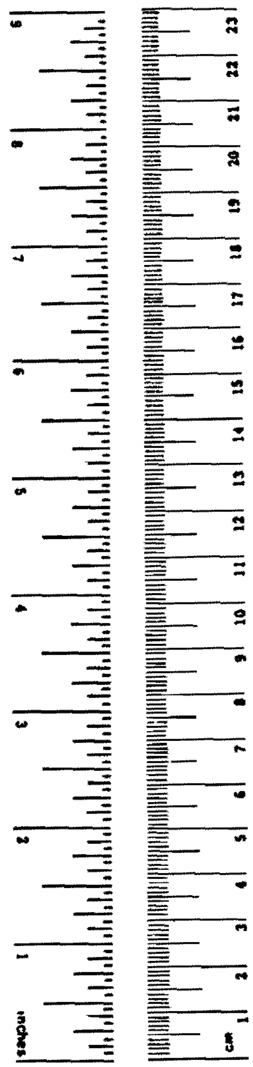
VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
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)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
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

Symbol	When You Know	Multiply By	To Find	Symbol
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)

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
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)

Symbol	When You Know	Multiply By	To Find	Symbol
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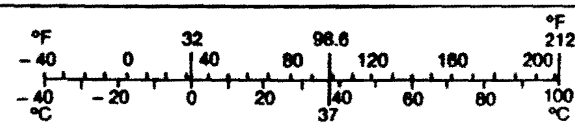

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

1989 ROADWAY CONGESTION ESTIMATES AND TRENDS

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Draft Research Report 1131-4

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Sponsored By

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ABSTRACT

This research report is the fourth year continuation of a six year research effort focused on quantifying urban mobility. This study contains the facility information for 50 urban areas throughout the country. The data base used for this research contains vehicle-miles of travel, urban area information, facility mileage, and facility lane-mile data from 1982 to 1989. Various federal, state, and local agencies provided the information used to update and verify the primary data base. The primary data base and source of information is the Federal Highway Administration's Highway Performance Monitoring System (HPMS).

Vehicle-miles of travel and lane-mile data were combined to develop Roadway Congestion Index (RCI) values for 50 urban areas including the seven largest in Texas. These RCI values provide an indicator of the relative mobility level within an urban area.

An analysis of the impacts and cost of congestion were also performed using travel delay, increased fuel consumption, and additional facility lane-miles as measures of urban mobility. Congestion costs were estimated on an areawide, per registered vehicle, and per capita basis.

Key Words: Mobility, Congestion, Economic Analysis, Transportation Planning, Travel Delay.

IMPLEMENTATION STATEMENT

To determine future highway needs and assist the Texas Department of Transportation in planning, it is desirable to measure and monitor the severity of the congestion and mobility in the large Texas metropolitan areas. This report provides a quantification of those mobility levels and the economic impact of congestion on urban motorists. The report also presents data on other large metropolitan areas throughout the country to assist in determining the nationwide mobility trends. Information in this report should be of value in identifying and prioritizing transportation trends and needs.

DISCLAIMER

SUMMARY

This report represents the fourth year of a planned six year study to measure and monitor urban mobility in 50 urbanized areas throughout the United States. This research study estimates the level of congestion in the seven largest Texas urban areas and 43 other areas representing a cross-section of urban areas throughout the country. Quantitative estimates of mobility levels allow comparisons of transportation systems in the various urbanized areas and assist the transportation community in analyzing urban mobility.

The level of congestion in an urban area was estimated using procedures developed in previous research (1,2,3,4,5). The Roadway Congestion Index (RCI) combines the daily vehicle-miles of travel per lane-mile (DVMT) for freeways and principal arterial streets systems in a ratio comparing the existing DVMT to calculated DVMT values identified with congested conditions. Equation S-1 illustrates how the existing and congested level DVMTs are combined into the RCI values for each urban area.

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

A RCI value of 1.0 or greater indicates that congested conditions exist areawide. It should be noted that urban areas with areawide values less than 1.0 may have sections of roadway that experience periods of heavy congestion, but the average mobility level within the urban area could be defined as uncongested. The RCI analyses presented in this report are intended to evaluate entire urban areas and not site specific locations. The nature of the RCI equation (Eq. S-1) will underestimate point or specific facility congestion if the overall system has "good" operational characteristics.

Areawide Mobility

The Roadway Congestion Index (RCI) is one measure of urban mobility levels. This value is based on daily vehicle-miles of travel per lane-mile operation under congested conditions. The RCI values, as stated in this report, are intended to be areawide representations not site specific locations of spot congestion.

Table S-1 combines the freeway and principal arterial street system DVMT and DVMT per lane-mile into the 1989 estimated roadway congestion index (RCI). Of the 50 urban areas studied, 23 have RCI values exceeding 1.0. These urbanized areas have estimated RCI values ranging from 1.54 to 1.01. RCI values for the ten most congested urban areas range from 1.54 (Los Angeles) to 1.13 (New Orleans). Sacramento and Denver complete the urban areas with RCI values exceeding 1.0 both with 1.01. The Baltimore urban area has a RCI value of 0.99 indicating that undesirable level of congestion could occur in the near future. Twelve more urban areas have estimated RCI values ranging between 0.97 and 0.90. These areas may not experience undesirable levels of congestion in the immediate future; however, congestion levels could become undesirable within the next five to ten years.

Reviewing the Table S-1 summary statistics, the estimated 1989 RCI values range from 1.54 (Los Angeles) to 0.71 (Corpus Christi). The Western region has the highest average RCI value of 1.18. Other regional averages exceeding 1.0 include the Northeastern (1.05). The Southwestern, South, and Midwestern regions have average RCI values below 1.0. The Texas regional average was the lowest of all the regions studied (0.90).

Table S-1. Principal Arterial Street Travel Frequency and Population Density Statistics for 1989

Urban Area	Freeway / Expressway		Principal Arterial Street		Roadway[3] Congestion Index	Rank
	DVMT[1] (1000)	DVMT/[2] Ln-Mile	DVMT[1] (1000)	DVMT/[2] Ln-Mile		
Los Angeles CA	106,680	20,840	79,810	6,550	1.54	1
San Fran-Oak CA	41,970	17,860	13,710	6,470	1.36	2
Washington DC	25,020	16,460	19,130	8,370	1.36	2
Miami FL	8,350	14,400	14,810	7,280	1.25	4
Chicago IL	34,440	14,970	27,980	6,910	1.21	5
Seattle-Everett WA	18,200	15,690	9,060	6,000	1.21	5
San Diego CA	26,760	15,560	8,930	5,350	1.18	7
San Bernardino-Riv CA	13,620	15,480	9,370	5,130	1.16	8
Atlanta GA	24,600	14,640	9,710	6,220	1.14	9
Houston TX	27,640	14,860	10,400	5,170	1.13	10
New Orleans LA	4,860	13,890	4,070	6,560	1.13	10
New York NY	80,920	13,800	50,830	6,920	1.12	12
Boston MA	22,080	14,570	12,650	4,680	1.09	13
Honolulu HI	4,530	13,310	1,560	7,970	1.09	13
Detroit MI	22,550	13,340	21,820	6,090	1.08	15
Portland OR	7,470	13,580	3,370	6,180	1.07	16
Philadelphia PA	18,280	12,140	21,140	6,510	1.05	17
Phoenix AZ	7,050	11,650	16,650	5,840	1.03	18
Tampa FL	3,430	11,630	4,180	6,630	1.03	18
Dallas TX	22,650	13,400	8,230	4,860	1.02	20
San Jose CA	15,540	13,400	6,760	4,880	1.02	20
Denver CO	10,730	12,480	10,600	5,760	1.01	22
Sacramento CA	8,850	12,120	6,810	6,310	1.01	22
Baltimore MD	15,180	12,340	9,330	5,700	0.99	24
Milwaukee WI	7,520	12,740	4,670	4,670	0.97	25
Austin TX	5,300	12,470	2,050	4,820	0.96	26
St. Louis MO	18,720	11,110	12,210	6,800	0.96	26
Cleveland OH	13,210	12,460	5,190	4,650	0.95	28
Nashville TN	5,410	11,270	5,400	5,780	0.95	28
Norfolk VA	5,340	11,600	4,080	5,630	0.95	28
Cincinnati OH	10,890	12,240	3,620	4,550	0.94	31
Ft. Lauderdale FL	6,830	11,580	5,610	5,100	0.92	32
Jacksonville FL	5,200	11,820	5,750	4,790	0.92	32
Albuquerque NM	2,310	11,000	3,580	5,110	0.91	34
Memphis TN	4,260	11,200	4,120	5,120	0.91	34
Minn-St. Paul MN	16,860	11,630	5,390	4,550	0.90	36
Hartford CT	6,180	10,660	3,640	5,870	0.89	37
Fort Worth TX	11,280	11,110	4,220	4,880	0.87	38
San Antonio TX	9,180	11,120	5,180	4,800	0.87	38
Louisville KY	6,140	10,500	2,890	5,670	0.86	40
Indianapolis IN	7,890	10,960	3,830	4,510	0.85	41
Columbus OH	8,100	10,250	3,040	5,070	0.82	42
Pittsburgh PA	7,750	7,910	10,770	6,080	0.82	42
Salt Lake City UT	5,080	9,960	1,950	5,490	0.81	44
Oklahoma City OK	6,830	9,490	3,590	5,270	0.78	45
Charlotte NC	2,220	7,530	2,860	5,390	0.74	46
El Paso TX	3,300	9,430	3,180	3,830	0.74	46
Kansas City MO	12,370	9,130	4,370	4,180	0.72	48
Orlando FL	5,820	10,120	3,730	2,370	0.72	48
Corpus Christi TX	1,520	8,220	1,450	4,530	0.71	50
Northeastern Avg	25,060	12,550	18,210	6,310	1.05	
Midwestern Avg	13,790	11,570	8,220	5,240	0.92	
Southern Avg	6,940	11,790	5,840	5,530	0.97	
Southwestern Avg	9,640	11,430	6,130	5,010	0.91	
Western Avg	27,070	15,310	15,490	6,090	1.18	
Texas Avg	11,550	11,520	4,960	4,700	0.90	
Total Avg	15,340	12,400	9,940	5,560	0.99	
Maximum Value	106,680	20,840	79,810	8,370	1.54	
Minimum Value	1,520	7,530	1,450	2,370	0.71	

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

Source: Equation 1 and Tables 2 and 3

None of the urban areas studied in Texas were included in the ten most congested urban areas. Houston (10th) and Dallas (20th) were the highest ranked areas within the state. Austin was the next highest ranked (26th) urbanized area in the state with the remaining four Texas cities not ranked in the top 30.

Impacts of Congestion

Congestion may be quantified in terms of additional lane-miles and travel delay. While these indicators are independent of travel demand, they do indicate on which system the burden of the travel demand is placed. This section contains five case studies illustrate that the expansion of the existing roadway systems will involve extensive cash expenditures. The relationship between the increasing vehicle-miles of travel (VMT) and lane-miles of freeways and principal arterial streets make it apparent that the construction of additional lane-miles as the sole alternative to alleviate congestion is not feasible. Regardless of whether the area's DVMT is served by the freeway or principal arterial street system extensive facility construction efforts and methods to alter travel patterns are required to improve the congestion levels in most urban areas.

Travel delay is the most apparent impact of congestion to the motoring public. Analyses in this identified two types of delay -- recurring and incident. Delay was categorized by the severity (moderate, heavy, and severe) for freeways and principal arterial street systems. The congestion categories are based on average daily traffic volumes per lane. Table S-2 summarizes the vehicle-hours of delay by type and urban area. The rankings in Tables S-2 are similar to the rankings by RCI (Table S-1). Vehicle-hours of delay are also ranked after being normalized by population. Summary statistics show that the Western and Northeastern regions have the largest average delay while the Southern region has the least. The average delay in Texas urban areas exceeds that of the Southern region but is less than studywide average.

Table S-2. Freeway and Expressway Recurring and Incident Hours of Daily Delay for 1989*c41E[1]

Urban Area	Recurring Hours of Delay				Incident Hours of Delay			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	3,950	8,380	11,390	23,720	9,100	19,280	26,190	54,570
Boston MA	7,610	21,510	35,060	64,180	26,650	75,290	122,710	224,650
Hartford CT	1,150	2,030	2,480	5,660	3,100	5,480	6,700	15,280
New York NY	89,780	38,610	161,810	290,200	224,450	96,520	404,530	725,500
Philadelphia PA	10,860	7,930	5,820	24,610	22,800	16,660	12,220	51,680
Pittsburgh PA	4,040	0	4,650	8,690	11,710	0	13,490	25,200
Washington DC	11,300	43,910	48,790	104,000	24,860	96,600	107,340	228,800
Midwestern Cities								
Chicago IL	13,520	17,520	97,300	128,340	16,230	21,020	116,760	154,010
Cincinnati OH	9,460	4,630	2,510	16,600	7,570	3,700	2,010	13,280
Cleveland OH	7,170	7,430	3,300	17,900	5,020	5,200	2,310	12,530
Columbus OH	880	2,900	10,130	13,910	620	2,030	7,090	9,740
Detroit MI	9,470	6,250	43,650	59,370	20,840	13,750	96,030	130,620
Indianapolis IN	3,430	0	0	3,430	5,140	0	0	5,140
Kansas City MO	1,340	420	1,800	3,560	4,160	1,310	5,590	11,060
Louisville KY	580	0	1,300	1,880	640	0	1,440	2,080
Milwaukee WI	3,150	4,200	6,340	13,690	3,150	4,200	6,340	13,690
Minn-St. Paul MN	4,880	8,050	19,670	32,600	4,390	7,240	17,700	29,330
Oklahoma City OK	2,020	1,340	0	3,360	2,220	1,480	0	3,700
St. Louis MO	6,150	4,970	11,380	22,500	7,380	5,960	13,660	27,000
Southern Cities								
Atlanta GA	8,850	17,880	45,870	72,600	9,740	19,660	50,460	79,860
Charlotte NC	850	2,400	3,090	6,340	680	1,920	2,470	5,070
Ft. Lauderdale FL	0	790	11,840	12,630	0	1,190	17,760	18,950
Jacksonville FL	6,040	2,630	0	8,670	9,060	3,940	0	13,000
Memphis TN	1,850	0	0	1,850	2,030	0	0	2,030
Miami FL	4,170	7,850	20,790	32,810	6,250	11,770	31,180	49,200
Nashville TN	3,430	2,420	1,270	7,120	3,770	2,660	1,390	7,820
New Orleans LA	810	5,960	9,530	16,300	1,460	10,740	17,160	29,360
Norfolk VA	800	5,380	10,040	16,220	2,000	13,460	25,100	40,560
Orlando FL	7,490	740	3,610	11,840	11,240	1,110	5,420	17,770
Tampa FL	1,130	2,520	1,400	5,050	1,700	3,780	2,100	7,580
Southwestern Cities								
Albuquerque NM	670	1,130	920	2,720	740	1,250	1,020	3,010
Austin TX	5,590	4,160	7,120	16,870	6,150	4,580	7,830	18,560
Corpus Christi TX	660	0	0	660	730	0	0	730
Dallas TX	17,020	18,400	41,510	76,930	30,640	33,110	74,720	138,470
Denver CO	6,850	12,260	13,410	32,520	6,850	12,260	13,410	32,520
El Paso TX	2,700	240	0	2,940	2,970	260	0	3,230
Fort Worth TX	6,170	6,660	15,040	27,870	11,100	12,000	27,070	50,170
Houston TX	8,170	32,980	90,690	131,840	11,430	46,180	126,970	184,580
Phoenix AZ	5,570	3,540	17,790	26,900	2,230	1,420	7,110	10,760
Salt Lake City UT	1,290	910	2,380	4,580	770	550	1,430	2,750
San Antonio TX	2,390	9,010	12,390	23,790	2,630	9,910	13,620	26,160
Western Cities								
Honolulu HI	2,050	2,890	9,900	14,840	3,680	5,210	17,820	26,710
Los Angeles CA	18,690	21,110	541,990	581,790	22,430	25,330	650,390	698,150
Portland OR	6,120	2,880	8,320	17,320	12,230	5,760	16,650	34,640
Sacramento CA	8,210	4,970	9,620	22,800	4,920	2,980	5,770	13,670
San Bernardino-Riv CA	3,030	12,860	60,770	76,660	3,640	15,430	72,920	91,990
San Diego CA	13,610	11,140	53,200	77,950	8,170	6,680	31,920	46,770
San Fran-Oak CA	20,100	11,850	202,610	234,560	26,140	15,400	263,400	304,940
San Jose CA	6,750	14,740	51,920	73,410	8,100	17,690	62,300	88,090
Seattle-Everett WA	6,750	39,090	36,120	81,960	9,450	54,720	50,570	114,740
Northeastern Avg	18,380	17,480	38,570	74,430	46,090	44,260	99,030	189,380
Midwestern Avg	5,170	4,810	16,450	26,430	6,450	5,490	22,410	34,350
Southern Avg	3,220	4,420	9,770	17,410	4,360	6,380	13,910	24,650
Southwestern Avg	5,190	8,120	18,300	31,610	6,930	11,050	24,840	42,820
Western Avg	9,480	13,500	108,270	131,250	10,970	16,580	130,190	157,740
Texas Avg	6,100	10,210	23,820	40,130	9,380	15,150	35,750	60,280
Total Avg	7,370	8,790	35,010	51,170	12,460	14,330	51,200	77,990
Maximum Value	89,780	43,910	541,990	675,680	224,450	96,600	650,390	971,440
Minimum Value	0	0	0	0	0	0	0	0

Note: [1] Delay calculated based on vehicular speed in Table 1.

Source: TTI Analysis

Cost of Congestion

The economic impact of congestion was stated in terms of annual congestion cost, cost per registered vehicle, and cost per capita. The component and total congestion costs for each urban area are shown in Tables S-3. In 1989, the total cost of congestion for the urban areas studied was approximately $39.2 billion. This represents a 12 percent increase in the economic impact of congestion in 1988 ($35.1 billion).

Studywide averages indicate that recurring and incident delay accounted for approximately 85 percent of an urban area's congestion cost while excess fuel consumption was 15 percent of the total cost. The average economic burden placed on urban areas in 1989 due to congestion was $780 million compared to $700 million in 1988.

Eight of the top ten urban areas had total congestion costs exceeding $1 billion. Of the seven urban areas studied in Texas only two, Houston - 6th and Dallas - 11th, ranked in the top fifteen. Congestion in the Texas urbanized areas resulted in a cost of approximately $3.3 billion, a seven percent increase from 1988 congestion costs.

Tables S-4 illustrates the estimated economic impact of congestion per capita and per registered vehicle. The urban area with the highest per vehicle cost was Washington, D.C., ($1,280 per registered vehicle) while San Bernardino, CA, had the highest per capita cost ($840 per person). This variation of congestion costs between the Northeastern and Western regions show the effects of the lower vehicle ownership rate in the Northeast.

Table S-5 illustrates the rankings of urban areas by the annual, per capita, and per registered vehicle costs. The rankings are fairly consistent with 13 urban areas occupying the top ten positions in all three categories. However, Table S-5 indicates that with the omission of insurance costs the correspondence between cost per capita and RCI rankings no longer exist. The results of this table indicates that congestion costs may be used as congestion index but not directly related to the rankings associated with the Roadway Congestion Index values.

Table S-3. Component and Total Congestion Costs By Urban Area for 1989

Urban Area	Annual Cost Due to Congestion ($Millions)					
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost	Rank
Los Angeles CA	2,750	3,220	480	560	7,000	1
New York NY	1,810	3,380	300	560	6,040	2
San Fran-Oak CA	980	1,240	170	220	2,620	3
Washington DC	690	1,140	110	190	2,130	4
Chicago IL	780	900	130	150	1,970	5
Houston TX	550	740	90	120	1,500	6
Detroit MI	480	740	80	120	1,410	7
Boston MA	320	880	50	140	1,390	8
Philadelphia PA	400	520	60	80	1,060	9
Seattle-Everett WA	380	500	60	80	1,020	10
Dallas TX	310	530	50	90	980	11
San Bernardino-Riv CA	360	420	60	70	920	12
Atlanta GA	370	410	60	70	910	13
San Jose CA	360	420	60	70	910	13
Miami FL	330	410	50	70	870	15
Phoenix AZ	320	290	50	50	700	16
San Diego CA	320	210	60	40	620	17
St. Louis MO	220	250	30	40	540	18
Denver CO	200	210	30	30	480	19
Baltimore MD	150	260	30	40	470	20
Pittsburgh PA	160	230	20	30	440	21
Minn-St. Paul MN	170	160	30	30	390	22
Fort Worth TX	120	200	20	30	370	23
Sacramento CA	150	120	30	20	320	24
Portland OR	100	160	20	30	310	25
Ft. Lauderdale FL	110	140	20	20	290	26
Norfolk VA	80	170	10	30	290	26
New Orleans LA	90	140	20	20	270	28
Orlando FL	100	130	20	20	270	28
San Antonio TX	100	110	20	20	240	30
Honolulu HI	70	110	10	20	220	31
Jacksonville FL	80	100	10	20	210	32
Cleveland OH	90	70	20	10	190	33
Austin TX	70	80	10	10	180	34
Milwaukee WI	70	80	10	10	180	34
Nashville TN	70	80	10	10	170	36
Tampa FL	70	80	10	10	170	36
Cincinnati OH	70	60	10	10	160	38
Columbus OH	70	60	10	10	160	38
Hartford CT	40	80	10	10	140	40
Charlotte NC	60	60	10	10	130	41
Kansas City MO	30	60	0	10	100	42
Albuquerque NM	30	40	10	10	80	43
Louisville KY	30	40	10	10	80	43
Memphis TN	30	30	10	10	80	43
Oklahoma City OK	30	40	10	10	80	43
Indianapolis IN	20	30	0	10	60	47
Salt Lake City UT	30	20	0	0	60	47
El Paso TX	10	10	0	0	30	49
Corpus Christi TX	0	0	0	0	10	50
Northeastern Avg	510	930	80	150	1,670	
Midwestern Avg	170	210	30	30	440	
Southern Avg	130	160	20	30	330	
Southwestern Avg	160	200	30	30	420	
Western Avg	610	710	110	120	1,550	
Texas Avg	170	240	30	40	470	
Total Avg	280	390	50	60	780	
Maximum Value	2,750	3,380	480	560	7,000	
Minimum Value	0	0	0	0	10	

Source: TTI Analysis and Local Transportation Agency References

Table S-4. Estimated Economic Impact of Congestion in 1989

	Total Congestion Cost	
	Per Registered Vehicle (Dollars)	Per Capita (Dollars)
Northeastern Cities		
Baltimore MD	460	250
Boston MA	840	470
Hartford CT	270	230
New York NY	1,020	370
Philadelphia PA	380	250
Pittsburgh PA	360	240
Washington DC	1,280	690
Midwestern Cities		
Chicago IL	480	270
Cincinnati OH	170	140
Cleveland OH	130	110
Columbus OH	210	190
Detroit MI	490	360
Indianapolis IN	110	70
Kansas City MO	150	90
Louisville KY	170	100
Milwaukee WI	330	140
Minn-St. Paul MN	240	200
Oklahoma City OK	180	120
St. Louis MO	570	280
Southern Cities		
Atlanta GA	590	490
Charlotte NC	360	310
Ft. Lauderdale FL	280	230
Jacksonville FL	360	300
Memphis TN	120	90
Miami FL	610	470
Nashville TN	330	310
New Orleans LA	320	260
Norfolk VA	360	310
Orlando FL	380	340
Tampa FL	270	250
Southwestern Cities		
Albuquerque NM	190	160
Austin TX	370	360
Corpus Christi TX	50	50
Dallas TX	660	500
Denver CO	350	310
El Paso TX	90	90
Fort Worth TX	380	320
Houston TX	690	520
Phoenix AZ	590	370
Salt Lake City UT	90	90
San Antonio TX	270	200
Western Cities		
Honolulu HI	440	330
Los Angeles CA	900	620
Portland OR	460	300
Sacramento CA	250	300
San Bernardino-Riv CA	1,200	840
San Diego CA	440	280
San Fran-Oak CA	850	720
San Jose CA	900	650
Seattle-Everett WA	810	610
Northeastern Avg	660	360
Midwestern Avg	270	170
Southern Avg	360	310
Southwestern Avg	340	270
Western Avg	690	520
Texas Avg	360	290
Total Avg	440	310
Maximum Value	1,280	840
Minimum Value	50	50

Source: TTI Analysis and Local Transportation Agency References

Table S-5. 1989 Urban Area Rankings By Roadway Congestion Index and Cost Per Capita

Urban Area	Roadway Congestion Index	Rank	Congestion Cost per Capita (Dollars)	Rank	Congestion Cost Per Vehicle (Dollars)	Rank
Los Angeles CA	1.54	1	620	5	900	4
San Fran-Oak CA	1.36	2	720	2	850	6
Washington DC	1.36	2	690	3	1,280	1
Miami FL	1.25	4	470	10	610	11
Chicago IL	1.21	5	270	28	480	16
Seattle-Everett WA	1.21	5	610	6	810	8
San Diego CA	1.18	7	280	26	440	19
San Bernardino-Riv CA	1.16	8	840	1	1,200	2
Atlanta GA	1.14	9	490	9	590	12
Houston TX	1.13	10	520	7	690	9
New Orleans LA	1.13	10	260	29	320	32
New York NY	1.12	12	370	12	1,020	3
Boston MA	1.09	13	470	10	840	7
Honolulu HI	1.09	13	330	17	440	19
Detroit MI	1.08	15	360	14	490	15
Portland OR	1.07	16	300	23	460	17
Philadelphia PA	1.05	17	250	30	380	21
Phoenix AZ	1.03	18	370	12	590	12
Tampa FL	1.03	18	250	30	270	34
Dallas TX	1.02	20	500	8	660	10
San Jose CA	1.02	20	650	4	900	4
Denver CO	1.01	22	310	19	350	29
Sacramento CA	1.01	22	300	23	250	37
Baltimore MD	0.99	24	250	30	460	17
Milwaukee WI	0.97	25	140	40	330	30
Austin TX	0.96	26	360	14	370	24
St. Louis MO	0.96	26	280	26	570	14
Cleveland OH	0.95	28	110	43	130	45
Nashville TN	0.95	28	310	19	330	30
Norfolk VA	0.95	28	310	19	360	25
Cincinnati OH	0.94	31	140	40	170	42
Ft. Lauderdale FL	0.92	32	230	34	280	33
Jacksonville FL	0.92	32	300	23	360	25
Albuquerque NM	0.91	34	160	39	190	40
Memphis TN	0.91	34	90	45	120	46
Minn-St. Paul MN	0.90	36	200	36	240	38
Hartford CT	0.89	37	230	34	270	34
Fort Worth TX	0.87	38	320	18	380	21
San Antonio TX	0.87	38	200	36	270	34
Louisville KY	0.86	40	100	44	170	42
Indianapolis IN	0.85	41	70	48	110	47
Columbus OH	0.82	42	190	38	210	39
Pittsburgh PA	0.82	42	240	33	360	25
Salt Lake City UT	0.81	44	80	47	90	48
Oklahoma City OK	0.78	45	120	42	180	41
Charlotte NC	0.74	46	310	19	360	25
El Paso TX	0.74	46	60	49	90	48
Kansas City MO	0.72	48	90	45	150	44
Orlando FL	0.72	48	340	16	380	21
Corpus Christi TX	0.71	50	40	50	50	50

Source: TTI Analysis

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INTRODUCTION

Congestion within the inner city has long been recognized as a severe problem. Congested streets and freeways have forced residents and businesses to relocate in the surrounding suburbs. Relocating to the suburbs however proved to be only a temporary solution to the metropolitan area congestion problems. Now congestion has expanded into the suburbs, street systems designed for aesthetics are overburdened providing service to shopping malls, business parks, and freeway access.

The decline in urban mobility resulting from congestion has become a major concern to not only the transportation community but also the motoring public and business community. Measuring congestion provides an understanding of the phenomenon which assists transportation professionals, policy makers, and the general public in effectively communicating problems and developing necessary transportation system improvements.

Purpose of Congestion Research

Why should we research and investigate effects of urban congestion? Quite simply, old solutions are not working any more. The current mobility situation in most metropolitan areas leaves the limited choices of controlling area growth, large expenditures for general use and transit facility improvements, or accepting intercity and suburb decline. Transportation professionals, policy makers, the media, and the general public generally view these options as undesirable. Therefore, measuring congestion is an important step to enhance their comprehension of the problem and to aid in the development of effective solutions to the urban mobility problem.

This research developed a quantitative procedure to compare traffic volumes and roadway mileage. The procedure estimates the mobility levels within an urban area and permits the comparison of transportation systems. Having the ability to compare transportation systems from one urban area to another provides a tool for analyzing urban mobility.

Congestion Research Background

This research study uses existing data from federal, state, and local agencies to develop planning estimates of the level of mobility within an urban area. The analyses presented in this report are the result of previous research (1,2,3,4,5)[1] conducted at the Texas Transportation Institute. The methodology developed by the previous research provides a procedure which yields a quantitative estimate of urbanized area mobility levels utilizing generally available data while minimizing the need for extensive data collection.

The methodology primarily uses the Federal Highway Administration's Highway Performance Monitoring System (HPMS) data base with supporting information from various state and local agencies. Currently, the data base developed for this research contains vehicle travel, travel per lane-mile, population, urban area size, and facility mileage from 1982 to 1989. Primarily, vehicle travel and vehicle travel per lane-mile are used as the basis of measuring urban mobility and comparison of areawide transportation systems.

Report Organization/Content

Those of you familiar with the most recent congestion reports (3,4,5) published by TTI under the 2-10-91-1131 project will recognize a marked difference in the organization of this report. Past TTI congestion reports (3,4,5) have contained detailed discussions of development for both the roadway congestion index (RCI) and cost methodology. This research report will focus on the results of analyses estimating 1989 congestion levels and trends displayed by the data from 1982 to 1989. Also included in the past reports have been extensive appendices containing data compiled during the study. This report will contain only data for 1989 analyses.

This report summarizes and discusses urban mobility levels in 50 metropolitan areas throughout the United States. Seven of the areas studied represent the largest metropolitan areas in Texas, the remaining 43 areas are located in 27 states (Figure 1). Figure 1 illustrates the geographic regions used in the analyses to combine urban areas studied.

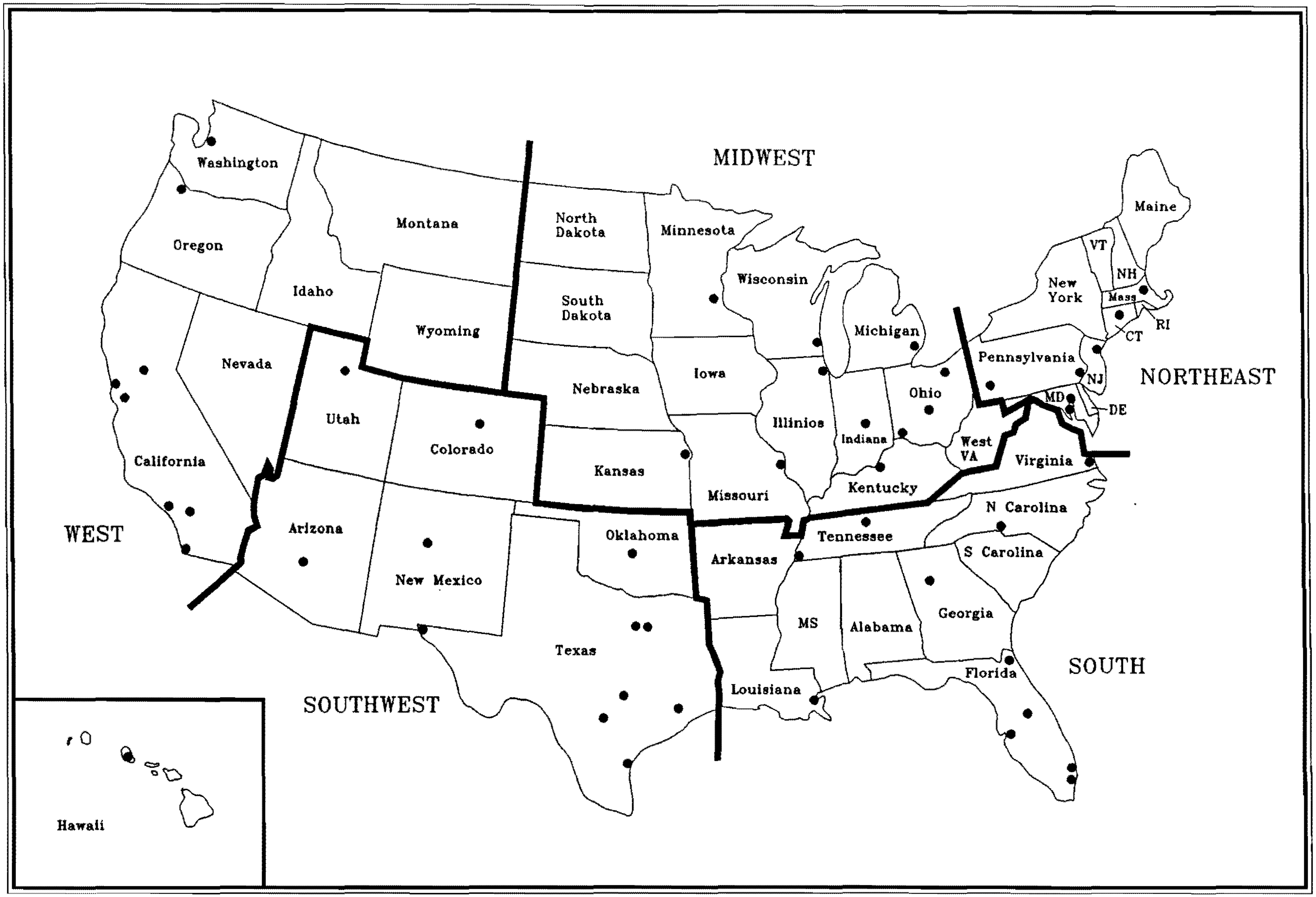

Figure 1. Regional Area Map

There are three major topics addressed in this report. Those topics include areawide mobility, the impacts of congestion, and the cost of congestion. The following are brief descriptions of the information included within each of these topics.

Areawide Mobility

Understanding the reasons for the type of urban development currently prevailing has become of utmost importance to transportation planners and policy makers. Obtaining quantitative estimates of mobility levels allowing the comparisons of transportation systems provides a tool to analyze the variances between different transportation systems and urban areas. This section discusses the trends in urban development, travel and mileage statistics, and the 1989 Roadway Congestion Index (RCI) values for 50 urban areas included within the study.

Impacts of Congestion

The most quantifiable impacts of congestion are additional capacity required to eliminate congested conditions and the amount of time spent by motorists in congestion. This section discusses the relationship different urban areas have with their freeway and principal arterial street systems. Also discussed is how that relationship impacts which system should be expanded to address the needs of the specific urban area. This relationship is demonstrated with five case studies representing major metropolitan areas within the different geographic regions. Travel delays are also addressed in this section. Delay, the most apparent impact of congestion to the motoring public, may be categorized into two general areas -- recurring and nonrecurring. The impacts of travel delay and the relationship with an urban area's RCI are analyzed.

Cost of Congestion

Within this section the economic impact of congestion was estimated for the 50 urban areas studied. Congestion costs are comprised of two primary costs -- delay and fuel. Estimating the costs associated with congestion provides another tool for comparing urban mobility from one area to another. More importantly estimating congestion costs allows a method of tracking changes in congestion levels and their impact on an urbanized area over an extended period of time.

AREAWIDE MOBILITY

A recent report (6) identified several trends shaping traffic congestion. Six interrelated forces impacting the nature and severity of congestion include: (1) suburban development, (2) the economy, (3) the labor force, (4) automobile usage, (5) percent of truck traffic, and (6) the highway infrastructure. The following is an example of how these forces interact:

> Trends in suburban and economic development have supported and generated increased automobile usage and truck traffic. This has resulted in increasing traffic congestion in many metropolitan areas throughout the country (6).

Trends in Urban Development

Overall, most metropolitan areas are experiencing dynamic suburban growth. Suburban development is encouraged by the prevailing desire to live away from the inner city but yet be in close enough proximity to enjoy urban amenities. This evolutionary process begins with families and then expands to commercial services and jobs. The process shapes the traffic congestion within most large and small metropolitan areas by altering the commuting patterns.

The demands placed on the existing highway infrastructure in general and by the migration of the population and employment opportunities have not been met by new facility construction. Demands for suburban traffic movement, increasing vehicle-miles of travel, and more freeway access points have greatly altered the function of the freeway/expressway system in most metropolitan areas. Increases in delay are the result of the roadway system capacity not increasing to meet new demands.

Reasons for the decline in new facility construction, during the past 20 years, may be attributed to reduced funding, increased construction costs, and public resistance to building and widening transportation facilities. These factors have promoted lower levels of mobility and greater dispersion of the metropolitan area's population. In more recent years, an increasing negative perception of the mobility level has renewed interest in the transportation infrastructure. This same perception of the transportation infrastructure has also enhanced the desire of the transportation community, general public, policy makers, and numerous others to understand the causes, effects, and solution to urban congestion.

Travel and Mileage Statistics

Previous TTI research (3,4,5) used freeway and principal arterial street daily vehicle-miles of travel per lane (DVMT) as indicators of urban congestion levels. The previous studies established the constant values of 13,000 DVMT per lane-mile (freeways) and 5,000 DVMT per lane-mile (principal arterial streets) as the thresholds for undesirable congestion levels. Briefly, when freeway travel volumes exceed an average of 13,000 DVMT per lane-mile undesirable levels of congestion occur. The corresponding level of service is reached on principal arterial streets when travel volumes average 5,000 DVMT per lane-mile.

In this section, we will discuss the urbanized area mileage and travel statistics and their relationship with population and urban area. Mobility within the geographic regions and between individual urban areas will be compared on the basis of DVMT per lane-mile.

Freeway Travel and Mileage Statistics

Areawide freeway operating conditions with regards to DVMT and lane-miles are summarized in Table 1. The urban areas in Table 1 are ranked according to the primary congestion indicator, DVMT per lane-mile. Summary statistics for each geographical region are located at the bottom of Table 1.

Eighteen urbanized areas exceeded the 13,000 DVMT per lane-mile level indicating areawide congested conditions on the freeway systems. Of the ten urban areas with the highest DVMT per lane-mile values, five have experienced congested freeway systems since 1982. An additional eight urban areas studied have DVMT per lane-mile values only two to seven percent below the 13,000 level. Urban areas with travel demands in this range

Table 1. 1989 Freeway Mileage and Travel Volume

Urban Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Rank[3]
Los Angeles CA	106,680	5,120	8.2	20,840	1
San Fran-Oak CA	41,970	2,350	6.8	17,860	2
Washington DC	25,020	1,520	5.3	16,460	3
Seattle-Everett WA	18,200	1,160	3.4	15,690	4
San Diego CA	26,760	1,720	7.4	15,560	5
San Bernardino-Riv CA	13,620	880	7.0	15,480	6
Chicago IL	34,440	2,300	5.7	14,970	7
Houston TX	27,640	1,860	6.2	14,860	8
Atlanta GA	24,600	1,680	6.1	14,640	9
Boston MA	22,080	1,520	5.9	14,570	10
Miami FL	8,350	580	5.4	14,400	11
New Orleans LA	4,860	350	5.8	13,890	12
New York NY	80,920	5,870	5.6	13,800	13
Portland OR	7,470	550	5.0	13,580	14
Dallas TX	22,650	1,690	5.9	13,400	15
San Jose CA	15,540	1,160	6.9	13,400	15
Detroit MI	22,550	1,690	5.8	13,340	17
Honolulu HI	4,530	340	5.2	13,310	18
Milwaukee WI	7,520	590	5.6	12,740	19
Denver CO	10,730	860	5.1	12,480	20
Austin TX	5,300	430	5.6	12,470	21
Cleveland OH	13,210	1,060	4.7	12,460	22
Baltimore MD	15,180	1,230	5.4	12,340	23
Cincinnati OH	10,890	890	5.5	12,240	24
Philadelphia PA	18,280	1,510	5.1	12,140	25
Sacramento CA	8,850	730	6.9	12,120	26
Jacksonville FL	5,200	440	4.5	11,820	27
Phoenix AZ	7,050	610	5.6	11,650	28
Minn-St. Paul MN	16,860	1,450	4.9	11,630	29
Tampa FL	3,430	300	4.9	11,630	29
Norfolk VA	5,340	460	4.9	11,600	31
Ft. Lauderdale FL	6,830	590	5.4	11,580	32
Nashville TN	5,410	480	5.0	11,270	33
Memphis TN	4,260	380	5.4	11,200	34
San Antonio TX	9,180	830	5.2	11,120	35
Fort Worth TX	11,280	1,020	5.7	11,110	36
St. Louis MO	18,720	1,690	5.5	11,110	36
Albuquerque NM	2,310	210	5.0	11,000	38
Indianapolis IN	7,890	720	5.3	10,960	39
Hartford CT	6,180	580	5.5	10,660	40
Louisville KY	6,140	590	4.6	10,500	41
Columbus OH	8,100	790	5.8	10,250	42
Orlando FL	5,820	580	4.9	10,120	43
Salt Lake City UT	5,080	510	5.6	9,960	44
Oklahoma City OK	6,830	720	5.1	9,490	45
El Paso TX	3,300	350	5.2	9,430	46
Kansas City MO	12,370	1,360	4.3	9,130	47
Corpus Christi TX	1,520	190	5.3	8,220	48
Pittsburgh PA	7,750	980	4.3	7,910	49
Charlotte NC	2,220	300	4.2	7,530	50
Northeastern Avg	25,060	1,890	5.3	12,550	
Midwestern Avg	13,790	1,150	5.2	11,570	
Southern Avg	6,940	560	5.1	11,790	
Southwestern Avg	9,640	780	5.5	11,430	
Western Avg	27,070	1,560	6.3	15,310	
Texas Avg	11,550	910	5.6	11,520	
Total Avg	15,340	1,110	5.5	12,400	
Maximum Value	106,680	5,870	8.2	20,840	
Minimum Value	1,520	190	3.4	7,530	

Note: [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
Ranked by DVMT/Lane-mile

Source: TTI Analysis and Local Transportation Agency References

would only have to experience moderate to slight increases in travel demands to cause their freeway systems to operate under congested conditions.

The summary statistics at the bottom of Table 1 show average DVMT per lane-mile values by geographic region. Every region except the Western region have DVMT per lane-mile values below the 13,000 level. Comparing these statistics with the similar 1988 analysis (5) shows that the average DVMT per lane-mile value for every geographic region has increased from one to two percent. However, over the same period the Texas DVMT per lane-mile average has actually decreased slightly (less than one percent).

Principal Arterial Street Travel and Mileage Statistics

Table 2 shows the operating characteristics of the principal arterial street system for each urban area included in this study. As in Table 1, Table 2 ranks urban areas by travel demand per lane-mile and contains regional summary statistics.

In 1989, 34 of the urban areas studied experienced DVMT per lane-mile levels exceeding 5,000. Of these 34 urban areas, 27 have had travel demands exceeding 5,000 DVMT per lane-mile since 1982. Comparing these statistics to urban area freeway system statistics indicates that a large portion of an certain area's congestion problems may be attributed to deficiencies in the principal arterial street system.

The summary statistics show that all the regional averages except Texas exceed the 5,000 DVMT per lane-mile level. This indicates that generally the principal arterial street systems in the urban areas studied are operating under congested conditions. However, the regional average travel demand on principal arterial street systems decreased (approximately one percent) from 1988 levels in all of the geographic regions studied. Urban areas in Texas had the smallest decrease in travel demand; however, comparing the average travel demand value for Texas urban areas to other regions indicated that urban areas in Texas also have the smallest travel demand of the other regions.

Table 2. 1989 Principal Arterial Street Mileage and Travel Volume

Urban Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Rank[3]
Washington DC	19,130	2,290	4.0	8,370	1
Honolulu HI	1,560	200	3.8	7,970	2
Miami FL	14,810	2,040	4.3	7,280	3
New York NY	50,830	7,350	3.4	6,920	4
Chicago IL	27,980	4,050	3.8	6,910	5
St. Louis MO	12,210	1,800	3.2	6,800	6
Tampa FL	4,180	630	3.8	6,630	7
New Orleans LA	4,070	620	4.2	6,560	8
Los Angeles CA	79,810	12,180	4.0	6,550	9
Philadelphia PA	21,140	3,250	3.0	6,510	10
San Fran-Oak CA	13,710	2,120	3.9	6,470	11
Sacramento CA	6,810	1,080	4.0	6,310	12
Atlanta GA	9,710	1,560	3.6	6,220	13
Portland OR	3,370	550	3.3	6,180	14
Detroit MI	21,820	3,580	4.4	6,090	15
Pittsburgh PA	10,770	1,770	3.1	6,080	16
Seattle-Everett WA	9,060	1,510	3.4	6,000	17
Hartford CT	3,640	620	3.7	5,870	18
Phoenix AZ	16,650	2,850	4.0	5,840	19
Nashville TN	5,400	940	3.3	5,780	20
Denver CO	10,600	1,840	3.9	5,760	21
Baltimore MD	9,330	1,640	4.0	5,700	22
Louisville KY	2,890	510	3.7	5,670	23
Norfolk VA	4,080	730	3.5	5,630	24
Salt Lake City UT	1,950	360	3.5	5,490	25
Charlotte NC	2,860	530	3.0	5,390	26
San Diego CA	8,930	1,670	3.4	5,350	27
Oklahoma City OK	3,590	680	3.2	5,270	28
Houston TX	10,400	2,010	4.3	5,170	29
San Bernardino-Riv CA	9,370	1,830	4.2	5,130	30
Memphis TN	4,120	810	4.3	5,120	31
Albuquerque NM	3,580	700	3.5	5,110	32
Ft. Lauderdale FL	5,610	1,100	4.3	5,100	33
Columbus OH	3,040	600	3.3	5,070	34
Fort Worth TX	4,220	870	4.0	4,880	35
San Jose CA	6,760	1,390	4.2	4,880	35
Dallas TX	8,230	1,700	4.8	4,860	37
Austin TX	2,050	430	4.2	4,820	38
San Antonio TX	5,180	1,080	3.5	4,800	39
Jacksonville FL	5,750	1,200	3.7	4,790	40
Boston MA	12,650	2,710	2.3	4,680	41
Milwaukee WI	4,670	1,000	3.3	4,670	42
Cleveland OH	5,190	1,120	3.0	4,650	43
Cincinnati OH	3,620	800	3.3	4,550	44
Minn-St. Paul MN	5,390	1,190	3.3	4,550	44
Corpus Christi TX	1,450	320	3.8	4,530	46
Indianapolis IN	3,830	850	3.7	4,510	47
Kansas City MO	4,370	1,050	3.5	4,180	48
El Paso TX	3,180	830	4.2	3,830	49
Orlando FL	3,730	1,520	3.7	2,370	50
Northeastern Avg	18,210	2,800	3.4	6,310	
Midwestern Avg	8,220	1,430	3.5	5,240	
Southern Avg	5,840	1,060	3.8	5,530	
Southwestern Avg	6,130	1,180	4.0	5,010	
Western Avg	15,490	2,500	3.8	6,090	
Texas Avg	4,960	1,030	4.1	4,700	
Total Avg	9,940	1,680	3.7	5,560	
Maximum Value	79,810	12,180	4.8	8,370	
Minimum Value	1,450	200	2.3	2,370	

Notes: [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
Ranked by DVMT/Lane-mile

Source: TTI Analysis and Local Transportation Agency References

Relationship Between Travel Demand and Urban Area Population/Size

In previous reports (4,5), reference was made to relationships between DVMT and facility lane-miles and urban area population and size. The relationship between travel demand and lane-miles and population indicates on what facilities the general populace places highest demand, while the relationship between DVMT and facility lane-miles and area size indicates the density of both the freeway and principal arterial street systems.

Tables 3 and 4 show the relationship, for freeways and principal arterial streets, between DVMT and urban area population. In both tables, the urban areas are ranked by DVMT and facility lane-miles per person. Comparing the summary statistics of these tables indicate:

- The DVMT per person value shows each geographic region studied depends on the freeway system for service of the majority of travel demand.
- All the geographic regions evaluated have a more dense principal arterial street system than freeway system.

Roadway Congestion Index Values, 1989

Table 5 combines the freeway and principal arterial street system DVMT and DVMT per lane-mile values (Tables 2 and 3) into the estimated 1989 Roadway Congestion Index (RCI). Equation 1 illustrates how the DVMT values are used to calculate the RCI value for individual urban areas. The RCI value is a relative measure of the level of congestion for a given urban area. An RCI value of 1.0 or greater indicates an undesirable areawide congestion level.

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

Table 3. Summary of Freeway Travel Frequency and Urban Population Statistics for 1989

Urban Area	Popn. (1000)	Urban Area (Sq.Mi)	Popn Density Pers/Sq Mi	DVMT[1] Per Person	Rank[3]	Ln Mi[2] Per 1000 Pers	Rank[3]
Northeastern Cities							
Baltimore MD	1,920	540	3,580	7.93	23	0.64	23
Boston MA	2,950	1,040	2,850	7.48	26	0.51	16
Hartford CT	610	360	1,680	10.21	10	0.96	48
New York NY	16,420	3,180	5,170	4.93	43	0.36	5
Philadelphia PA	4,220	1,130	3,750	4.33	48	0.36	5
Pittsburgh PA	1,850	730	2,530	4.19	49	0.53	18
Washington DC	3,080	840	3,690	8.12	22	0.49	14
Midwestern Cities							
Chicago IL	7,410	1,990	3,730	4.65	44	0.31	1
Cincinnati OH	1,140	570	2,020	9.55	16	0.78	38
Cleveland OH	1,790	640	2,790	7.40	27	0.59	21
Columbus OH	840	310	2,750	9.64	14	0.94	47
Detroit MI	3,900	1,250	3,120	5.78	37	0.43	8
Indianapolis IN	930	440	2,140	8.48	20	0.77	36
Kansas City MO	1,160	610	1,890	10.71	8	1.17	50
Louisville KY	810	380	2,150	7.63	25	0.73	34
Milwaukee WI	1,230	550	2,230	6.13	35	0.48	13
Minn-St. Paul MN	1,970	1,020	1,940	8.56	19	0.74	35
Oklahoma City OK	730	500	1,460	9.36	18	0.99	49
St. Louis MO	1,960	730	2,700	9.58	15	0.86	42
Southern Cities							
Atlanta GA	1,860	1,540	1,210	13.22	1	0.90	46
Charlotte NC	440	240	1,830	5.05	41	0.67	27
Ft. Lauderdale FL	1,260	430	2,920	5.44	39	0.47	12
Jacksonville FL	720	540	1,320	7.27	30	0.62	22
Memphis TN	850	420	2,020	5.01	42	0.45	10
Miami FL	1,840	480	3,870	4.54	47	0.32	2
Nashville TN	550	500	1,110	9.84	11	0.87	44
New Orleans LA	1,050	360	2,920	4.63	45	0.33	4
Norfolk VA	920	810	1,140	5.80	36	0.50	15
Orlando FL	800	400	2,000	7.28	29	0.72	33
Tampa FL	670	440	1,540	5.12	40	0.44	9
Southwestern Cities							
Albuquerque NM	500	250	2,000	4.62	46	0.42	7
Austin TX	510	350	1,460	10.50	9	0.84	41
Corpus Christi TX	280	180	1,570	5.53	38	0.67	27
Dallas TX	1,970	1,440	1,370	11.49	5	0.86	42
Denver CO	1,570	890	1,770	6.86	31	0.55	20
El Paso TX	520	210	2,540	6.35	34	0.67	27
Fort Worth TX	1,170	850	1,380	9.68	12	0.87	44
Houston TX	2,870	1,640	1,750	9.65	13	0.65	24
Phoenix AZ	1,880	970	1,930	3.76	50	0.32	2
Salt Lake City UT	790	460	1,710	6.47	33	0.65	24
San Antonio TX	1,170	480	2,430	7.88	24	0.71	32
Western Cities							
Honolulu HI	660	140	4,890	6.86	31	0.52	17
Los Angeles CA	11,310	2,170	5,210	9.44	17	0.45	10
Portland OR	1,010	410	2,460	7.40	27	0.54	19
Sacramento CA	1,060	360	2,970	8.39	21	0.69	30
San Bernardino-Riv CA	1,100	480	2,290	12.38	2	0.80	39
San Diego CA	2,220	710	3,150	12.05	3	0.77	36
San Fran-Oak CA	3,620	840	4,340	11.59	4	0.65	24
San Jose CA	1,390	450	3,120	11.18	6	0.83	40
Seattle-Everett WA	1,680	720	2,350	10.83	7	0.69	30
Northeastern Avg	4,430	1,110	3,320	6.74		0.55	
Midwestern Avg	1,990	750	2,410	8.12		0.73	
Southern Avg	1,000	560	1,990	6.65		0.57	
Southwestern Avg	1,200	700	1,810	7.53		0.66	
Western Avg	2,670	690	3,420	10.01		0.66	
Texas Avg	1,210	730	1,790	8.73		0.75	
Total Avg	2,060	740	2,490	7.82		0.64	
Maximum Value	16,420	3,180	5,210	13.22		1.17	
Minimum Value	280	140	1,110	3.76		0.31	

Notes: [1] Daily vehicle-miles of travel per person
[2] Lane-miles per 1000 persons
[3] Rank value of 1 associated with most congested condition

Source: TTI Analysis and Local Transportation Agency References

Table 4. Principal Arterial Street Travel Frequency and Population Density Statistics for 1989

Urban Area	Popn. (1000)	Urban Area (Sq.Mi)	Popn Density Pers/Sq Mi	DVMT[1] Per Person	Rank[3]	Ln Mi[2] Per 1000 Pers	Rank[3]
Northeastern Cities							
Baltimore MD	1,920	540	3,580	4.87	23	0.85	22
Boston MA	2,950	1,040	2,850	4.29	30	0.92	28
Hartford CT	610	360	1,680	6.02	15	1.02	37
New York NY	16,420	3,180	5,170	3.10	46	0.45	2
Philadelphia PA	4,220	1,130	3,750	5.01	21	0.77	17
Pittsburgh PA	1,850	730	2,530	5.82	16	0.96	35
Washington DC	3,080	840	3,690	6.21	13	0.74	14
Midwestern Cities							
Chicago IL	7,410	1,990	3,730	3.78	38	0.55	5
Cincinnati OH	1,140	570	2,020	3.18	45	0.70	11
Cleveland OH	1,790	640	2,790	2.90	47	0.62	9
Columbus OH	840	310	2,750	3.62	41	0.71	13
Detroit MI	3,900	1,250	3,120	5.59	17	0.92	28
Indianapolis IN	930	440	2,140	4.12	32	0.91	27
Kansas City MO	1,160	610	1,890	3.78	38	0.90	25
Louisville KY	810	380	2,150	3.59	43	0.63	10
Milwaukee WI	1,230	550	2,230	3.81	36	0.82	19
Minn-St. Paul MN	1,970	1,020	1,940	2.74	48	0.60	8
Oklahoma City OK	730	500	1,460	4.91	22	0.93	31
St. Louis MO	1,960	730	2,700	6.25	11	0.92	28
Southern Cities							
Atlanta GA	1,860	1,540	1,210	5.22	20	0.84	20
Charlotte NC	440	240	1,830	6.49	9	1.20	43
Ft. Lauderdale FL	1,260	430	2,920	4.50	27	0.79	18
Jacksonville FL	720	540	1,320	8.00	5	1.68	48
Memphis TN	850	420	2,020	4.85	25	0.95	34
Miami FL	1,840	480	3,870	8.05	4	1.11	40
Nashville TN	550	500	1,110	9.82	1	1.70	49
New Orleans LA	1,050	360	2,920	3.87	35	0.59	6
Norfolk VA	920	810	1,140	4.43	29	0.88	24
Orlando FL	800	400	2,000	4.70	26	1.96	50
Tampa FL	670	440	1,540	6.24	12	0.94	33
Southwestern Cities							
Albuquerque NM	500	250	2,000	7.16	6	1.40	44
Austin TX	510	350	1,460	4.06	33	0.84	20
Corpus Christi TX	280	180	1,570	5.27	19	1.16	41
Dallas TX	1,970	1,440	1,370	4.18	31	0.86	23
Denver CO	1,570	890	1,770	6.77	8	1.18	42
El Paso TX	520	210	2,540	6.11	14	1.60	46
Fort Worth TX	1,170	850	1,380	3.62	41	0.74	14
Houston TX	2,870	1,640	1,750	3.63	40	0.70	11
Phoenix AZ	1,880	970	1,930	8.88	2	1.52	45
Salt Lake City UT	790	460	1,710	2.48	49	0.45	2
San Antonio TX	1,170	480	2,430	4.45	28	0.93	31
Western Cities							
Honolulu HI	660	140	4,890	2.36	50	0.30	1
Los Angeles CA	11,310	2,170	5,210	7.06	7	1.08	39
Portland OR	1,010	410	2,460	3.34	44	0.54	4
Sacramento CA	1,060	360	2,970	6.45	10	1.02	37
San Bernardino-Riv CA	1,100	480	2,290	8.52	3	1.66	47
San Diego CA	2,220	710	3,150	4.02	34	0.75	16
San Fran-Oak CA	3,620	840	4,340	3.79	37	0.59	6
San Jose CA	1,390	450	3,120	4.86	24	1.00	36
Seattle-Everett WA	1,680	720	2,350	5.39	18	0.90	25
Northeastern Avg	4,430	1,110	3,320	5.05		0.82	
Midwestern Avg	1,990	750	2,410	4.02		0.77	
Southern Avg	1,000	560	1,990	6.02		1.15	
Southwestern Avg	1,200	700	1,810	5.15		1.03	
Western Avg	2,670	690	3,420	5.09		0.87	
Texas Avg	1,210	730	1,790	4.47		0.98	
Total Avg	2,060	740	2,490	5.04		0.94	
Maximum Value	16,420	3,180	5,210	9.82		1.96	
Minimum Value	280	140	1,110	2.36		0.30	

Notes: [1] Daily vehicle-miles of travel per person
[2] Lane-miles per 1000 persons
[3] Rank value of 1 associated

Source: TTI Analysis and Local Transportation Agency References

Table 5. 1989 Roadway Congestion Index Value

Urban Area	Freeway / Expressway		Principal Arterial Street		Roadway[3] Congestion Index	Rank
	DVMT[1] (1000)	DVMT/[2] Ln-Mile	DVMT[1] (1000)	DVMT/[2] Ln-Mile		
Los Angeles CA	106,680	20,840	79,810	6,550	1.54	1
San Fran-Oak CA	41,970	17,860	13,710	6,470	1.36	2
Washington DC	25,020	16,460	19,130	8,370	1.36	2
Miami FL	8,350	14,400	14,810	7,280	1.25	4
Chicago IL	34,440	14,970	27,980	6,910	1.21	5
Seattle-Everett WA	18,200	15,690	9,060	6,000	1.21	5
San Diego CA	26,760	15,560	8,930	5,350	1.18	7
San Bernardino-Riv CA	13,620	15,480	9,370	5,130	1.16	8
Atlanta GA	24,600	14,640	9,710	6,220	1.14	9
Houston TX	27,640	14,860	10,400	5,170	1.13	10
New Orleans LA	4,860	13,890	4,070	6,560	1.13	10
New York NY	80,920	13,800	50,830	6,920	1.12	12
Boston MA	22,080	14,570	12,650	4,680	1.09	13
Honolulu HI	4,530	13,310	1,560	7,970	1.09	13
Detroit MI	22,550	13,340	21,820	6,090	1.08	15
Portland OR	7,470	13,580	3,370	6,180	1.07	16
Philadelphia PA	18,280	12,140	21,140	6,510	1.05	17
Phoenix AZ	7,050	11,650	16,650	5,840	1.03	18
Tampa FL	3,430	11,630	4,180	6,630	1.03	18
Dallas TX	22,650	13,400	8,230	4,860	1.02	20
San Jose CA	15,540	13,400	6,760	4,880	1.02	20
Denver CO	10,730	12,480	10,600	5,760	1.01	22
Sacramento CA	8,850	12,120	6,810	6,310	1.01	22
Baltimore MD	15,180	12,340	9,330	5,700	0.99	24
Milwaukee WI	7,520	12,740	4,670	4,670	0.97	25
Austin TX	5,300	12,470	2,050	4,820	0.96	26
St. Louis MO	18,720	11,110	12,210	6,800	0.96	26
Cleveland OH	13,210	12,460	5,190	4,650	0.95	28
Nashville TN	5,410	11,270	5,400	5,780	0.95	28
Norfolk VA	5,340	11,600	4,080	5,630	0.95	28
Cincinnati OH	10,890	12,240	3,620	4,550	0.94	31
Ft. Lauderdale FL	6,830	11,580	5,610	5,100	0.92	32
Jacksonville FL	5,200	11,820	5,750	4,790	0.92	32
Albuquerque NM	2,310	11,000	3,580	5,110	0.91	34
Memphis TN	4,260	11,200	4,120	5,120	0.91	34
Minn-St. Paul MN	16,860	11,630	5,390	4,550	0.90	36
Hartford CT	6,180	10,660	3,640	5,870	0.89	37
Fort Worth TX	11,280	11,110	4,220	4,880	0.87	38
San Antonio TX	9,180	11,120	5,180	4,800	0.87	38
Louisville KY	6,140	10,500	2,890	5,670	0.86	40
Indianapolis IN	7,890	10,960	3,830	4,510	0.85	41
Columbus OH	8,100	10,250	3,040	5,070	0.82	42
Pittsburgh PA	7,750	7,910	10,770	6,080	0.82	42
Salt Lake City UT	5,080	9,960	1,950	5,490	0.81	44
Oklahoma City OK	6,830	9,490	3,590	5,270	0.78	45
Charlotte NC	2,220	7,530	2,860	5,390	0.74	46
El Paso TX	3,300	9,430	3,180	3,830	0.74	46
Kansas City MO	12,370	9,130	4,370	4,180	0.72	48
Orlando FL	5,820	10,120	3,730	2,370	0.72	48
Corpus Christi TX	1,520	8,220	1,450	4,530	0.71	50
Northeastern Avg	25,060	12,550	18,210	6,310	1.05	
Midwestern Avg	13,790	11,570	8,220	5,240	0.92	
Southern Avg	6,940	11,790	5,840	5,530	0.97	
Southwestern Avg	9,640	11,430	6,130	5,010	0.91	
Western Avg	27,070	15,310	15,490	6,090	1.18	
Texas Avg	11,550	11,520	4,960	4,700	0.90	
Total Avg	15,340	12,400	9,940	5,560	0.99	
Maximum Value	106,680	20,840	79,810	8,370	1.54	
Minimum Value	1,520	7,530	1,450	2,370	0.71	

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

Source: Equation 1 and Tables 1 and 2

1989 Roadway Congestion Index Estimates

Of the 50 urban areas studied, 23 have RCI values exceeding 1.0. RCI values for the ten most congested urban areas range from 1.54 (Los Angeles) to 1.13 (New Orleans). In all, thirteen more urban areas have estimated RCI values ranging between 0.97 and 0.90. These areas may not experience undesirable levels of congestion in the immediate future; however, congestion levels could become undesirable within the next five to ten years.

The Western region has the highest average RCI value of 1.18. The only other regional averages exceeding 1.0 was the Northeastern (1.05). The Southwestern, Southern, and Midwestern regions have average RCI values below 1.0. The Texas regional average was the lowest of all the regions studied (0.90).

None of the urban areas studied in Texas were included in the ten most congested urban areas. Houston (10th) and Dallas (20th) were the highest ranked areas within the state. Austin was the next highest ranked (26th) urbanized area in the state with the remaining four Texas cities not ranked in the top 30.

Historical RCI Estimates, 1982 to 1989

Roadway congestion index values for all 50 urban areas from 1982 to 1989 are summarized in Table 6. During the study period, San Diego, San Francisco, and Salt Lake City were estimated to have experienced the fastest increase in congestion while Phoenix, Detroit, and Houston have experienced the smallest. Of the urban areas in Texas, Austin has the largest increase in RCI from 1982 levels (25 percent). The summary statistics show that all the geographic regions except Texas experienced an increase in average 1989 RCI values from 1988 levels.

The trend of congestion levels in the ten most congested urban areas are shown in Figure 2. This figure illustrates the change or growth in congestion levels from 1982 to 1989. Los

Angeles has the most consistent growth rate of the ten most congested urban areas. All the urban areas shown in this figure exhibit an increasing trend in their RCI values.

Figure 3 illustrates similar trend data for the Texas urban areas studied. This figure graphically shows the improving trend of congestion in Houston which is currently below 1982 levels. Dallas, Fort Worth, and Austin experienced increasing congestion levels until 1986, since that time congestion levels have been relatively constant. San Antonio, El Paso, and Corpus Christi exhibited a slightly increasing trend in their RCI values.

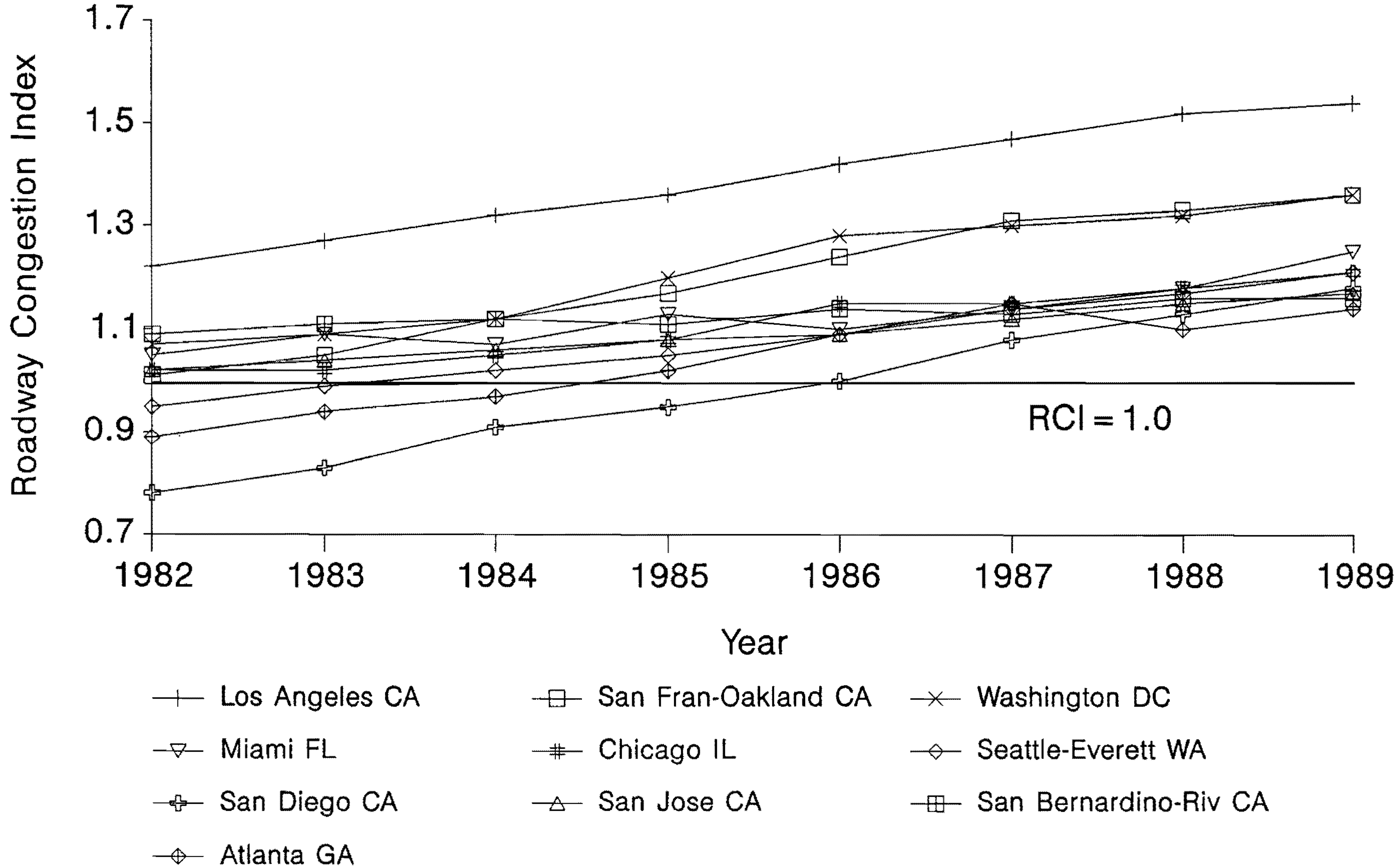

Figure 2. Ten Most Congested Urban Area RCIs - 1982 to 1989

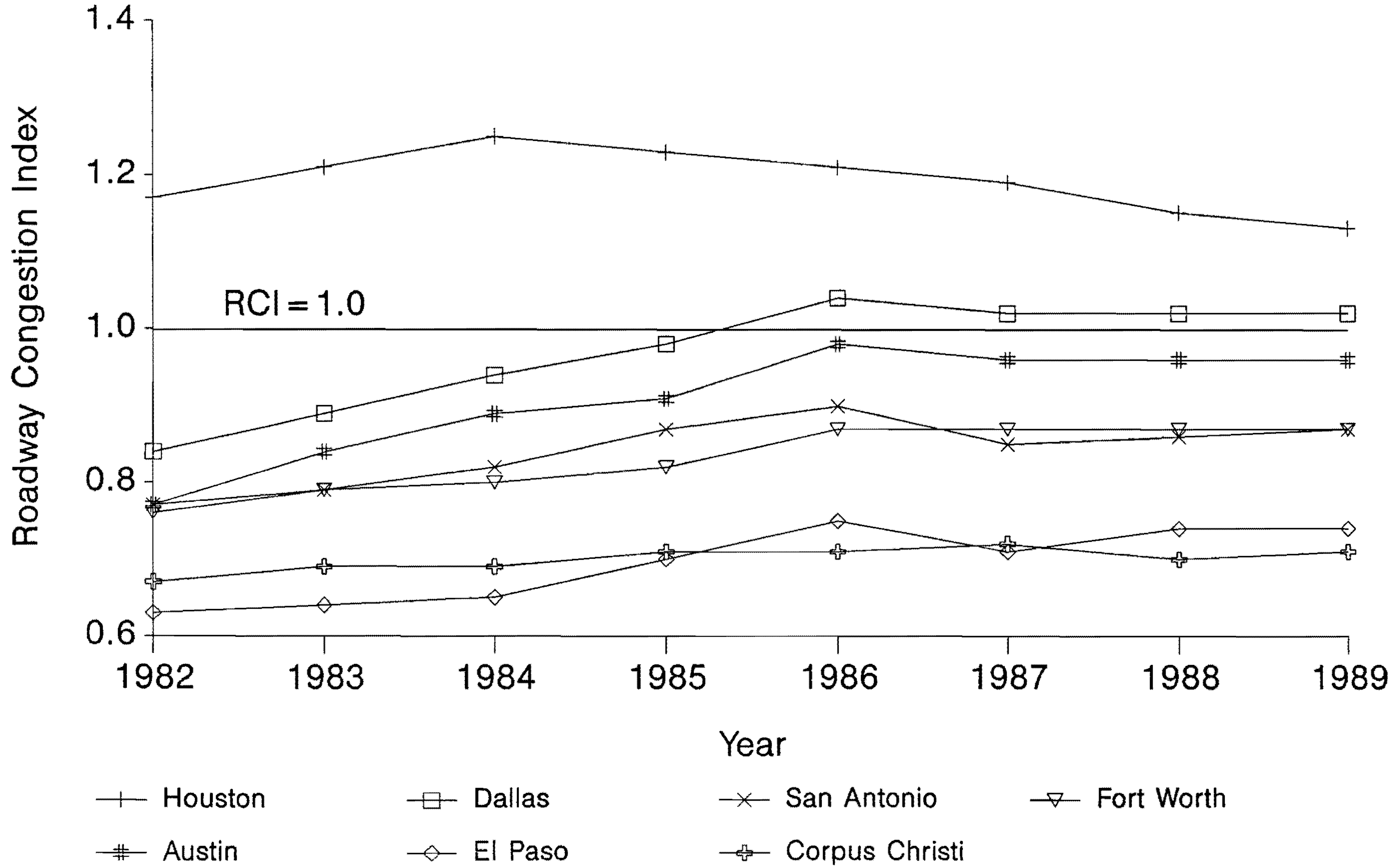

Figure 3. Texas Urban Area RCIs - 1982 to 1989

Table 6. Roadway Congestion Index Values, 1982 to 1989

Urban Area	Year								Percent Change 1982 to 1989
	1982	1983	1984	1985	1986	1987	1988	1989	
Phoenix AZ	1.15	1.16	1.10	1.13	1.20	1.18	1.00	1.03	-10
Detroit MI	1.13	1.10	1.13	1.12	1.11	1.10	1.09	1.08	-4
Houston TX	1.17	1.21	1.25	1.23	1.21	1.19	1.15	1.13	-3
Louisville KY	0.84	0.82	0.81	0.79	0.80	0.88	0.87	0.86	2
Philadelphia PA	1.00	1.03	1.04	0.90	1.06	1.06	1.07	1.05	5
Pittsburgh PA	0.78	0.76	0.76	0.78	0.79	0.79	0.81	0.82	5
Jacksonville FL	0.87	0.98	0.98	0.98	0.95	0.94	0.95	0.92	6
Memphis TN	0.86	0.80	0.76	0.75	0.77	0.84	0.86	0.91	6
Corpus Christi TX	0.67	0.69	0.69	0.71	0.71	0.72	0.70	0.71	6
San Bernardino-Riv CA	1.09	1.11	1.12	1.11	1.14	1.13	1.16	1.16	6
Ft. Lauderdale FL	0.86	0.85	0.84	0.84	0.84	0.90	0.90	0.92	7
Oklahoma City OK	0.72	0.72	0.75	0.74	0.71	0.76	0.78	0.78	8
Orlando FL	0.66	0.68	0.67	0.71	0.71	0.72	0.74	0.72	9
Cincinnati OH	0.86	0.83	0.82	0.83	0.84	0.87	0.88	0.94	9
Tampa FL	0.94	0.91	1.03	1.00	0.96	1.02	1.03	1.03	10
Charlotte NC	0.67	0.72	0.72	0.73	0.73	0.74	0.73	0.74	10
New York NY	1.01	1.02	0.99	1.00	1.06	1.06	1.10	1.12	11
San Antonio TX	0.77	0.79	0.82	0.87	0.90	0.85	0.86	0.87	13
Fort Worth TX	0.76	0.79	0.80	0.82	0.87	0.87	0.87	0.87	14
New Orleans LA	0.98	0.99	1.02	1.11	1.11	1.14	1.13	1.13	15
St. Louis MO	0.83	0.87	0.88	0.89	0.93	0.96	0.98	0.96	16
Kansas City MO	0.62	0.62	0.60	0.65	0.69	0.71	0.72	0.72	16
Albuquerque NM	0.78	0.83	0.89	0.93	0.88	0.91	0.90	0.91	17
Milwaukee WI	0.83	0.84	0.87	0.88	0.90	0.95	0.94	0.97	17
Hartford CT	0.76	0.79	0.86	0.85	0.85	0.87	0.91	0.89	17
Honolulu HI	0.93	0.95	0.97	0.97	1.05	1.07	1.10	1.09	17
El Paso TX	0.63	0.64	0.65	0.70	0.75	0.71	0.74	0.74	17
Baltimore MD	0.84	0.84	0.85	0.84	0.88	0.90	0.92	0.99	18
Chicago IL	1.02	1.02	1.05	1.08	1.15	1.15	1.18	1.21	19
Cleveland OH	0.80	0.82	0.83	0.81	0.86	0.89	0.97	0.95	19
Denver CO	0.85	0.88	0.93	0.96	0.97	0.95	0.99	1.01	19
Miami FL	1.05	1.09	1.07	1.13	1.10	1.14	1.18	1.25	19
Indianapolis IN	0.71	0.66	0.75	0.76	0.80	0.85	0.84	0.85	20
San Jose CA	0.85	0.87	0.90	0.94	0.96	0.98	0.99	1.02	20
Norfolk VA	0.79	0.77	0.79	0.84	0.90	0.93	0.94	0.95	20
Columbus OH	0.68	0.71	0.71	0.71	0.75	0.78	0.79	0.82	21
Boston MA	0.90	0.93	0.95	0.98	1.04	1.04	1.12	1.09	21
Dallas TX	0.84	0.89	0.94	0.98	1.04	1.02	1.02	1.02	21
Minn-St. Paul MN	0.74	0.79	0.81	0.83	0.87	0.87	0.88	0.90	22
Portland OR	0.87	0.86	0.88	0.93	0.97	1.00	1.05	1.07	23
Austin TX	0.77	0.84	0.89	0.91	0.98	0.96	0.96	0.96	25
Los Angeles CA	1.22	1.27	1.32	1.36	1.42	1.47	1.52	1.54	26
Sacramento CA	0.80	0.84	0.88	0.92	0.95	1.00	1.03	1.01	26
Washington DC	1.07	1.09	1.12	1.20	1.28	1.30	1.32	1.36	27
Seattle-Everett WA	0.95	0.99	1.02	1.05	1.09	1.14	1.17	1.21	27
Atlanta GA	0.89	0.94	0.97	1.02	1.09	1.15	1.10	1.14	28
Nashville TN	0.74	0.76	0.83	0.81	0.86	0.95	0.99	0.95	28
Salt Lake City UT	0.63	0.63	0.65	0.68	0.68	0.70	0.72	0.81	29
San Fran-Oak CA	1.01	1.05	1.12	1.17	1.24	1.31	1.33	1.36	35
San Diego CA	0.78	0.83	0.91	0.95	1.00	1.08	1.13	1.18	51
Northeastern Avg	0.91	0.92	0.94	0.94	0.99	1.00	1.04	1.05	
Midwestern Avg	0.82	0.82	0.83	0.84	0.87	0.90	0.91	0.92	
Southern Avg	0.85	0.86	0.88	0.90	0.91	0.95	0.96	0.97	
Southwestern Avg	0.82	0.85	0.87	0.90	0.93	0.91	0.90	0.91	
Western Avg	0.94	0.97	1.01	1.04	1.09	1.13	1.16	1.18	
Texas Avg	0.80	0.84	0.86	0.89	0.92	0.90	0.90	0.90	
Total Avg	0.86	0.88	0.90	0.92	0.95	0.97	0.98	0.99	
Maximum Value	1.22	1.27	1.32	1.36	1.42	1.47	1.52	1.54	
Minimum Value	0.62	0.62	0.60	0.65	0.68	0.70	0.70	0.71	

Source: TTI Analysis

IMPACTS OF CONGESTION

The most quantifiable impacts of congestion are additional capacity required to eliminate the congested conditions and the time spent in congested traffic conditions. Additional capacity or lane-miles indicate the burden of congestion on the transportation infrastructure and available roadway funds. Travel delay is the measure of inconvenience congestion imposes on the motoring public.

Additional Lane-Miles of Capacity

Historically, congestion has been alleviated by providing additional capacity. Freeway and principal arterial street systems are primarily the facilities selected for expansion because the majority (60 to 70 percent) of an urban area's DVMT is served by these facilities. Table 7 illustrates the percentage of daily VMT served by the freeway and principal arterial street systems. While the average amount of daily VMT served by these facilities is significant in all areas, comparing the percentage for each urban and geographic area (Table 8) does give some indication of the facility carrying the majority of the demand.

Figure 4 illustrates the regional daily VMT served by the freeway system for each geographical area studied. During the study period, the percent difference has remained constant for each individual area. The Western region places the highest demand on the freeway system while the Southern region places the lowest. Texas motorists place the second highest demand on the freeway system of all geographic regions.

Figure 5 shows the corresponding demands placed on the principal arterial street systems. This Figure shows that the highest demand on the principal arterial street system is placed by the Northeastern and Southern regions. The Texas and Midwestern regions depend the least on this system for urban mobility.

Table 7. 1989 Urban Area Travel by Facility Type

Urban Area	Daily Vehicle-Miles of Travel			Fwy/Expwy[1] % of Total	Prin.Art.Str.[1] % of Total	Fwy/Prin.Art.Str. % of Total
	Fwy/Expwy	Prin.Art.Str.	Area Total			
Northeastern Cities						
Baltimore MD	15,180	9,330	34,950	43	27	70
Boston MA	22,080	12,650	51,420	43	25	68
Hartford CT	6,180	3,640	13,590	45	27	72
New York NY	80,920	50,830	225,510	36	23	59
Philadelphia PA	18,280	21,140	65,630	28	32	60
Pittsburgh PA	7,750	10,770	31,120	25	35	60
Washington DC	25,020	19,130	62,980	40	30	70
Midwestern Cities						
Chicago IL	34,440	27,980	119,640	29	23	52
Cincinnati OH	10,890	3,620	22,970	47	16	63
Cleveland OH	13,210	5,190	31,600	42	16	58
Columbus OH	8,100	3,040	16,470	49	18	67
Detroit MI	22,550	21,820	79,050	29	28	57
Indianapolis IN	7,890	3,830	19,320	41	20	61
Kansas City MO	12,370	4,370	25,220	49	17	66
Louisville KY	6,140	2,890	17,300	36	17	53
Milwaukee WI	7,520	4,670	28,080	27	17	44
Minn-St. Paul MN	16,860	5,390	41,270	41	13	54
Oklahoma City OK	6,830	3,590	18,630	37	19	56
St. Louis MO	18,720	12,210	44,870	42	27	69
Southern Cities						
Atlanta GA	24,600	9,710	73,730	33	13	46
Charlotte NC	2,220	2,860	9,210	24	31	55
Ft. Lauderdale FL	6,830	5,610	23,770	29	24	53
Jacksonville FL	5,200	5,750	17,840	29	32	61
Memphis TN	4,260	4,120	15,610	27	26	53
Miami FL	8,350	14,810	35,080	24	42	66
Nashville TN	5,410	5,400	15,340	35	35	70
New Orleans LA	4,860	4,070	15,170	32	27	59
Norfolk VA	5,340	4,080	20,020	27	20	47
Orlando FL	5,820	3,730	17,710	33	21	54
Tampa FL	3,430	4,180	14,740	23	28	51
Southwestern Cities						
Albuquerque NM	2,310	3,580	10,170	23	35	58
Austin TX	5,300	2,050	11,630	46	18	64
Corpus Christi TX	1,520	1,450	6,370	24	23	47
Dallas TX	22,650	8,230	50,310	45	16	61
Denver CO	10,730	10,600	27,210	39	39	78
El Paso TX	3,300	3,180	9,110	36	35	71
Fort Worth TX	11,280	4,220	27,090	42	16	58
Houston TX	27,640	10,400	72,630	38	14	52
Phoenix AZ	7,050	16,650	37,320	19	45	64
Salt Lake City UT	5,080	1,950	14,570	35	13	48
San Antonio TX	9,180	5,180	24,230	38	21	59
Western Cities						
Honolulu HI	4,530	1,560	11,230	40	14	54
Los Angeles CA	106,680	79,810	244,960	44	33	77
Portland OR	7,470	3,370	19,260	39	17	56
Sacramento CA	8,850	6,810	22,840	39	30	69
San Bernardino-Riv CA	13,620	9,370	23,660	58	40	98
San Diego CA	26,760	8,930	50,290	53	18	71
San Fran-Oak CA	41,970	13,710	77,800	54	18	72
San Jose CA	15,540	6,760	32,190	48	21	69
Seattle-Everett WA	18,200	9,060	40,790	45	22	67
Northeastern Avg	25,060	18,210	69,310	37	28	65
Midwestern Avg	13,790	8,220	38,700	39	19	58
Southern Avg	6,940	5,840	23,480	29	27	56
Southwestern Avg	9,640	6,130	26,420	35	25	60
Western Avg	27,070	15,490	58,110	47	24	71
Texas Avg	11,550	4,960	28,770	38	20	58
Total Avg	15,340	9,940	40,430	37	24	61
Maximum Value	106,680	79,810	244,960	58	45	98
Minimum Value	1,520	1,450	6,370	19	13	44

Notes: [1] Percentage of Total Daily Vehicle-Miles of Travel serviced by specified facility
Source: TTI Analysis and Local Transportation Agency References

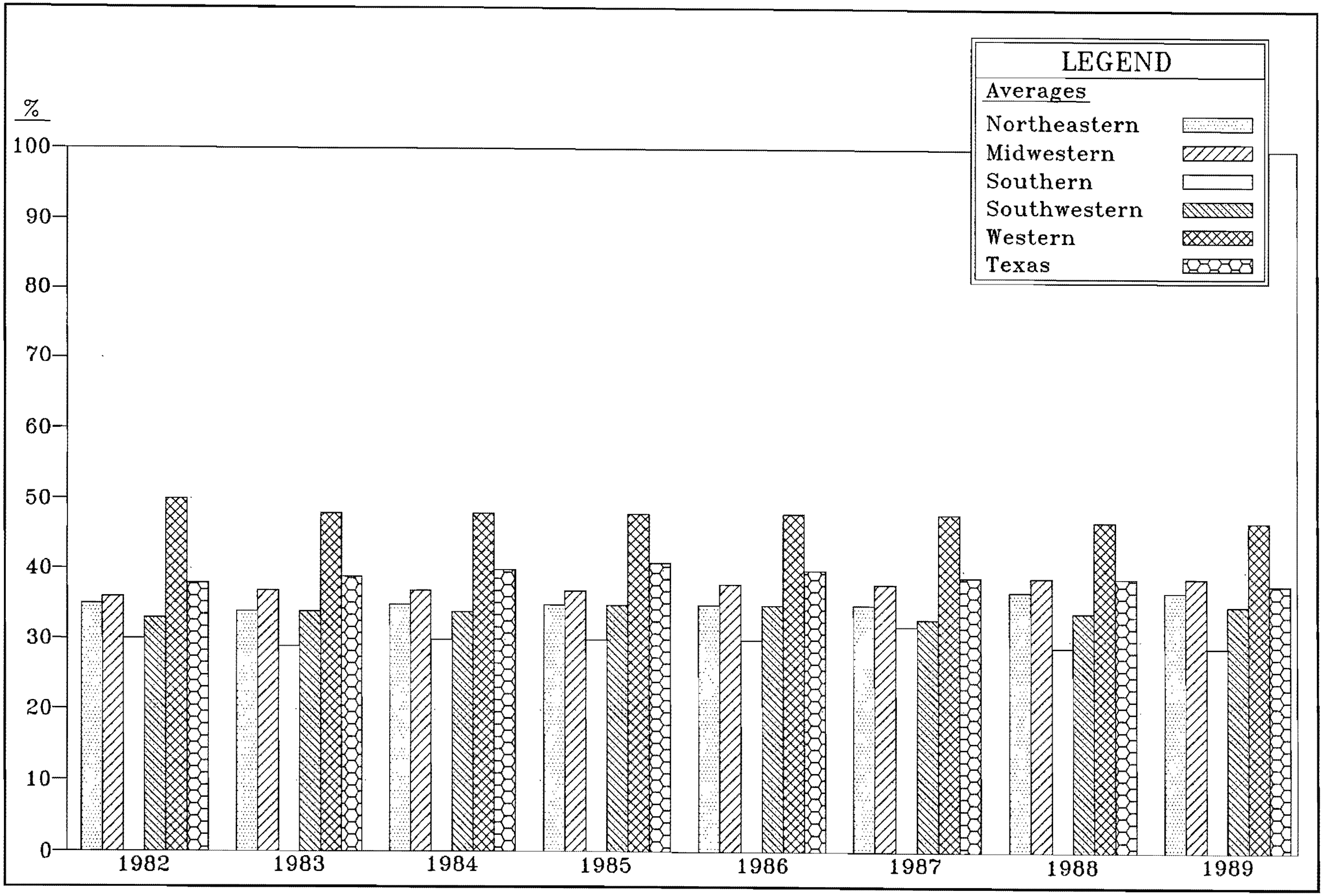

Figure 4. Freeway P

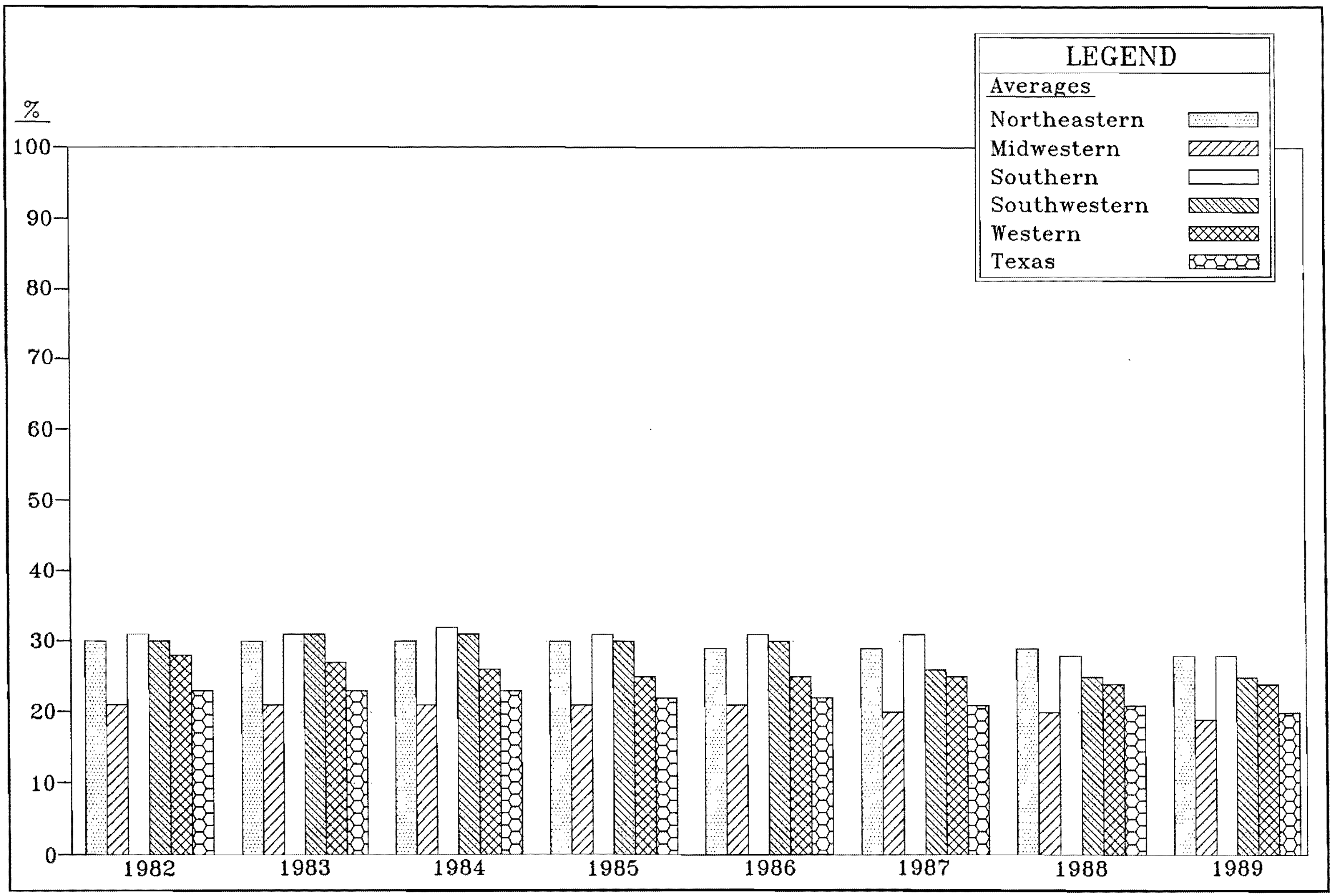

Figure 5. Principal Arterial street Percentage of DVMT

Figure 6 illustrates the regional average percentage of daily VMT served by the freeway and principal arterial street systems. The primary trends shown in this graph indicate that VMT demand has remained fairly constant in the Northeastern and Midwestern regions and has decreased in the Southern, Southwestern, Western, and Texas regions.

Five case studies are discussed below to illustrate the use of DVMT data and required number of lane-miles to alleviate the congested conditions. Selection of the urban areas used for case studies was based solely on representing one of the major urban areas in each geographic region experiencing areawide congested conditions.

Northeastern Region -- Washington, D.C.

The Washington, D.C. urban area lane-mile characteristics are illustrated in Figure 7. From Table 7, 70 percent of the DVMT is served by the freeway and principal arterial street systems. This urban area represents one with a fairly even split in the demand (40 percent -- freeway system and 30 percent -- principal arterial street system) with a slightly heavier demand on the freeway system. Washington has an RCI value of 1.36 with the freeway DVMT per lane-mile exceeding the congested level by 27 percent and a principal arterial street DVMT per lane-mile 64 percent higher than the congested level.

Figure 7 illustrates these characteristics by showing the large deficiency between existing and required lane-miles of principal arterial streets and the growing shortage of freeway lane-miles. Using the RCI equation, approximately 1,540 lane-miles of principal arterial streets and 405 lane-miles of freeways would have to be constructed to achieve a RCI of 1.0. Using an estimated construction cost of $25 per square foot, the proposed additional lane-miles result in approximately $2.4 billion of principal arterial streets and $640 million of freeways.

Midwestern Region -- Detroit, MI

Detroit has an evenly distributed VMT demand on the freeway and principal arterial street systems. Approximately 57 percent of the total daily VMT is served by these systems with

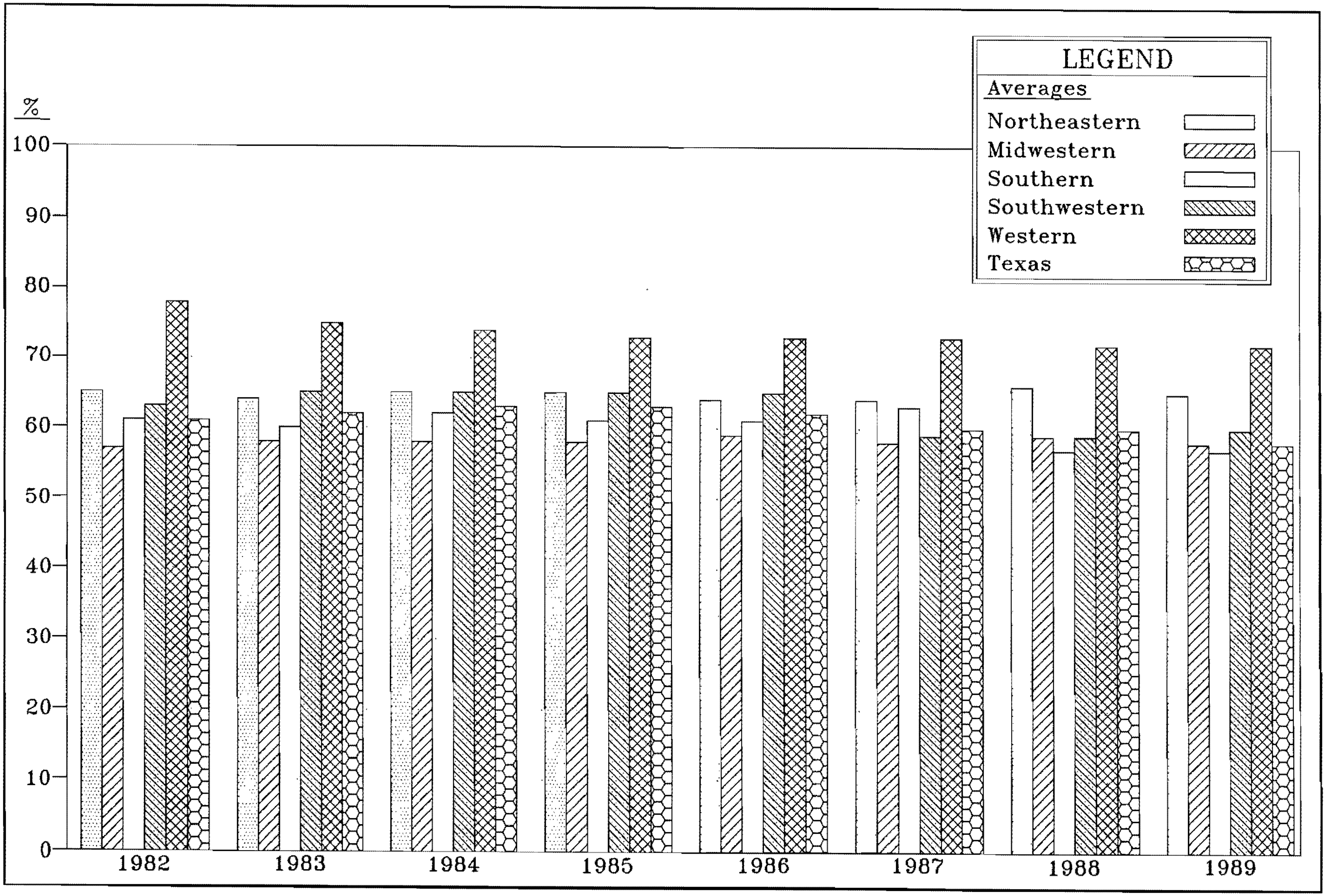

Figure 6. Total DVMT Served by Freeway and Principal Arterial Street Systems

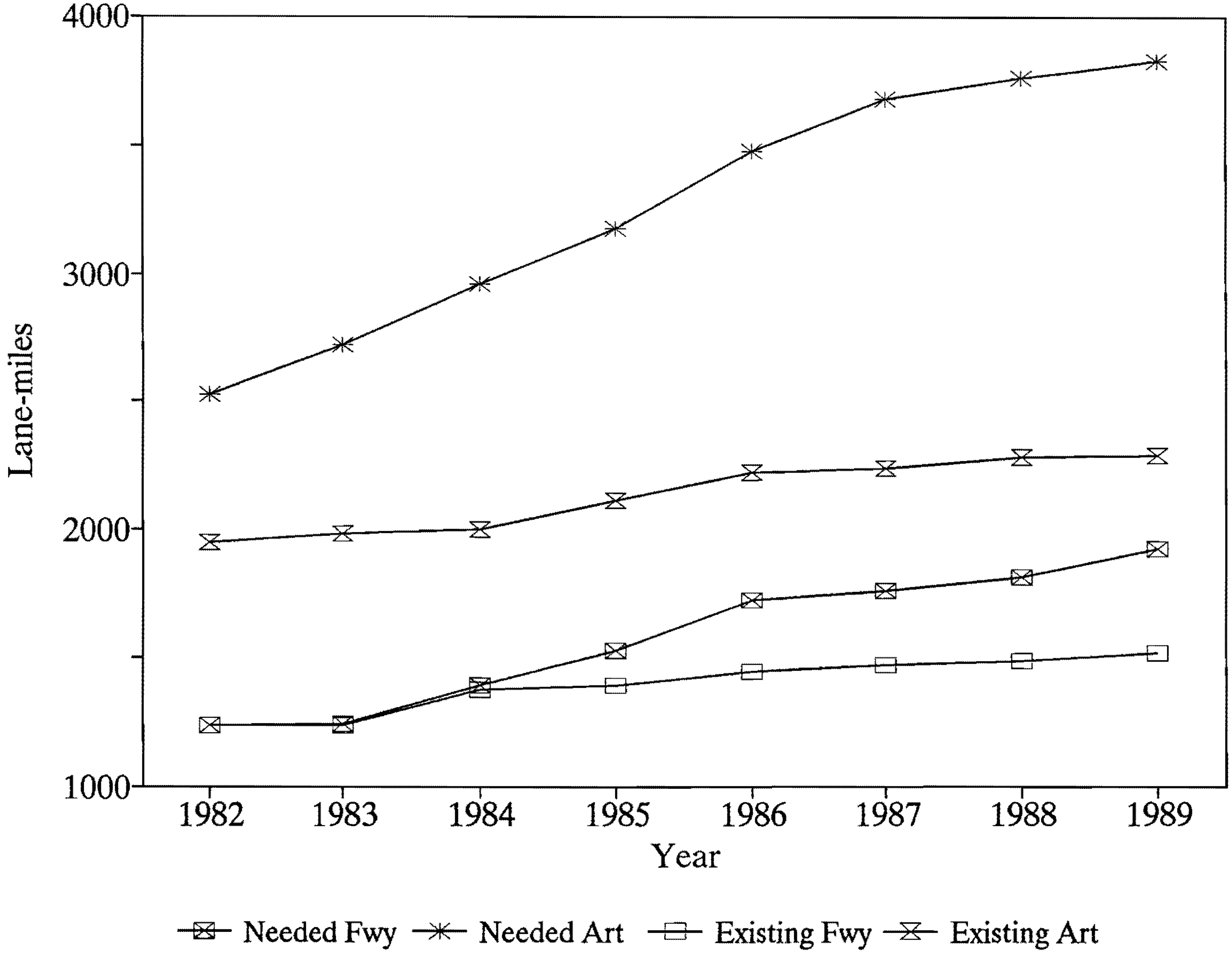

Figure 7. Existing and Required Facility Lane-Miles - Washington, D.C.

29 percent served by the freeway system and 28 percent by the principal arterial streets. Detroit has an estimated RCI value of 1.08 (Table 5). Table 5 also indicates that the primary reason for the undesirable congestion is the DVMT per lane-mile demand on the principal arterial street system (22 percent above the congested level).

Figure 8 indicates that the existing and required freeway lane-miles are essentially equal while a substantial deficiency exists between the existing and required lane-miles of principal arterial streets. In 1989, approximately $1.2 billion would have had to be spent to construct 780 lane-miles on principal arterial streets and $70 million on 45 freeway lane-miles to achieve an areawide RCI of approximately 1.0.

Southern Region -- Miami, FL

The demand characteristics of Miami and Detroit are very similar. The freeway system serves approximately 27 percent and the principal arterial street system serves 26 percent of the total areawide DVMT. The estimated 1989 RCI value (Table 5) for Miami is 1.25 with the freeway DVMT per lane-mile 11 percent and principal arterial street DVMT per lane-mile 46 percent above congested levels.

Figure 9 shows that Miami has an increasing deficit in principal arterial street system with a slight difference between the existing and required lane-miles of freeways. Approximately 930 lane-miles of principal arterial streets representing about $1.5 billion of construction and 62 freeway lane-miles ($98 million) would have to be constructed to reduce the RCI to the 1.0 level.

From Figure 9, the existing principal arterial street system has lagged behind the required level since 1982 while freeway lane-miles have become a concern more recently. Figure 9 also indicates that the deficiency in principal arterial street lane-miles can be expected to increase unless additional lane-mile are constructed or alternatives decreasing the areawide DVMT are implemented.

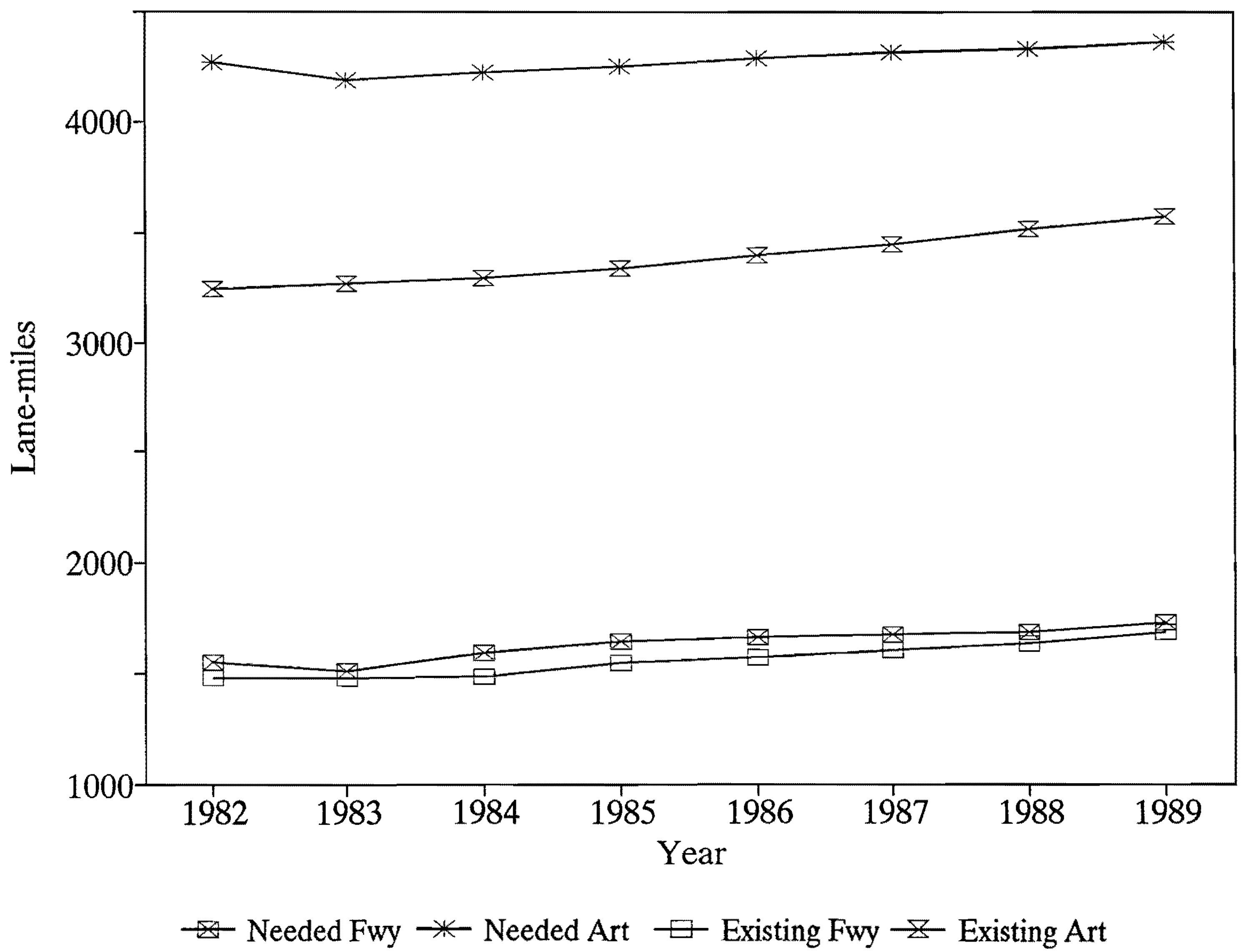

Figure 8. Existing and Required Facility Lane-Miles - Detroit, MI

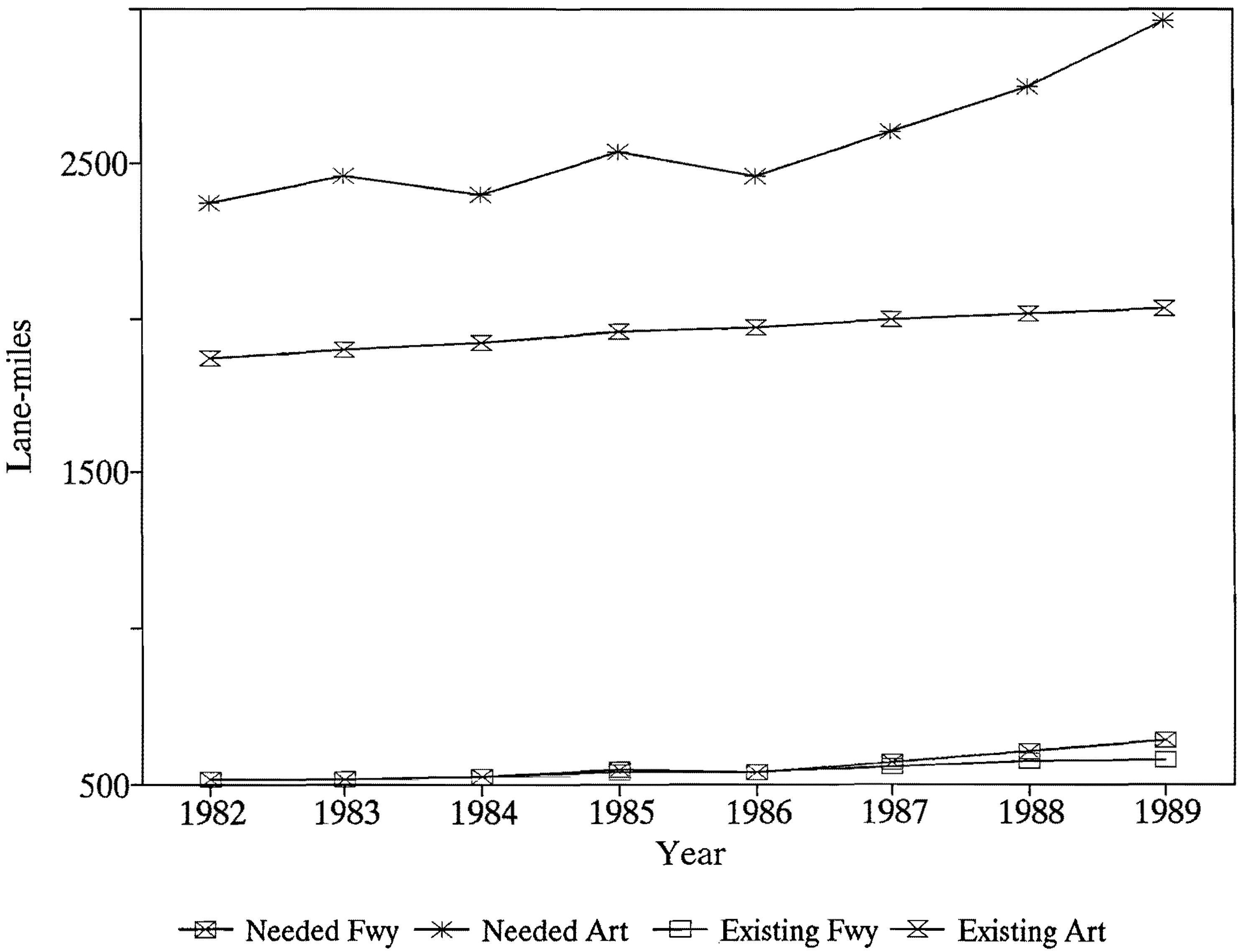

Figure 9. Existing and Required Facility Lane-Miles - Miami, FL

Southwestern Region -- Houston, TX

The Houston urban area vehicle travel demand is orientated differently than the previous case studies. Houston's freeway system supports approximately 38 percent of the total area's freeway travel while principal arterial streets serve only 14 percent. This representation is typical of urban areas both in the Southwestern and Western regions. In 1989, Houston's had an estimated RCI value of 1.13 (Table 5). Freeway DVMT per lane-mile values exceeded the congested level by 14 percent and the principal arterial street congestion level was estimated to be 3 percent above the congested level.

Figure 10 illustrates that new lane-miles are being added at a slightly higher rate than required to maintain an RCI value of 1.0. This Figure also shows that for Houston to obtain a 1.0 RCI value both the freeway and principal arterial street systems should have approximately 2100 lane-miles. Approximately $530 million would have had to been spent in 1989 to construct 266 lane-miles of freeways and 70 lane-miles of principal arterial streets to obtain an RCI value of 1.0.

Western Region -- Los Angeles, CA

Like Houston, Los Angeles relies heavily on the freeway system for the majority (44 percent) area travel. In contrast to the Houston area, the principal arterial street system also serves a large percentage (33 percent) of the total urban area DVMT. The Los Angeles area has been ranked the most congested urban area since 1982 (Table 6). In 1989, the estimated RCI value was 1.54 representing an value 27 percent higher than estimated in 1982. Freeway DVMT per lane-mile exceeds the congested level by 60 percent and the principal arterial street DVMT per lane-mile is 30 percent above the congested level.

Figure 11 shows that the demand for facility lane-miles is much larger than the number of lane-miles being added to either system. To obtain an areawide RCI value of 1.0, the construction of 3,080 freeway lane-miles and an additional 3,780 lane-miles to the principal

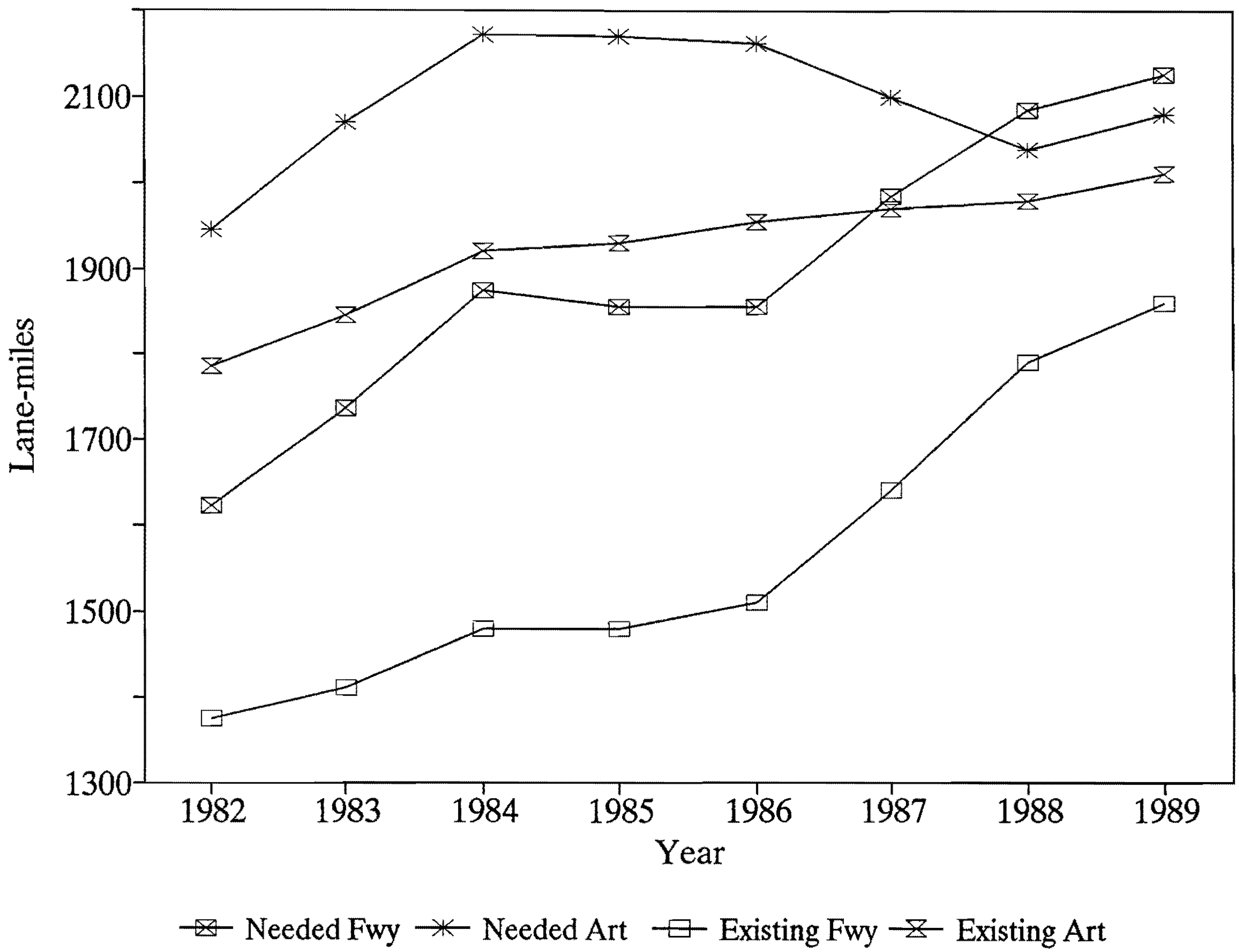

Figure 10. Existing and Required Facility Lane-Miles - Houston, TX

arterial street system. The estimated construction would result in $4.9 billion of freeway construction and $6.0 billion of construction on principal arterial streets.

Conclusion

Many of the larger urban areas included within this study face situations very similar to the areas used in the case studies. In the case of most urban areas, the expansion of the existing roadway systems will involve extensive expenditures. The relationship between the increasing vehicle travel and freeways and principal arterial streets capacity make it apparent that the construction of additional lane-miles as the sole alternative to alleviate congestion is not feasible. Regardless of whether the area's travel is served by the freeway or principal arterial street system, extensive facility construction efforts and methods to alter travel patterns are required to improve the congestion levels in most urban areas.

Travel Delays

Travel delay is the most apparent impact of congestion to the motoring public. Analyses identified two types of delay -- recurring and incident. Recurring delay is delay that occurs due to normal daily operations. The most common example of recurring delay is the increased travel time during peak periods of operation. The other type of delay related to congestion is incident delay. Incidental delay is the delay caused by accidents, breakdowns, or other random occurrences not typical of normal daily operations. When congestion levels increase (creating higher RCI values) it is the recurring delay that is directly affected. While incidental delay is not directly related to or caused by congestion, the delay resulting from incidents significantly increases under congested conditions.

Tables 8 and 9 categorize delay by the severity (moderate, heavy, and severe) for freeways and principal arterial street systems. The congestion categories are based on average daily traffic volumes per lane (8). Table 10 summarizes the vehicle-hours of delay by type and

Table 8. Freeway and Expressway Recurring and Incident Hours of Daily Delay for 1989[1]

Urban Area	Recurring Hours of Delay				Incident Hours of Delay			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	3,950	8,380	11,390	23,720	9,100	19,280	26,190	54,570
Boston MA	7,610	21,510	35,060	64,180	26,650	75,290	122,710	224,650
Hartford CT	1,150	2,030	2,480	5,660	3,100	5,480	6,700	15,280
New York NY	89,780	38,610	161,810	290,200	224,450	96,520	404,530	725,500
Philadelphia PA	10,860	7,930	5,820	24,610	22,800	16,660	12,220	51,680
Pittsburgh PA	4,040	0	4,650	8,690	11,710	0	13,490	25,200
Washington DC	11,300	43,910	48,790	104,000	24,860	96,600	107,340	228,800
Midwestern Cities								
Chicago IL	13,520	17,520	97,300	128,340	16,230	21,020	116,760	154,010
Cincinnati OH	9,460	4,630	2,510	16,600	7,570	3,700	2,010	13,280
Cleveland OH	7,170	7,430	3,300	17,900	5,020	5,200	2,310	12,530
Columbus OH	880	2,900	10,130	13,910	620	2,030	7,090	9,740
Detroit MI	9,470	6,250	43,650	59,370	20,840	13,750	96,030	130,620
Indianapolis IN	3,430	0	0	3,430	5,140	0	0	5,140
Kansas City MO	1,340	420	1,800	3,560	4,160	1,310	5,590	11,060
Louisville KY	580	0	1,300	1,880	640	0	1,440	2,080
Milwaukee WI	3,150	4,200	6,340	13,690	3,150	4,200	6,340	13,690
Minn-St. Paul MN	4,880	8,050	19,670	32,600	4,390	7,240	17,700	29,330
Oklahoma City OK	2,020	1,340	0	3,360	2,220	1,480	0	3,700
St. Louis MO	6,150	4,970	11,380	22,500	7,380	5,960	13,660	27,000
Southern Cities								
Atlanta GA	8,850	17,880	45,870	72,600	9,740	19,660	50,460	79,860
Charlotte NC	850	2,400	3,090	6,340	680	1,920	2,470	5,070
Ft. Lauderdale FL	0	790	11,840	12,630	0	1,190	17,760	18,950
Jacksonville FL	6,040	2,630	0	8,670	9,060	3,940	0	13,000
Memphis TN	1,850	0	0	1,850	2,030	0	0	2,030
Miami FL	4,170	7,850	20,790	32,810	6,250	11,770	31,180	49,200
Nashville TN	3,430	2,420	1,270	7,120	3,770	2,660	1,390	7,820
New Orleans LA	810	5,960	9,530	16,300	1,460	10,740	17,160	29,360
Norfolk VA	800	5,380	10,040	16,220	2,000	13,460	25,100	40,560
Orlando FL	7,490	740	3,610	11,840	11,240	1,110	5,420	17,770
Tampa FL	1,130	2,520	1,400	5,050	1,700	3,780	2,100	7,580
Southwestern Cities								
Albuquerque NM	670	1,130	920	2,720	740	1,250	1,020	3,010
Austin TX	5,590	4,160	7,120	16,870	6,150	4,580	7,830	18,560
Corpus Christi TX	660	0	0	660	730	0	0	730
Dallas TX	17,020	18,400	41,510	76,930	30,640	33,110	74,720	138,470
Denver CO	6,850	12,260	13,410	32,520	6,850	12,260	13,410	32,520
El Paso TX	2,700	240	0	2,940	2,970	260	0	3,230
Fort Worth TX	6,170	6,660	15,040	27,870	11,100	12,000	27,070	50,170
Houston TX	8,170	32,980	90,690	131,840	11,430	46,180	126,970	184,580
Phoenix AZ	5,570	3,540	17,790	26,900	2,230	1,420	7,110	10,760
Salt Lake City UT	1,290	910	2,380	4,580	770	550	1,430	2,750
San Antonio TX	2,390	9,010	12,390	23,790	2,630	9,910	13,620	26,160
Western Cities								
Honolulu HI	2,050	2,890	9,900	14,840	3,680	5,210	17,820	26,710
Los Angeles CA	18,690	21,110	541,990	581,790	22,430	25,330	650,390	698,150
Portland OR	6,120	2,880	8,320	17,320	12,230	5,760	16,650	34,640
Sacramento CA	8,210	4,970	9,620	22,800	4,920	2,980	5,770	13,670
San Bernardino-Riv CA	3,030	12,860	60,770	76,660	3,640	15,430	72,920	91,990
San Diego CA	13,610	11,140	53,200	77,950	8,170	6,680	31,920	46,770
San Fran-Oak CA	20,100	11,850	202,610	234,560	26,140	15,400	263,400	304,940
San Jose CA	6,750	14,740	51,920	73,410	8,100	17,690	62,300	88,090
Seattle-Everett WA	6,750	39,090	36,120	81,960	9,450	54,720	50,570	114,740
Northeastern Avg	18,380	17,480	38,570	74,430	46,090	44,260	99,030	189,380
Midwestern Avg	5,170	4,810	16,450	26,430	6,450	5,490	22,410	34,350
Southern Avg	3,220	4,420	9,770	17,410	4,360	6,380	13,910	24,650
Southwestern Avg	5,190	8,120	18,300	31,610	6,930	11,050	24,840	42,820
Western Avg	9,480	13,500	108,270	131,250	10,970	16,580	130,190	157,740
Texas Avg	6,100	10,210	23,820	40,130	9,380	15,150	35,750	60,280
Total Avg	7,370	8,790	35,010	51,170	12,460	14,330	51,200	77,990
Maximum Value	89,780	43,910	541,990	675,680	224,450	96,600	650,390	971,440
Minimum Value	0	0	0	0	0	0	0	0

Note: [1] Delay calculated based on vehicular speed in Table 1.

Source: TTI Analysis

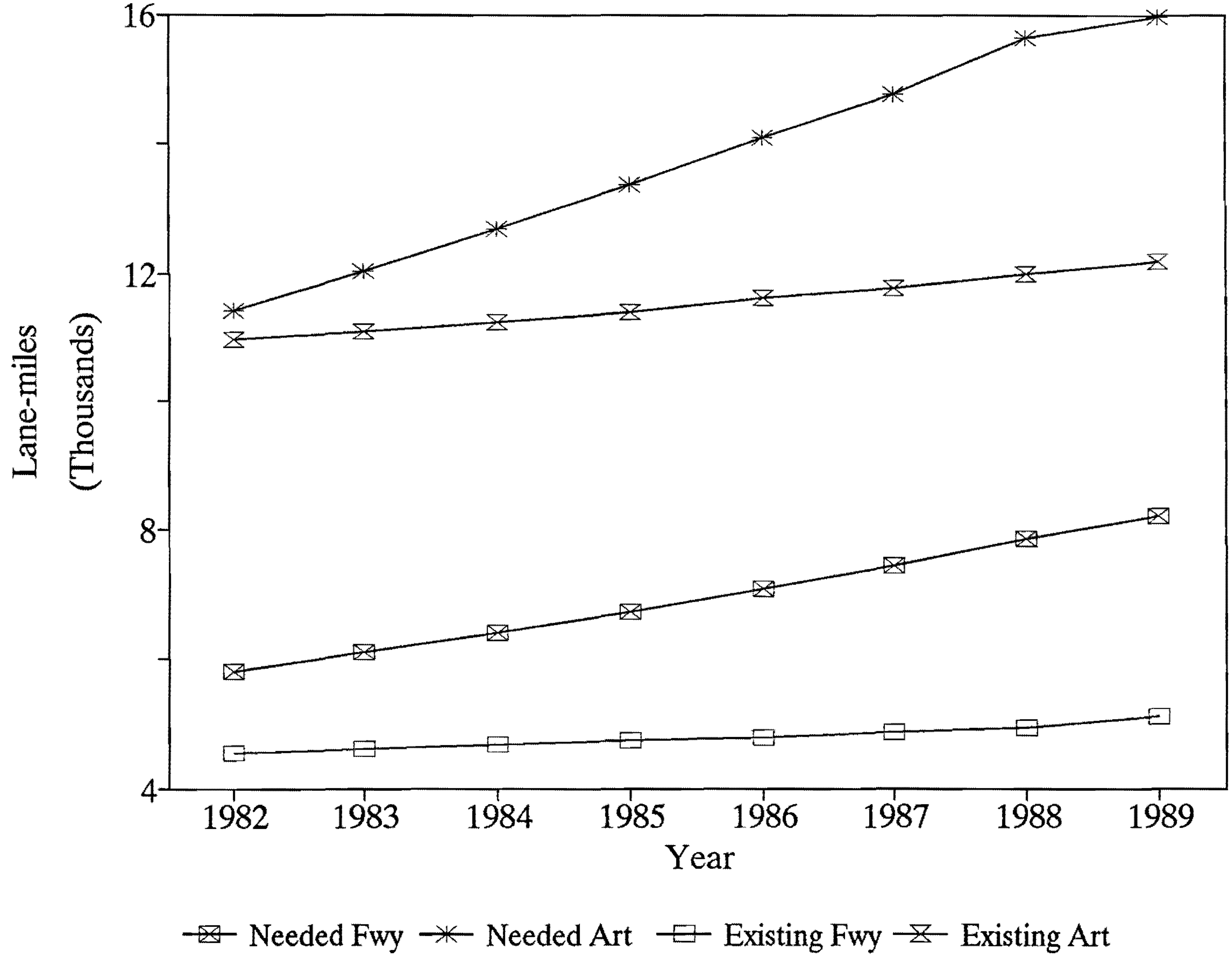

Figure 11. Existing and Required Facility Lane-Miles - Los Angeles, CA

Table 9. Principal Arterial Street Recurring and Incident Hours of Daily Delay for 1989[1]

	Recurring Hours of Delay				Incident Hours of Delay			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	1,830	3,710	13,240	18,780	2,010	4,080	14,560	20,650
Boston MA	3,040	5,200	20,820	29,060	3,340	5,730	22,900	31,970
Hartford CT	1,100	2,920	2,440	6,460	1,210	3,220	2,690	7,120
New York NY	25,250	28,530	182,900	236,680	27,780	31,380	201,190	260,350
Philadelphia PA	9,320	9,950	73,930	93,200	10,250	10,940	81,320	102,510
Pittsburgh PA	3,010	4,810	30,770	38,590	3,310	5,290	33,840	42,440
Washington DC	4,980	19,910	72,720	97,610	5,470	21,900	79,990	107,360
Midwestern Cities								
Chicago IL	11,690	24,550	65,570	101,810	12,860	27,010	72,130	112,000
Cincinnati OH	1,190	600	2,800	4,590	1,310	660	3,080	5,050
Cleveland OH	1,720	3,340	2,490	7,550	1,890	3,680	2,740	8,310
Columbus OH	560	3,890	2,930	7,380	620	4,280	3,220	8,120
Detroit MI	3,470	8,710	69,220	81,400	3,810	9,580	76,140	89,530
Indianapolis IN	1,570	600	1,090	3,260	1,720	660	1,200	3,580
Kansas City MO	1,080	1,990	2,480	5,550	1,190	2,190	2,730	6,110
Louisville KY	1,700	3,870	2,060	7,630	1,870	4,260	2,260	8,390
Milwaukee WI	1,810	3,510	2,590	7,910	1,990	3,860	2,850	8,700
Minn-St. Paul MN	2,860	1,520	11,930	16,310	3,140	1,680	13,120	17,940
Oklahoma City OK	830	2,090	3,960	6,880	910	2,300	4,360	7,570
St. Louis MO	3,210	10,850	28,300	42,360	3,530	11,930	31,130	46,590
Southern Cities								
Atlanta GA	3,710	5,940	26,830	36,480	4,090	6,540	29,520	40,150
Charlotte NC	710	2,140	8,170	11,020	780	2,350	8,990	12,120
Ft. Lauderdale FL	2,520	12,840	4,310	19,670	2,770	14,130	4,740	21,640
Jacksonville FL	2,690	4,920	7,230	14,840	2,960	5,420	7,950	16,330
Memphis TN	1,340	2,890	3,110	7,340	1,470	3,180	3,430	8,080
Miami FL	720	6,370	59,700	66,790	800	7,010	65,670	73,480
Nashville TN	950	1,260	10,870	13,080	1,040	1,390	11,950	14,380
New Orleans LA	1,950	550	8,850	11,350	2,140	600	9,730	12,470
Norfolk VA	1,460	1,000	5,230	7,690	1,610	1,100	5,750	8,460
Orlando FL	480	3,680	14,190	18,350	530	4,050	15,610	20,190
Tampa FL	2,740	1,790	10,170	14,700	3,020	1,970	11,190	16,180
Southwestern Cities								
Albuquerque NM	2,000	2,080	2,720	6,800	2,200	2,290	2,990	7,480
Austin TX	1,090	1,800	1,570	4,460	1,190	1,980	1,730	4,900
Corpus Christi TX	260	230	120	610	290	250	140	680
Dallas TX	2,300	5,350	4,790	12,440	2,530	5,880	5,270	13,680
Denver CO	6,280	7,650	12,480	26,410	6,900	8,420	13,720	29,040
El Paso TX	240	180	320	740	270	200	360	830
Fort Worth TX	1,180	2,740	2,460	6,380	1,300	3,020	2,700	7,020
Houston TX	3,010	12,270	12,580	27,860	3,310	13,500	13,840	30,650
Phoenix AZ	10,440	15,830	41,300	67,570	11,490	17,420	45,430	74,340
Salt Lake City UT	1,120	1,450	1,000	3,570	1,230	1,600	1,100	3,930
San Antonio TX	830	350	3,020	4,200	920	390	3,320	4,630
Western Cities								
Honolulu HI	1,420	970	3,070	5,460	1,560	1,070	3,380	6,010
Los Angeles CA	23,750	55,740	145,400	224,890	26,130	61,310	159,940	247,380
Portland OR	1,050	4,280	5,780	11,110	1,160	4,710	6,360	12,230
Sacramento CA	640	5,840	13,880	20,360	710	6,420	15,270	22,400
San Bernardino-Riv CA	7,940	11,800	8,880	28,620	8,740	12,980	9,770	31,490
San Diego CA	1,040	11,270	1,090	13,400	1,150	12,400	1,200	14,750
San Fran-Oak CA	2,680	2,140	46,800	51,620	2,950	2,350	51,480	56,780
San Jose CA	2,520	2,950	24,880	30,350	2,770	3,250	27,360	33,380
Seattle-Everett WA	3,940	3,550	20,570	28,060	4,340	3,900	22,630	30,870
Northeastern Avg	6,930	10,720	56,690	74,340	7,620	11,790	62,360	81,770
Midwestern Avg	2,640	5,460	16,290	24,390	2,910	6,010	17,910	26,830
Southern Avg	1,750	3,940	14,420	20,110	1,930	4,340	15,870	22,140
Southwestern Avg	2,610	4,540	7,490	14,640	2,880	4,990	8,240	16,110
Western Avg	5,000	10,950	30,040	45,990	5,500	12,040	33,040	50,580
Texas Avg	1,270	3,280	3,550	8,100	1,400	3,600	3,910	8,910
Total Avg	3,460	6,650	22,070	32,180	3,810	7,310	24,280	35,400
Maximum Value	25,250	55,740	182,900	263,890	27,780	61,310	201,190	290,280
Minimum Value	240	180	120	540	270	200	140	610

Note: [1] Delay calculation based on vehicular speed in Table 1.

Source: TTI Analysis

Table 10. Total Vehicle Hours of Delay for 1989

Urban Area	Vehicle Hours of Delay				Total Delay per 1000 Persons	Rank[1]
	Recurring	Incident	Total	Rank[1]		
Northeastern Cities						
Baltimore MD	42,500	75,220	117,720	20	60	30
Boston MA	93,240	256,620	349,860	8	120	8
Hartford CT	12,130	22,400	34,530	41	60	30
New York NY	526,880	985,860	1,512,740	2	90	13
Philadelphia PA	117,810	154,190	272,000	9	60	30
Pittsburgh PA	47,280	67,640	114,920	21	60	30
Washington DC	201,610	336,160	537,770	4	170	3
Midwestern Cities						
Chicago IL	230,160	266,010	496,160	5	70	24
Cincinnati OH	21,190	18,330	39,520	38	30	41
Cleveland OH	25,450	20,840	46,290	33	30	41
Columbus OH	21,290	17,850	39,140	39	50	36
Detroit MI	140,770	220,160	360,930	7	90	13
Indianapolis IN	6,680	8,720	15,400	47	20	44
Kansas City MO	9,120	17,170	26,280	42	20	44
Louisville KY	9,520	10,470	19,980	45	20	44
Milwaukee WI	21,600	22,390	43,990	35	40	39
Minn-St. Paul MN	48,910	47,280	96,200	22	50	36
Oklahoma City OK	10,240	11,260	21,500	43	30	41
St. Louis MO	64,860	73,590	138,450	18	70	24
Southern Cities						
Atlanta GA	109,090	120,000	229,090	12	120	8
Charlotte NC	17,360	17,200	34,560	40	80	17
Ft. Lauderdale FL	32,300	40,580	72,880	27	60	30
Jacksonville FL	23,510	29,330	52,850	32	70	24
Memphis TN	9,190	10,110	19,300	46	20	44
Miami FL	99,590	122,670	222,270	15	120	8
Nashville TN	20,190	22,210	42,400	37	80	17
New Orleans LA	27,660	41,840	69,500	28	70	24
Norfolk VA	23,910	49,020	72,940	26	80	17
Orlando FL	30,200	37,950	68,150	29	90	13
Tampa FL	19,750	23,740	43,490	36	60	30
Southwestern Cities						
Albuquerque NM	9,530	10,480	20,010	44	40	39
Austin TX	21,330	23,460	44,800	34	90	13
Corpus Christi TX	1,280	1,400	2,680	50	10	49
Dallas TX	89,370	152,160	241,530	11	120	8
Denver CO	58,930	61,570	120,500	19	80	17
El Paso TX	3,680	4,050	7,730	49	10	49
Fort Worth TX	34,250	57,180	91,430	23	80	17
Houston TX	159,710	215,240	374,950	6	130	7
Phoenix AZ	94,470	85,090	179,560	16	100	12
Salt Lake City UT	8,150	6,680	14,830	48	20	44
San Antonio TX	27,980	30,780	58,770	30	50	36
Western Cities						
Honolulu HI	20,300	32,710	53,010	31	80	17
Los Angeles CA	806,680	945,520	1,752,200	1	150	5
Portland OR	28,440	46,870	75,310	25	70	24
Sacramento CA	43,160	36,080	79,230	24	80	17
San Bernardino-Riv CA	105,290	123,480	228,770	13	210	1
San Diego CA	91,350	61,510	152,860	17	70	24
San Fran-Oak CA	286,180	361,720	647,900	3	180	2
San Jose CA	103,760	121,470	225,230	14	160	4
Seattle-Everett WA	110,020	145,610	255,630	10	150	5
Northeastern Avg	148,780	271,160	419,930		90	
Midwestern Avg	50,820	61,170	111,990		40	
Southern Avg	37,520	46,790	84,310		80	
Southwestern Avg	46,240	58,920	105,160		70	
Western Avg	177,240	208,330	385,570		130	
Texas Avg	48,230	69,180	117,410		70	
Total Avg	83,360	113,400	196,750		80	
Maximum Value	806,680	985,860	1,752,200		210	
Minimum Value	1,280	1,400	2,680		10	

Note: [1] Rank value of 1 associated with most congested conditions

Source: TTI Analysis

urban area. These values were also used to estimate the economic impacts of congestion in a subsequent section. The rankings in Table 10 are similar to the rankings by RCI (Table 5). Vehicle-hours of delay are also ranked after being normalized by population. The total delay per 1000 persons quantifies the congestion levels independent of urban area size and population. Ranking delay in this manner allows an evaluation similar to the RCI in that it analyzes the effects on individual motorists. Summary statistics show that the Western and Northeastern regions have the largest average delay while the Southern region has the least. The average delay in Texas urban areas exceeds that of the studywide average and three other regions.

COST OF CONGESTION

Today, the cost of congestion to the community is foremost in the minds of most transportation officials and policy makers. The economic impact of congestion was estimated in 50 urbanized areas located in five geographic regions. The urban areas include the seven largest in Texas and 43 other urban areas represent a cross-section of other large urbanized areas throughout the country.

Economic Impact Estimates

Estimates of congestion costs were based on the congested peak-period VMT on freeways and principal arterial street systems. Table 11 lists the freeway and principal arterial street DVMT and populations utilized in the congestion cost estimates. The data shown in this table was obtained through the HPMS data base and various state and local agencies.

The two primary components of the congestion cost estimates were traffic delay and excess fuel consumed. Congestion severity affects both the travel time and fuel consumption by decreasing the speed and vehicle fuel efficiency as the congestion becomes worse. For this reason, the same congestion categories used to estimate the vehicle-hours of delay (Table 10) were also used to estimate fuel consumption. The vehicular speeds used in the congestion cost estimates are shown in Table 12.

Congestion cost estimates also used several study constants and urban area variables in the calculations. The six independent variables used in the congestion cost analyses and calculations included:

1. Average vehicle occupancy -- 1.25 persons per vehicle
2. Working days per year -- 250 days
3. Average cost of time (9) -- $9.25 per person-hour
4. Commercial vehicle operating cost (10) -- $1.85 per mile
5. Vehicle mix -- 95 percent passenger and 5 percent commercial

Table 11. Summary of 1989 DVMT Values and Population for Congestion Cost Estimates

Urban Area	Daily Vehicle-Miles of Travel (1000)			Population (1000)
	Freeway/ Expressway	Principal Arterial Street	Freeway and Arterial	
Northeastern Cities				
Baltimore MD	15,180	9,330	24,510	1,920
Boston MA	22,080	12,650	34,730	2,950
Hartford CT	6,180	3,640	9,820	610
New York NY	80,920	50,830	131,750	16,420
Philadelphia PA	18,280	21,140	39,420	4,220
Pittsburgh PA	7,750	10,770	18,520	1,850
Washington DC	25,020	19,130	44,150	3,080
Midwestern Cities				
Chicago IL	34,440	27,980	62,420	7,410
Cincinnati OH	10,890	3,620	14,510	1,140
Cleveland OH	13,210	5,190	18,400	1,790
Columbus OH	8,100	3,040	11,140	840
Detroit MI	22,550	21,820	44,370	3,900
Indianapolis IN	7,890	3,830	11,720	930
Kansas City MO	12,370	4,370	16,740	1,160
Louisville KY	6,140	2,890	9,030	810
Milwaukee WI	7,520	4,670	12,180	1,230
Minn-St. Paul MN	16,860	5,390	22,250	1,970
Oklahoma City OK	6,830	3,590	10,420	730
St. Louis MO	18,720	12,210	30,930	1,960
Southern Cities				
Atlanta GA	24,600	9,710	34,310	1,860
Charlotte NC	2,220	2,860	5,080	440
Ft. Lauderdale FL	6,830	5,610	12,440	1,260
Jacksonville FL	5,200	5,750	10,950	720
Memphis TN	4,260	4,120	8,380	850
Miami FL	8,350	14,810	23,160	1,840
Nashville TN	5,410	5,400	10,810	550
New Orleans LA	4,860	4,070	8,930	1,050
Norfolk VA	5,340	4,080	9,420	920
Orlando FL	5,820	3,730	9,550	800
Tampa FL	3,430	4,180	7,610	670
Southwestern Cities				
Albuquerque NM	2,310	3,580	5,890	500
Austin TX	5,300	2,050	7,350	510
Corpus Christi TX	1,520	1,450	2,970	280
Dallas TX	22,650	8,230	30,880	1,970
Denver CO	10,730	10,600	21,330	1,570
El Paso TX	3,300	3,180	6,480	520
Fort Worth TX	11,280	4,220	15,500	1,170
Houston TX	27,640	10,400	38,040	2,870
Phoenix AZ	7,050	16,650	23,700	1,880
Salt Lake City UT	5,080	1,950	7,030	790
San Antonio TX	9,180	5,180	14,360	1,170
Western Cities				
Honolulu HI	4,530	1,560	6,080	660
Los Angeles CA	106,680	79,810	186,490	11,310
Portland OR	7,470	3,370	10,840	1,010
Sacramento CA	8,850	6,810	15,660	1,060
San Bernardino-Riv CA	13,620	9,370	22,990	1,100
San Diego CA	26,760	8,930	35,690	2,220
San Fran-Oak CA	41,970	13,710	55,680	3,620
San Jose CA	15,540	6,760	22,300	1,390
Seattle-Everett WA	18,200	9,060	27,260	1,680
Northeastern Avg	25,060	18,210	43,270	4,430
Midwestern Avg	13,790	8,220	22,010	1,990
Southern Avg	6,940	5,840	12,780	1,000
Southwestern Avg	9,640	6,130	15,770	1,200
Western Avg	27,070	15,490	42,550	2,670
Texas Avg	11,550	4,960	16,510	1,210
Total Avg	15,340	9,940	25,280	2,060
Maximum Value	106,680	79,810	186,490	16,420
Minimum Value	1,520	1,450	2,970	280

Source: TTI Analysis and Local Transportation Agency References

Table 12. Speed Relationships with Average Daily Traffic per Lane Volumes

Functional Class	Parameters	Severity of Congestion[1,2]		
		Moderate	Heavy	Severe
Freeway/Expressway	ADT/Lane	15,000 - 17,500	17,501 - 20,000	Over 20,000
	Speed (mph)[3]	40	35	32
Principal Arterial Streets	ADT/Lane	5,750 - 7,000	7,001 - 8,500	Over 8,500
	Speed (mph)[3]	32	28	25

Note: [1]Assumes congested freeway operation when ADT/Lane exceeds 15,000.
[2]Assumes congested principal arterial street operations when ADT/lane exceeds 5,750.
[3]Value represents a weighted average

Source: TTI Analysis and Houston-Galveston Regional Transportation Study

Four area specific variables were also used in the congestion cost estimates. These variables are briefly described below:

1. Daily vehicle-miles of travel (DVMT) -- the average daily traffic (ADT) of a section of roadway multiplied by the length (in miles) of that roadway section.

2. Fuel cost -- the state average fuel cost per gallon for 1989.

3. Registered vehicles -- the number of registered vehicles as reported by local agencies.

4. Population -- estimated using the 1989 Census Bureau estimates and HPMS data.

These variables were used to estimate and analyze the effects of congestion in each urban area. The economic impact of congestion was stated in terms of annual congestion cost, cost per registered vehicle, and cost per capita. Previous reports have included additional insurance costs resulting from operating vehicle in larger metropolitan areas. Due to the difficulty in obtaining insurance data, these costs were omitted from the cost analyses.

Economic Analysis

The component and total congestion costs for each urban area are shown in Table 13. In 1989, the total cost of congestion for the urban areas studied was approximately $39.2

billion. This represents a 12 percent increase in the economic impact of congestion in 1988 ($35.1 billion). Studywide averages indicate that recurring and incident delay accounted for approximately 85 percent of an urban area's congestion cost while excess fuel consumption was 15 percent of the total cost. The average economic burden placed on urban areas in 1989 due to congestion was $780 million compared to $700 million in 1988.

All of the top ten urban areas had total congestion costs exceeding $1 billion. Of the seven urban areas studied in Texas only two, Houston -- 6th and Dallas -- 11th, ranked in the top fifteen. Congestion in the Texas urbanized areas resulted in a cost of approximately $3.3 billion, an seven percent increase from 1988 congestion costs.

Table 14 illustrates the estimated economic impact of congestion per capita and per registered vehicle. The urban area with the highest per vehicle cost was Washington, D.C., ($1,280 per registered vehicle) while San Bernardino, CA, had the highest per capita cost ($840 per person). This variation of congestion costs between the Northeastern and Western regions shows the effects of the lower vehicle ownership rate in the Northeast.

Table 15 illustrates the rankings of urban areas by the annual, per capita, and per registered vehicle costs. The rankings are fairly consistent with 13 urban areas occupying the top ten positions in all three categories. However, Table 16 indicates that omitting insurance costs, the correspondence between cost per capita and RCI rankings no longer exist.

Tables 17 through 22 present estimates of congestion cost from 1986 to 1988. Some of the data missing in 1986 and 1987 was unattainable because of the various methods of reporting information in the HPMS data base. In 1988, the information used to categorize congestion levels by severity was included within the TTI data base so that yearly congestion costs for all 50 urban areas could be estimated.

Table 13. Component and Total Congestion Costs By Urban Area for 1989

Urban Area	Annual Cost Due to Congestion ($Millions)					Rank
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost	
Los Angeles CA	2,750	3,220	480	560	7,000	1
New York NY	1,810	3,380	300	560	6,040	2
San Fran-Oak CA	980	1,240	170	220	2,620	3
Washington DC	690	1,140	110	190	2,130	4
Chicago IL	780	900	130	150	1,970	5
Houston TX	550	740	90	120	1,500	6
Detroit MI	480	740	80	120	1,410	7
Boston MA	320	880	50	140	1,390	8
Philadelphia PA	400	520	60	80	1,060	9
Seattle-Everett WA	380	500	60	80	1,020	10
Dallas TX	310	530	50	90	980	11
San Bernardino-Riv CA	360	420	60	70	920	12
Atlanta GA	370	410	60	70	910	14
San Jose CA	360	420	60	70	910	14
Miami FL	330	410	50	70	870	15
Phoenix AZ	320	290	50	50	700	16
San Diego CA	320	210	60	40	620	17
St. Louis MO	220	250	30	40	540	18
Denver CO	200	210	30	30	480	19
Baltimore MD	150	260	30	40	470	20
Pittsburgh PA	160	230	20	30	440	21
Minn-St. Paul MN	170	160	30	30	390	22
Fort Worth TX	120	200	20	30	370	23
Sacramento CA	150	120	30	20	320	24
Portland OR	100	160	20	30	310	25
Ft. Lauderdale FL	110	140	20	20	290	27
Norfolk VA	80	170	10	30	290	27
New Orleans LA	90	140	20	20	270	29
Orlando FL	100	130	20	20	270	29
San Antonio TX	100	110	20	20	240	30
Honolulu HI	70	110	10	20	220	31
Jacksonville FL	80	100	10	20	210	32
Cleveland OH	90	70	20	10	190	33
Austin TX	70	80	10	10	180	35
Milwaukee WI	70	80	10	10	180	35
Nashville TN	70	80	10	10	170	37
Tampa FL	70	80	10	10	170	37
Cincinnati OH	70	60	10	10	160	39
Columbus OH	70	60	10	10	160	39
Hartford CT	40	80	10	10	140	40
Charlotte NC	60	60	10	10	130	41
Kansas City MO	30	60	0	10	100	42
Albuquerque NM	30	40	10	10	80	45
Louisville KY	30	40	10	10	80	45
Memphis TN	30	30	10	10	80	45
Oklahoma City OK	30	40	10	10	80	45
Indianapolis IN	20	30	0	10	60	48
Salt Lake City UT	30	20	0	0	60	48
El Paso TX	10	10	0	0	30	49
Corpus Christi TX	0	0	0	0	10	50
Northeastern Avg	510	930	80	150	1,670	
Midwestern Avg	170	210	30	30	440	
Southern Avg	130	160	20	30	330	
Southwestern Avg	160	200	30	30	420	
Western Avg	610	710	110	120	1,550	
Texas Avg	170	240	30	40	470	
Total Avg	280	390	50	60	780	
Maximum Value	2,750	3,380	480	560	7,000	
Minimum Value	0	0	0	0	10	

Source: TTI Analysis and Local Transportation Agency References

Table 14. Estimated Impact of Congestion in 1989

	Total Congestion Cost	
	Per Registered Vehicle (Dollars)	Per Capita (Dollars)
Northeastern Cities		
Baltimore MD	460	250
Boston MA	840	470
Hartford CT	270	230
New York NY	1,020	370
Philadelphia PA	380	250
Pittsburgh PA	360	240
Washington DC	1,280	690
Midwestern Cities		
Chicago IL	480	270
Cincinnati OH	170	140
Cleveland OH	130	110
Columbus OH	210	190
Detroit MI	490	360
Indianapolis IN	110	70
Kansas City MO	150	90
Louisville KY	170	100
Milwaukee WI	330	140
Minn-St. Paul MN	240	200
Oklahoma City OK	180	120
St. Louis MO	570	280
Southern Cities		
Atlanta GA	590	490
Charlotte NC	360	310
Ft. Lauderdale FL	280	230
Jacksonville FL	360	300
Memphis TN	120	90
Miami FL	610	470
Nashville TN	330	310
New Orleans LA	320	260
Norfolk VA	360	310
Orlando FL	380	340
Tampa FL	270	250
Southwestern Cities		
Albuquerque NM	190	160
Austin TX	370	360
Corpus Christi TX	50	40
Dallas TX	660	500
Denver CO	350	310
El Paso TX	90	60
Fort Worth TX	380	320
Houston TX	690	520
Phoenix AZ	590	370
Salt Lake City UT	90	80
San Antonio TX	270	200
Western Cities		
Honolulu HI	440	330
Los Angeles CA	900	620
Portland OR	460	300
Sacramento CA	250	300
San Bernardino-Riv CA	1,200	840
San Diego CA	440	280
San Fran-Oak CA	850	720
San Jose CA	900	650
Seattle-Everett WA	810	610
Northeastern Avg	660	360
Midwestern Avg	270	170
Southern Avg	360	310
Southwestern Avg	340	270
Western Avg	690	520
Texas Avg	360	290
Total Avg	440	310
Maximum Value	1,280	840
Minimum Value	50	50

Source: TTI Analysis and Local Transportation Agency References

Table 15. 1989 Rankings of Urban Area by Estimated Impact of Congestion

Urban Area	Areawide Cost Congestion	Cost Per Capita Congestion	Cost Per Reg. Vehicle Congestion
Northeastern Cities			
Baltimore MD	20	32	17
Boston MA	8	10	7
Hartford CT	40	34	36
New York NY	2	13	3
Philadelphia PA	9	31	21
Pittsburgh PA	21	33	25
Washington DC	4	3	1
Midwestern Cities			
Chicago IL	5	28	16
Cincinnati OH	38	41	42
Cleveland OH	33	43	45
Columbus OH	39	38	39
Detroit MI	7	14	15
Indianapolis IN	47	48	47
Kansas City MO	42	45	44
Louisville KY	45	44	43
Milwaukee WI	35	40	31
Minn-St. Paul MN	22	37	38
Oklahoma City OK	43	42	41
St. Louis MO	18	27	14
Southern Cities			
Atlanta GA	13	9	13
Charlotte NC	41	21	26
Ft. Lauderdale FL	27	35	33
Jacksonville FL	32	25	27
Memphis TN	46	46	46
Miami FL	15	11	11
Nashville TN	37	22	30
New Orleans LA	28	29	32
Norfolk VA	26	19	28
Orlando FL	29	16	22
Tampa FL	36	30	35
Southwestern Cities			
Albuquerque NM	44	39	40
Austin TX	34	15	24
Corpus Christi TX	50	50	50
Dallas TX	11	8	10
Denver CO	19	20	29
El Paso TX	49	49	48
Fort Worth TX	23	18	23
Houston TX	6	7	9
Phoenix AZ	16	12	12
Salt Lake City UT	48	47	49
San Antonio TX	30	36	34
Western Cities			
Honolulu HI	31	17	20
Los Angeles CA	1	5	5
Portland OR	25	24	18
Sacramento CA	24	23	37
San Bernardino-Riv CA	12	1	2
San Diego CA	17	26	19
San Fran-Oak CA	3	2	6
San Jose CA	14	4	4
Seattle-Everett WA	10	6	8

Table 16. 1989 Congestion Index Values

Urban Area	DVMT/Ln-Miles		Roadway Congestion Index			Congestion Costs[1] Per Capita	
	Frwy	Prin. Art Street	1989 Value	Rank 1988	Rank 1989	1988	1989
Northeastern Cities							
Baltimore MD	12,340	5,700	0.99	31	24	210	250
Boston MA	14,570	4,680	1.09	11	13	480	470
Hartford CT	10,660	5,870	0.89	32	37	190	230
New York NY	13,800	6,920	1.12	12	12	310	370
Philadelphia PA	12,140	6,510	1.05	16	17	240	250
Pittsburgh PA	7,910	6,080	0.82	42	42	220	240
Washington DC	16,460	8,370	1.36	3	2	610	690
Midwestern Cities							
Chicago IL	14,970	6,910	1.21	4	5	230	270
Cincinnati OH	12,240	4,550	0.94	35	31	150	140
Cleveland OH	12,460	4,650	0.95	26	28	90	110
Columbus OH	10,250	5,070	0.82	43	42	160	190
Detroit MI	13,340	6,090	1.08	15	15	330	360
Indianapolis IN	10,960	4,510	0.85	41	41	60	70
Kansas City MO	9,130	4,180	0.72	48	48	90	90
Louisville KY	10,500	5,670	0.86	37	40	90	100
Milwaukee WI	12,740	4,670	0.97	29	25	140	140
Minn-St. Paul MN	11,630	4,550	0.90	35	36	190	200
Oklahoma City OK	9,490	5,270	0.78	44	45	120	120
St. Louis MO	11,110	6,800	0.96	25	26	200	280
Southern Cities							
Atlanta GA	14,640	6,220	1.14	12	9	450	490
Charlotte NC	7,530	5,390	0.74	47	46	270	310
Ft. Lauderdale FL	11,580	5,100	0.92	33	32	230	230
Jacksonville FL	11,820	4,790	0.92	28	32	240	300
Memphis TN	11,200	5,120	0.91	39	34	80	90
Miami FL	14,400	7,280	1.25	4	4	420	470
Nashville TN	11,270	5,780	0.95	22	28	300	310
New Orleans LA	13,890	6,560	1.13	9	10	240	260
Norfolk VA	11,600	5,630	0.95	29	28	300	310
Orlando FL	10,120	2,370	0.72	45	48	300	340
Tampa FL	11,630	6,630	1.03	18	18	250	250
Southwestern Cities							
Albuquerque NM	11,000	5,110	0.91	33	34	130	160
Austin TX	12,470	4,820	0.96	27	26	330	360
Corpus Christi TX	8,220	4,530	0.71	50	50	40	40
Dallas TX	13,400	4,860	1.02	20	20	480	500
Denver CO	12,480	5,760	1.01	22	22	280	310
El Paso TX	9,430	3,830	0.74	45	46	70	60
Fort Worth TX	11,110	4,880	0.87	37	38	300	320
Houston TX	14,860	5,170	1.13	8	10	490	520
Phoenix AZ	11,650	5,840	1.03	21	18	370	370
Salt Lake City UT	9,960	5,490	0.81	48	44	60	80
San Antonio TX	11,120	4,800	0.87	39	38	190	200
Western Cities							
Honolulu HI	13,310	7,970	1.09	12	13	300	330
Los Angeles CA	20,840	6,550	1.54	1	1	570	620
Portland OR	13,580	6,180	1.07	17	16	280	300
Sacramento CA	12,120	6,310	1.01	18	22	250	300
San Bernardino-Riv CA	15,480	5,130	1.16	7	8	790	840
San Diego CA	15,560	5,350	1.18	9	7	250	280
San Fran-Oak CA	17,860	6,470	1.36	2	2	660	720
San Jose CA	13,400	4,880	1.02	22	20	600	650
Seattle-Everett WA	15,690	6,000	1.21	6	5	550	610

Notes: [1] Cost includes delay, fuel, and insurance
[2] HPMS sample data was missing in 1987, cost and RCI ranks based on Research Report No. 1131-2

Source: TTI Analysis and Local Transportation Agency References

Table 17. Component and Total Congestion Costs By Urban Area for 1986

Urban Area	Annual Cost Due to Congestion ($Millions) Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost
Northeastern Cities					
Baltimore MD	-	-	-	-	-
Boston MA	-	-	-	-	-
Hartford CT	20	40	-	-	-
New York NY	-	-	-	-	-
Philadelphia PA	-	-	-	-	-
Pittsburgh PA	-	-	-	-	-
Washington DC	-	-	-	-	-
Midwestern Cities					
Chicago IL	-	-	-	-	-
Cincinnati OH	-	-	-	-	-
Cleveland OH	-	-	-	-	-
Columbus OH	50	40	-	-	-
Detroit MI	-	-	-	-	-
Indianapolis IN	-	-	-	-	-
Kansas City MO	20	40	0	10	70
Louisville KY	30	30	0	0	60
Milwaukee WI	60	60	10	10	130
Minn-St. Paul MN	110	110	20	20	250
Oklahoma City OK	-	-	-	-	-
St. Louis MO	160	180	90	100	540
Southern Cities					
Atlanta GA	310	340	40	50	740
Charlotte NC	40	40	-	-	-
Ft. Lauderdale FL	90	110	10	20	240
Jacksonville FL	50	70	10	10	140
Memphis TN	20	20	0	0	50
Miami FL	210	250	30	40	520
Nashville TN	40	50	10	10	110
New Orleans LA	80	120	10	20	220
Norfolk VA	60	130	-	-	-
Orlando FL	90	110	10	20	220
Tampa FL	50	60	10	10	130
Southwestern Cities					
Albuquerque NM	20	20	0	0	50
Austin TX	70	80	10	10	180
Corpus Christi TX	0	0	0	0	10
Dallas TX	290	500	40	70	910
Denver CO	160	170	20	30	380
El Paso TX	20	20	0	0	40
Fort Worth TX	110	180	20	30	330
Houston TX	490	650	70	90	1,290
Phoenix AZ	230	210	40	30	500
Salt Lake City UT	20	20	0	0	40
San Antonio TX	90	100	10	10	220
Western Cities					
Honolulu HI	50	90	10	10	170
Los Angeles CA	2,300	2,690	360	420	5,760
Portland OR	60	90	10	10	170
Sacramento CA	70	60	10	10	150
San Bernardino-Riv CA	220	250	30	40	540
San Diego CA	180	120	30	20	350
San Fran-Oak CA	730	920	110	140	1,900
San Jose CA	260	300	40	50	650
Seattle-Everett WA	230	300	40	50	620
Northeastern Avg	20	40	-	-	-
Midwestern Avg	70	80	20	30	210
Southern Avg	90	120	20	20	260
Southwestern Avg	140	180	20	30	360
Western Avg	450	540	70	80	1,150
Texas Avg	150	220	20	30	420
Total Avg	190	230	30	40	520
Maximum Value	2,300	2,690	360	420	5,760
Minimum Value	0	0	0	0	10

Note: - Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

Table 18. Estimated Impact of Congestion in 1986

	Total Congestion Cost	
	Per Registered Vehicle (Dollars)	Per Capita (Dollars)
Northeastern Cities		
Baltimore MD	-	-
Boston MA	-	-
Hartford CT	-	-
New York NY	-	-
Philadelphia PA	-	-
Pittsburgh PA	-	-
Washington DC	-	-
Midwestern Cities		
Chicago IL	-	-
Cincinnati OH	-	-
Cleveland OH	-	-
Columbus OH	-	-
Detroit MI	-	-
Indianapolis IN	-	-
Kansas City MO	120	70
Louisville KY	140	80
Milwaukee WI	160	110
Minn-St. Paul MN	220	130
Oklahoma City OK	-	-
St. Louis MO	390	280
Southern Cities		
Atlanta GA	520	430
Charlotte NC	-	-
Ft. Lauderdale FL	250	200
Jacksonville FL	250	210
Memphis TN	110	60
Miami FL	370	290
Nashville TN	300	210
New Orleans LA	270	210
Norfolk VA	-	-
Orlando FL	400	330
Tampa FL	190	210
Southwestern Cities		
Albuquerque NM	130	100
Austin TX	390	380
Corpus Christi TX	40	40
Dallas TX	560	480
Denver CO	300	250
El Paso TX	110	80
Fort Worth TX	360	290
Houston TX	680	460
Phoenix AZ	450	290
Salt Lake City UT	60	50
San Antonio TX	280	230
Western Cities		
Honolulu HI	340	280
Los Angeles CA	750	540
Portland OR	290	170
Sacramento CA	140	160
San Bernardino-Riv CA	800	550
San Diego CA	320	180
San Fran-Oak CA	710	550
San Jose CA	670	480
Seattle-Everett WA	590	400
Northeastern Avg	-	-
Midwestern Avg	210	130
Southern Avg	300	240
Southwestern Avg	300	240
Western Avg	510	370
Texas Avg	340	280
Total Avg	340	260
Maximum Value	800	550
Minimum Value	40	40

Note: - Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

Table 19. Component and Total Congestion Costs By Urban Area for 1987

Urban Area	Annual Cost Due to Congestion ($Millions)				
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost
Northeastern Cities					
Baltimore MD	120	200	20	30	360
Boston MA	240	620	30	90	970
Hartford CT	20	40	0	10	80
New York NY	1,390	2,570	200	370	4,540
Philadelphia PA	360	460	50	60	940
Pittsburgh PA	120	190	20	30	360
Washington DC	560	920	90	140	1,710
Midwestern Cities					
Chicago IL	680	780	100	120	1,680
Cincinnati OH	50	50	10	10	110
Cleveland OH	70	50	10	10	140
Columbus OH	60	50	10	10	120
Detroit MI	420	650	60	100	1,230
Indianapolis IN	-	-	-	-	-
Kansas City MO	20	50	0	10	80
Louisville KY	30	30	0	0	80
Milwaukee WI	60	70	10	10	150
Minn-St. Paul MN	150	140	20	20	340
Oklahoma City OK	-	-	-	-	-
St. Louis MO	180	200	20	30	430
Southern Cities					
Atlanta GA	350	390	50	60	850
Charlotte NC	40	40	10	10	90
Ft. Lauderdale FL	100	130	20	20	270
Jacksonville FL	60	80	10	10	170
Memphis TN	20	30	0	0	60
Miami FL	240	290	40	40	600
Nashville TN	50	60	10	10	120
New Orleans LA	80	120	10	20	230
Norfolk VA	70	150	10	20	250
Orlando FL	90	110	10	20	220
Tampa FL	60	70	10	10	140
Southwestern Cities					
Albuquerque NM	-	-	-	-	-
Austin TX	70	70	10	10	160
Corpus Christi TX	0	0	0	0	10
Dallas TX	280	470	40	70	860
Denver CO	160	170	30	30	390
El Paso TX	10	10	0	0	30
Fort Worth TX	110	180	20	30	330
Houston TX	480	640	70	100	1,290
Phoenix AZ	240	210	40	30	520
Salt Lake City UT	20	20	0	0	50
San Antonio TX	90	100	10	20	230
Western Cities					
Honolulu HI	50	90	10	20	170
Los Angeles CA	2,460	2,890	390	460	6,190
Portland OR	70	120	10	20	220
Sacramento CA	90	80	10	10	200
San Bernardino-Riv CA	250	290	40	50	630
San Diego CA	240	160	40	30	460
San Fran-Oak CA	850	1,070	130	170	2,230
San Jose CA	280	330	40	50	710
Seattle-Everett WA	290	380	50	60	770
Northeastern Avg	400	710	60	100	1,280
Midwestern Avg	170	210	30	30	440
Southern Avg	110	130	20	20	270
Southwestern Avg	150	190	20	30	390
Western Avg	510	600	80	100	1,290
Texas Avg	150	210	20	30	420
Total Avg	250	340	40	50	680
Maximum Value	2,460	2,890	390	460	6,190
Minimum Value	0	0	0	0	10

Note: - Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

Table 20. Estimated Impact of Congestion in 1987

	Total Congestion Cost	
	Per Registered Vehicle (Dollars)	Per Capita (Dollars)
Northeastern Cities		
Baltimore MD	370	190
Boston MA	640	340
Hartford CT	160	130
New York NY	790	280
Philadelphia PA	350	230
Pittsburgh PA	300	200
Washington DC	1,060	570
Midwestern Cities		
Chicago IL	430	230
Cincinnati OH	130	120
Cleveland OH	100	80
Columbus OH	170	150
Detroit MI	430	320
Indianapolis IN	-	-
Kansas City MO	120	70
Louisville KY	170	100
Milwaukee WI	290	120
Minn-St. Paul MN	210	180
Oklahoma City OK	-	-
St. Louis MO	450	220
Southern Cities		
Atlanta GA	560	480
Charlotte NC	240	210
Ft. Lauderdale FL	280	230
Jacksonville FL	290	250
Memphis TN	100	70
Miami FL	450	340
Nashville TN	260	240
New Orleans LA	280	220
Norfolk VA	320	290
Orlando FL	360	290
Tampa FL	250	220
Southwestern Cities		
Albuquerque NM	-	-
Austin TX	350	340
Corpus Christi TX	50	40
Dallas TX	550	450
Denver CO	300	260
El Paso TX	90	60
Fort Worth TX	330	290
Houston TX	580	460
Phoenix AZ	440	280
Salt Lake City UT	70	60
San Antonio TX	280	220
Western Cities		
Honolulu HI	340	280
Los Angeles CA	810	570
Portland OR	350	210
Sacramento CA	170	200
San Bernardino-Riv CA	890	620
San Diego CA	350	220
San Fran-Oak CA	760	630
San Jose CA	730	530
Seattle-Everett WA	670	480
Northeastern Avg	520	280
Midwestern Avg	250	160
Southern Avg	310	260
Southwestern Avg	300	250
Western Avg	560	410
Texas Avg	320	270
Total Avg	380	270
Maximum Value	1,060	630
Minimum Value	50	40

Note: - Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

Table 21. Component and Total Congestion Costs By Urban Area for 1988

Urban Area	Annual Cost Due to Congestion ($Millions)				
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost
Northeastern Cities					
Baltimore MD	130	220	20	40	400
Boston MA	320	890	50	130	1,380
Hartford CT	30	70	10	10	120
New York NY	1,580	2,880	240	440	5,130
Philadelphia PA	390	490	60	70	1,010
Pittsburgh PA	150	210	20	30	410
Washington DC	600	990	100	160	1,850
Midwestern Cities					
Chicago IL	690	790	110	130	1,720
Cincinnati OH	70	60	10	10	150
Cleveland OH	80	60	10	10	170
Columbus OH	70	50	10	10	140
Detroit MI	440	680	70	110	1,290
Indianapolis IN	20	30	0	0	60
Kansas City MO	30	60	0	10	100
Louisville KY	30	30	0	0	70
Milwaukee WI	70	70	10	10	170
Minn-St. Paul MN	160	150	30	30	360
Oklahoma City OK	30	40	10	10	80
St. Louis MO	160	180	20	30	390
Southern Cities					
Atlanta GA	330	370	50	60	810
Charlotte NC	50	50	10	10	120
Ft. Lauderdale FL	110	140	20	20	280
Jacksonville FL	60	80	10	10	160
Memphis TN	30	30	0	0	70
Miami FL	300	370	50	60	770
Nashville TN	70	70	10	10	160
New Orleans LA	90	130	10	20	260
Norfolk VA	80	160	10	20	270
Orlando FL	90	110	10	20	230
Tampa FL	60	80	10	10	160
Southwestern Cities					
Albuquerque NM	30	30	0	0	60
Austin TX	70	70	10	10	160
Corpus Christi TX	0	0	0	0	10
Dallas TX	300	510	50	80	930
Denver CO	180	190	30	30	430
El Paso TX	10	20	0	0	40
Fort Worth TX	110	190	20	30	350
Houston TX	510	690	80	110	1,390
Phoenix AZ	300	290	50	50	680
Salt Lake City UT	20	20	0	0	50
San Antonio TX	90	100	10	20	230
Western Cities					
Honolulu HI	60	100	10	20	200
Los Angeles CA	2,510	2,940	410	480	6,340
Portland OR	90	140	10	20	260
Sacramento CA	120	100	20	20	260
San Bernardino-Riv CA	320	380	50	60	820
San Diego CA	280	190	50	30	550
San Fran-Oak CA	900	1,140	150	190	2,380
San Jose CA	330	380	50	60	820
Seattle-Everett WA	330	430	50	70	890
Northeastern Avg	460	820	70	130	1,470
Midwestern Avg	150	180	20	30	390
Southern Avg	110	140	20	20	300
Southwestern Avg	150	190	20	30	390
Western Avg	550	650	90	110	1,390
Texas Avg	160	230	30	40	440
Total Avg	260	350	40	60	700
Maximum Value	2,510	2,940	410	480	6,340
Minimum Value	0	0	0	0	10

Note: - Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

Table 22. Estimated Impact of Congestion in 1988

	Total Congestion Cost	
	Per Registered Vehicle (Dollars)	Per Capita (Dollars)
Northeastern Cities		
Baltimore MD	390	210
Boston MA	900	480
Hartford CT	230	190
New York NY	880	310
Philadelphia PA	370	240
Pittsburgh PA	340	220
Washington DC	1,130	610
Midwestern Cities		
Chicago IL	430	230
Cincinnati OH	160	150
Cleveland OH	110	90
Columbus OH	190	160
Detroit MI	450	330
Indianapolis IN	110	60
Kansas City MO	150	90
Louisville KY	160	90
Milwaukee WI	320	140
Minn-St. Paul MN	220	190
Oklahoma City OK	180	120
St. Louis MO	410	200
Southern Cities		
Atlanta GA	530	450
Charlotte NC	320	270
Ft. Lauderdale FL	290	230
Jacksonville FL	280	240
Memphis TN	110	80
Miami FL	570	420
Nashville TN	330	300
New Orleans LA	310	240
Norfolk VA	340	300
Orlando FL	360	300
Tampa FL	270	250
Southwestern Cities		
Albuquerque NM	180	130
Austin TX	330	330
Corpus Christi TX	50	40
Dallas TX	580	480
Denver CO	320	280
El Paso TX	100	70
Fort Worth TX	340	300
Houston TX	620	490
Phoenix AZ	580	370
Salt Lake City UT	70	60
San Antonio TX	250	190
Western Cities		
Honolulu HI	400	300
Los Angeles CA	810	570
Portland OR	430	280
Sacramento CA	210	250
San Bernardino-Riv CA	1,130	790
San Diego CA	400	250
San Fran-Oak CA	790	660
San Jose CA	830	600
Seattle-Everett WA	760	550
Northeastern Avg	610	320
Midwestern Avg	240	160
Southern Avg	340	280
Southwestern Avg	310	250
Western Avg	640	470
Texas Avg	330	270
Total Avg	400	280
Maximum Value	1,130	790
Minimum Value	50	40

Note: - Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

CONCLUSIONS

This research report represents the results of the fourth year analysis of a six-year research effort focused on quantifying urban mobility. Relative mobility levels in 50 urban areas throughout the country were presented and discussed in this report. The 50 urban areas studied include the seven largest in Texas and a representative cross-section of other large urban areas.

Areawide Mobility

The Roadway Congestion Index (RCI) is one measure of urban mobility levels. This value is based on daily vehicle-miles of travel per lane-mile operating under congested conditions. The RCI values, as stated in this report, are intended to be areawide representations not site specific locations of spot congestion.

Tables 1 and 2 summarized the travel characteristics for the freeway and principal arterial street system in the individual urban areas included within the study. Tables 3 and 4 show the relationship for both the freeway and principal arterial street systems between DVMT and urban area population. Comparing the summary statistics of these tables indicates:

- The DVMT per person value shows each geographic region studied depends on the freeway system for service of the majority of travel demand.
- All the geographic regions evaluated have a more dense principal arterial street system than freeway system.

Table 5 combines the freeway and principal arterial street system DVMT and DVMT per lane-mile (Tables 1 and 2) into the estimated 1989 Roadway Congestion Index (RCI). Of the 50 urban areas studied, 24 have RCI values exceeding 1.0. These urbanized areas have estimated RCI values ranging from 1.54 to 1.01. RCI values for the ten most congested urban areas range from 1.54 (Los Angeles) to 1.14 (Atlanta). Sacramento and Denver complete the urban areas with RCI values exceeding 1.0 both with 1.01. Three urban areas

(Baltimore, Ft. Lauderdale, and Norfolk) have RCI values of 0.99 indicating that undesirable levels of congestion could occur in the near future. Ten more urban areas have estimated RCI values ranging between 0.97 and 0.90. These areas may not experience undesirable levels of congestion in the immediate future; however, congestion levels could become undesirable within the next five to ten years.

None of the urban areas studied in Texas were included in the ten most congested urban areas. Houston (10th) and Dallas (22nd) were the highest ranked areas within the state. Austin was the next highest ranked (28th) urbanized area in the state with the remaining four Texas cities not ranked in the top 30.

Impacts of Congestion

Figure 4 illustrates the daily VMT served by the freeway system for each geographical area studied. During the study period, the percent difference has remained constant for each area. The Western region places the highest demand on the freeway system while the Southern region places the lowest. Texas motorists place the second highest demand on the freeway system of all geographic regions.

Figure 5 shows the corresponding demands placed on the principal arterial street systems. This Figure shows that the highest demand on the principal arterial street system is placed by the Northeastern and Southern regions while the Texas and Midwestern regions depend the least on this system for urban mobility.

Figure 6 illustrates the regional average percentage of total daily VMT served by the freeway and principal arterial street systems. The primary trends shown in this graph indicate that VMT demand has remained fairly constant in the Northeastern and Midwestern regions and has decreased in the Southern, Southwestern, Western, and Texas regions.

Five case studies illustrate that the expansion of the expansion of the existing roadway systems will involve extensive cash expenditures. The relationship between the increasing vehicle-miles of travel (VMT) and lane-miles of freeways and principal arterial streets make it apparent that the construction of additional lane-miles as the sole alternative to alleviate congestion is not feasible. Regardless of whether the area's DVMT is served by the freeway or principal arterial street system, extensive facility construction efforts and methods to alter travel patterns are required to improve the congestion levels in most urban areas.

Travel delay is the most apparent impact of congestion to the motoring public. Analyses in the this identified two types of delay -- recurring and incident. Tables 8 and 9 categorized delay by the severity (moderate, heavy, and severe) for freeways and principal arterial street systems. The congestion categories are based on average daily traffic volumes per lane (8). Table 10 summarizes the vehicle-hours of delay by type and urban area. The rankings in Table 10 are similar to the rankings by RCI (Table 5). Vehicle-hours of delay are also ranked after being normalized by population. Summary statistics show that the Western and Northeastern regions have the largest average delay while the Southern region has the least. The average delay in Texas urban areas exceeds that of the studywide average and the other three regions.

Cost of Congestion

Estimates of congestion costs were based on the congested peak-period VMT on freeways and principal arterial street systems. Table 11 lists the freeway and principal arterial street DVMT and populations utilized in the congestion cost estimates.

The economic impact of congestion was stated in terms of annual congestion cost, cost per registered vehicle, and cost per capita. The component and total congestion costs for each urban area are shown in Table 13. In 1989, the total cost of congestion for the urban areas studied was approximately $39.2 billion. This represents a 12 percent increase in the economic impact of congestion in 1988 ($35.1 billion).

Studywide averages indicate that recurring and incident delay accounted for approximately 85 percent of an urban area's congestion cost while excess fuel consumption was 15 percent of the total cost. The average economic burden placed on urban areas in 1989 due to congestion was $780 million compared to $700 million in 1988.

All of the top ten urban areas had total congestion costs exceeding $1 billion. Of the seven urban areas studied in Texas only two, Houston -- 6th and Dallas -- 11th, ranked in the top fifteen. Congestion in the Texas urbanized areas resulted in a cost of approximately $2.8 billion, a seven percent increase from 1988 congestion costs.

Table 14 illustrates the estimated economic impact of congestion per capita and per registered vehicle. The urban area with the highest per vehicle cost was Washington, D.C., ($1,280 per registered vehicle) while San Bernardino, CA, had the highest per capita cost ($840 per person). This variation of congestion costs between the Northeastern and Western regions shows the effects of the lower vehicle ownership rate in the Northeast.

Table 15 illustrates the rankings of urban areas by the annual, per capita, and per registered vehicle costs. The rankings are fairly consistent with 13 urban areas occupying the top ten positions in all three categories. However, Table 16 indicates that with the omission of insurance costs the correspondence between cost per capita and RCI rankings no longer exist. The results of these two tables indicate that congestion costs may be used as congestion indices but not directly related to the rankings associated with the Roadway Congestion Index values.

REFERENCES

1. Texas Transportation Institute. "Estimates of Relative Mobility In Major Texas Cities," Research Report 323-1F, 1982.
2. Texas Transportation Institute. "Relative Mobility In Texas Cities, 1975 to 1984," Research Report 339-8, 1986.
3. Texas Transportation Institute. "The Impact Of Declining Mobility In Major Texas And Other U.S. Cities," Research Report 431-1F, 1988.
4. Texas Transportation Institute. "Roadway Congestion In Major Urbanized Areas: 1982 to 1987," Research Report 1131-2, 1989.
5. Texas Transportation Institute. "Roadway Congestion In Major Urbanized Areas: 1982 to 1988," Research Report 1131-3, 1990.
6. United States General Accounting Office. "Traffic Congestion: Trends, Measures, and Effects," Washington, D.C., 1989.
7. National Council on Public Works Improvements. "Fragile Foundations: A Report on America's Public Works," Washington, D.C., 1988.
8. United States Department of Transportation, Federal Highway Administration. "Highway Performance Monitoring System," 1982 to 1989 Data.
9. Chui, Margaret K., and William E. McFarland, "The Value of Travel Time: New Estimates Developed Using a Speed Choice Model," Texas Transportation Institute, January 1987.
10. "Private Truck Counsel of America Cost Index Survey," Houston Post, July 6, 1987.