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16. Abstract
This research report represents the results of the third year analysis of a six year research effort focused on quantifying urban mobility. The study contains roadway information for 39 urban areas representing a geographic cross-section throughout the country. The data base used for this research contains vehicle travel, urban area information, facility mileage, and vehicle travel per lane-mile information from 1982 to 1988. Various federal, state, and local information sources were used to develop and update the data base with the primary source being the Federal Highway Administration's Highway Performance Monitoring System.

Vehicle-miles of travel and lane-mile data were used to develop roadway congestion index values for the seven largest Texas and 32 other U.S. urban areas. These index values serve as indicators of the relative mobility level within an urban area.

An analysis of the cost of congestion was performed using travel delay, increased fuel consumption and increased auto insurance premiums as the economic analysis factors. Congestion costs were estimated on an urban areawide, per registered vehicle, and per capita basis.

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

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ROADWAY CONGESTION IN MAJOR URBANIZED AREAS 1982 TO 1988

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Research Report 1131-3

Research Study Number 2-10-88-1131

Sponsored By

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

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

July 1990

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

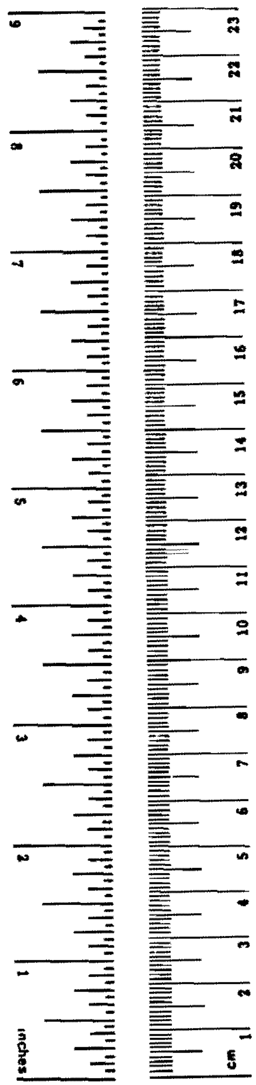
VOLUME

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)

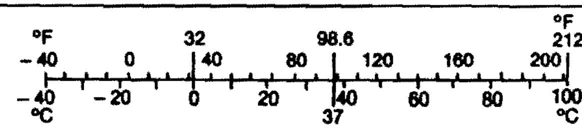
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

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



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

* SI is the symbol for the International System of Measurements

ABSTRACT

This research report represents the results of the third year analysis of a six year research effort focused on quantifying urban mobility. The study contains roadway information for 39 urbanized areas representing a geographic cross-section throughout the country. The data base used for this research contains vehicle travel, urbanized area information, facility mileage, and vehicle travel per lane-mile information from 1982 to 1988. Various federal, state, and local information sources were used to develop and update the data base with the primary source being the Federal Highway Administration's Highway Performance Monitoring System.

Vehicle-miles of travel and lane-mile data were used to develop roadway congestion index values for the seven largest Texas and 32 other U.S. urbanized areas. These index values serve as indicators of the relative mobility level within an urbanized area.

An analysis of the cost of congestion was performed using travel delay, increased fuel consumption, and increased auto insurance premiums as the economic analysis factors. Congestion costs were estimated on an urbanized 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 Highways and Public Transportation in planning, it is desirable to measure and monitor the severity of the congestion and mobility probable in the large Texas metropolitan areas. This report provides a quantification of those mobility levels and the economic impact of congestion on urban motorist. 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 third year effort of a planned six year study to measure and monitor urban mobility in several urbanized areas throughout the continental U.S. This research study estimates level of congestion in 39 large urbanized areas including the seven largest urbanized areas in Texas. Quantitative estimates of mobility levels will allow comparisons of transportation systems in the various urbanized areas and assist the transportation community in analyzing urban mobility.

Measurement of Relative Mobility

The level of congestion in an urbanized area was estimated by the roadway congestion index. This index combines the daily vehicle-miles of travel per lane-mile for freeway and principal arterial street systems in each urbanized area in a ratio defined by the amount of daily vehicle-miles of travel in each functional class. Equation S-1 illustrates how these daily vehicle-miles of travel per lane-mile values are used to calculate the roadway congestion index.

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

Roadway congestion index values equal to or greater than 1.0 indicate undesirable levels of congestion. Urbanized areas with a roadway congestion index value less than 1.0 may have roadway sections which experience intense traffic congestion, but the average mobility level for the urbanized area could be defined as desirable.

Due to the evolving nature of this methodology, two modifications have been included in the latest analysis. The first impacts the method of estimating the lane-miles for the facilities. Facility lane-miles are estimated using the average number of facility lanes and the length in miles of the facility. Originally, the average number of lanes was calculated using an average of the Highway Performance Monitoring System sample data for all urbanized areas included in this study. This procedure was primarily used because some states reported "grouped" or combined urbanized area data. Grouped data implies that roadway information for all or some of the urbanized areas within a state is grouped together and a statistically significant sample is selected and reported in the Highway Performance Monitoring System data base. An average of the sample data was utilized in Florida, California, Ohio, Oregon, and Washington for this reason. In areas not utilizing "grouped" data, the average number of lanes was calculated using a more precise technique involving the expansion factor in the Highway Performance Monitoring System data. This method provides an improved areawide representation of facility lane-miles. Secondly, the congested daily vehicle-miles of travel is categorized by severity. This provides an estimate of the percentage of travel volumes operating under varying levels of congestion. Table S-1 illustrates the peak-period speeds used to determine the amount of travel delay.

Table S-1. 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 (5).

Source: TTI Analysis and Houston-Galveston Regional Transportation Study Data

The roadway congestion index analyses presented in this report are intended to result in an urbanized area value representing an entire urbanized area, not site specific locations. This index is based on areawide freeway and principal arterial street travel and, therefore, if a large percentage of an urbanized area's system has "good" operational characteristics, the effects of point or specific facility congestion could be underestimated.

The methodology was originally developed for urbanized areas in the Western and Southern regions of the country. Urbanized areas in the Northeastern and Midwestern regions have significantly different roadway and development patterns. Freeways in many of these urbanized areas have designs with narrower lanes and shoulders than system designs prevalent in the Southern and Western portions of the country. These factors may result in the current methodology underestimating congestion in the Northeastern and Midwestern areas.

Urbanized Area Mobility

Figure S-1 illustrates facility travel demand by geographic region. This figure shows the percentage of total urbanized area travel demand served by the freeway system and principal arterial street system. The highest regional percentage of daily vehicle-miles of travel utilizing the freeway system is in the Western region.

Both the Midwestern and Western region indicate a heavy reliance on the freeway system for serving the daily travel demand while the Northeastern and Southern region have a more "balanced" demand on freeways and principal arterial street systems.

The Southwestern region appears to also have a "balanced" travel demand on both systems. However, removing the Texas urbanized areas from the Southwestern region indicates that Texas motorists, in the cities analyzed, have a much greater dependence on the freeway system than the Southwestern regional average. For the cities studied in Texas, an average of 36 percent of the urbanized area total vehicle-miles of travel is served by the freeway system while principal arterial streets provided 19 percent of the total vehicle-miles of travel. The remaining 45 percent of the urbanized area travel demand is provided by minor arterials, collectors and local street systems.

Table S-2 presents the estimates of daily vehicle-miles of travel per lane-mile of freeway and principal arterial street systems for 1988. Of the 39 urbanized areas studied, 18 have roadway congestion index values exceeding 1.0. The average roadway congestion index value for the Texas cities studied was approximately nine percent below the study

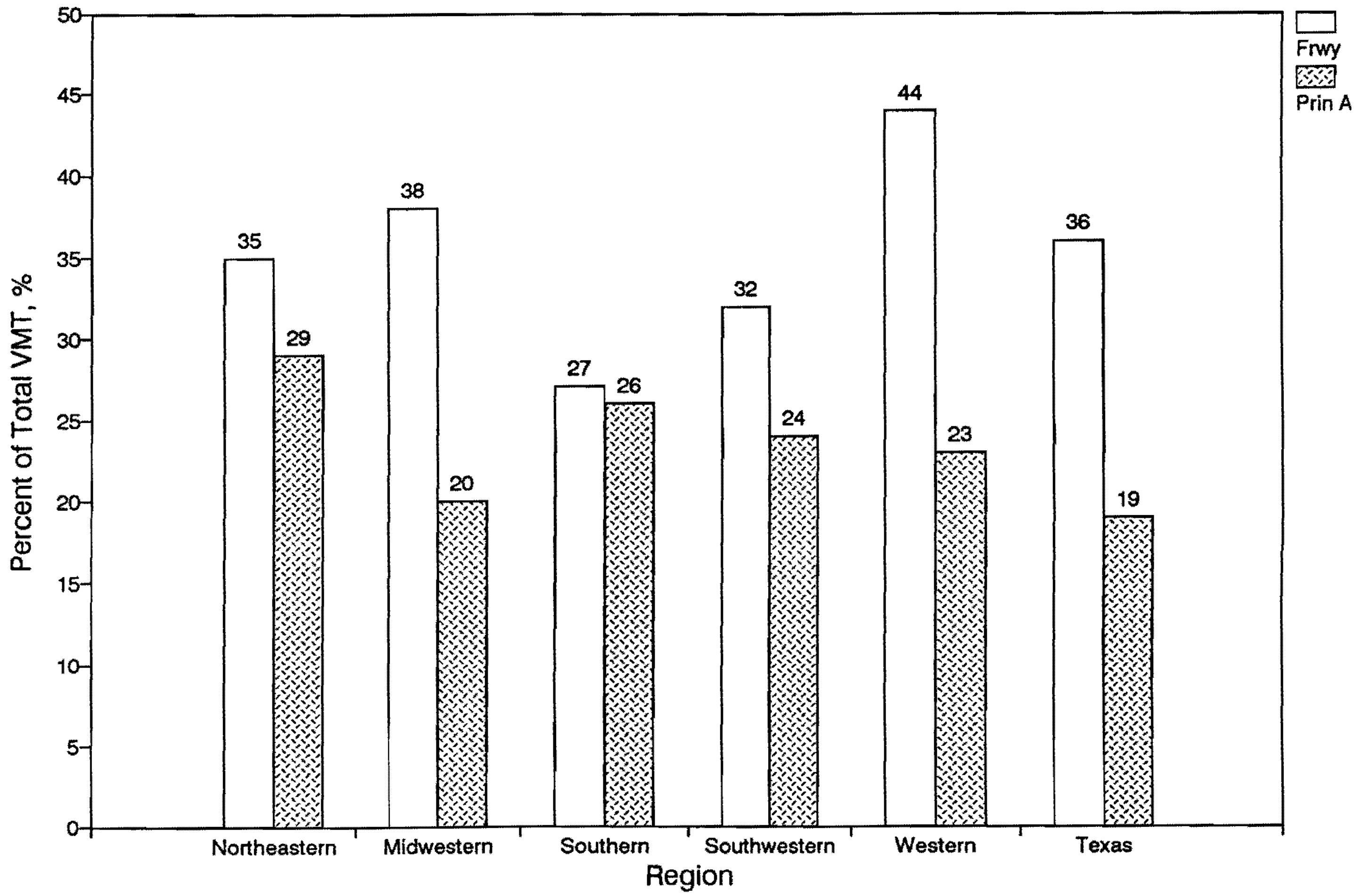


Figure S-1. Facility Travel Volume by Geographic Region

Note. Texas Urban areas are included in the Southwestern Regional Average

Table S-2. 1988 Roadway Congestion Index Value

Urbanized 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	102,140	20,590	78,240	6,520	1.52	1
San Fran-Oak CA	40,370	17,360	13,540	6,620	1.33	2
Washington DC	23,600	15,850	18,800	8,250	1.32	3
Chicago IL	31,970	14,500	26,070	6,940	1.18	4
Miami FL	7,890	13,710	13,740	6,800	1.18	4
Seattle-Everett WA	17,190	15,080	8,820	5,980	1.17	6
Houston TX	27,100	15,140	10,190	5,150	1.15	7
San Diego CA	25,040	14,770	8,850	5,460	1.13	8
Boston MA	22,720	15,040	12,860	4,780	1.12	9
New York NY	78,010	13,430	49,710	6,990	1.10	10
Atlanta GA	22,970	13,920	9,790	6,570	1.10	10
Detroit MI	22,020	13,430	21,670	6,160	1.09	12
Philadelphia PA	16,680	11,910	22,120	6,850	1.07	13
Portland OR	7,100	13,150	3,280	6,250	1.05	14
Tampa FL	3,440	11,860	4,070	6,500	1.03	15
Sacramento CA	8,420	12,470	6,660	6,340	1.03	15
Dallas TX	22,380	13,360	8,150	4,810	1.02	17
Phoenix AZ	5,550	10,670	16,680	5,790	1.00	18
Nashville TN	5,250	11,930	5,390	5,890	0.99	19
Denver CO	10,490	12,200	10,450	5,690	0.99	19
St. Louis MO	17,390	11,710	11,470	6,570	0.98	21
Cleveland OH	12,670	12,800	5,010	4,510	0.97	22
Austin TX	5,220	12,430	2,070	4,920	0.96	23
Milwaukee WI	7,140	12,200	4,730	4,770	0.94	24
Baltimore MD	13,920	11,500	9,160	5,260	0.92	25
Albuquerque NM	2,230	11,130	3,390	4,840	0.90	26
Cincinnati OH	9,750	11,540	3,440	4,320	0.88	27
Minn-St. Paul MN	16,420	11,440	5,300	4,530	0.88	27
Louisville KY	6,040	10,690	2,860	5,610	0.87	29
Fort Worth TX	11,150	11,150	4,200	4,860	0.87	29
Memphis TN	3,950	10,390	4,050	5,030	0.86	31
San Antonio TX	9,050	11,040	4,990	4,660	0.86	31
Indianapolis IN	7,750	10,760	3,940	4,640	0.84	33
Pittsburgh PA	7,380	7,770	10,630	6,020	0.81	34
Oklahoma City OK	6,620	9,390	3,450	5,260	0.78	35
El Paso TX	3,320	9,490	3,110	3,860	0.74	36
Kansas City MO	12,220	9,090	4,490	4,300	0.72	37
Salt Lake City UT	4,080	8,490	1,910	5,460	0.72	37
Corpus Christi TX	1,510	8,160	1,440	4,500	0.70	39
Northeastern Avg.	27,050	12,580	20,550	6,360	1.06	
Midwestern Avg.	13,630	11,590	8,400	5,240	0.92	
Southern Avg.	8,700	12,360	7,410	6,160	1.03	
Southwestern Avg.	9,280	11,200	6,050	4,960	0.90	
Western Avg.	33,380	15,570	19,900	6,190	1.21	
Total Avg.	16,870	12,350	11,250	5,600	0.99	
Maximum Value	102,140	20,590	78,240	8,250	1.52	
Minimum Value	1,510	7,770	1,440	3,860	0.70	

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 5

average. Houston was the only urbanized area in Texas ranked in the top ten. Dallas (17th) was the only other city in Texas ranked in the top half.

Economic Impact of Congestion

Travel delay, excess fuel consumption, and higher insurance premiums were used to estimate the effect of congestion in an urbanized area. These costs are summarized in Table S-3. The cost of congestion including all components exceeded $34 billion in 1988 or an average of $880 million per urbanized area. Overall, ten of the 39 urbanized areas studied had total congestion costs exceeding $1 billion. Delay accounts for approximately 65 percent of the total cost, an average of $570 million per city. Table S-4 illustrates annual congestion costs per capita and per vehicle. These values represent the congestion "tax" paid urbanized area residents and motorist.

Table S-5 compares the urbanized areas ranks based on estimated roadway congestion index, cost per capita, and cost per registered vehicle. Fourteen different cities occupy the top ten positions in all ranking categories. Ranking urbanized areas by congestion cost per vehicle and per capita generally correspond to roadway congestion index ranks.

Table S-3. Component and Total Congestion Costs By Urbanized Area for 1988

Urbanized Area	Annual Cost Due to Congestion ($Millions)						Total Delay, Fuel &Insurance	Rank
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost	Insurance		
Los Angeles CA	2,060	2,420	350	410	5,240	1,640	6,880	1
New York NY	1,270	2,440	200	380	4,290	1,760	6,040	2
San Fran-Oak CA	760	960	130	160	2,010	340	2,340	3
Chicago IL	530	620	90	100	1,340	540	1,880	4
Washington DC	480	820	80	130	1,510	220	1,730	5
Philadelphia PA	290	380	40	60	770	780	1,550	6
Detroit MI	340	550	50	90	1,030	470	1,510	7
Houston TX	420	570	70	90	1,150	310	1,470	8
Boston MA	260	750	40	120	1,170	120	1,280	9
Miami FL	230	290	40	50	610	430	1,040	10
Dallas TX	250	430	40	70	790	170	960	11
Seattle-Everett WA	270	360	50	60	740	60	800	12
Atlanta GA	260	290	40	50	640	100	730	13
San Diego CA	240	160	40	30	470	110	570	14
Pittsburgh PA	110	160	20	20	310	250	570	14
Baltimore MD	100	180	20	30	330	190	520	16
Phoenix AZ	220	200	40	30	490	40	520	16
Denver CO	140	140	20	20	320	70	400	18
Fort Worth TX	90	160	20	30	300	80	380	19
Minn-St. Paul MN	130	120	20	20	290	70	360	20
St. Louis MO	110	120	20	20	270	80	350	21
Sacramento CA	100	80	20	10	210	100	300	22
Cleveland OH	70	50	10	10	140	140	290	23
Portland OR	70	120	10	20	220	50	270	24
San Antonio TX	80	80	10	10	180	70	250	25
Nashville TN	50	60	10	10	130	40	170	26
Milwaukee WI	60	60	10	10	140	30	160	27
Tampa FL	50	60	10	10	130	30	160	27
Austin TX	60	60	10	10	140	10	160	27
Cincinnati OH	60	50	10	10	130	20	150	30
Memphis TN	20	20	0	0	40	70	120	31
Kansas City MO	30	50	0	10	90	20	110	32
Oklahoma City OK	30	30	0	0	60	30	90	33
Indianapolis IN	20	30	0	0	50	20	80	34
Louisville KY	20	20	0	0	40	30	70	35
Albuquerque NM	20	20	0	0	40	10	60	36
Salt Lake City UT	20	10	0	0	30	20	60	36
El Paso TX	10	10	0	0	20	20	50	38
Corpus Christi TX	0	0	0	0	0	10	20	39
Northeastern Avg.	420	790	70	120	1,390	550	1,950	
Midwestern Avg.	130	160	20	30	330	130	460	
Southern Avg.	120	140	20	20	310	130	440	
Southwestern Avg.	120	160	20	30	320	70	390	
Western Avg.	580	680	100	120	1,480	380	1,860	
Total Avg.	240	330	40	50	660	220	880	
Maximum Value	2,060	2,440	350	410	5,230	1,760	6,870	
Minimum Value	0	0	0	0	10	10	20	

Source: TTI Analysis and Local Transportation Agency References

Table S-4. Estimated Economic Impact of Congestion in 1988

Urbanized Area	Cost Per Registered Vehicle: Total Congestion (Dollars)	Cost Per Registered Vehicle: Delay & Fuel (Dollars)	Cost Per Capita: Total Congestion (Dollars)	Cost Per Capita: Delay & Fuel (Dollars)
Northeastern Cities				
Baltimore MD	520	330	270	170
Boston MA	830	760	440	400
New York NY	1,030	730	370	260
Philadelphia PA	570	280	380	190
Pittsburgh PA	470	260	310	170
Washington DC	1,050	920	570	500
Midwestern Cities				
Chicago IL	470	330	260	180
Cincinnati OH	160	140	150	130
Cleveland OH	200	100	160	80
Detroit MI	520	360	390	270
Indianapolis IN	140	100	80	60
Kansas City MO	170	130	100	80
Louisville KY	160	110	90	60
Milwaukee WI	310	250	130	110
Minn-St. Paul MN	220	180	180	150
Oklahoma City OK	200	130	130	90
St. Louis MO	370	280	180	140
Southern Cities				
Atlanta GA	480	420	410	360
Memphis TN	200	90	140	60
Miami FL	770	450	570	330
Nashville TN	340	260	310	240
Tampa FL	270	210	240	190
Southwestern Cities				
Albuquerque NM	160	130	120	100
Austin TX	320	300	320	290
Corpus Christi TX	60	40	50	30
Dallas TX	600	500	490	410
Denver CO	290	250	260	220
El Paso TX	150	90	100	60
Fort Worth TX	370	290	330	260
Houston TX	660	520	520	410
Phoenix AZ	450	410	290	260
Salt Lake City UT	90	60	80	50
San Antonio TX	280	210	220	160
Western Cities				
Los Angeles CA	880	670	620	470
Portland OR	440	350	280	230
Sacramento CA	240	170	290	200
San Diego CA	410	330	260	210
San Fran-Oak CA	780	670	650	560
Seattle-Everett WA	680	630	490	460
Northeastern Avg.	750	550	390	280
Midwestern Avg.	260	190	170	120
Southern Avg.	410	280	340	240
Southwestern Avg.	310	250	250	200
Western Avg.	570	470	430	350
Total Avg.	420	320	290	220
Maximum Value	1,050	920	650	560
Minimum Value	70	40	50	30

Source: TTI Analysis and Local Transportation Agency References

Table S-5. 1988 Urbanized Area Rankings By Roadway Congestion Index and Cost Per Capita

Urbanized Area	Roadway Congestion Index	Rank	Congestion Cost Per Capita (Dollars)	Rank	Congestion Cost Per Vehicle (Dollars)	Rank
Los Angeles CA	1.52	1	620	2	880	3
San Fran-Oak CA	1.33	2	650	1	780	5
Washington DC	1.32	3	570	3	1,050	1
Chicago IL	1.18	4	260	21	470	14
Miami FL	1.18	4	570	3	770	6
Seattle-Everett WA	1.17	6	490	6	680	7
Houston TX	1.15	7	520	5	660	8
San Diego CA	1.13	8	260	21	410	18
Boston MA	1.12	9	440	8	830	4
New York NY	1.10	10	370	12	1,030	2
Atlanta GA	1.10	10	410	9	480	13
Detroit MI	1.09	12	390	10	520	11
Philadelphia PA	1.07	13	380	11	570	10
Portland OR	1.05	14	290	19	440	17
Tampa FL	1.03	15	240	24	270	26
Sacramento CA	1.03	15	290	17	240	27
Dallas TX	1.02	17	490	6	600	9
Phoenix AZ	1.00	18	290	17	450	16
Nashville TN	0.99	19	310	15	340	21
Denver CO	0.99	19	260	21	290	24
St. Louis MO	0.98	21	180	26	370	19
Cleveland OH	0.97	22	160	28	200	29
Austin TX	0.96	23	320	14	320	22
Milwaukee WI	0.94	24	130	31	310	23
Baltimore MD	0.92	25	280	20	520	11
Albuquerque NM	0.90	26	120	33	160	33
Cincinnati OH	0.88	27	160	29	160	33
Minn-St. Paul MN	0.88	27	180	26	220	28
Louisville KY	0.87	29	90	36	160	33
Fort Worth TX	0.87	29	330	13	370	19
Memphis TN	0.86	31	140	30	200	29
San Antonio TX	0.86	31	220	25	280	25
Indianapolis IN	0.84	33	90	37	140	37
Pittsburgh PA	0.81	34	310	15	470	14
Oklahoma City OK	0.78	35	130	31	200	29
El Paso TX	0.74	36	100	34	150	36
Kansas City MO	0.72	37	100	34	170	29
Salt Lake City UT	0.72	37	80	37	90	38
Corpus Christi TX	0.70	39	50	39	60	39

Source: TTI Analysis

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INTRODUCTION

During the past decade, congestion has become common place in most urbanized areas throughout the country. Today, urban mobility has become one of the key issues facing the transportation professionals. Because urbanized areas largely depend on freeway and principal arterial street systems to provide the majority of travel demand requirements, the mobility in urbanized area has been adversely affected by undesirable traffic congestion levels on these systems.

During the past 20 years, there has been a decline in new highway construction. This may be attributed to reduced funding, increased construction costs, and public resistance to construction of additional highways. The most noticeable effect of these factors on urban mobility, from the public's perspective, is increased travel delay. Traffic congestion directly affects the travel time motorists experience during daily commutes. In most urbanized areas, "rush-hour" traffic is no longer encountered only during morning and afternoon peak-periods, but rather extends into much of the day.

In more recent years, an increasing negative public perception of transportation mobility levels has spurred renewed interest in the transportation infrastructure. The net result of this public reaction has been an increase in reconstruction, restoration, and rehabilitation of urban roadway systems.

Measuring Mobility

Obtaining quantitative estimates of mobility levels which allow comparisons of transportation systems in various urbanized areas would assist the transportation community and policy groups in analyzing urban mobility. Recent research (1, 2, 3, 4)[1] has resulted in the development of a methodology to provide quantitative estimates of urbanized area

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

mobility levels. This methodology primarily utilizes the Federal Highway Administration's Highway Performance Monitoring System (HPMS) data base with supporting and verifying information from various state and local agencies. The methodology uses vehicle travel and vehicle travel per lane-mile as a basis for measuring urban mobility. This allows comparisons between various transportation systems with respect to the level of areawide mobility being provided by the existing freeway and principal arterial street facilities.

This research report uses existing data from federal, state, and local agencies to develop planning level estimates of mobility on the freeway and principal arterial street systems in 39 urbanized areas. Currently, the data base developed for this research contains vehicle travel, travel per lane-mile, population, urbanized area size, and facility mileage from 1982 to 1988. This study includes the seven largest urbanized areas (population of 250,000 or greater) in Texas.

Urban Mobility

Urban mobility is characterized by urbanized area travel volume and capacity statistics. The relative level of mobility is estimated in this report by the roadway congestion index (RCI). Roadway congestion index values are based on the major indicators of daily vehicle-miles of travel (DVMT) per lane-mile for freeways and principal arterial streets. Combining the freeway and principal arterial street DVMT per lane-mile into a roadway congestion index value provides a quantitative method to estimate the urbanized areawide mobility. A roadway congestion index value equal to or greater than 1.0 indicates an undesirable level of congestion.

While the roadway congestion index provides an estimate and a basis for comparing of urban mobility, other indicators are also extremely useful. Two other means of quantifying congestion presented in this report include vehicle-hours of delay per person and the relationship between vehicle-miles of travel and facility lane-miles by functional class. These two indicators somewhat negate the affects of population densities, development and land use patterns, and roadway system configurations which vary across the country.

Cost of Congestion

Transportation professionals and the general public have become increasingly aware of the economic impact of congestion. This research study considered three factors in the analysis of the cost of congestion. Travel delay is by far the most critical factor affected by congestion. Traffic congestion also increases the amount of fuel consumed and insurance premiums paid by motorists operating vehicles in these conditions. Combining the effects of these factors, congestion costs were estimated on an areawide, per registered vehicle, and per capita basis. Estimating congestion costs provides a basis for the comparison of urban mobility from one urbanized area to another but more importantly it allows a method to "track" changes in congestion levels and their impact on an urbanized area over time.

MEASUREMENT OF RELATIVE MOBILITY

This study uses the major indicators of daily vehicle-miles of travel (DVMT) per lane-mile for freeways and principal arterial streets combined in a roadway congestion index to estimate and rank the relative areawide mobility. A roadway congestion index value of 1.0 or greater indicates an undesirable areawide congestion level. It should be noted that the methodology used in this research study has some limitations induced by population densities, development and land use patterns, and overall urbanized area mobility characteristics. These topics and others will be addressed later within this section.

Methodology

Congestion indicators and indices used in this study are the result of research conducted by the Texas Transportation Institute (TTI) (1, 2, 3, 4). The most important indicators of congestion, used in this methodology, are freeway and principal arterial street daily vehicle-miles of travel per lane-mile. Equation 1 illustrates how these values are utilized to calculate the roadway congestion index.

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

The two constant values, 13,000 and 5,000 are the result of the previously mentioned TTI research. It was found that when areawide freeway travel volumes reached 13,000 daily vehicle-miles of travel per lane-mile, congested conditions (level of service D) are estimated to occur. The corresponding level of service for principal arterial street travel volumes is represented by a system average of 5,000 daily vehicle-miles of travel per lane-mile. The methodology used to develop these values is discussed in detail in Appendix A of this report.

Methodology Modifications

Because of the evolving nature of this methodology and the attempt to quantify urban mobility, certain modifications have been implemented in this report. These changes are reflected in all published values for 1982 through 1988 contained within this report. This adjustment had an affect on the congestion indicators and indices; care should be exercised if congestion values contained in this report are compared to similar values in previous reports. The two areas affected by the modifications are the estimation of the number of lane-miles and the classification of congested vehicle travel using annual average daily traffic (ADT) per lane ranges.

The most important indicator of congestion presented in this methodology is the daily vehicle-miles of travel per lane-mile. Lane-miles are estimated by determining the average number of lanes and the length of the facility. In the previous reports, the average number of lanes were estimated from Highway Performance Monitoring System (HPMS) (5) sample data. This method was used because some urbanized areas are located in states that utilize "grouped" or combined data. Florida, California, Ohio, Oregon, and Washington combine their roadway information, for all or some urbanized areas and then select a statistically significant sample to report in HPMS data for the total of various urbanized areas. Due to this reporting practice, it was originally believed that estimating the average number of lanes from the average of all the sample sections in the HPMS data was the best available method. This method has now been modified for urbanized areas that do not "group" their HPMS data. The method presented in this report utilizes the expansion factor and number of lanes for each roadway segment in the HPMS sample data. Using the expansion factor to expand disaggregated sample data provides an improved areawide representation of facility characteristics within the urbanized area. The average number of lanes in states with grouped data were estimated by the same manner used in previous analyses.

This procedure provides a more accurate input value from the HPMS data base used to estimate the number of roadway lane-miles for each urbanized area. Improving the estimate of an urbanized area's lane-miles also improves the estimate of the level of congestion. It should be noted that the HPMS data was also verified by local informational sources to ensure that the estimates were reasonable.

The second modification to the methodology was associated with categorizing the congested daily vehicle-miles of travel. Average annual daily traffic per lane ranges were established to identify travel speeds for three categories of congestion (Table 1).

Table 1. 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 (5).

Source: TTI Analysis and Houston-Galveston Regional Transportation Study

A relationship between ADT per lane and average travel speed was developed using travel time and ADT data for freeways and principal arterial streets in Houston, Texas (5) from 1982 to 1989 to obtain better estimates of travel delay. Peak-period speeds in Table 1 represent weighted for the averages for various ADT per lane ranges (Table 1).

The percentage of the total DVMT operating under moderate, heavy, and severe conditions was estimated for each urbanized area, shown in Appendix B. The travel delay was estimated applying the speeds. This procedure provides a better estimate of travel delay within individual urbanized areas because the operating characteristics of the freeway and principal arterial street systems are defined in a more disaggregate form. The previous method used only one set of congested speed and travel per lane values.

The new procedure provides a better delineation of the differences in urbanized areas with moderate congestion on several highways and those with severe congestion on only a few roadways, a difference that previously was not evident.

Limitations of Roadway Congestion Estimates

The roadway congestion index (RCI) is intended to be an urbanized area value, representing the entire area and not site specific locations. This index is based on areawide freeway and principal arterial street travel. Therefore, if a large percentage of these systems have "good" operational characteristics, the effects of point or specific facility congestion may be underestimated with this analysis. It should also be noted that the RCI and its methodology were developed for urbanized areas similar to those in Texas. Urbanized areas in the Northeast and Midwestern states have different roadway and development patterns. The RCI methodology also does not include considerations of traffic signal system operations, freeway desings, freeway system configuration, arterial street continutiy, HOV lanes or the role of transit. While these factors have a definite impact on urban congestion, much more detailed urbanized area information is required than presently is available through regional data bases.

URBANIZED AREA MOBILITY

This section discusses and summarizes urbanized area mileage and travel statistics, roadway congestion index values, and vehicle-hours of delay for the 39 urbanized areas studied. The statistics, in this section, are the result of the Texas Transportation Institute's analyses of the data base compiled for this research study. This data base contains information from federal, state and local sources. Figure 1 illustrates the geographic regions used in these analyses to combine the 39 urbanized areas included in this study. The 39 urbanized areas are located in 25 states and are distributed as follows: Northeastern region - 6, Midwestern region - 11, Southern region - 5, Southwestern region - 11, and Western region - 6. Mobility within these regions, as well within as the individual urbanized areas was compared on the basis of daily vehicle-miles of travel (DVMT) per lane-mile and travel delay.

Freeway/Expressway Travel and Mileage Statistics

Areawide freeway operating conditions were summarized in terms of daily vehicle-miles of travel (DVMT) and lane-miles. Table 2 summarizes these data, and the primary congestion indicator (DVMT per lane-mile) for each urbanized area. Urbanized areas listed in Table 2 were ranked according to DVMT per lane-mile. The summary data located at the bottom of Table 2 are shown by geographic region.

In 1988, fourteen of the 39 urbanized areas studied exceeded the 13,000 DVMT per lane-mile which was used as the indicator of an undesirable level of congestion on areawide freeway/expressway systems. This is a rather significant increase from 1982 (Table B-3) and 1985 (Table B-9) when five and eight urbanized areas, respectively, exceeded the 13,000 DVMT per lane-mile level. Of the ten most congested freeway systems, Los Angeles, San Francisco-Oakland, and Houston have all experienced increased DVMT per lane-mile levels exceeding 13,000 since 1982. Since 1985, Washington, D.C., Seattle-Everett, Chicago, and Miami have also experienced undesirable congestion levels on their freeways.

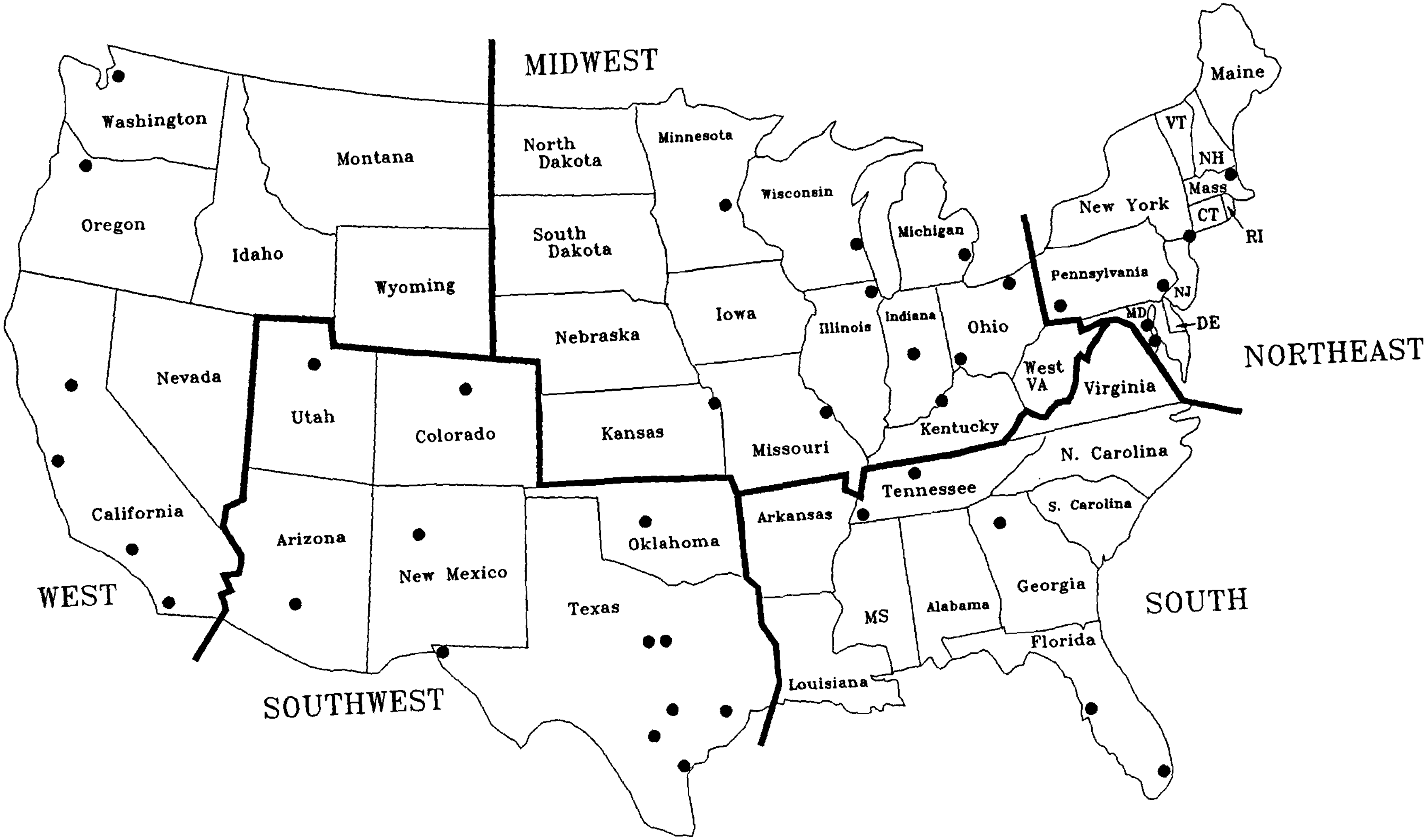

Figure 1. Geographic Regions

Of the 14 urbanized areas exceeding 13,000 DVMT per lane-mile, only two, Miami (10th) and Portland (14th), have freeway systems of less than 1,000 lane-miles. It appears that the congestion on the freeway systems in these cities may be attributed to the high vehicle travel demand (DVMT) on those systems or dependency on the freeway system for areawide mobility. This analysis also indicates that five additional urbanized areas (Cleveland, Sacramento, Austin, Denver and Milwaukee) would have to experience only a two to seven percent increase in travel demand to exceed the undesirable DVMT per lane-mile value.

Houston and Dallas are the only two Texas urbanized areas studied with DVMT per lane-mile values exceeding the undesirable level. Houston was the only urbanized area in Texas ranked in the top ten. Austin, however, would only require a five percent increase in travel demand to reach an undesirable levels of congestion on its freeway system. The Texas urbanized area average DVMT per lane-mile was 11,540 for the seven cities studied representing a value well below undesirable DVMT per lane-mile level and a slight decrease from the 1987 value.

Summary statistics also show the average DVMT per lane-mile values for the geographic regions (Northeastern, Midwestern, Southern, Southwestern, and Western). In 1988, all of the geographic regions with the exception of the Western region had DVMT per lane-mile values less than 13,000. The overall study average was 12,350 DVMT per lane-mile, five percent less than the 13,000 level. The Southwestern regional average was approximately 14 percent below the congested level, and was lower than the other regions studied. It should be noted that the Texas urbanized areas are located in the Southwestern region and comprise 78 percent of the freeway travel within the urbanized areas studied in that region. The remaining five urbanized areas in the Southwestern region are smaller than the majority of the Texas cities.

Ten of the 39 study areas have population densities in excess of 3,000 persons per square mile, with the highest average densities located in the Northeastern and Western regions. The densities in those regions are greatly influenced by New York City and Los Angeles, both with population densities over 5,000 persons per square mile. Texas cities included in this study have an average population density of 1,770 persons per square mile, on average the least densely populated areas in the study.

The daily vehicle-miles of travel (DVMT) per person statistic is an indicator of the reliance of an urbanized area upon the freeway system for areawide mobility. The five most congested Texas cities (Austin, Dallas, Fort Worth, Houston and San Antonio) have the highest average freeway travel per capita (9.8). This value is slightly higher than the Western regional average (9.7) which is the highest of the five regions shown in the summary statistics. The Northeastern region, with several large urbanized areas, had the lowest (5.9) DVMT per lane-mile value. These values indicate the greater dependance of the Texas cities studied on the freeway system than other larger and more populated urbanized areas.

The statistics in Table 4 describe the urbanized area's freeway system and travel demand densities. Large DVMT per square-mile values indicate either dense urban development and/or heavier than average dependance on the freeway system. Likewise, large lane-mile per square mile values indicate how dense the area is or how densely the freeway system has been developed. The largest average values for both these statistics are in the Western region and the lowest are in the Southern region. The Western regional average can be attributed to San Francisco-Oakland, Los Angeles, and San Diego which have lane-mile per square-mile values in excess of 2.0. These values indicate a very dense travel demand and freeway network or land development.

Table 2. 1988 Freeway Mileage and Travel Volume

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Rank[3,4]
Los Angeles CA	102,140	4,960	8.2	20,590	1
San Fran-Oak CA	40,370	2,330	6.8	17,360	2
Washington DC	23,600	1,490	5.2	15,850	3
Houston TX	27,100	1,790	6.2	15,140	4
Seattle-Everett WA	17,190	1,140	5.8	15,080	5
Boston MA	22,720	1,510	5.9	15,040	6
San Diego CA	25,040	1,700	7.4	14,770	7
Chicago IL	31,970	2,210	5.6	14,500	8
Atlanta GA	22,970	1,650	6.1	13,920	9
Miami FL	7,890	580	5.4	13,710	10
New York NY	78,010	5,810	5.5	13,430	11
Detroit MI	22,020	1,640	5.8	13,430	11
Dallas TX	22,380	1,680	5.9	13,360	13
Portland OR	7,100	540	5.0	13,150	14
Cleveland OH	12,670	990	4.6	12,800	15
Sacramento CA	8,420	680	6.9	12,470	16
Austin TX	5,220	420	5.6	12,430	17
Denver CO	10,490	860	5.2	12,200	18
Milwaukee WI	7,140	590	5.6	12,200	18
Nashville TN	5,250	440	4.8	11,930	20
Philadelphia PA	16,680	1,400	5.2	11,910	21
Tampa FL	3,440	290	4.9	11,860	22
St. Louis MO	17,390	1,490	5.5	11,710	23
Cincinnati OH	9,750	850	5.3	11,540	24
Baltimore MD	13,920	1,210	5.4	11,500	25
Minn-St. Paul MN	16,420	1,440	4.9	11,440	26
Fort Worth TX	11,150	1,000	5.7	11,150	27
Albuquerque NM	2,230	200	5.0	11,130	28
San Antonio TX	9,050	820	5.2	11,040	29
Indianapolis IN	7,750	720	5.3	10,760	30
Louisville KY	6,040	570	4.4	10,690	31
Phoenix AZ	5,550	520	5.6	10,670	32
Memphis TN	3,950	380	5.4	10,390	33
El Paso TX	3,320	350	5.2	9,490	34
Oklahoma City OK	6,620	710	5.0	9,390	35
Kansas City MO	12,220	1,350	4.4	9,090	36
Salt Lake City UT	4,080	480	5.6	8,490	37
Corpus Christi TX	1,510	190	5.3	8,160	38
Pittsburgh PA	7,380	950	4.3	7,770	39
Northeastern Avg.	27,050	2,060	5.3	12,580	
Midwestern Avg.	13,630	1,140	5.1	11,590	
Southern Avg.	8,700	670	5.3	12,360	
Southwestern Avg.	9,280	760	5.5	11,200	
Western Avg.	33,380	1,890	6.7	15,570	
Total Avg.	16,870	1,230	5.5	12,350	
Maximum Value	102,140	5,810	8.2	20,590	
Minimum Value	1,510	190	4.3	7,770	

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
[4]Ranked by DVMT/ln.-mi.

Source: TTI Analysis and Local Transportation Agency References

Table 3. Summary of Freeway Travel Frequency and Urban Population Statistics for 1988

Urbanized 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	1,910	530	3,590	7.31	23	0.64	20
Boston MA	2,910	1,060	2,750	7.82	18	0.52	14
New York NY	16,320	3,190	5,120	4.78	32	0.36	5
Philadelphia PA	4,130	1,120	3,690	4.04	37	0.34	4
Pittsburgh PA	1,850	730	2,540	4.00	38	0.51	13
Washington DC	3,040	830	3,660	7.76	20	0.49	12
Midwestern Cities							
Chicago IL	7,340	1,990	3,690	4.35	36	0.30	2
Cincinnati OH	950	430	2,210	10.26	8	0.89	36
Cleveland OH	1,790	640	2,790	7.10	24	0.55	15
Detroit MI	3,900	1,250	3,120	5.65	28	0.42	7
Indianapolis IN	930	440	2,140	8.33	16	0.77	30
Kansas City MO	1,150	600	1,910	10.67	5	1.17	39
Louisville KY	810	380	2,150	7.50	22	0.70	25
Milwaukee WI	1,230	550	2,230	5.82	27	0.48	11
Minn-St. Paul MN	1,930	1,020	1,900	8.53	15	0.75	28
Oklahoma City OK	720	500	1,440	9.19	12	0.98	38
St. Louis MO	1,950	720	2,710	8.92	14	0.76	29
Southern Cities							
Atlanta GA	1,780	1,540	1,150	12.94	1	0.93	37
Memphis TN	830	420	1,980	4.76	33	0.46	10
Miami FL	1,810	470	3,850	4.36	35	0.32	3
Nashville TN	540	490	1,110	9.72	9	0.81	32
Tampa FL	670	440	1,530	5.17	31	0.44	8
Southwestern Cities							
Albuquerque NM	490	250	1,940	4.59	34	0.41	6
Austin TX	500	350	1,430	10.55	7	0.85	33
Corpus Christi TX	280	180	1,570	5.49	29	0.67	23
Dallas TX	1,950	1,440	1,360	11.48	3	0.86	34
Denver CO	1,550	890	1,750	6.77	25	0.55	15
El Paso TX	510	210	2,490	6.51	26	0.69	24
Fort Worth TX	1,150	850	1,360	9.70	10	0.87	35
Houston TX	2,850	1,630	1,750	9.51	11	0.63	19
Phoenix AZ	1,830	970	1,890	3.03	39	0.28	1
Salt Lake City UT	790	460	1,710	5.19	30	0.61	18
San Antonio TX	1,170	480	2,450	7.77	19	0.70	25
Western Cities							
Los Angeles CA	11,140	2,150	5,180	9.17	13	0.45	9
Portland OR	950	410	2,300	7.51	21	0.57	17
Sacramento CA	1,040	350	2,970	8.10	17	0.65	22
San Diego CA	2,180	700	3,130	11.51	2	0.78	31
San Fran-Oak CA	3,610	830	4,350	11.18	4	0.64	20
Seattle-Everett WA	1,630	720	2,270	10.58	6	0.70	25
Northeastern Avg.	5,020	1,240	3,560	5.95		0.48	
Midwestern Avg.	2,060	770	2,390	7.85		0.71	
Southern Avg.	1,120	670	1,920	7.39		0.59	
Southwestern Avg.	1,190	700	1,790	7.33		0.65	
Western Avg.	3,420	860	3,370	9.68		0.63	
Total Avg.	2,360	820	2,490	7.63		0.63	
Maximum Value	16,320	3,190	5,180	12.94		1.17	
Minimum Value	280	190	1,110	3.03		0.28	

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. Summary of Freeway Travel Frequency and Urbanized Area Statistics for 1988

Urbanized Area	Popn. (1000)	Urban Area (Sq.Mi)	Popn Density Pers/Sq Mi	DVMT[1] Per Sq. Mi	Rank[3]	Ln Mi[2] per Sq. Mi	Rank[3]
Northeastern Cities							
Baltimore MD	1,910	530	3,590	26,260	5	2.28	36
Boston MA	2,910	1,060	2,750	21,530	11	1.43	23
New York NY	16,320	3,190	5,120	24,490	6	1.82	31
Philadelphia PA	4,130	1,120	3,690	14,890	27	1.25	17
Pittsburgh PA	1,850	730	2,540	10,180	33	1.31	18
Washington DC	3,040	830	3,660	28,430	4	1.79	30
Midwestern Cities							
Chicago IL	7,340	1,990	3,690	16,060	23	1.11	12
Cincinnati OH	950	430	2,210	22,670	10	1.97	33
Cleveland OH	1,790	640	2,790	19,800	13	1.55	25
Detroit MI	3,900	1,250	3,120	17,610	16	1.31	18
Indianapolis IN	930	440	2,140	17,800	15	1.66	27
Kansas City MO	1,150	600	1,910	20,370	12	2.24	35
Louisville KY	810	380	2,150	16,110	22	1.51	24
Milwaukee WI	1,230	550	2,230	12,970	30	1.06	8
Minn-St. Paul MN	1,930	1,020	1,900	16,180	21	1.41	21
Oklahoma City OK	720	500	1,440	13,240	28	1.41	21
St. Louis MO	1,950	720	2,710	24,150	7	2.06	34
Southern Cities							
Atlanta GA	1,780	1,540	1,150	14,910	26	1.07	10
Memphis TN	830	420	1,980	9,400	34	0.90	4
Miami FL	1,810	470	3,850	16,780	18	1.22	15
Nashville TN	540	490	1,110	10,820	32	0.91	5
Tampa FL	670	440	1,530	7,910	38	0.67	2
Southwestern Cities							
Albuquerque NM	490	250	1,940	8,900	35	0.80	3
Austin TX	500	350	1,430	15,130	25	1.22	15
Corpus Christi TX	280	180	1,570	8,630	37	1.06	8
Dallas TX	1,950	1,440	1,360	15,600	24	1.17	13
Denver CO	1,550	890	1,750	11,850	31	0.97	6
El Paso TX	510	210	2,490	16,200	20	1.71	28
Fort Worth TX	1,150	850	1,360	13,200	29	1.18	14
Houston TX	2,850	1,630	1,750	16,630	19	1.10	11
Phoenix AZ	1,830	970	1,890	5,720	39	0.54	1
Salt Lake City UT	790	460	1,710	8,860	36	1.04	7
San Antonio TX	1,170	480	2,450	19,050	14	1.73	29
Western Cities							
Los Angeles CA	11,140	2,150	5,180	47,510	2	2.31	37
Portland OR	950	410	2,300	17,320	17	1.32	20
Sacramento CA	1,040	350	2,970	24,060	8	1.93	32
San Diego CA	2,180	700	3,130	36,020	3	2.44	38
San Fran-Oak CA	3,610	830	4,350	48,630	1	2.80	39
Seattle-Everett WA	1,630	720	2,270	24,040	9	1.59	26
Northeastern Avg.	5,020	1,240	3,560	20,960		1.65	
Midwestern Avg.	2,060	770	2,390	17,910		1.57	
Southern Avg.	1,120	670	1,920	11,960		0.95	
Southwestern Avg.	1,190	700	1,790	12,710		1.14	
Western Avg.	3,420	860	3,370	32,930		2.07	
Total Avg.	2,360	820	2,490	18,460		1.46	
Maximum Value	16,320	3,190	5,180	48,630		2.80	
Minimum Value	280	180	1,110	5,720		0.54	

Notes: [1]Daily vehicle-miles of travel per square mile of urbanized area
[2]Lane-miles per square mile of urbanized area
[3]Rank value of 1 associated with most congested condition

Source: TTI Analysis and Local Transportation Agency References

To negate the effects of development patterns, the freeway statistics in Tables 3 and 4 were normalized by population density. The results of these analyses are illustrated in Table C-1 (Appendix C). Table C-1 shows the dependency of Texas urbanized areas on the freeway system with four of the five largest urbanized areas in the top ten when ranked by travel demand per capita. The largest effect on the rankings was in Western urbanized area with more densely populated areas, resulting in significantly lower rankings.

Principal Arterial Street Travel and Mileage Statistics

The 1988 estimates of principal arterial street travel and mileage are presented in Tables 5, 6, and 7. These tables have the same format as the tables presented in the previous section. As in the freeway analysis, a systemwide DVMT per lane-mile level was established for principal arterial streets to indicate undesirable congestion levels. For the purposes of this study, 5,000 DVMT per lane-mile or greater indicate undesirable traffic conditions on principal arterial streets. Of the 39 urbanized areas studied, 25 have DVMT per lane-mile values exceeding 5,000. Fourteen (36 percent) of the urbanized areas are experiencing DVMT per lane-mile values in excess of 6,000. Summary statistics show that the highest DVMT per lane-mile values occur in the Northeastern and Western regions, and the lowest in the Southwestern region. This indicates the residents of urbanized areas in the Southwestern region are not as dependent on their principal arterial street system for mobility as residents of urbanized areas in other regions of the country.

The average DVMT per lane-mile in the Texas cities studied was 4,680. Houston was the only urbanized area in Texas with a value above 5,000 DVMT per lane-mile. Texas, has the lowest travel volume per lane-mile of principal arterial street than any other area included in the study. The typical principal arterial street in Texas is a four-lane facility primarily distributing traffic to the freeway systems and serving short sub-regional trips. The same description could also be applied to almost all principal arterial streets in the urbanized areas within the Southwestern region.

Table 5. 1988 Principal Arterial Street Mileage and Travel Volume

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Rank[3,4]
Washington DC	18,800	2,280	4.1	8,250	1
New York NY	49,710	7,110	3.4	6,990	2
Chicago IL	26,070	3,760	3.6	6,940	3
Philadelphia PA	22,120	3,230	3.0	6,850	4
Miami FL	13,740	2,020	4.3	6,800	5
San Fran-Oak CA	13,540	2,050	3.9	6,620	6
St. Louis MO	11,470	1,750	3.2	6,570	7
Atlanta GA	9,790	1,490	3.5	6,570	8
Los Angeles CA	78,240	12,000	4.0	6,520	9
Tampa FL	4,070	630	3.8	6,500	10
Sacramento CA	6,660	1,050	4.0	6,340	11
Portland OR	3,280	530	3.3	6,250	12
Detroit MI	21,670	3,520	4.4	6,160	13
Pittsburgh PA	10,630	1,770	3.1	6,020	14
Seattle-Everett WA	8,820	1,480	3.4	5,980	15
Nashville TN	5,390	920	3.2	5,890	16
Phoenix AZ	16,680	2,880	4.0	5,790	17
Denver CO	10,450	1,840	3.8	5,690	18
Louisville KY	2,860	510	3.7	5,610	19
San Diego CA	8,850	1,620	3.4	5,460	20
Salt Lake City UT	1,910	350	3.5	5,460	21
Baltimore MD	9,160	1,740	4.0	5,260	22
Oklahoma City OK	3,450	660	3.1	5,260	23
Houston TX	10,190	1,980	4.2	5,150	24
Memphis TN	4,050	810	4.3	5,030	25
Austin TX	2,070	420	4.2	4,920	26
Fort Worth TX	4,200	870	4.0	4,860	27
Albuquerque NM	3,390	700	3.5	4,840	28
Dallas TX	8,150	1,700	4.8	4,810	29
Boston MA	12,860	2,690	2.3	4,780	30
Milwaukee WI	4,730	990	3.4	4,770	31
San Antonio TX	4,990	1,070	3.5	4,660	32
Indianapolis IN	3,940	850	3.7	4,640	33
Minn-St. Paul MN	5,300	1,170	3.4	4,530	34
Cleveland OH	5,010	1,110	2.9	4,510	35
Corpus Christi TX	1,440	320	3.8	4,500	36
Cincinnati OH	3,440	800	3.3	4,320	37
Kansas City MO	4,490	1,050	3.5	4,300	38
El Paso TX	3,110	810	4.2	3,860	39
Northeastern Avg.	20,550	3,140	3.3	6,360	
Midwestern Avg.	8,400	1,470	3.5	5,240	
Southern Avg.	7,410	1,170	3.8	6,160	
Southwestern Avg.	6,050	1,180	4.0	4,960	
Western Avg.	19,900	3,120	3.7	6,190	
Total Avg.	11,250	1,860	3.7	5,600	
Maximum Value	78,240	12,000	4.8	8,250	
Minimum Value	1,440	320	2.3	3,860	

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
[4]Ranked by DVMT/Ln.-mi.

Source: TTI Analysis and Local Transportation Agency References

Table 6 presents the 1988 principal arterial street statistics in terms of urbanized area population. These values indicate the reliance of the general populace on the principal arterial street system for mobility. Table 7 illustrates the densities of travel demand and system design. Comparing Tables 6 and 7 to Tables 3 and 4 illustrates which roadway system, freeway or principal arterial street, provides the most mobility by geographic region or urbanized area. The travel volume in the Northeastern and Southern regions is approximately equal between the two roadway systems. The other regions are weighted more heavily toward the freeway system than toward the principal arterial street system.

In Texas, there is much larger dependency on the freeway system for mobility. Urban freeway systems in Texas support more than twice as much of the travel volume than the principal arterial street systems. This statistic is supported by urbanized area statistics which show that Texas travel demand and the principal arterial street system mileage are much less dense when compared to other regions in the study (Table 7).

The relationship between travel volume, facility type, and geographic region is illustrated in Figure 2. This Figure shows the percentage of total vehicle-miles of travel supported by the respective freeway systems. The largest regional percentage (44 percent) occurs in the Western region. This value indicates that approximately 44 percent of the total urbanized area travel volume is supported by the freeway system and 23 percent relying on the principal arterial street system. Urbanized areas studied in the Southern region had the lowest dependance on freeways (27 percent) for urban mobility.

Table 8 summarizes the relationship between daily vehicle-miles of travel and facility type for each urbanized area studied. The total urbanized area DVMT served by freeway facilities ranges from 15 to 54 percent with a studywide average of 36 percent. Principal arterial streets serve between 13 to 44 percent of the total urbanized area DVMT or a studywide average of 24 percent. While the freeway and principal

Table 6. Principal Arterial Street Travel Frequency and Population Density Statistics for 1988

Urbanized Area	1988 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	1,910	530	3,590	4.81	19	0.91	25
Boston MA	2,910	1,060	2,750	4.43	21	0.93	27
New York NY	16,320	3,190	5,120	3.05	36	0.44	1
Philadelphia PA	4,130	1,120	3,690	5.35	16	0.78	13
Pittsburgh PA	1,850	730	2,540	5.76	12	0.96	29
Washington DC	3,040	830	3,660	6.18	8	0.75	11
Midwestern Cities							
Chicago IL	7,340	1,990	3,690	3.55	33	0.51	3
Cincinnati OH	950	430	2,210	3.62	31	0.84	16
Cleveland OH	1,790	640	2,790	2.81	37	0.62	7
Detroit MI	3,900	1,250	3,120	5.56	13	0.90	20
Indianapolis IN	930	440	2,140	4.24	23	0.91	25
Kansas City MO	1,150	600	1,910	3.92	27	0.91	25
Louisville KY	810	380	2,150	3.55	33	0.63	8
Milwaukee WI	1,230	550	2,230	3.86	28	0.81	14
Minn-St. Paul MN	1,930	1,020	1,900	2.75	38	0.61	6
Oklahoma City OK	720	500	1,440	4.78	20	0.91	25
St. Louis MO	1,950	720	2,710	5.88	11	0.89	19
Southern Cities							
Atlanta GA	1,780	1,540	1,150	5.51	14	0.84	16
Memphis TN	830	420	1,980	4.88	18	0.97	30
Miami FL	1,810	470	3,850	7.59	3	1.12	33
Nashville TN	540	490	1,110	9.97	1	1.69	39
Tampa FL	670	440	1,530	6.11	9	0.94	28
Southwestern Cities							
Albuquerque NM	490	250	1,940	6.98	5	1.44	36
Austin TX	500	350	1,430	4.17	25	0.85	17
Corpus Christi TX	280	180	1,570	5.24	17	1.16	34
Dallas TX	1,950	1,440	1,360	4.18	24	0.87	18
Denver CO	1,550	890	1,750	6.74	6	1.18	35
El Paso TX	510	210	2,490	6.10	10	1.58	38
Fort Worth TX	1,150	850	1,360	3.65	30	0.75	11
Houston TX	2,850	1,630	1,750	3.58	32	0.69	9
Phoenix AZ	1,830	970	1,890	9.11	2	1.57	37
Salt Lake City UT	790	460	1,710	2.43	39	0.45	2
San Antonio TX	1,170	480	2,450	4.28	22	0.92	26
Western Cities							
Los Angeles CA	11,140	2,150	5,180	7.02	4	1.08	32
Portland OR	950	410	2,300	3.47	35	0.56	4
Sacramento CA	1,040	350	2,970	6.40	7	1.01	31
San Diego CA	2,180	700	3,130	4.07	26	0.74	10
San Fran-Oak CA	3,610	830	4,350	3.75	29	0.57	5
Seattle-Everett WA	1,630	720	2,270	5.42	15	0.91	25
Northeastern Avg.	5,020	1,240	3,560	4.93		0.79	
Midwestern Avg.	2,060	770	2,390	4.05		0.78	
Southern Avg.	1,120	670	1,920	6.81		1.11	
Southwestern Avg.	1,190	700	1,790	5.13		1.04	
Western Avg.	3,420	860	3,370	5.02		0.81	
Total Avg.	2,360	820	2,490	4.99		0.90	
Maximum Value	16,320	3,190	5,180	9.97		1.69	
Minimum Value	280	180	1,110	2.43		0.44	

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 7. Principal Arterial Street Travel Frequency and Urbanized Area Statistics for 1988

Urbanized Area	1988 Popn. (1000)	Urban Area (Sq.Mi.)	Popn. Density Pers/Sq Mi	DVMT[1] Per Sq Mi	Rank[3]	Ln Mi[2] Per Sq Mi	Rank[3]
Northeastern Cities							
Baltimore MD	1,910	530	3,590	17,280	7	3.28	36
Boston MA	2,910	1,060	2,750	12,190	18	2.55	29
New York NY	16,320	3,190	5,120	15,610	11	2.23	23
Philadelphia PA	4,130	1,120	3,690	19,750	4	2.88	33
Pittsburgh PA	1,850	730	2,540	14,660	13	2.43	27
Washington DC	3,040	830	3,660	22,650	3	2.75	30
Midwestern Cities							
Chicago IL	7,340	1,990	3,690	13,100	15	1.89	18
Cincinnati OH	950	430	2,210	7,990	28	1.85	16
Cleveland OH	1,790	640	2,790	7,830	29	1.73	12
Detroit MI	3,900	1,250	3,120	17,340	6	2.82	32
Indianapolis IN	930	440	2,140	9,060	24	1.95	20
Kansas City MO	1,150	600	1,910	7,480	31	1.74	13
Louisville KY	810	380	2,150	7,630	30	1.36	10
Milwaukee WI	1,230	550	2,230	8,590	25	1.80	14
Minn-St. Paul MN	1,930	1,020	1,900	5,220	37	1.15	4
Oklahoma City OK	720	500	1,440	6,890	32	1.31	9
St. Louis MO	1,950	720	2,710	15,930	10	2.42	26
Southern Cities							
Atlanta GA	1,780	1,540	1,150	6,350	33	0.97	2
Memphis TN	830	420	1,980	9,640	22	1.92	19
Miami FL	1,810	470	3,850	29,230	2	4.30	38
Nashville TN	540	490	1,110	11,100	20	1.89	18
Tampa FL	670	440	1,530	9,340	23	1.44	11
Southwestern Cities							
Albuquerque NM	490	250	1,940	13,540	14	2.80	31
Austin TX	500	350	1,430	5,990	35	1.22	7
Corpus Christi TX	280	180	1,570	8,230	26	1.83	15
Dallas TX	1,950	1,440	1,360	5,680	36	1.18	5
Denver CO	1,550	890	1,750	11,800	19	2.07	22
El Paso TX	510	210	2,490	15,170	12	3.93	37
Fort Worth TX	1,150	850	1,360	4,970	38	1.02	3
Houston TX	2,850	1,630	1,750	6,250	34	1.21	6
Phoenix AZ	1,830	970	1,890	17,200	8	2.97	34
Salt Lake City UT	790	460	1,710	4,150	39	0.76	1
San Antonio TX	1,170	480	2,450	10,510	21	2.25	24
Western Cities							
Los Angeles CA	11,140	2,150	5,180	36,390	1	5.58	39
Portland OR	950	410	2,300	8,000	27	1.28	2
Sacramento CA	1,040	350	2,970	19,010	5	3.00	35
San Diego CA	2,180	700	3,130	12,730	16	2.33	25
San Fran-Oak CA	3,610	830	4,350	16,310	9	2.46	28
Seattle-Everett WA	1,630	720	2,270	12,330	17	2.06	21
Northeastern Avg.	5,020	1,240	3,560	17,020		2.69	
Midwestern Avg.	2,060	770	2,390	9,730		1.82	
Southern Avg.	1,120	670	1,920	13,130		2.10	
Southwestern Avg.	1,190	700	1,790	9,410		1.93	
Western Avg.	3,420	860	3,370	17,460		2.79	
Total Avg.	2,360	820	2,490	12,390		2.17	
Maximum Value	16,320	3,190	5,180	36,390		5.58	
Minimum Value	280	180	1,110	4,150		0.76	

Notes: [1]Daily vehicle-miles of travel per square mile of urbanized area
[2]Lane-miles per square mile of urbanized area
[3]Rank value of 1 associated with most congested condition

Source: TTI Analysis and Local Transportation Agency References

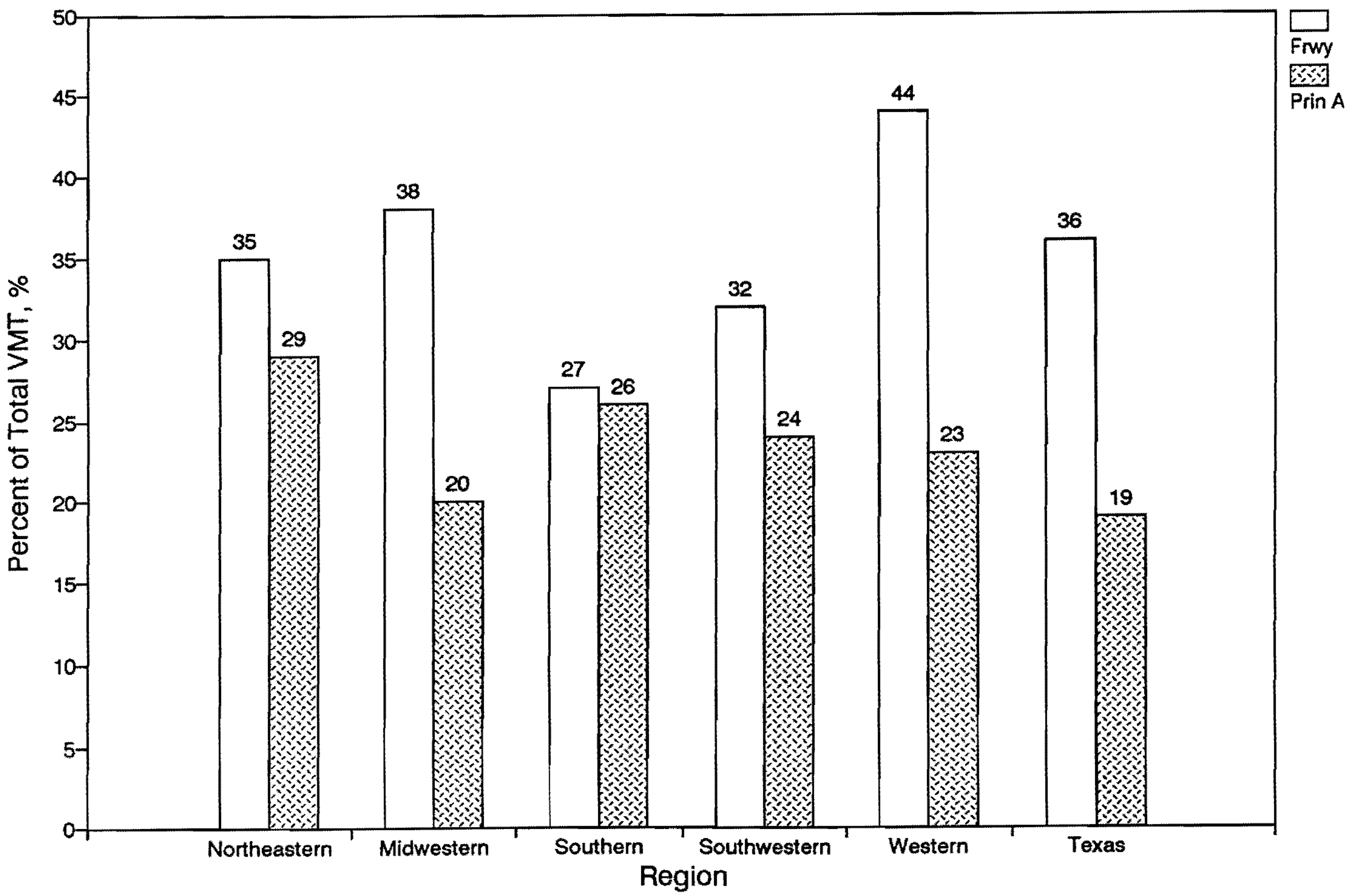

Figure 2. Facility Travel Volume by Geographic Region

Note. Texas Urban areas are included in the Southwestern Regional Average

Table 8. 1988 Urbanized Area Travel by Facility Type

Urbanized Area	Daily Vehicle-Miles of Travel Fwy/Expwy	Prin.Art.Str.	Area Total	Fwy/Expwy[1] % of Total	Prin.Art.Str.[1] % of Total	Fwy/Prin.Art.Str. % of Total
Northeastern Cities						
Baltimore MD	13,920	9,160	33,330	42	27	69
Boston MA	22,720	12,860	49,260	46	26	72
New York NY	78,010	49,710	221,430	35	22	57
Philadelphia PA	16,680	22,120	64,250	26	34	60
Pittsburgh PA	7,380	10,630	30,490	24	35	59
Washington DC	23,600	18,800	61,480	38	31	69
Midwestern Cities						
Chicago IL	31,970	26,070	113,010	28	23	51
Cincinnati OH	9,750	3,440	22,430	43	15	58
Cleveland OH	12,670	5,010	29,730	43	17	60
Detroit MI	22,020	21,670	76,620	29	28	57
Indianapolis IN	7,750	3,940	18,550	42	21	63
Kansas City MO	12,220	4,490	25,270	48	18	66
Louisville KY	6,040	2,860	17,450	35	16	51
Milwaukee WI	7,140	4,730	27,810	26	17	43
Minn-St. Paul MN	16,420	5,300	41,430	40	13	53
Oklahoma City OK	6,620	3,450	18,000	37	19	56
St. Louis MO	17,390	11,470	40,780	43	28	71
Southern Cities						
Atlanta GA	22,970	9,790	57,210	40	17	57
Memphis TN	3,950	4,050	14,970	26	27	53
Miami FL	7,890	13,740	33,540	24	41	65
Nashville TN	5,250	5,390	15,050	35	36	71
Tampa FL	3,440	4,070	14,690	23	28	51
Southwestern Cities						
Albuquerque NM	2,230	3,390	9,710	23	35	58
Austin TX	5,220	2,070	11,660	45	18	63
Corpus Christi TX	1,510	1,440	6,260	24	23	47
Dallas TX	22,380	8,150	49,400	45	16	61
Denver CO	10,490	10,450	28,870	36	36	72
El Paso TX	3,320	3,110	8,900	37	35	72
Fort Worth TX	11,150	4,200	26,600	42	16	58
Houston TX	27,100	10,190	69,170	39	15	54
Phoenix AZ	5,550	16,680	38,060	15	44	59
Salt Lake City UT	4,080	1,910	14,140	29	14	43
San Antonio TX	9,050	4,990	22,910	39	22	61
Western Cities						
Los Angeles CA	102,140	78,240	234,410	44	33	77
Portland OR	7,100	3,280	18,550	38	18	56
Sacramento CA	8,420	6,660	21,960	38	30	68
San Diego CA	25,040	8,850	47,480	53	19	72
San Fran-Oak CA	40,370	13,540	74,790	54	18	72
Seattle-Everett WA	17,190	8,820	39,030	44	23	67
Northeastern Avg	27,050	20,550	76,710	35	29	64
Midwestern Avg	13,630	8,400	39,190	38	20	58
Southern Avg	8,700	7,410	27,090	30	30	60
Southwestern Avg	9,280	6,050	25,970	34	25	59
Western Avg	33,380	19,900	72,700	45	24	69
Texas Avg	11,390	4,880	27,840	39	21	60
Total Avg	16,870	11,250	44,840	36	24	60
Maximum Value	102,140	78,240	234,410	54	44	77
Minimum Value	1,510	1,440	6,260	15	13	43

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

arterial street component percentages vary, the combined percentage of area DVMT served is approximately 60 percent for both the regional and studywide average.

The Midwestern and Western regions are shown to rely the most on freeway systems for the majority of their mobility needs. While the Northeastern, Southern, and Southwestern regions have a somewhat balanced demand on freeway and principal arterial street system. Analyzing the Texas cities, again show the tendancy of depending on freeways for the majority of the urbanized areas' mobility. For the Texas cities studied, an average 36 percent of the total VMT is served by the freeway system and 19 percent by the principal arterial street system. The remaining 46 percent of the area's VMT occurs on the lower functional classes of roadways, i.e., collectors and locals.

1988 Roadway Congestion Index Values

Urbanized Area freeway and principal arterial street system travel volume and travel volume per lane-mile are summarized in Table 9. Combining these statistics (Equation 1) results in the 1988 estimated roadway congestion index (RCI) (Table 9). An RCI value of 1.0 or greater indicates an undesirable areawide congestion level.

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

Of the 39 urbanized areas studied, 18 have RCI values equal to or greater than 1.0. The ten most congested urbanized areas have RCI values ranging between 1.52 (Los Angeles) and 1.10 (New York and Atlanta). Eight urbanized areas have roadway congestion index values between 0.99 and 0.90. Cities in this range could reach undesirable congestion levels in the near future. Urbanized areas in the Western region had the highest average RCI value while the Southwestern region experienced the lowest (Figure 3).

Houston, ranked 7th, was the only urbanized area in Texas among the top ten congested urbanized areas. Dallas (17th) was the only other Texas city exceeding the

Table 9. 1988 Roadway Congestion Index Value

Urbanized 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	102,140	20,590	78,240	6,520	1.52	1
San Fran-Oak CA	40,370	17,360	13,540	6,620	1.33	2
Washington DC	23,600	15,850	18,800	8,250	1.32	3
Chicago IL	31,970	14,500	26,070	6,940	1.18	4
Miami FL	7,890	13,710	13,740	6,800	1.18	4
Seattle-Everett WA	17,190	15,080	8,820	5,980	1.17	6
Houston TX	27,100	15,140	10,190	5,150	1.15	7
San Diego CA	25,040	14,770	8,850	5,460	1.13	8
Boston MA	22,720	15,040	12,860	4,780	1.12	9
New York NY	78,010	13,430	49,710	6,990	1.10	10
Atlanta GA	22,970	13,920	9,790	6,570	1.10	10
Detroit MI	22,020	13,430	21,670	6,160	1.09	12
Philadelphia PA	16,680	11,910	22,120	6,850	1.07	13
Portland OR	7,100	13,150	3,280	6,250	1.05	14
Tampa FL	3,440	11,860	4,070	6,500	1.03	15
Sacramento CA	8,420	12,470	6,660	6,340	1.03	15
Dallas TX	22,380	13,360	8,150	4,810	1.02	17
Phoenix AZ	5,550	10,670	16,680	5,790	1.00	18
Nashville TN	5,250	11,930	5,390	5,890	0.99	19
Denver CO	10,490	12,200	10,450	5,690	0.99	19
St. Louis MO	17,390	11,710	11,470	6,570	0.98	21
Cleveland OH	12,670	12,800	5,010	4,510	0.97	22
Austin TX	5,220	12,430	2,070	4,920	0.96	23
Milwaukee WI	7,140	12,200	4,730	4,770	0.94	24
Baltimore MD	13,920	11,500	9,160	5,260	0.92	25
Albuquerque NM	2,230	11,130	3,390	4,840	0.90	26
Cincinnati OH	9,750	11,540	3,440	4,320	0.88	27
Minn-St. Paul MN	16,420	11,440	5,300	4,530	0.88	27
Louisville KY	6,040	10,690	2,860	5,610	0.87	29
Fort Worth TX	11,150	11,150	4,200	4,860	0.87	29
Memphis TN	3,950	10,390	4,050	5,030	0.86	31
San Antonio TX	9,050	11,040	4,990	4,660	0.86	31
Indianapolis IN	7,750	10,760	3,940	4,640	0.84	33
Pittsburgh PA	7,380	7,770	10,630	6,020	0.81	34
Oklahoma City OK	6,620	9,390	3,450	5,260	0.78	35
El Paso TX	3,320	9,490	3,110	3,860	0.74	36
Kansas City MO	12,220	9,090	4,490	4,300	0.72	37
Salt Lake City UT	4,080	8,490	1,910	5,460	0.72	37
Corpus Christi TX	1,510	8,160	1,440	4,500	0.70	39
Northeastern Avg.	27,050	12,580	20,550	6,360	1.06	
Midwestern Avg.	13,630	11,590	8,400	5,240	0.92	
Southern Avg.	8,700	12,360	7,410	6,160	1.03	
Southwestern Avg.	9,280	11,200	6,050	4,960	0.90	
Western Avg.	33,380	15,570	19,900	6,190	1.21	
Total Avg.	16,870	12,350	11,250	5,600	0.99	
Maximum Value	102,140	20,590	78,240	8,250	1.52	
Minimum Value	1,510	7,770	1,440	3,860	0.70	

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 5

undesirable congestion level. The average RCI value for the five largest Texas urbanized areas (Austin, Dallas, Fort Worth, Houston, and San Antonio) was 0.97 while the average for all seven Texas cities studied was slightly lower (0.90).

Traffic Congestion Growth, 1982 to 1988

The roadway congestion index values for each urbanized area from 1982 to 1988 are summarized in Table 10. Tables C-3 through C-16 provide additional detailed yearly system information for the cities in this study. From 1982 to 1988, San Diego, Nashville, and San Francisco-Oakland were estimated to have the fastest congestion growth rate while Phoenix, Detroit, and Houston experienced the lowest.

The annual percent change in RCI value for the ten most congested urbanized areas in 1988 is shown in Figure 4. This Figure illustrates the change for the entire study period (1982 to 1988), an intermediate period (1985 to 1988), and the most recent percent change (1987 to 1988). Los Angeles and Atlanta data indicates that the congestion growth rate has declined in recent years. Conversely, Boston has experienced an increasing congestion growth rate for all years included in this study. Houston is the only urbanized area in the top ten that has shown a consistent decreasing congestion growth rate for these time periods.

The summary statistics show that all regions have experienced annual increases in average RCI values during the study period with the exception of the Southwestern region (Figure 5). This region had approximately a one percent decrease in the average regional RCI value from 1987 to 1988. The urbanized areas in Texas had an average that remained constant at 0.90 from 1987 to 1988 after showing a two percent decrease from 1986 to 1987. San Antonio and El Paso were the only two Texas urbanized areas that had increasing RCI values from 1987 to 1988. The RCI value for Fort Worth and Dallas remained unchanged from the 1987 level. Overall, urbanized areas studied in Texas showed a constant decreasing trend over the past three years.

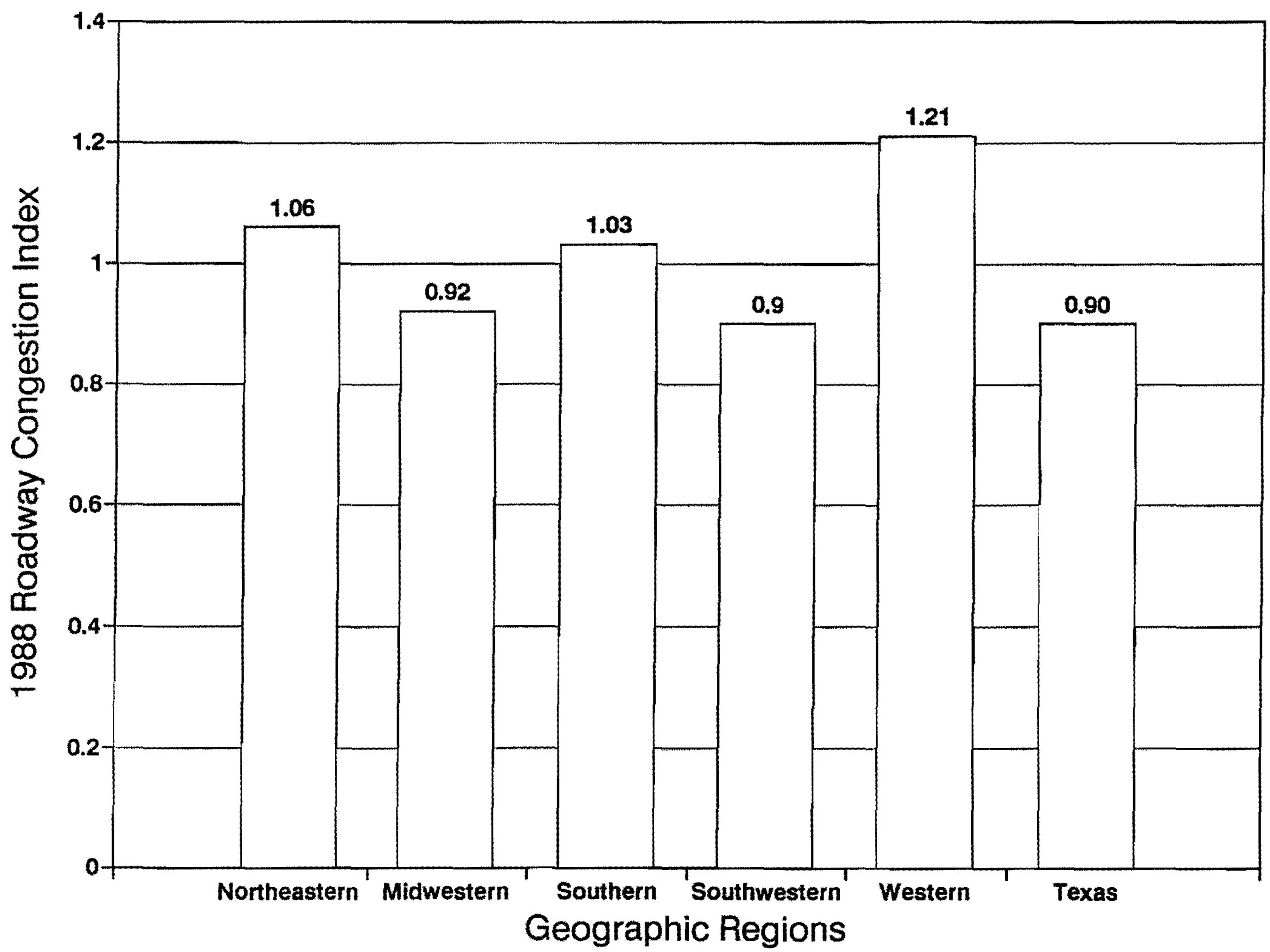

Figure 3. 1988 Roadway Congestion Index

Table 10. Roadway Congestion Index Values, 1982 to 1988

Urbanized Area	Year							Percent Change 1982 to 1988
	1982	1983	1984	1985	1986	1987	1988	
Phoenix AZ	1.15	1.16	1.10	1.13	1.20	1.18	1.00	-13
Detroit MI	1.13	1.10	1.13	1.12	1.11	1.10	1.09	-4
Houston TX	1.17	1.21	1.25	1.23	1.21	1.19	1.15	-2
Memphis TN	0.86	0.80	0.76	0.75	0.77	0.84	0.86	0
Cincinnati OH	0.86	0.83	0.82	0.83	0.84	0.87	0.88	2
Pittsburgh PA	0.78	0.76	0.76	0.78	0.79	0.79	0.81	4
Louisville KY	0.84	0.82	0.81	0.79	0.80	0.88	0.87	4
Corpus Christi TX	0.67	0.69	0.69	0.71	0.71	0.72	0.70	4
Philadelphia PA	1.00	1.03	1.04	0.90	1.06	1.06	1.07	7
Oklahoma City OK	0.72	0.72	0.75	0.74	0.71	0.76	0.78	8
New York NY	1.01	1.02	0.99	1.00	1.06	1.06	1.10	9
Baltimore MD	0.84	0.84	0.85	0.84	0.88	0.90	0.92	10
Tampa FL	0.94	0.91	1.03	1.00	0.96	1.02	1.03	10
Miami FL	1.05	1.09	1.07	1.13	1.10	1.14	1.18	12
San Antonio TX	0.77	0.79	0.82	0.87	0.90	0.85	0.86	12
Milwaukee WI	0.83	0.84	0.87	0.88	0.90	0.95	0.94	13
Fort Worth TX	0.76	0.79	0.80	0.82	0.87	0.87	0.87	14
Salt Lake City UT	0.63	0.63	0.65	0.68	0.68	0.70	0.72	14
Albuquerque NM	0.78	0.83	0.89	0.93	0.88	0.91	0.90	15
Chicago IL	1.02	1.02	1.05	1.08	1.15	1.15	1.18	16
Kansas City MO	0.62	0.62	0.60	0.65	0.69	0.71	0.72	16
Denver CO	0.85	0.88	0.93	0.96	0.97	0.95	0.99	16
El Paso TX	0.63	0.64	0.65	0.70	0.75	0.71	0.74	17
Indianapolis IN	0.71	0.66	0.75	0.76	0.80	0.85	0.84	18
St. Louis MO	0.83	0.87	0.88	0.89	0.93	0.96	0.98	18
Minn-St. Paul MN	0.74	0.79	0.81	0.83	0.87	0.87	0.88	19
Cleveland OH	0.80	0.82	0.83	0.81	0.86	0.89	0.97	21
Dallas TX	0.84	0.89	0.94	0.98	1.04	1.02	1.02	21
Portland OR	0.87	0.86	0.88	0.93	0.97	1.00	1.05	21
Washington DC	1.07	1.09	1.12	1.20	1.28	1.30	1.32	23
Seattle-Everett WA	0.95	0.99	1.02	1.05	1.09	1.14	1.17	23
Boston MA	0.90	0.93	0.95	0.98	1.04	1.04	1.12	24
Atlanta GA	0.89	0.94	0.97	1.02	1.09	1.15	1.10	24
Austin TX	0.77	0.84	0.89	0.91	0.98	0.96	0.96	25
Los Angeles CA	1.22	1.27	1.32	1.36	1.42	1.47	1.52	25
Sacramento CA	0.80	0.84	0.88	0.92	0.95	1.00	1.03	29
San Fran-Oak CA	1.01	1.05	1.12	1.17	1.24	1.31	1.33	32
Nashville TN	0.74	0.76	0.83	0.81	0.86	0.95	0.99	34
San Diego CA	0.78	0.83	0.91	0.95	1.00	1.08	1.13	45
Northeastern Avg.	0.93	0.95	0.95	0.95	1.02	1.03	1.06	
Midwestern Avg.	0.83	0.83	0.85	0.85	0.88	0.91	0.92	
Southern Avg.	0.90	0.90	0.93	0.94	0.96	1.02	1.03	
Southwestern Avg.	0.82	0.85	0.87	0.90	0.93	0.91	0.90	
Western Avg.	0.94	0.97	1.02	1.06	1.11	1.17	1.21	
Total Avg.	0.87	0.88	0.91	0.93	0.96	0.98	0.99	
Maximum Value	1.22	1.27	1.32	1.36	1.42	1.47	1.52	
Minimum Value	0.62	0.62	0.60	0.65	0.68	0.70	0.70	

Source: Equation 1 and Tables 2, 5, and C-3 to C-16

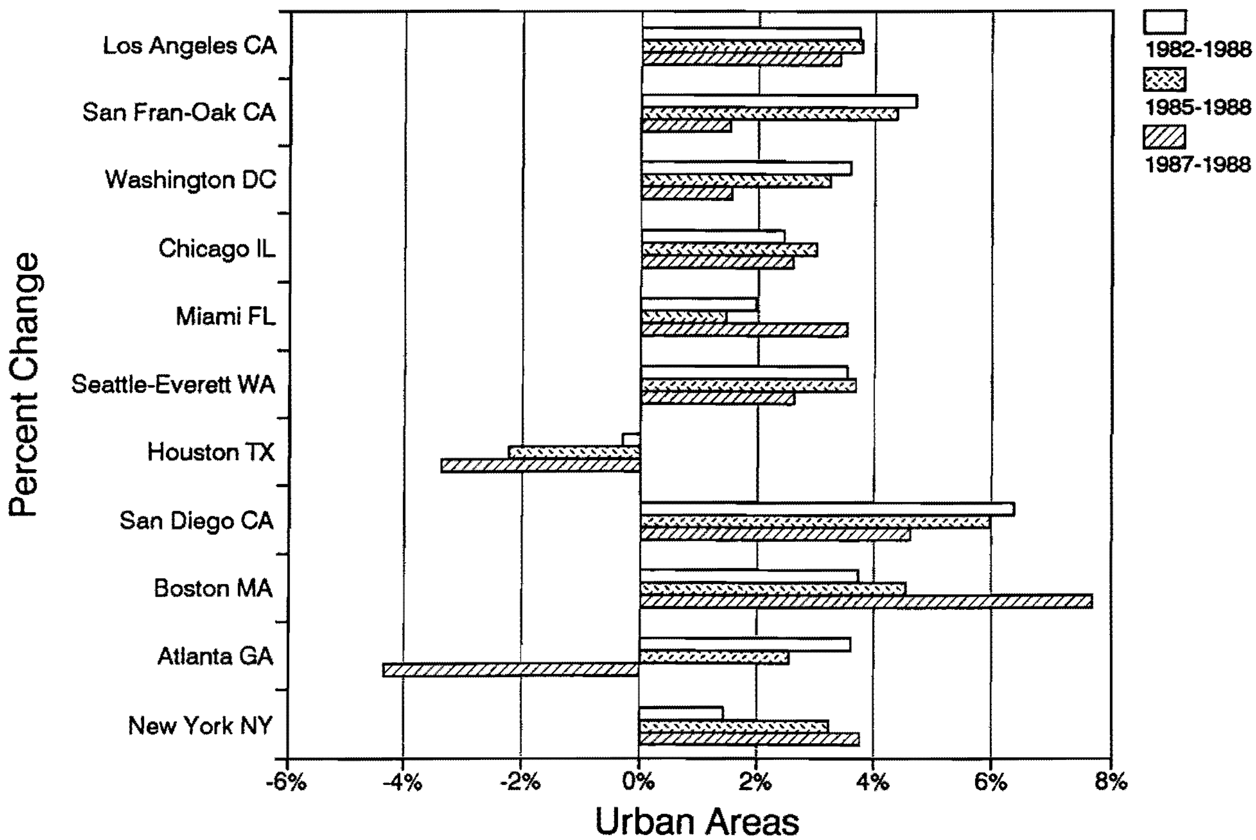

Figure 4. Annual Percent Change of Roadway Congestion Index Value for the Ten Most Congested Urbanized Areas.

Figure 5 shows RCI changes during the same time periods as Figure 4. The Northeast was the only region with increasing congestion growth rates between 1982 and 1988. The urbanized areas in Texas account for much of the decrease in the growth rate in the Southwest. Between 1987 and 1988, however, Phoenix had the largest decrease in congestion growth at a rate of 15 percent. The graph indicates the other three regions are all experiencing decreasing congestion growth rates. The Southern region has the highest increase of those regions from 1987 to 1988.

Conclusions

Freeway and principal arterial street system travel volumes and travel volume per lane-mile characteristics were collected for 39 urbanized areas in five geographic regions from 1982 to 1988. The analysis presented in this section combined these roadway characteristics into a roadway congestion index (RCI). This value provides an estimate of the areawide congestion level prevailing within the urbanized area and a method to compare mobility in the various urbanized areas included in this study.

The travel volume characteristics were also analyzed on a per facility type basis. This analysis indicated that urbanized areas in the Southern region depend heavily on both the freeway and principal arterial street systems for mobility. In contrast, Texas has the highest travel volumes placed upon its freeway system and the Northeastern region had higher travel volumes on the principal arterial street system than other regions in the study. These "unbalanced" travel demands may be attributed to the design of each roadway system. In Texas and many other urbanized areas throughout the Southwest and West, the freeway systems are highly developed while many of the principal arterial street systems are not used for longer trips. Urbanized areas in the Northeastern region have more highly developed principal arterial street systems, and more constrictive freeway system designs.

The average roadway congestion index values have increased each year in all regions, with the Western region having the highest average and the Southwestern region

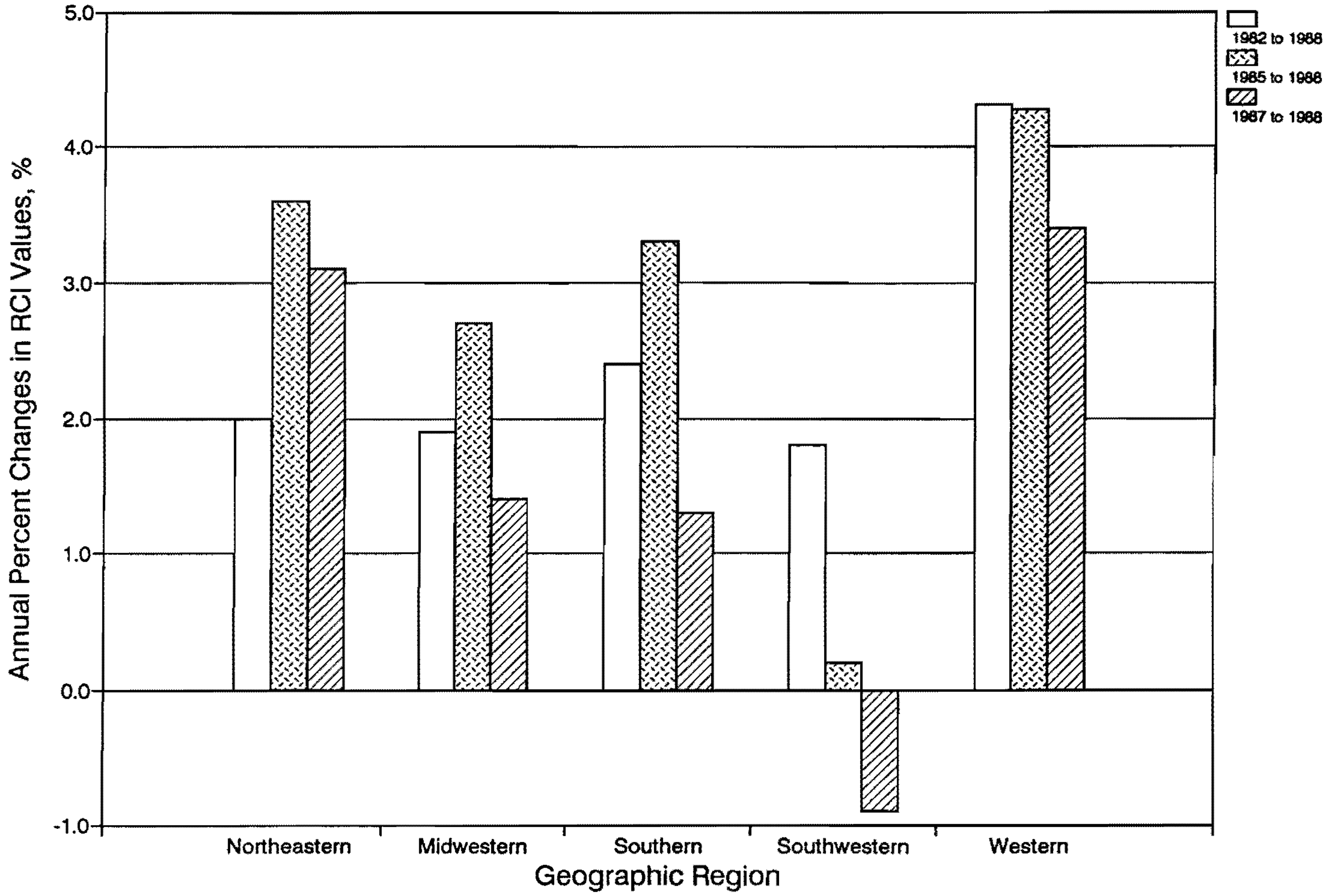

Figure 5. Annual Percent Change in Roadway Congestion Indices by Geographic Region

the lowest. The average Texas RCI has decreased since 1986 when the average peaked at 0.92. Eighteen of the 39 urbanized areas studied have RCI values in excess or equal to 1.0, the undesirable congestion level. Of these 18 cities, only five (Phoenix, Detroit, Houston, Atlanta, and Dallas) had a decreasing congestion index value from 1987 to 1988. Houston is the only urbanized area in the ten most congested exhibiting a continual decrease in the RCI value since 1985.

While the Midwestern, Southern, Southwestern, and Western regions experienced decreasing congestion growth rates, the Northeastern region has an increasing growth rate (Figure 5). The majority of the reduction in the Southwestern congestion growth rate may be attributed to urbanized areas within Texas. The urbanized areas studied in Texas have experienced a declining congestion growth rate since 1985.

IMPACTS OF URBAN CONGESTION

The impacts of urban congestion in terms of additional lane-miles, travel delay, and air quality will be summarized and presented in this section. These indicators represent the burden of congestion on both the urbanized area transportation agencies and the general population.

Additional Lane-Miles Required to Achieve RCI = 1.0

One method to alleviate urban congestion is to provide additional freeway and principal arterial street lane-miles. Table 11 illustrates the number of lane-miles required to achieve an RCI value of 1.0. The assumptions used in this analysis were that the only measure used to alleviate congestion was added system lane-miles, and that travel volumes and patterns remained constant.

In the case of Los Angeles, 2,580 freeway lane-miles and 6,240 principal arterial street lane-miles would have to be constructed in order to reduce the RCI value from 1.52 to 1.0. This represents increasing the number of freeway and principal arterial street lane-miles by approximately 52 percent for each type of facility. Using a conservative at-grade construction estimate of $25 (freeways) and $10 (principal arterial streets) per square foot, the estimated construction cost would be approximately $8 billion. Reducing Houston's RCI value to 1.0 would require increasing freeway lane-miles by 18 percent (270 lane-miles) and principal arterial street lane-miles by approximately 15 percent (300 lane-miles) at an estimated cost of $620 million. The average reliance on the freeway system in the Texas cities studied was quite high when compared to the principal arterial street system. Improving the RCI values, therefore, with the area's travel volumes and patterns remaining constant will require a larger percentage of additional freeway lane-miles.

In summary, the total cost of adding the additional lane-miles required to reduce the RCI values studywide to 1.0 would be approximately $17 billion. Approximately $7 billion would be required to increase the principal arterial street lane-miles with the remaining $10 billion for freeway system lane-mile construction. To achieve RCI values equal or below 1.0 for all 39 cities within the study, 11,280 principal arterial street lane-miles and 6,270 freeway lane-miles would have to be constructed in 17 urbanized areas. Reviewing the results of this analysis it is apparent that construction of additional lane-miles as the sole alternative is not feasible.

The relationship between change in vehicle-miles of travel (VMT) and lane-miles on freeways and principal arterial street systems is illustrated in Figure 6. This graph shows the combined percent change from 1982 to 1988 in VMT and facility lane-miles for the ten most congested urbanized areas in 1988. In every urbanized area with the exception of Houston, traffic volumes (VMT) increased at approximately twice the rate of facility lane-miles. All of the ten most congested urbanized areas except Houston also have worse levels of congestion, (larger RCI values), in 1988 than 1982. Houston has had a larger increase in facility lane-miles than vehicle-miles of travel resulting in a lower 1988 RCI value than estimated in 1982.

Table 11. Cost of Additional Facilities Required to Achieve a Roadway Congestion Index of 1.0

Urbanized Area	Additional Lane-Miles Required[1,2]		Cost of Additional Lane-Miles ($Million)[3]		
	Freeway	Prin. Arterial St.	Freeway	Prin. Arterial St.	Total
Los Angeles CA	2,580	6,240	$4,090	$3,950	$ 8,040
San Fran-Oak CA	770	680	1,220	430	1,650
New York NY	580	710	920	450	1,370
Washington DC	480	730	760	460	1,220
Chicago IL	400	680	630	430	1,060
Houston TX	270	300	430	190	620
Boston MA	180	320	290	200	490
San Diego CA	220	210	350	130	480
Seattle-Everett WA	190	250	300	160	460
Detroit MI	150	320	240	200	440
Miami FL	100	360	160	230	390
Atlanta GA	170	150	270	100	370
Philadelphia PA	100	230	160	150	310
Dallas TX	30	30	50	20	70
Portland OR	30	30	50	20	70
Sacramento CA	20	30	30	20	50
Tampa FL	10	20	20	10	30
Totals	6,270	11,280	$9,970	$7,150	$17,120

Notes: [1]Assumes travel demand and patterns remain constant
[2]Additional lane-miles is the only system modification
[3]Assumes at-grade construction cost of $25/sq.ft. (freeways) and $10/sq.ft. (principal arterial streets)

Source: TTI Analysis

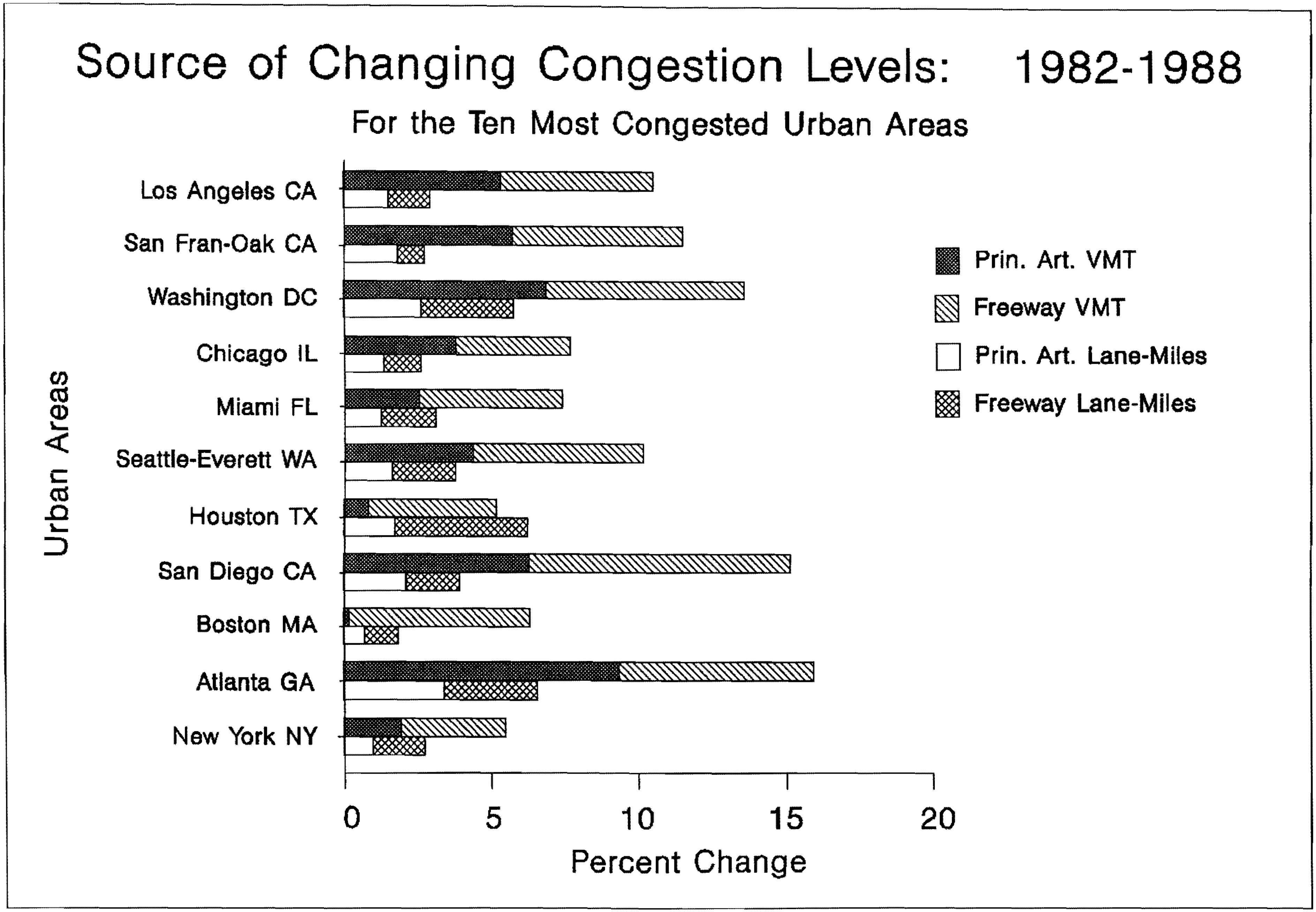

Figure 6. Source of Changing Roadway Congestion Levels

Travel Delay

The impact of congestion that may be most apparent to residents of an urbanized area is travel delay. Analyses utilized in this study identified two types of delay -- recurring and incident. Recurring delay was defined as delay which occurs due to normal daily operations. An example of recurring delay would be the increasing of travel time during peak periods of operation. Incident delay refers to delay occurring from an accident, vehicle breakdown, fire, or other random occurrence not expected during a routine day.

Delay was also categorized by the severity (moderate, heavy, and severe) of the congestion based on average daily traffic volumes per lane (5). Tables 12 and 13 illustrate the delay types and categories on the freeway and principal arterial street systems. Table 14 summarizes vehicle-hours of delay by type of delay and the ranks of the urbanized areas studied. The rankings in Table 14 are similar to those derived from RCI values. Summary statistics show that the Northeastern and Western regions have the largest amount of average vehicle-hours of delay, while the remaining three regions are approximately equal.

Table 12. Freeway and Expressway Recurring and Incident Hours of Daily Delay for 1988[1]

Urbanized Area	Recurring Hours of Delay				Incident Hours of Delay			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	2,610	12,310	3,190	18,110	5,990	28,320	7,350	41,660
Boston MA	4,960	20,300	33,530	58,790	17,370	71,050	117,340	205,760
New York NY	29,270	153,460	42,350	225,080	73,160	383,650	105,860	562,670
Philadelphia PA	4,980	14,200	1,250	20,430	10,460	29,810	2,630	42,900
Pittsburgh PA	140	7,580	160	7,880	400	21,990	450	22,840
Washington DC	12,120	49,070	19,350	80,540	26,670	107,950	42,570	177,190
Midwestern Cities								
Chicago IL	9,870	35,150	55,040	100,060	11,840	42,180	66,050	120,070
Cincinnati OH	2,200	11,840	840	14,880	1,760	9,480	670	11,910
Cleveland OH	1,120	15,270	120	16,510	790	10,690	80	11,560
Detroit MI	5,370	21,110	22,540	49,020	11,820	46,440	49,580	107,840
Indianapolis IN	950	2,790	0	3,740	1,420	4,190	0	5,610
Kansas City MO	200	2,490	610	3,300	620	7,730	1,880	10,230
Louisville KY	190	1,050	360	1,600	210	1,150	400	1,760
Milwaukee WI	740	8,250	2,650	11,640	740	8,250	2,650	11,640
Minn-St. Paul MN	1,080	21,110	4,570	26,760	970	19,000	4,110	24,080
Oklahoma City OK	350	3,040	0	3,390	390	3,340	0	3,730
St. Louis MO	900	12,680	0	13,580	1,080	15,220	0	16,300
Southern Cities								
Atlanta GA	1,300	44,120	11,500	56,920	1,430	48,540	12,650	62,620
Memphis TN	230	1,790	0	2,020	250	1,970	0	2,220
Miami FL	2,180	6,860	18,830	27,870	3,270	10,280	28,250	41,800
Nashville TN	610	5,670	600	6,880	670	6,240	660	7,570
Tampa FL	1,020	1,200	2,400	4,620	1,520	1,800	3,590	6,910
Southwestern Cities								
Albuquerque NM	70	1,110	1,440	2,620	80	1,220	1,580	2,880
Austin TX	2,340	12,030	0	14,370	2,580	13,230	0	15,810
Corpus Christi TX	80	700	0	780	80	770	0	850
Dallas TX	6,990	37,560	22,540	67,090	12,580	67,610	40,570	120,760
Denver CO	2,300	19,870	6,070	28,240	2,300	19,870	6,070	28,240
El Paso TX	300	3,130	0	3,430	330	3,440	0	3,770
Fort Worth TX	2,530	13,610	8,170	24,310	4,560	24,500	14,700	43,760
Houston TX	7,920	41,310	60,030	109,260	11,080	57,830	84,040	152,950
Phoenix AZ	2,580	9,790	5,350	17,720	1,030	3,920	2,140	7,090
Salt Lake City UT	240	2,790	170	3,200	140	1,670	100	1,910
San Antonio TX	1,060	12,790	6,220	20,070	1,170	14,070	6,840	22,080
Western Cities								
Los Angeles CA	14,910	56,350	407,610	478,870	17,890	67,610	489,130	574,630
Portland OR	3,310	8,340	2,620	14,270	6,630	16,680	5,240	28,550
Sacramento CA	4,060	14,130	450	18,640	2,430	8,480	270	11,180
San Diego CA	8,280	24,640	29,260	62,180	4,970	14,790	17,560	37,320
San Fran-Oak CA	12,420	36,660	145,270	194,350	16,150	47,650	188,850	252,650
Seattle-Everett WA	11,290	29,830	22,670	63,790	15,810	41,760	31,740	89,310
Northeastern Avg.	9,010	42,820	16,640	68,470	22,340	107,130	46,030	175,500
Midwestern Avg.	2,090	12,250	7,890	22,230	2,880	15,240	11,400	29,520
Southern Avg.	1,070	11,930	6,670	19,660	1,430	13,770	9,030	24,230
Southwestern Avg.	2,400	14,060	10,000	26,460	3,270	18,920	14,190	36,370
Western Avg.	9,050	28,320	101,310	138,680	10,650	32,830	122,130	165,610
Total Avg.	4,180	19,900	24,050	48,120	6,990	32,930	34,250	74,170
Maximum Value	29,270	153,460	407,610	478,860	73,160	383,650	489,130	574,630
Minimum Value	70	700	0	780	80	770	0	850

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

Source: TTI Analysis

Table 13. Principal Arterial Street Recurring and Incident Hours of Daily Delay for 1988[1]

Urbanized Area	Recurring Hours of Delay				Incident Hours of Delay			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	680	2,560	9,470	12,710	750	2,820	10,420	13,990
Boston MA	1,070	6,280	11,830	19,180	1,180	6,910	13,010	21,100
New York NY	6,680	38,180	114,940	159,800	7,350	42,000	126,430	175,780
Philadelphia PA	2,550	14,050	51,920	68,520	2,810	15,460	57,110	75,380
Pittsburgh PA	560	9,840	14,680	25,080	620	10,820	16,140	27,580
Washington DC	1,870	19,480	43,060	64,410	2,050	21,430	47,360	70,840
Midwestern Cities								
Chicago IL	3,610	22,090	36,390	62,090	3,970	24,300	40,020	68,290
Cincinnati OH	170	1,810	810	2,790	180	1,990	900	3,070
Cleveland OH	480	3,300	380	4,160	530	3,630	420	4,580
Detroit MI	2,250	5,640	48,240	56,130	2,480	6,210	53,060	61,750
Indianapolis IN	200	1,830	280	2,310	210	2,020	310	2,540
Kansas City MO	60	930	4,040	5,030	60	1,030	4,450	5,540
Louisville KY	500	3,230	810	4,540	550	3,550	890	4,990
Milwaukee WI	390	3,650	1,010	5,050	430	4,010	1,110	5,550
Minn-St. Paul MN	730	2,630	7,680	11,040	800	2,900	8,450	12,150
Oklahoma City OK	20	2,920	1,440	4,380	30	3,210	1,590	4,830
St. Louis MO	1,640	12,540	5,380	19,560	1,800	13,800	5,920	21,520
Southern Cities								
Atlanta GA	2,420	4,130	15,760	22,310	2,660	4,550	17,340	24,550
Memphis TN	340	2,830	1,310	4,480	370	3,120	1,450	4,940
Miami FL	130	9,630	33,480	43,240	150	10,590	36,830	47,570
Nashville TN	280	1,510	7,480	9,270	310	1,660	8,230	10,200
Tampa FL	280	2,060	8,040	10,380	310	2,260	8,840	11,410
Southwestern Cities								
Albuquerque NM	380	2,600	320	3,300	410	2,860	350	3,620
Austin TX	260	1,480	1,320	3,060	280	1,630	1,450	3,360
Corpus Christi TX	10	200	20	230	10	220	20	250
Dallas TX	470	6,200	630	7,300	520	6,820	690	8,030
Denver CO	2,370	8,590	2,980	13,940	2,610	9,450	3,280	15,340
El Paso TX	30	430	0	460	30	480	0	510
Fort Worth TX	240	3,200	320	3,760	270	3,520	350	4,140
Houston TX	610	11,970	4,440	17,020	670	13,170	4,880	18,720
Phoenix AZ	2,520	19,530	26,640	48,690	2,770	21,490	29,300	53,560
Salt Lake City UT	190	1,730	360	2,280	210	1,910	390	2,510
San Antonio TX	180	1,240	1,090	2,510	200	1,360	1,200	2,760
Western Cities								
Los Angeles CA	8,600	44,200	93,770	146,570	9,460	48,620	103,150	161,230
Portland OR	450	3,410	2,730	6,590	500	3,750	3,000	7,250
Sacramento CA	670	6,250	4,240	11,160	740	6,870	4,670	12,280
San Diego CA	150	7,740	640	8,530	160	8,510	700	9,370
San Fran-Oak CA	1,650	4,630	27,320	33,600	1,820	5,090	30,050	36,960
Seattle-Everett WA	890	7,180	9,650	17,720	980	7,900	10,610	19,490
Northeastern Avg.	2,240	15,070	40,980	58,280	2,460	16,570	45,080	64,110
Midwestern Avg.	910	5,510	9,680	16,100	1,000	6,060	10,650	17,710
Southern Avg.	690	4,030	13,220	17,940	760	4,440	14,540	19,730
Southwestern Avg.	660	5,200	3,470	9,320	730	5,720	3,810	10,260
Western Avg.	2,070	12,230	23,060	37,360	2,280	13,460	25,360	41,100
Total Avg.	1,190	7,740	15,250	24,190	1,310	8,510	16,780	26,600
Maximum Value	8,600	44,200	114,940	159,800	9,460	48,620	126,440	175,780
Minimum Value	10	200	0	230	10	220	0	250

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

Source: TTI Analysis

Table 14. Total Vehicle Hours of Delay for 1988

Urbanized Area	Vehicle Hours of Delay: Recurring	Vehicle Hours of Delay: Incident	Vehicle Hours of Delay: Total	Vehicle Hours of Delay: Rank[1]	Total Delay per 1000 Persons	Rank[1]
Northeastern Cities						
Baltimore MD	30,830	55,650	86,480	16	50	23
Boston MA	77,980	226,870	304,850	6	110	5
New York NY	384,870	738,460	1,123,330	2	70	12
Philadelphia PA	88,960	118,280	207,240	9	50	20
Pittsburgh PA	32,950	50,420	83,370	18	50	23
Washington DC	144,940	248,020	392,960	4	130	2
Midwestern Cities						
Chicago IL	162,150	188,370	350,520	5	50	22
Cincinnati OH	17,670	14,970	32,640	30	30	28
Cleveland OH	20,680	16,140	36,820	25	20	32
Detroit MI	105,150	169,580	274,730	8	70	11
Indianapolis IN	6,060	8,160	14,220	33	20	37
Kansas City MO	8,330	15,760	24,090	31	20	32
Louisville KY	6,140	6,750	12,890	35	20	34
Milwaukee WI	16,690	17,190	33,880	28	30	29
Minn-St. Paul MN	37,800	36,230	74,030	20	40	26
Oklahoma City OK	7,780	8,560	16,340	32	20	31
St. Louis MO	33,150	37,820	70,970	21	40	27
Southern Cities						
Atlanta GA	79,240	87,170	166,410	12	90	8
Memphis TN	6,500	7,150	13,650	34	20	34
Miami FL	71,110	89,370	160,480	13	90	9
Nashville TN	16,150	17,760	33,910	27	60	15
Tampa FL	14,990	18,340	33,330	29	50	20
Southwestern Cities						
Albuquerque NM	5,920	6,510	12,430	36	30	30
Austin TX	17,430	19,170	36,600	26	70	10
Corpus Christi TX	1,000	1,100	2,100	39	10	39
Dallas TX	74,390	128,790	203,180	10	100	7
Denver CO	42,180	43,570	85,750	17	60	17
El Paso TX	3,890	4,270	8,160	38	20	34
Fort Worth TX	28,070	47,890	75,960	19	70	14
Houston TX	126,280	171,690	297,970	7	110	5
Phoenix AZ	66,410	60,640	127,050	14	70	12
Salt Lake City UT	5,480	4,430	9,910	37	10	38
San Antonio TX	22,590	24,850	47,440	24	40	25
Western Cities						
Los Angeles CA	625,430	735,860	1,361,290	1	120	3
Portland OR	20,870	35,800	56,670	22	60	16
Sacramento CA	29,810	23,470	53,280	23	50	19
San Diego CA	70,700	46,680	117,380	15	50	18
San Fran-Oak CA	227,950	289,610	517,560	3	140	1
Seattle-Everett WA	81,510	108,800	190,310	11	120	4
Northeastern Avg.	126,750	239,620	366,370		70	
Midwestern Avg.	38,330	47,230	85,560		30	
Southern Avg.	37,600	43,960	81,560		60	
Southwestern Avg.	35,790	46,630	82,410		50	
Western Avg.	176,050	206,700	382,750		90	
Total Avg.	72,310	100,770	173,080		60	
Maximum Value	625,430	738,460	1,361,290		140	
Minimum Value	1,000	1,100	2,100		10	

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

Source: TTI Analysis

Air Quality

The primary pollutant resulting from motor vehicles is carbon monoxide, however, the primary pollutant resulting from traffic congestion is ozone. It has been estimated that 50 to 60 percent of ozone precursors are caused by vehicle emissions. For this reason, the Environmental Protection Agency has established air quality standards for acceptable ozone levels. An ozone level of 0.12 parts per million (ppm) daily maximum one hour average may not be exceeded more than once per year on average for an urbanized area to meet air quality standards (7). Table 15 compares the 1988 RCI values and ozone levels. This table contains ozone level data for 30 of the 39 urbanized areas studied. The nine urbanized areas either having acceptable ozone levels or not reported include: Seattle-Everett, Denver, Austin, Albuquerque, Minneapolis-St. Paul, Fort Worth, San Antonio, Oklahoma City, and Corpus Christi. All of the remaining urbanized areas are non-attainment areas, with the exception of Tampa. Comparing the RCI and ozone level values does not indicate a close correlation between the respective rankings.

Table 15. Congestion in Relation with Air Quality Standards

Urbanized Area	Roadway Congestion Index	Rank	Ozone[1,2] Level (ppm)	Rank
Los Angeles	1.52	1	0.330	1
San Fran-Oak	1.33	2	0.140	24
Washington	1.32	3	0.179	10
Chicago	1.18	4	0.215	4
Miami	1.18	5	0.147	21
Seattle-Everett	1.17	6	--[3]	--[3]
Houston	1.15	7	0.220	2
San Diego	1.13	8	0.190	7
Boston	1.12	9	0.169	14
New York	1.10	10	0.217	3
Atlanta	1.10	11	0.170	11
Detroit	1.09	12	0.147	21
Philadelphia	1.07	13	0.200	5
Portland	1.05	14	0.127	28
Tampa	1.03	15	0.117	30
Sacramento	1.03	15	0.170	11
Dallas	1.02	17	0.140	24
Phoenix	1.00	18	0.120	29
Nashville	0.99	19	0.138	26
Denver	0.99	19	--	--
St. Louis	0.98	21	0.153	18
Cleveland	0.97	22	0.167	16
Austin	0.96	23	--	--
Milwaukee	0.94	24	0.188	8
Baltimore	0.92	25	0.194	6
Albuquerque	0.90	26	--	--
Cincinnati	0.88	27	0.169	14
Minn-St. Paul	0.88	27	--	--
Louisville	0.87	29	0.183	9
Fort Worth	0.87	29	--	--
Memphis	0.86	31	0.148	20
San Antonio	0.86	31	--	--
Indianapolis	0.84	33	0.137	27
Pittsburgh	0.81	34	0.157	17
Oklahoma City	0.78	35	--	--
El Paso	0.74	36	0.170	11
Kansas City	0.72	37	0.153	18
Salt Lake City	0.72	37	0.143	23
Corpus Christi	0.70	39	--	--

Notes: [1]National Ambient Air Quality Standard is 0.12 parts per million (ppm)
[2]Considered non-attainment area if ozone level exceeds 0.12 ppm more than one day per year.
[3]Data not reported or available

Source: TTI Analysis and Environmental Protection Agency 1988 data

COST OF URBAN CONGESTION

This section presents the analysis of the economic impact of congestion. The analysis procedure was based on a methodology developed for the Houston Regional Mobility Plan (8). This procedure is discussed in detail in Appendix D of this report. The economic impact of congestion was estimated in 39 urbanized areas located in five geographic regions. Seven of the largest Texas urbanized areas (Austin, Corpus Christi, Dallas, El Paso, Fort Worth, Houston, and San Antonio) are contained in the Southwestern region. The remaining 32 cities represent a cross-sectional sample of other large metropolitan areas throughout the country.

Methodology

The analysis procedure used to evaluate the impact of congestion in a specific urbanized area had two basic input units. These units were daily vehicle-miles of travel (DVMT) and population. Table 16 provides a summary of the basic data for each urbanized area analyzed. The DVMT data was obtained from the Federal Highway Administration's Highway Performance Monitoring System (HPMS) (5) and various state and local agencies. The population data were estimated from HPMS and U.S. Census Bureau estimates. Appendix E discusses the estimation procedure used for this data.

Congestion costs were based on the congested peak-period VMT for both freeways and principal arterial streets. The congested VMT consist of the percentage of total vehicle travel operating in congested conditions. Congested conditions were estimated to begin at the transition from level-of-service C to D (Appendix A). Traffic volumes representative of congested conditions were estimated as 15,000 vehicles per lane per day for freeway/expressway facilities and 5,750 vehicles per lane per day for principal arterial street facilities. HPMS sample data were utilized to estimate the percentage of an urbanized area's DVMT occurring on facilities with traffic volumes exceeding congested levels.

The amount of DVMT operating in congested conditions was identified for each urbanized area then congested DVMT was categorized by severity. Congestion severity affects travel time and delay by causing decreased facility speeds as the congestion increases. The categories and associated peak-period speeds used in this study were illustrated in Table 1. Categorizing facility congestion levels and assigning the appropriate travel speed allows a more appropriate areawide representation of congestion and the associated costs.

Economic Impact Estimates

The economic impact of congestion was estimated by three cost components: traffic delay, excess fuel and increased vehicle insurance premiums. Traffic delay and excess fuel costs were estimated for incident and recurring events encountered by motorists. For the purpose of this study, recurring congestion was defined as congestion resulting from normal daily facility operations. Incident congestion occurs as a result of an accident, vehicle breakdown, or any other event not typically encountered during normal operations. Appendix D discusses the congestion cost calculation in detail.

Study Constants

The congestion cost analysis and calculations utilize six independent variables. These constant values were utilized in the calculations for each urbanized area studied.

1. Average vehicle occupancy -- 1.25 persons
2. Working days per year -- 250
3. Average cost of time (9) -- $8.80 per person-hour[1]
4. Commercial vehicle operation cost (10) -- $1.75 per mile
5. Vehicle mix -- 95 percent passenger and 5 percent commercial
6. Vehicular speeds -- as shown in Table 1

[1]The referenced value of $8.00 per hour in 1985 was adjusted using the 1988 Consumer Price Index (CPI).

Table 16. Summary of 1988 DVMT Values and Population for Congestion Cost Estimates

Urbanized Area	Daily Vehicle-Miles of Travel (1000)			Population (1000)
	Freeway/ Expressway	Principal Arterial Street	Freeway and Arterial	
Northeastern Cities				
Baltimore MD	13,920	9,160	23,080	1,910
Boston MA	22,720	12,860	35,580	2,910
New York NY	78,010	49,710	127,720	16,320
Philadelphia PA	16,680	22,120	38,790	4,130
Pittsburgh PA	7,380	10,630	18,010	1,850
Washington DC	23,600	18,800	42,400	3,040
Midwestern Cities				
Chicago IL	31,970	26,070	58,030	7,340
Cincinnati OH	9,750	3,440	13,190	950
Cleveland OH	12,670	5,010	17,680	1,790
Detroit MI	22,020	21,670	43,690	3,900
Indianapolis IN	7,750	3,940	11,690	930
Kansas City MO	12,220	4,490	16,710	1,150
Louisville KY	6,040	2,860	8,900	810
Milwaukee WI	7,140	4,730	11,860	1,230
Minn-St. Paul MN	16,420	5,300	21,720	1,930
Oklahoma City OK	6,620	3,450	10,070	720
St. Louis MO	17,390	11,470	28,860	1,950
Southern Cities				
Atlanta GA	22,970	9,790	32,750	1,780
Memphis TN	3,950	4,050	8,000	830
Miami FL	7,890	13,740	21,630	1,810
Nashville TN	5,250	5,390	10,640	540
Tampa FL	3,440	4,070	7,510	670
Southwestern Cities				
Albuquerque NM	2,230	3,390	5,610	490
Austin TX	5,220	2,070	7,290	500
Corpus Christi TX	1,510	1,440	2,950	280
Dallas TX	22,380	8,150	30,530	1,950
Denver CO	10,490	10,450	20,940	1,550
El Paso TX	3,320	3,110	6,430	510
Fort Worth TX	11,150	4,200	15,350	1,150
Houston TX	27,100	10,190	37,290	2,850
Phoenix AZ	5,550	16,680	22,230	1,830
Salt Lake City UT	4,080	1,910	5,990	790
San Antonio TX	9,050	4,990	14,040	1,170
Western Cities				
Los Angeles CA	102,140	78,240	180,380	11,140
Portland OR	7,100	3,280	10,380	950
Sacramento CA	8,420	6,660	15,080	1,040
San Diego CA	25,040	8,850	33,880	2,180
San Fran-Oak CA	40,370	13,540	53,910	3,610
Seattle-Everett WA	17,190	8,820	26,010	1,630
Northeastern Avg.	27,050	20,550	47,600	5,020
Midwestern Avg.	13,630	8,400	22,030	2,060
Southern Avg.	8,700	7,410	16,100	1,120
Southwestern Avg.	9,280	6,050	15,330	1,190
Western Avg.	33,380	19,900	53,270	3,420
Total Avg.	16,870	11,250	28,120	2,360
Maximum Value	102,140	78,240	180,380	16,320
Minimum Value	1,510	1,440	2,950	280

Source: TTI Analysis and Local Transportation Agency References

Urbanized Area Variables

Five area-specific variables were also utilized in the congestion cost estimate. These variables are discussed in Appendix D of this report; this section will briefly describe each variable.

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. Insurance rates -- the difference between the urban average, excluding large metropolitan areas, and the average premium paid within a specific urbanized area.
3. Fuel cost -- the state average fuel cost per gallon for 1988.
4. Registered vehicles -- the number of registered vehicles as reported by local agencies.
5. Population -- estimate using 1988 U.S. Census Bureau estimates and 1988 HPMS data.

Measures of Effectiveness

This study utilized the delay, fuel, and insurance costs to estimate and analyze the effect of congestion in each urbanized area. The economic impact of congestion was stated in terms of annual urbanized area congestion cost, cost per registered vehicle, and cost per capita.

Delay and fuel costs were calculated for both incident and recurring events. These costs were affected by the severity of congestion present on the freeway and principal arterial street systems. The additional insurance premium cost for each area was also estimated. For the purpose of this study, the total cost reported was the sum of delay, fuel, and insurance costs.

The cost component accounting for the majority of congestion costs was travel delay. As estimated in this study, delay is defined as the total vehicle-hours per day spent by motorists operating vehicles on facilities under congested conditions. As the facility becomes more congested, travel conditions deteriorate and travel speeds become slower. The more speeds are reduced, the greater delay encountered by the motorists. For this reason, congested traffic ranges with associated peak-condition speeds were established (Table 1) to better represent areawide congested travel speeds. Delay is the most noticeable impact of congestion to motorists because it directly impacts their commuting travel time.

Fuel cost represents the excess fuel consumed by vehicles operating under congested conditions. Slower speeds result in less efficient and longer periods of operation for vehicles. This congestion cost element is relatively small when compared to delay, however, it is still a major congestion cost factor.

Insurance premiums are the third major congestion related cost estimate in this study. Vehicles operating in congested conditions generally are at greater risk of being involved in an accident. Higher accident rates in large urbanized areas usually equate to higher insurance premiums paid by motorist operating vehicles in this area when compared to a more rural setting. For this reason, 70 percent of the insurance premiums were estimated to be associated with claims, while the remaining 30 percent was related to overhead and expense costs of the carrier. Because insurance premiums are not solely a function of the accident rates, congestion costs were reported including and excluding insurance related costs.

The congestion cost estimates were presented in terms of total annual costs, cost per capita, and cost per registered vehicle. Presenting cost values on a per capita basis allows a comparison of these costs with respect to individual urbanized area residents. A cost comparison was also made with respect to the number of registered vehicles within the urbanized area. This comparison displays cost in terms of the vehicles operating on the freeway and principal arterial street systems. As previously mentioned, all of these cost comparisons were reported including and excluding insurance costs.

Result of the Economic Analysis

Table 17 illustrates the component and total congestion cost for each urbanized area. The cost of congestion including all components exceeded $34 billion in 1988. This results in an average cost per urbanized area of $880 million. Delay, both recurring and non-recurring, accounted for approximately 65 percent of congestion cost of all urbanized areas studied, while fuel costs represented approximately ten percent of the total cost.

All of the top ten urbanized areas with regards to cost had a total congestion cost exceeding $1 billion in 1988. The only Texas city ranked in the top ten was Houston (8th). Dallas (11th) and Fort Worth (19th) were the only other Texas cities ranked in the top half of those cities studied. Congestion in the Texas urbanized areas included in this study resulted in a cost of approximately $3.3 billion including insurance, and $2.6 billion excluding insurance.

Reviewing the summary statistics, the highest congestion cost for delay and fuel occurs in the Western region while the highest total congestion cost (delay, fuel, and insurance) is in the Northeastern region. The average urbanized area total congestion cost in Texas was approximately 52 percent lower than the average of urbanized areas outside Texas. However, the Texas urbanized area average of ($470) was marginally higher than the Midwestern and Southern regional averages and eighty percent larger than the remaining Southwestern regional average eliminating the Texas urbanized areas from the regional average.

Table 18 illustrates the estimated economic impact of congestion on a per capita and per registered vehicle basis. These values represent the "tax" on an individual resident and vehicle imposed by congestion within an urbanized area. Urbanized areas in the Midwestern region had the lowest cost values in all four categories. The highest per vehicle costs are in the Northeastern region, while the highest per capita costs are

Table 17. Component and Total Congestion Costs By Urbanized Area for 1988

Urbanized Area	Annual Cost Due to Congestion ($Millions)						Total Delay, Fuel &Insurance	Rank
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost	Insurance		
Los Angeles CA	2,060	2,420	350	410	5,240	1,640	6,880	1
New York NY	1,270	2,440	200	380	4,290	1,760	6,040	2
San Fran-Oak CA	760	960	130	160	2,010	340	2,340	3
Chicago IL	530	620	90	100	1,340	540	1,880	4
Washington DC	480	820	80	130	1,510	220	1,730	5
Philadelphia PA	290	380	40	60	770	780	1,550	6
Detroit MI	340	550	50	90	1,030	470	1,510	7
Houston TX	420	570	70	90	1,150	310	1,470	8
Boston MA	260	750	40	120	1,170	120	1,280	9
Miami FL	230	290	40	50	610	430	1,040	10
Dallas TX	250	430	40	70	790	170	960	11
Seattle-Everett WA	270	360	50	60	740	60	800	12
Atlanta GA	260	290	40	50	640	100	730	13
San Diego CA	240	160	40	30	470	110	570	14
Pittsburgh PA	110	160	20	20	310	250	570	14
Baltimore MD	100	180	20	30	330	190	520	16
Phoenix AZ	220	200	40	30	490	40	520	16
Denver CO	140	140	20	20	320	70	400	18
Fort Worth TX	90	160	20	30	300	80	380	19
Minn-St. Paul MN	130	120	20	20	290	70	360	20
St. Louis MO	110	120	20	20	270	80	350	21
Sacramento CA	100	80	20	10	210	100	300	22
Cleveland OH	70	50	10	10	140	140	290	23
Portland OR	70	120	10	20	220	50	270	24
San Antonio TX	80	80	10	10	180	70	250	25
Nashville TN	50	60	10	10	130	40	170	26
Milwaukee WI	60	60	10	10	140	30	160	27
Tampa FL	50	60	10	10	130	30	160	27
Austin TX	60	60	10	10	140	10	160	27
Cincinnati OH	60	50	10	10	130	20	150	30
Memphis TN	20	20	0	0	40	70	120	31
Kansas City MO	30	50	0	10	90	20	110	32
Oklahoma City OK	30	30	0	0	60	30	90	33
Indianapolis IN	20	30	0	0	50	20	80	34
Louisville KY	20	20	0	0	40	30	70	35
Albuquerque NM	20	20	0	0	40	10	60	36
Salt Lake City UT	20	10	0	0	30	20	60	36
El Paso TX	10	10	0	0	20	20	50	38
Corpus Christi TX	0	0	0	0	0	10	20	39
Northeastern Avg.	420	790	70	120	1,390	550	1,950	
Midwestern Avg.	130	160	20	30	330	130	460	
Southern Avg.	120	140	20	20	310	130	440	
Southwestern Avg.	120	160	20	30	320	70	390	
Western Avg.	580	680	100	120	1,480	380	1,860	
Total Avg.	240	330	40	50	660	220	880	
Maximum Value	2,060	2,440	350	410	5,230	1,760	6,870	
Minimum Value	0	0	0	0	10	10	20	

Source: TTI Analysis and Local Transportation Agency References

Table 18. Estimated Economic Impact of Congestion in 1988

Urbanized Area	Cost Per Registered Vehicle		Cost Per Capita	
	Total Congestion (Dollars)	Delay & Fuel (Dollars)	Total Congestion (Dollars)	Delay & Fuel (Dollars)
Northeastern Cities				
Baltimore MD	520	330	270	170
Boston MA	830	760	440	400
New York NY	1,030	730	370	260
Philadelphia PA	570	280	380	190
Pittsburgh PA	470	260	310	170
Washington DC	1,050	920	570	500
Midwestern Cities				
Chicago IL	470	330	260	180
Cincinnati OH	160	140	150	130
Cleveland OH	200	100	160	80
Detroit MI	520	360	390	270
Indianapolis IN	140	100	80	60
Kansas City MO	170	130	100	80
Louisville KY	160	110	90	60
Milwaukee WI	310	250	130	110
Minn-St. Paul MN	220	180	180	150
Oklahoma City OK	200	130	130	90
St. Louis MO	370	280	180	140
Southern Cities				
Atlanta GA	480	420	410	360
Memphis TN	200	90	140	60
Miami FL	770	450	570	330
Nashville TN	340	260	310	240
Tampa FL	270	210	240	190
Southwestern Cities				
Albuquerque NM	160	130	120	100
Austin TX	320	300	320	290
Corpus Christi TX	60	40	50	30
Dallas TX	600	500	490	410
Denver CO	290	250	260	220
El Paso TX	150	90	100	60
Fort Worth TX	370	290	330	260
Houston TX	660	520	520	410
Phoenix AZ	450	410	290	260
Salt Lake City UT	90	60	80	50
San Antonio TX	280	210	220	160
Western Cities				
Los Angeles CA	880	670	620	470
Portland OR	440	350	280	230
Sacramento CA	240	170	290	200
San Diego CA	410	330	260	210
San Fran-Oak CA	780	670	650	560
Seattle-Everett WA	680	630	490	460
Northeastern Avg.	750	550	390	280
Midwestern Avg.	260	190	170	120
Southern Avg.	410	280	340	240
Southwestern Avg.	310	250	250	200
Western Avg.	570	470	430	350
Total Avg.	420	320	290	220
Maximum Value	1,050	920	650	560
Minimum Value	60	40	50	30

Source: TTI Analysis and Local Transportation Agency References

in the Western region. This cost is the result of the lower vehicle ownership rates in the Northeastern region.

Comparison of Urban Mobility Levels

Table 19 presents the ranking of urbanized areas for annual, per capita, and per registered vehicle cost both including and excluding insurance. Overall, the rank of urbanized areas does not seem to be affected by either normalizing with population or registered vehicles, with few exceptions. Fourteen urbanized areas occupy the top ten positions in all categories with minor variations in rank.

Five urbanized areas, Boston, Washington, Dallas, Houston, Los Angeles, and San Francisco-Oakland, occupy positions in the top ten regardless of the cost category analyzed. New York and Philadelphia typify the impact of the vehicle ownership rates prevalent in the Northeast. These two cities rank higher in the cost per vehicle category when compared to their respective ranking in the cost per capita category. The remaining urbanized areas in the study have more consistent rankings between these categories. Dallas, Fort Worth, and Houston are the only Texas cities consistently ranked in the top half in all categories. Dallas and Houston maintained positions in the top ten for all categories.

Conclusions

This section presented an economical analysis which estimated the congestion costs (delay, fuel and insurance) for 39 U.S. urbanized areas based on travel volume and facility supply. In general, the highest total annual congestion cost occurs in the Northeastern region, with the Western regional average marginally lower. The urbanized areas within these regions also rank high with respect to the roadway congestion index. The cost per capita and cost per vehicle analyses offer different indices that normalized the effects of size and population and may allow a better comparison between urbanized areas.

Table 19. 1988 Rankings of Urbanized Area by Estimated Economic Impact of Congestion

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

Table 20 summarizes daily vehicle-miles of travel, RCI values and congestion cost per capita for 1987 and 1988. The congestion cost values for 1987 were adjusted utilizing the methodology changes implemented in this report. Texas urbanized areas maintained a decreasing trend in roadway congestion index values and rankings. Overall, RCI and cost per capita value remained consistent from 1987 to 1988. Phoenix had the most dramatic RCI change 5th to 18th while cost per capita value remained virtually unchanged.

1986 and 1987 congestion cost estimates are shown in Tables 21, 22, 23, and 24. The costs presented in these Tables utilize the methodology as contained in this report. For that reason, congestion costs shown in these Tables are different than ones presented in previous reports.

Table 20. 1988 Congestion Index Values

Urbanized Area	DVMT/Ln-Mile		Roadway Congestion Index			Congestion Cost Per Capita	
	Frwy	Prin. Art Street	1988 Value	Rank 1987	Rank 1988	1987	1988
Northeastern Cities							
Baltimore MD	11,500	5,260	0.92	25	25	270	270
Boston MA	15,040	4,780	1.12	14	9	330	440
New York NY	13,430	6,990	1.10	12	10	340	370
Philadelphia PA	11,910	6,850	1.07	12	13	360	380
Pittsburgh PA	7,770	6,020	0.81	34	34	270	310
Washington DC	15,850	8,250	1.32	3	3	530	570
Midwestern Cities							
Chicago IL	14,500	6,940	1.18	6	4	250	260
Cincinnati OH	11,540	4,320	0.88	28	27	120	150
Cleveland OH	12,800	4,510	0.97	26	22	150	160
Detroit MI	13,430	6,160	1.09	10	12	370	390
Indianapolis IN	10,760	4,640	0.84	31	33	N/A	80
Kansas City MO	9,090	4,300	0.72	37	37	90	100
Louisville KY	10,690	5,610	0.87	27	29	90	90
Milwaukee WI	12,200	4,770	0.94	21	24	120	130
Minn-St. Paul MN	11,440	4,530	0.88	28	27	170	180
Oklahoma City OK	9,390	5,260	0.78	35	35	N/A	130
St. Louis MO	11,710	6,570	0.98	19	21	210	180
Southern Cities							
Atlanta GA	13,920	6,570	1.10	6	10	510	410
Memphis TN	10,390	5,030	0.86	33	31	130	140
Miami FL	13,710	6,800	1.18	8	4	480	570
Nashville TN	11,930	5,890	0.99	21	19	230	310
Tampa FL	11,860	6,500	1.03	15	15	190	240
Southwestern Cities							
Albuquerque NM	11,130	4,840	0.90	24	26	N/A	120
Austin TX	12,430	4,920	0.96	19	23	320	320
Corpus Christi TX	8,160	4,500	0.70	36	39	50	50
Dallas TX	13,360	4,810	1.02	15	17	470	490
Denver CO	12,200	5,690	0.99	21	19	250	260
El Paso TX	9,490	3,860	0.74	37	36	90	100
Fort Worth TX	11,150	4,860	0.87	28	29	310	330
Houston TX	15,140	5,150	1.15	4	7	490	520
Phoenix AZ	10,670	5,790	1.00	5	18	220	290
Salt Lake City UT	8,490	5,460	0.72	39	37	80	80
San Antonio TX	11,040	4,660	0.86	31	31	220	220
Western Cities							
Los Angeles CA	20,590	6,520	1.52	1	1	620	620
Portland OR	13,150	6,250	1.05	17	14	210	280
Sacramento CA	12,470	6,340	1.03	17	15	230	290
San Diego CA	14,770	5,460	1.13	11	8	220	260
San Fran-Oak CA	17,360	6,620	1.33	2	2	630	650
Seattle-Everett WA	15,080	5,980	1.17	8	6	440	490

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 21. Component and Total Congestion Costs By Urbanized Area for 1986

Urbanized Area	Annual Cost Due to Congestion ($ Millions)						
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay/Fuel Cost (Millions)	Insurance	Total
Northeastern Cities							
Baltimore MD	--[1]	--	--	--	--	--	--
Boston MA	--	--	--	--	--	--	--
New York NY	--	--	--	--	--	--	--
Philadelphia PA	--	--	--	--	--	--	--
Pittsburgh PA	--	--	--	--	--	--	--
Washington DC	--	--	--	--	--	--	--
Midwestern Cities							
Chicago IL	--	--	--	--	--	--	--
Cincinnati OH	--	--	--	--	--	--	--
Cleveland OH	--	--	--	--	--	--	--
Detroit MI	--	--	--	--	--	--	--
Indianapolis IN	--	--	--	--	--	--	--
Kansas City MO	20	40	0	0	60	40	100
Louisville KY	20	20	0	0	40	10	50
Milwaukee WI	40	40	10	10	100	30	130
Minn-St Paul MN	90	90	10	10	200	50	250
Oklahoma City OK	--	--	--	--	--	--	--
St Louis MO	120	140	70	80	410	130	550
Southern Cities							
Atlanta GA	250	280	40	40	610	100	700
Memphis TN	20	20	0	0	40	30	70
Miami FL	150	190	20	30	390	320	20
Nashville TN	30	40	10	10	90	10	90
Tampa FL	40	40	10	10	100	10	110
Southwestern Cities							
Albuquerque NM	10	20	0	0	30	10	40
Austin TX	60	70	10	10	150	20	170
Corpus Christi TX	0	0	0	0	0	0	10
Dallas TX	240	420	40	60	760	150	910
Denver CO	120	130	20	20	290	30	320
El Paso TX	10	10	0	0	20	0	20
Fort Worth TX	90	150	10	20	270	40	310
Houston TX	400	540	60	80	1,080	250	1,330
Phoenix AZ	170	140	30	20	360	60	420
Salt Lake City UT	10	10	0	0	20	10	30
San Antonio TX	70	80	10	10	170	20	190
Western Cities							
Los Angeles CA	1,880	2,220	300	350	4,750	2,470	7,220
Portland OR	50	80	10	10	150	30	180
Sacramento CA	60	50	10	10	130	130	260
San Diego CA	160	110	30	20	320	140	460
San Fran-Oakland CA	600	770	100	120	1,590	620	2,210
Seattle-Everett WA	190	250	30	40	510	10	520
Northeastern Avg.	--	--	--	--	--	--	--
Midwestern Ave.	40	50	10	20	120	40	160
Southern Avg.	100	110	20	20	240	90	340
Southwestern Avg.	110	140	20	20	290	50	340
Western Avg.	90	80	80	90	1,240	70	1,800
Total Avg.	70	200	30	30	440	160	600
Maximum Value	1,880	2,220	300	350	4,750	2,470	7,220
Minimum Value	0	0	0	0	0	0	10

Note: [1]Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

Table 22. Estimated Economic Impact of Congestion in 1986

Urbanized Area	Total Congestion Cost Per Capita (Dollars)	Delay/Fuel Cost Per Capita (Dollars)	Total Congestion Cost Per Reg. Veh. (Dollars)	Delay/Fuel Cost Per Reg. Veh. (Dollars)
Northeastern Cities				
Baltimore MD	--[1]	--	--	--
Boston MA	--	--	--	--
New York NY	--	--	--	--
Philadelphia PA	--	--	--	--
Pittsburgh PA	--	--	--	--
Washington DC	--	--	--	--
Midwestern Cities				
Chicago IL	--	--	--	--
Cincinnati OH	--	--	--	--
Cleveland OH	--	--	--	--
Detroit MI	--	--	--	--
Indianapolis IN	--	--	--	--
Kansas City MO	160	100	90	50
Louisville KY	110	90	60	50
Milwaukee WI	170	130	110	80
Minn-St Paul MN	220	180	140	110
Oklahoma City OK	--	--	--	--
St Louis MO	400	300	280	210
Southern Cities				
Atlanta GA	500	430	410	360
Memphis TN	140	80	80	50
Miami FL	500	280	400	220
Nashville TN	250	230	180	170
Tampa FL	150	140	170	150
Southwestern Cities				
Albuquerque NM	110	90	90	80
Austin TX	360	320	350	310
Corpus Christi TX	40	30	40	30
Dallas TX	560	470	480	400
Denver CO	250	230	210	190
El Paso TX	100	90	70	70
Fort Worth TX	350	300	280	240
Houston TX	700	570	480	390
Phoenix AZ	380	320	240	200
Salt Lake City UT	60	40	50	40
San Antonio TX	250	220	210	190
Western Cities				
Los Angeles CA	940	620	670	440
Portland OR	290	240	170	140
Sacramento CA	230	110	260	130
San Diego CA	400	280	220	150
San Fran-Oak CA	820	590	640	460
Seattle-Everett WA	500	490	340	330
Northeastern Avg.	--	--	--	--
Midwestern Avg.	160	110	100	70
Southern Avg.	310	230	250	190
Southwestern Avg.	290	250	230	190
Western Avg.	530	390	380	270
Total Avg.	310	240	230	180
Maximum Value	940	620	670	460
Minimum Value	30	0	20	0

Note: [1]Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

Table 23. Component and Total Congestion Costs By Urbanized Area for 1987

Urbanized Area	Annual Cost Due to Congestion ($ Millions)						Total
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay/Fuel Cost (Millions)	Insurance	
Northeastern Cities							
Baltimore MD	100	170	20	30	320	190	510
Boston MA	190	540	30	80	840	100	940
New York NY	1,110	2,170	170	320	3,770	1,600	5,370
Philadelphia PA	270	360	40	50	720	750	1,470
Pittsburgh PA	90	140	10	20	260	230	490
Washington DC	440	760	70	120	1,390	190	1,580
Midwestern Cities							
Chicago IL	530	620	80	100	1,330	500	1,830
Cincinnati OH	50	40	10	10	110	10	120
Cleveland OH	60	50	10	10	130	250	380
Detroit MI	340	530	50	80	1,000	420	1,420
Indianapolis IN	--[1]	--	--	--	--	--	--
Kansas City MO	20	40	0	10	70	40	110
Louisville KY	20	20	0	0	40	20	60
Milwaukee WI	50	50	10	10	120	30	150
Minn-St Paul MN	120	110	20	20	270	70	340
Oklahoma City OK	--	--	--	--	--	--	--
St Louis MO	130	150	20	20	320	90	410
Southern Cities							
Atlanta GA	290	310	40	50	690	210	900
Memphis TN	20	20	0	0	40	60	100
Miami FL	180	230	30	10	480	380	860
Nashville TN	40	50	10	10	110	20	130
Tampa FL	40	50	10	10	110	20	130
Southwestern Cities							
Albuquerque NM	--	--	--	--	--	--	--
Austin TX	60	60	10	10	140	10	150
Corpus Christi TX	0	0	0	0	0	0	10
Dallas TX	230	410	40	40	750	150	900
Denver CO	130	130	20	20	300	70	370
El Paso TX	10	10	0	0	20	20	40
Fort Worth TX	90	150	10	10	270	70	340
Houston TX	390	530	60	60	1,070	300	1,370
Phoenix AZ	170	140	30	30	360	40	400
Salt Lake City UT	20	10	0	0	30	20	50
San Antonio TX	70	80	10	10	170	50	220
Western Cities							
Los Angeles CA	2,020	2,380	330	390	5,120	1,660	6,780
Portland OR	60	100	10	10	180	40	220
Sacramento CA	70	60	10	10	150	80	230
San Diego CA	200	130	30	20	380	60	440
San Fran-Oakland CA	710	900	120	150	1,880	350	2,230
Seattle-Everett WA	240	310	40	50	640	60	700
Northeastern Avg.	370	690	60	100	1,220	510	1,730
Midwestern Ave.	120	150	20	20	310	120	430
Southern Avg.	110	130	20	20	280	140	420
Southwestern Avg.	110	140	20	20	290	70	360
Western Avg.	550	650	90	110	1,390	380	1,770
Total Avg.	220	300	40	50	610	210	810
Maximum Value	2,020	2,390	330	390	5,120	1,660	6,780
Minimum Value	0	0	0	0	0	0	0

Notes: [1] Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

Table 24. Estimated Economic Impact of Congestion in 1987

Urbanized Area	Total Congestion Cost Per Capita (Dollars)	Delay/Fuel Cost Per Capita (Dollars)	Total Congestion Cost Per Reg. Veh. (Dollars)	Delay/Fuel Cost Per Reg. Veh. (Dollars)
Northeastern Cities				
Baltimore MD	510	310	270	170
Boston MA	620	550	330	290
New York NY	940	660	340	240
Philadelphia PA	550	270	360	180
Pittsburgh PA	410	210	270	140
Washington DC	980	860	530	470
Midwestern Cities				
Chicago IL	460	340	250	190
Cincinnati OH	130	110	120	110
Cleveland OH	180	80	140	70
Detroit MI	490	350	370	260
Indianapolis IN	--[1]	--	--	--
Kansas City MO	160	110	90	60
Louisville KY	160	110	90	60
Milwaukee WI	290	230	120	100
Minn-St Paul MN	210	170	170	140
Oklahoma City OK	--	--	--	--
St Louis MO	440	340	210	160
Southern Cities				
Atlanta GA	590	450	510	390
Memphis TN	180	80	130	60
Miami FL	640	350	480	260
Nashville TN	250	210	230	190
Tampa FL	210	180	190	170
Southwestern Cities				
Albuquerque NM	--	--	--	--
Austin TX	330	300	320	290
Corpus Christi TX	60	40	50	40
Dallas TX	570	470	470	390
Denver CO	280	230	250	200
El Paso TX	130	80	90	60
Fort Worth TX	350	280	310	250
Houston TX	620	480	490	380
Phoenix AZ	350	310	220	200
Salt Lake City UT	90	50	80	50
San Antonio TX	280	220	220	170
Western Cities				
Los Angeles CA	890	670	620	470
Portland OR	360	290	210	170
Sacramento CA	190	130	230	160
San Diego CA	350	300	220	190
San Fran-Oakland CA	760	640	630	530
Seattle-Everett WA	610	560	440	400
Northeastern Avg.	670	480	350	250
Midwestern Ave.	240	170	150	100
Southern Avg.	380	260	310	210
Southwestern Avg.	280	230	230	180
Western Avg.	530	430	390	320
Total Avg.	380	280	260	200
Maximum Value	980	870	630	530
Minimum Value	30	0	0	0

Notes: [1] Denotes Data Not Available

Source: TTI Analysis and Local Transportation Agency References

CONCLUSIONS

Relative mobility levels between 1982 and 1988 were presented and discussed in this report. Seven of these urbanized areas are in Texas and represent the largest metropolitan areas in the state. The 39 urbanized areas evaluated in this study represent a wide variety of travel and development patterns. These urbanized areas characterize a cross-section of urban development with varying populations, densities, travel demands, and roadway systems.

Study Modifications

Several modifications designed to provide a better estimate of urban mobility were included in this report. Modifications to the study methodology included an improved calculation of the number of lane-miles and the more detailed classification of congested travel by severity of congestion.

Previously, the average number of lanes was calculated using data from all HPMS sample sections for an urbanized area (5). This method was utilized because some states combined the roadway data for individual urbanized areas into larger groups of several areas for statistical reporting. In areas that do not have "grouped" data, the expansion factor can be applied to the sample data providing a better areawide representation of the roadway systems. Using a weighted average of this data results in a more representative areawide value. In the states utilizing "grouped" data (California, Florida, Ohio, Oregon, and Washington) the original method of calculating the average number of lanes was used. This procedure provides a more accurate input value from the HPMS data base used to estimate the number of roadway lane-miles for each urbanized area.

The second modification was associated with providing a more representative estimation of the effects of congestion. As a facility becomes more congested, the level of operation deteriorates, resulting in lower speeds. Analyzing Houston (6) travel time data, a relationship was established between peak-period speed and AADT per lane for freeways and principal arterial streets. These ranges of volume per lane were used to represent moderate, heavy, and severe congestion. The average speed for those ranges was also estimated. Combining these peak-period speeds with the appropriate congested DVMT categories result in improved travel delay estimates and a better estimate of how congestion changes from year to year.

Urbanized Area Mobility

One measure of urban mobility levels is the roadway congestion index. This value is based on the travel volume (DVMT) per lane-mile operating under undesirable conditions on the freeway and principal arterial street systems. The roadway congestion index, as stated in this report, is intended to be an urbanized area value representing the entire area and not site specific locations, i.e. bridges, tunnels, or other point of congestion.

A comparison of Tables 2 and 5 indicate which system, freeway or principal arterial street, urbanized areas rely on for mobility. Figure 2 graphically shows the percent of the total travel volume served by the urbanized area freeway and principal arterial street systems. The Northeastern and Southern regions tend to rely on both systems equally, while the remaining three regions are more freeway oriented. Texas urbanized areas rely on the freeway system for mobility with 36 percent of the total travel volume placed on the area freeways.

Table 10 summarizes RCI values from 1982 to 1988. Of the 39 urbanized areas included in this study, three have lower 1988 RCI values than were estimated for 1982 (Phoenix, Detroit and Houston). Trends in congestion growth rates for the individual regions are shown in Figure 5. The Northeastern area was the only region with increasing congestion growth rates. The largest decrease in the congestion growth rate is in the Southwestern region, with Texas congestion levels being the major contributing factor in the decline.

Urbanized Area Congestion Impacts

Congestion may also be quantified in terms of additional lane-miles and travel delay. While these indicators are independent of travel demand, they do illustrate the burden placed on the urbanized area and population by congestion.

One method to alleviate urban congestion is to provide additional lane-miles. Assuming that urbanized area travel patterns and demand are static and adding facility lane-miles was the only measure used to relieve congestion, the 17 urbanized areas with RCI values exceeding 1.0 were analyzed (Table 11). To achieve RCI values equal to or below 1.0 would require the construction of 6,270 freeway lane-miles and 11,280 principal arterial street lane-miles.

The relationship between travel volume and facility lane-miles is illustrated in Figure 6. While this figure shows that increasing facility lane-miles at faster rate than travel demand increases results in a decrease in congestion, as in Houston, this method of alleviating congestion alone could prove extremely costly.

The most notable impact of congestion is delay. This study identifies and estimates two types of delay, recurring and incident, (Tables 12 and 13). Table 14 summarizes vehicle-hours of delay by type and ranks the urbanized areas studied. The ranking of urbanized areas by delay is comparable to the roadway congestion index ranks in Table 9. Summary statistics show that the Northwestern and Western regions have the largest amount of vehicle-hours of delay which also correspond to the roadway congestion index analysis (Table 9).

Economic Impact of Congestion

Three factors were used to estimate the economic impact of congestion.

- Travel delay due to congested roadways and incidents

- Increase fuel consumption
- Increase insurance premiums

For comparative purposes, the annual estimated congestion cost represents the economic impact on an urbanized area of an inadequate roadway system. Large urbanized areas will have significant congestion cost values by virtue of their size. The estimate of congestion experienced by individual motorists in different urbanized areas may be achieved by normalizing the areawide economic impact by urban population and number of registered vehicles.

The total annual cost of congestion exceeded $34 billion in 1988. Ten of the urbanized areas studied were estimated to have annual congestion costs exceeding $1 billion. The average annual cost of 39 urbanized areas was approximately $880 million, with 65 percent being attributed to travel delay. Table 18 illustrates the estimated economic impact of congestion on the basis of per capita and per registered vehicle. These values represent the congestion "tax" paid by urbanized area residents and motorists.

Table 25 presents the comparison between ranking urbanized areas by the roadway congestion index and cost per capita and per registered vehicle. The comparison between the RCI and cost per capita ranks shows the effect of urban population. Chicago and New York are both removed from the top ten by virtue of their large urbanized area populations diluting the cost of congestion. Comparing the cost per registered vehicle value to the roadway congestion index New York is ranked 2nd. This represents the effect of the lower vehicle ownership rates within the area. Overall, ranking urbanized areas by congestion cost per capita and per registered vehicle, in general, corresponds to ranking areas by the RCI values.

Table 25. 1988 Urbanized Area Rankings By Roadway Congestion Index and Cost Per Capita

Urbanized Area	Roadway Congestion Index	Rank	Congestion Cost Per Capita (Dollars)	Rank	Congestion Cost Per Vehicle (Dollars)	Rank
Los Angeles CA	1.52	1	620	2	880	3
San Fran-Oak CA	1.33	2	650	1	780	5
Washington DC	1.32	3	570	3	1,050	1
Chicago IL	1.18	4	260	21	470	14
Miami FL	1.18	4	570	3	770	6
Seattle-Everett WA	1.17	6	490	6	680	7
Houston TX	1.15	7	520	5	660	8
San Diego CA	1.13	8	260	21	410	18
Boston MA	1.12	9	440	8	830	4
New York NY	1.10	10	370	12	1,030	2
Atlanta GA	1.10	10	410	9	480	13
Detroit MI	1.09	12	390	10	520	11
Philadelphia PA	1.07	13	380	11	570	10
Portland OR	1.05	14	290	19	440	17
Tampa FL	1.03	15	240	24	270	26
Sacramento CA	1.03	15	290	17	240	27
Dallas TX	1.02	17	490	6	600	9
Phoenix AZ	1.00	18	290	17	450	16
Nashville TN	0.99	19	310	15	340	21
Denver CO	0.99	19	260	21	290	24
St. Louis MO	0.98	21	180	26	370	19
Cleveland OH	0.97	22	160	28	200	29
Austin TX	0.96	23	320	14	320	22
Milwaukee WI	0.94	24	130	31	310	23
Baltimore MD	0.92	25	280	20	520	11
Albuquerque NM	0.90	26	120	33	160	33
Cincinnati OH	0.88	27	160	29	160	33
Minn-St. Paul MN	0.88	27	180	26	220	28
Louisville KY	0.87	29	90	36	160	33
Fort Worth TX	0.87	29	330	13	370	19
Memphis TN	0.86	31	140	30	200	29
San Antonio TX	0.86	31	220	25	280	25
Indianapolis IN	0.84	33	90	37	140	37
Pittsburgh PA	0.81	34	310	15	470	14
Oklahoma City OK	0.78	35	130	31	200	29
El Paso TX	0.74	36	100	34	150	36
Kansas City MO	0.72	37	100	34	170	29
Salt Lake City UT	0.72	37	80	37	90	38
Corpus Christi TX	0.70	39	50	39	60	39

Source: TTI Analysis

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APPENDIX A

DEVELOPMENT OF URBANIZED AREAWIDE CONGESTION MEASUREMENT METHODOLOGY

APPENDIX A

URBANIZED AREAWIDE CONGESTION MEASUREMENT METHODOLOGY DEVELOPMENT

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

Purpose of Congestion Measurement Techniques

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

Previous Urban Mobility Comparison Studies

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

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

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

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

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

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

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

Study Design

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

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

Houston's Experience with Declining Mobility

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

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

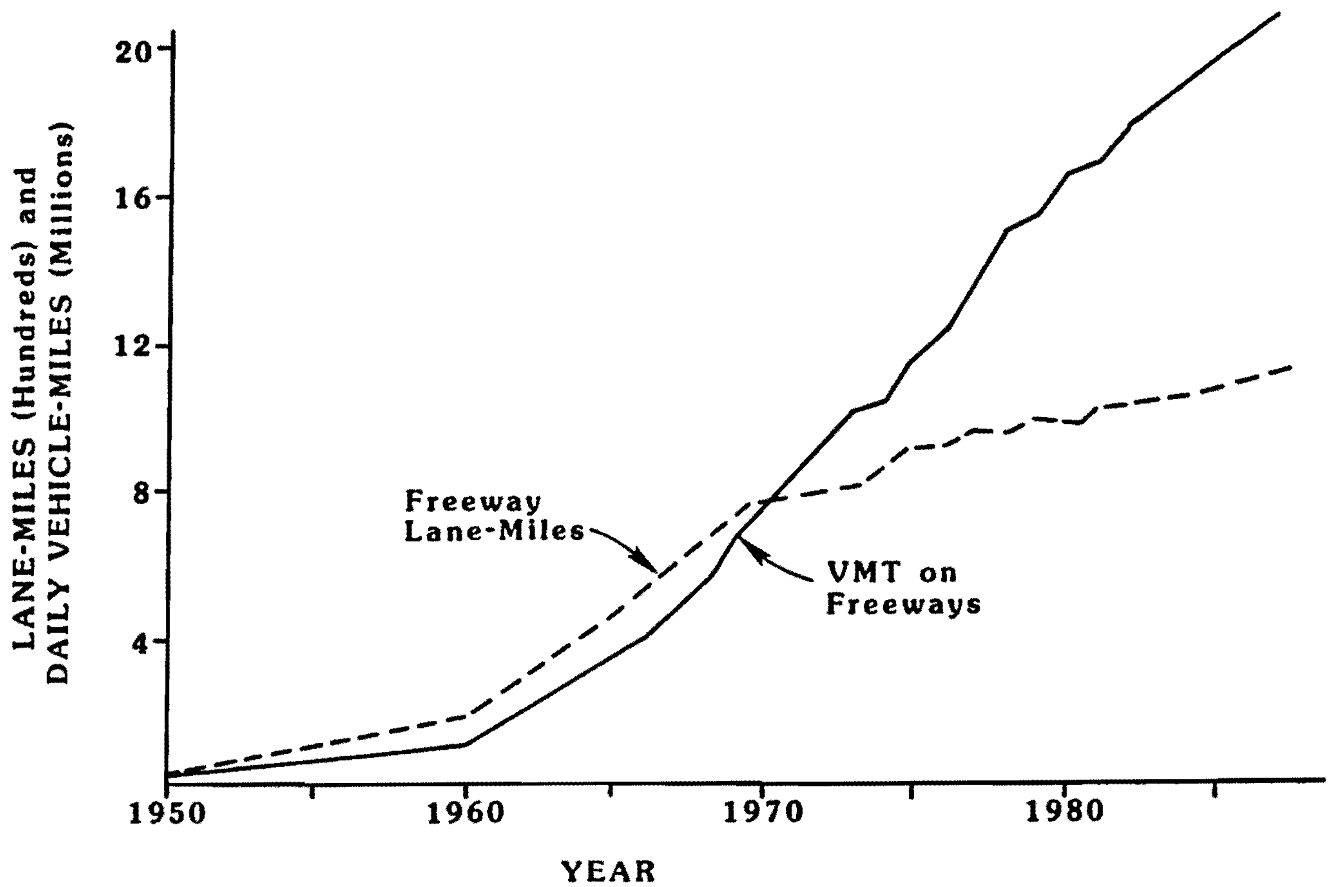
Table A-1. City of Houston Growth Trends, 1950 to 1985

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

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

Source: References 2, 3, 5, 9

Congestion increases were also apparent in the travel delay estimates. Peak-period volume and travel time information were utilized to generate the data in Table A-2 and Figure A-2. Six major radial freeways were evaluated in each of four travel studies



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

Source: References 2, 3, 8, 16.

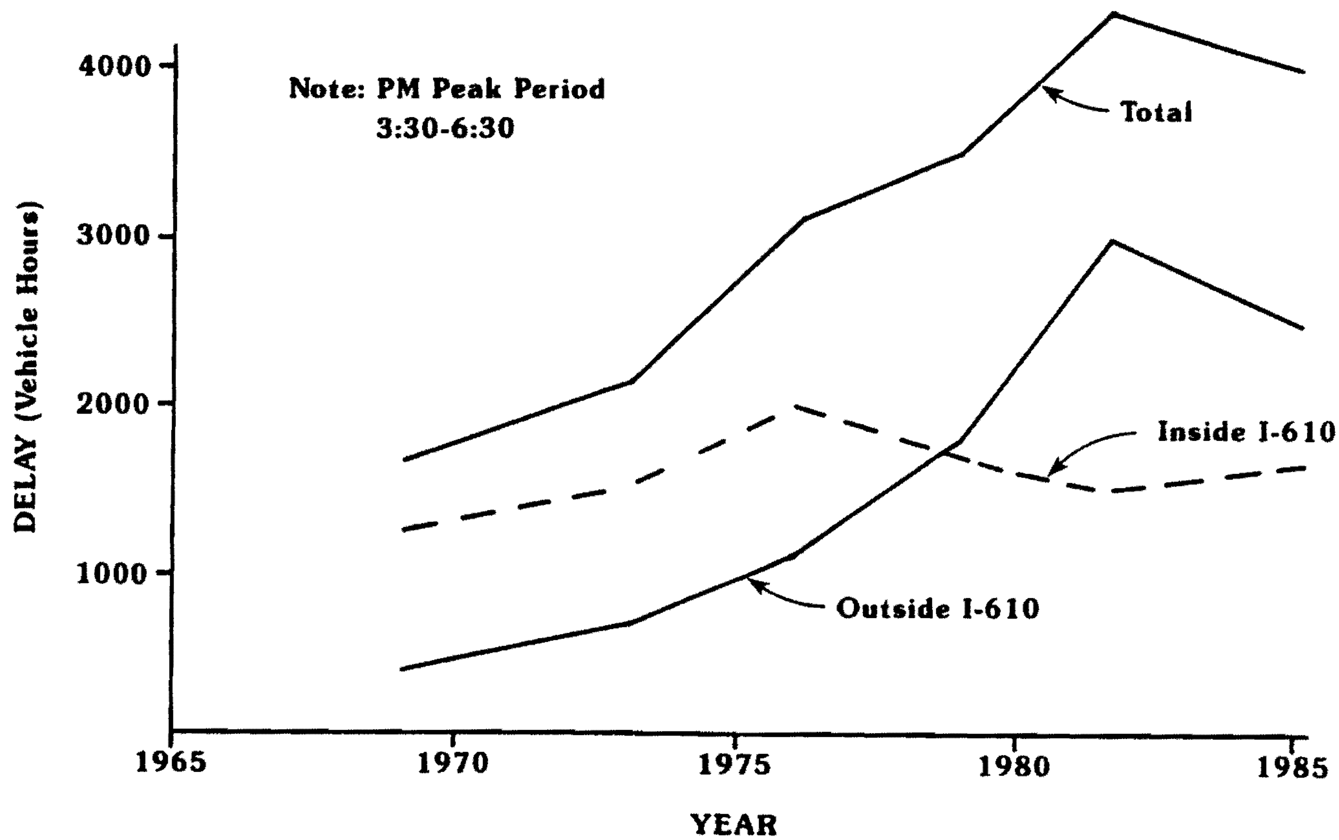
Figure A-1. Freeway Capacity and Travel in Houston, 1950 to 1986

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

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

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

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



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

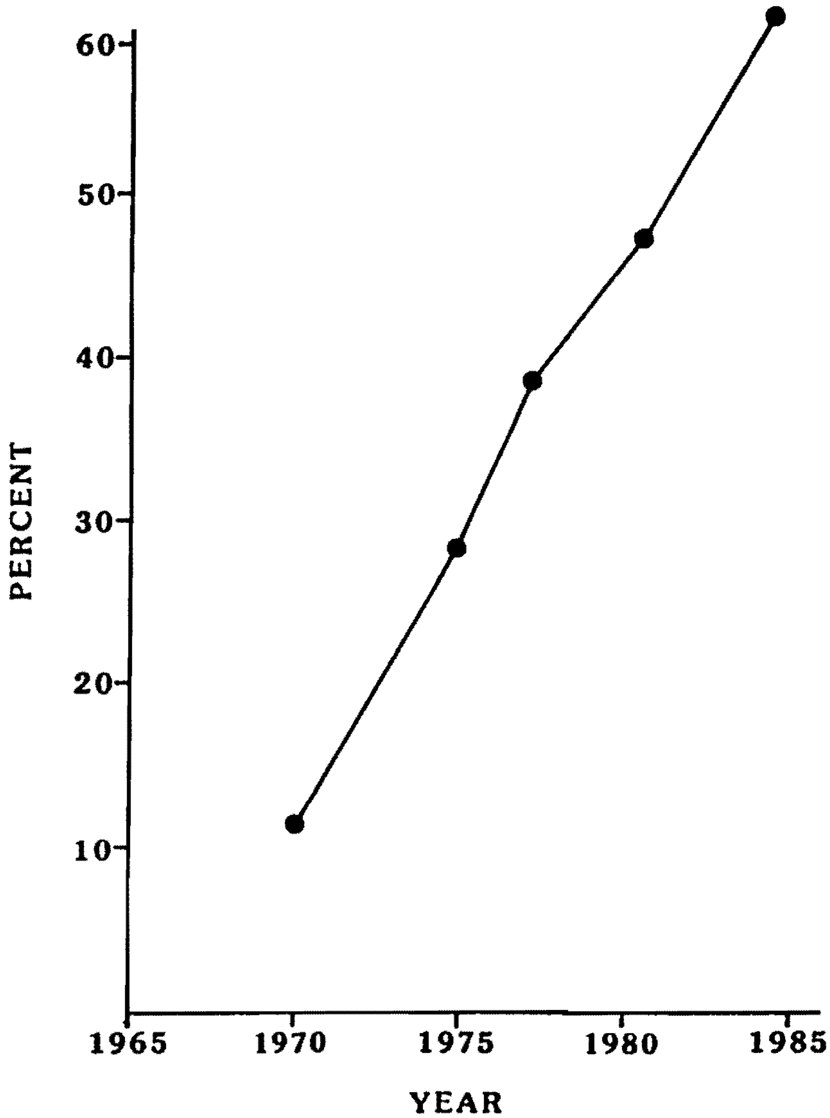
Source: References 1, 2, 8, 9, 10

Figure A-2. Delay by Segments for Houston Freeways, P.M. Peak Period conducted by the Houston-Galveston Regional Transportation Study (HGRTS) (6). The dramatic (380 percent) increase in delay between I-610 and Beltway 8 (Figure A-2) from 1969 to 1979 indicates the decline in mobility outside the central city area. The decrease in delay inside I-610 (a major circumferential freeway approximately five miles from downtown) may be attributable to several factors, including the completion of certain freeway sections and the traffic metering effect of I-610. On most radial freeways the number of lanes outside Loop 610 is less than that inside the Loop. Volumes, however, are not significantly lower, resulting in greater congestion outside I-610.

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

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

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



Source: 1, 2, 6

Figure A-3. Percent of Freeway Lane-Miles with more than 15,000 ADT for Harris County (Houston), 1970 to 1985 suggest county-wide deficiencies; however, the 45 percent in 1980 would appear to suggest such deficiencies did exist.

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

Congestion Indicator Determination

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

Traffic Per Lane

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

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

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

Roadway Congestion Index

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

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

Percentage of Congested Freeway

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

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

Summary

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

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

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

APPENDIX B

CONGESTION CLASSIFICATION

Table B-1. Percent of Congested DVMT by AADT Congestion Ranges for 1982

Urbanized Area	Freeway & Expressway				Principal Arterial Street			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	1	19	0	20	3	14	7	25
Boston MA	1	25	4	30	7	16	12	35
New York NY	9	41	5	55	17	41	17	75
Philadelphia PA	3	14	3	20	14	23	33	70
Pittsburgh PA	1	14	0	15	11	33	7	50
Washington DC	12	45	3	60	8	40	32	80
Midwestern Cities								
Chicago IL	5	31	14	50	11	33	16	60
Cincinnati OH	5	14	0	20	4	15	1	20
Cleveland OH	0	20	0	20	3	17	0	20
Detroit MI	8	27	5	40	17	25	18	60
Indianapolis IN	0	0	0	0	2	12	1	15
Kansas City MO	0	0	0	0	5	11	4	20
Louisville KY	1	4	0	5	11	41	3	55
Milwaukee WI	3	17	0	20	2	26	2	30
Minn-St. Paul MN	1	19	0	20	8	28	14	50
Oklahoma City OK	--[1]	--	--	--	--	--	--	--
St. Louis MO	3	22	0	25	12	40	14	65
Southwestern Cities								
Atlanta GA	--	--	--	--	--	--	--	--
Memphis TN	1	9	0	10	5	24	1	30
Miami FL	2	36	2	40	1	20	38	60
Nashville TN	1	18	1	20	2	35	2	40
Tampa FL	0	16	4	20	8	49	3	60
Southwestern Cities								
Albuquerque NM	1	4	0	5	5	29	1	35
Austin TX	2	48	0	50	2	37	1	40
Corpus Christi TX	0	5	0	5	0	6	4	10
Dallas TX	0	41	4	45	2	23	0	25
Denver CO	16	28	1	45	18	21	11	50
El Paso TX	4	11	0	15	1	4	0	5
Fort Worth TX	0	27	3	30	2	23	0	25
Houston TX	1	28	36	65	12	21	17	50
Phoenix AZ	29	21	0	50	16	39	10	65
Salt Lake City UT	1	9	0	10	7	22	6	35
San Antonio TX	0	19	16	35	1	4	0	5
Western Cities								
Los Angeles CA	13	31	31	75	4	29	2	35
Portland OR	5	22	3	30	22	26	13	60
Sacramento CA	0	25	0	25	0	18	22	40
San Diego CA	6	29	0	35	3	22	0	25
San Fran-Oak CA	12	29	24	65	27	18	16	60
Seattle-Everett WA	9	29	3	40	5	35	10	50

AADT per Lane Ranges:

	Moderate	Heavy	Severe
Freeway & Expressway	15,000-17,500	17,501-20,000	Over 20,000
Principal Arterial Street	5,750-7,000	7,001-8,500	Over 8,500

Note: [1] Denotes Data Not Available or Missing in HPMS Sample Data.

Source: TTI Analysis and Local Transportation Agency References.

Table B-2. Percent of Congested DVMT by AADT Congestion Ranges for 1983

Urbanized Area	Freeway & Expressway				Principal Arterial Street			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	2	18	0	20	3	14	9	25
Boston MA	1	25	4	30	5	18	13	35
New York NY	7	43	5	55	14	40	21	75
Philadelphia PA	2	16	2	20	19	31	20	70
Pittsburgh PA	1	14	0	15	9	37	9	55
Washington DC	8	49	3	60	9	31	40	80
Midwestern Cities								
Chicago IL	7	33	9	50	11	37	17	65
Cincinnati OH	4	16	0	20	4	16	0	20
Cleveland OH	1	19	0	20	3	17	0	20
Indianapolis IN	0	0	0	0	3	11	1	15
Kansas City MO	0	0	0	0	6	9	5	20
Louisville KY	0	4	1	5	10	37	3	50
Milwaukee WI	2	18	0	20	3	25	2	30
Minn-St. Paul MN	1	19	0	20	5	34	12	50
Oklahoma City OK	--[1]	--	--	--	--	--	--	--
St. Louis MO	4	26	0	30	13	40	12	65
Southern Cities								
Atlanta GA	4	35	1	40	7	41	11	60
Memphis TN	2	8	0	10	9	19	2	30
Miami FL	8	31	6	45	6	31	23	60
Nashville TN	2	17	1	20	2	31	7	40
Tampa FL	2	10	9	20	7	29	24	60
Southwestern Cities								
Albuquerque NM	1	4	0	5	12	25	3	40
Austin TX	5	34	11	50	5	31	4	40
Corpus Christi TX	0	5	0	5	1	6	3	10
Dallas TX	5	35	11	50	1	23	0	25
Denver CO	8	33	3	45	11	29	10	50
El Paso TX	4	11	0	15	1	4	0	5
Fort Worth TX	3	24	8	35	1	23	0	25
Houston TX	8	30	27	65	8	18	24	50
Phoenix AZ	31	24	0	55	17	39	8	65
Salt Lake City UT	0	10	0	10	2	27	6	35
San Antonio TX	0	29	6	35	2	7	2	10
Western Cities								
Los Angeles CA	14	25	41	80	6	20	9	35
Portland OR	4	20	1	25	20	26	14	60
Sacramento CA	0	25	0	25	0	18	22	40
San Diego CA	8	27	0	35	3	23	0	25
San Fran-Oak CA	8	34	27	70	16	25	14	55
Seattle-Everett WA	5	36	4	45	8	32	15	55

AADT per Lane Ranges:

	Moderate	Heavy	Severe
Freeway & Expressway	15,000-17,500	17,501-20,000	Over 20,000
Principal Arterial Street	5,750-7,000	7,001-8,500	Over 8,500

Note [1] Denotes Data Not Available or Missing in HPMS Data

Source: TTI Analysis and Local Transportation Agency References.

Table B-3. Percent of Congested DVMT by AADT Congestion Ranges for 1984

Urbanized Area	Freeway & Expressway				Principal Arterial Street			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	3	20	2	25	2	12	17	30
Boston MA	--[1]	--	--	--	--	--	--	--
New York NY	9	43	4	55	20	42	14	75
Philadelphia PA	4	14	2	20	11	37	22	70
Pittsburgh PA	0	14	0	15	8	37	10	55
Washington DC	8	52	5	65	10	29	41	80
Midwestern Cities								
Chicago IL	5	28	22	55	11	31	23	65
Cincinnati OH	0	20	0	20	4	15	2	20
Cleveland OH	2	23	0	25	3	17	0	20
Detriot MI	--	--	--	--	--	--	--	--
Indianapolis IN	0	0	0	0	1	10	4	15
Kansas City MO	0	5	0	5	5	11	4	20
Louisville KY	0	5	0	5	16	33	1	50
Milwaukee WI	4	21	0	25	8	25	2	35
Minn-St. Paul MN	2	18	1	20	7	27	22	55
Oklahoma City OK	--	--	--	--	--	--	--	--
St. Louis MO	4	14	2	20	11	34	19	65
Southern Cities								
Atlanta GA	8	37	0	45	15	38	12	65
Memphis TN	1	9	0	10	8	22	0	30
Miami FL	7	32	6	45	11	19	30	60
Nashville TN	2	17	2	20	5	14	21	40
Tampa FL	1	11	8	20	12	28	25	65
Southwestern Cities								
Albuquerque NM	1	4	0	5	14	27	4	45
Austin TX	9	28	12	50	8	32	5	45
Corpus Christi TX	0	5	0	5	0	10	0	10
Dallas TX	5	37	8	50	7	19	4	30
Denver CO	2	37	6	45	10	24	15	50
El Paso TX	4	11	0	15	1	4	0	5
Fort Worth TX	4	26	6	35	7	19	4	30
Houston TX	9	29	33	70	8	17	30	55
Phoenix AZ	0	50	10	60	17	39	8	65
Salt Lake City UT	1	9	0	10	8	27	5	40
San Antonio TX	6	25	4	35	1	6	3	10
Western Cities								
Los Angeles CA	14	25	41	80	7	19	15	40
Portland OR	5	24	1	30	32	15	14	60
Sacramento CA	1	24	0	25	13	22	10	45
San Diego CA	4	28	3	35	10	20	0	30
San Fran-Oak CA	4	33	38	75	9	23	28	60
Seattle-Everett WA	7	33	10	50	6	34	14	55

AADT per Lane Ranges:

	Moderate	Heavy	Severe
Freeway & Expressway	15,000-17,500	17,501-20,000	Over 20,000
Principal Arterial Street	5,750-7,000	7,001-8,500	Over 8,500

Note: [1] Denotes Data Not Available or Missing in HPMS Sample Data

Source: TTI Analysis and Local Transportation Agency References.

Table B-4. Percent of Congested DVMT by AADT Congestion Ranges for 1985

Urbanized Area	Freeway & Expressway				Principal Arterial Street			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	3	20	1	25	3	11	22	35
Boston MA	7	22	7	35	4	14	17	35
New York NY	6	45	4	55	16	30	29	75
Philadelphia PA	5	19	1	25	7	37	31	75
Pittsburgh PA	1	14	1	15	13	40	7	60
Washington DC	18	37	10	65	8	34	38	80
Midwestern Cities								
Chicago IL	4	20	32	55	14	19	37	70
Cincinnati OH	1	18	1	20	4	19	2	25
Cleveland OH	1	24	0	25	3	17	0	20
Detroit MI	--[1]	--	--	--	--	--	--	--
Indianapolis IN	--	--	--	--	--	--	--	--
Kansas City MO	0	4	0	5	6	11	3	20
Louisville KY	0	4	1	5	10	38	3	50
Milwaukee WI	2	23	0	25	2	28	5	35
Minn-St. Paul MN	1	18	1	20	12	22	21	55
Oklahoma City OK	--	--	--	--	--	--	--	--
St. Louis MO	1	19	0	20	9	38	18	65
Southern Cities								
Atlanta GA	10	38	3	50	9	29	27	65
Memphis TN	0	10	0	10	5	22	3	30
Miami FL	13	29	8	50	12	7	51	70
Nashville TN	1	14	0	15	7	18	16	40
Tampa FL	1	19	0	20	12	18	35	65
Southwestern Cities								
Albuquerque NM	2	9	0	10	11	25	4	40
Austin TX	20	25	11	55	7	29	9	45
Corpus Christi TX	0	5	0	5	1	8	1	10
Dallas TX	8	33	8	50	8	18	4	30
Denver CO	7	31	7	45	16	24	10	50
El Paso TX	7	13	0	20	1	4	0	5
Fort Worth TX	6	23	6	35	8	18	4	30
Houston TX	9	26	35	70	7	17	31	55
Phoenix AZ	0	26	44	70	15	46	9	70
Salt Lake City UT	1	8	1	10	11	24	5	40
San Antonio TX	6	24	10	40	4	6	5	15
Western Cities								
Los Angeles CA	12	27	41	80	5	23	17	45
Portland OR	4	24	1	30	29	21	10	60
Sacramento CA	6	24	1	30	0	18	27	45
San Diego CA	5	24	6	35	1	29	0	30
San Fran-Oak CA	4	29	42	75	9	23	29	60
Seattle-Everett WA	10	31	10	50	7	30	17	55

AADT per Lane Ranges:

	Moderate	Heavy	Severe
Freeway & Expressway	15,000-17,500	17,501-20,000	Over 20,000
Principal Arterial Street	5,750-7,000	7,001-8,500	Over 8,500

Note [1] Denotes Data Not Available or Missing in HPMS Data

Source: TTI Analysis and Local Transportation Agency References.

Table B-5. Percent of Congested DVMT by AADT Congestion Ranges for 1986

Urbanized Area	Freeway & Expressway				Principal Arterial Street			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	3	21	1	25	4	14	17	35
Boston MA	6	23	12	40	5	14	16	35
New York NY	9	43	4	55	19	19	37	75
Philadelphia PA	6	18	1	25	12	23	40	75
Pittsburgh PA	0	19	1	20	12	36	11	60
Washington DC	18	36	11	65	11	31	38	80
Midwestern Cities								
Chicago IL	3	20	32	55	9	22	39	70
Cincinnati OH	2	17	0	20	5	17	3	25
Cleveland OH	1	24	0	25	2	18	0	20
Detroit MI	8	21	11	40	4	11	45	60
Indianapolis IN	--[1]	--	--	0	--	--	--	15
Kansas City MO	1	4	0	5	4	13	3	20
Louisville KY	1	3	1	5	9	34	7	50
Milwaukee WI	2	22	1	25	1	28	6	35
Minn-St. Paul MN	2	22	1	25	8	20	23	50
Oklahoma City OK	--	--	--	5	--	--	--	35
St. Louis MO	3	17	0	20	11	37	17	65
Southern Cities								
Atlanta GA	5	40	6	50	7	26	32	65
Memphis TN	0	10	0	10	12	18	4	35
Miami FL	11	30	9	50	13	25	32	70
Nashville TN	1	14	0	15	3	14	23	40
Tampa FL	2	14	4	20	9	28	29	65
Southwestern Cities								
Albuquerque NM	0	10	0	10	9	29	2	40
Austin TX	9	32	15	55	8	16	22	45
Corpus Christi TX	1	9	0	10	2	7	2	10
Dallas TX	4	32	19	55	7	20	2	30
Denver CO	9	32	10	50	18	24	8	50
El Paso TX	2	13	5	20	1	4	0	5
Fort Worth TX	3	23	14	40	7	20	2	30
Houston TX	7	27	42	75	10	14	31	55
Phoenix AZ	4	12	54	70	17	39	14	70
Salt Lake City UT	1	8	1	10	16	23	6	45
San Antonio TX	2	24	14	40	3	9	3	15
Western Cities								
Los Angeles CA	5	22	58	85	6	21	23	50
Portland OR	4	25	1	30	24	28	8	60
Sacramento CA	11	18	1	30	1	36	3	40
San Diego CA	13	20	7	40	3	27	0	30
San Fran-Oak CA	5	21	48	75	13	14	33	60
Seattle-Everett WA	10	35	10	55	11	23	21	55

AADT per Lane Ranges:

	Moderate	Heavy	Severe
Freeway & Expressway	15,000-17,500	17,501-20,000	Over 20,000
Principal Arterial Street	5,750-7,000	7,001-8,500	Over 8,500

Note [1] Denotes Data Not Available or Missing in HPMS Data

Source: TTI Analysis and Local Transportation Agency References.

Table B-6. Percent of Congested DVMT by AADT Congestion Ranges for 1987

Urbanized Area	Freeway & Expressway				Principal Arterial Street			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	5	18	2	25	6	9	20	35
Boston MA	7	27	6	40	5	13	16	35
New York NY	8	41	6	55	13	26	36	75
Philadelphia PA	7	17	1	25	11	21	43	75
Pittsburgh PA	0	18	1	20	11	34	14	60
Washington DC	16	36	13	65	12	26	47	85
Midwestern Cities								
Chicago IL	4	23	29	55	12	18	40	70
Cincinnati OH	5	20	0	25	6	16	3	25
Cleveland OH	1	24	0	25	3	22	0	25
Detroit MI	7	22	11	40	4	8	49	60
Indianapolis IN	--[1]	--	--	5	--	--	--	15
Kansas City MO	1	4	0	5	3	11	6	20
Louisville KY	1	3	1	5	10	35	10	55
Milwaukee WI	3	23	4	30	6	25	4	35
Minn-St. Paul MN	1	24	4	30	12	17	26	55
Oklahoma City OK	--	--	--	5	--	--	--	35
St. Louis MO	2	17	1	20	13	34	18	65
Southern Cities								
Atlanta GA	7	27	16	50	9	25	30	65
Memphis TN	0	10	0	10	9	22	4	35
Miami FL	9	35	6	50	11	8	51	70
Nashville TN	2	18	0	20	7	10	24	40
Tampa FL	5	7	8	20	11	20	35	65
Southwestern Cities								
Albuquerque NM	--	--	--	10	--	--	--	40
Austin TX	11	43	1	55	2	28	14	45
Corpus Christi TX	1	9	0	10	1	7	2	10
Dallas TX	11	31	14	55	4	23	3	30
Denver CO	8	33	9	50	17	27	6	50
El Paso TX	3	17	0	20	1	4	0	5
Fort Worth TX	8	22	10	40	4	23	3	30
Houston TX	9	25	36	70	8	21	21	50
Phoenix AZ	3	30	37	70	17	43	10	70
Salt Lake City UT	2	13	1	15	7	28	5	40
San Antonio TX	2	27	11	40	4	9	7	20
Western Cities								
Los Angeles CA	4	19	62	85	10	22	18	50
Portland OR	9	23	4	35	12	32	16	61
Sacramento CA	11	23	1	35	5	30	10	45
San Diego CA	9	26	10	45	2	28	0	30
San Fran-Oak CA	7	16	57	80	10	17	33	60
Seattle-Everett WA	19	30	17	65	8	29	17	55

AADT per Lane Ranges:

	Moderate	Heavy	Severe
Freeway & Expressway	15,000-17,500	17,501-20,000	Over 20,000
Principal Arterial Street	5,750-7,000	7,001-8,500	Over 8,500

Note [1] Denotes Data Not Available or Missing in HPMS Data

Source: TTI Analysis and Local Transportation Agency References.

Table B-7. Percent of Congested DVMT by AADT Congestion Ranges for 1988

Urbanized Area	Freeway & Expressway				Principal Arterial Street			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	5	17	4	25	6	9	20	35
Boston MA	6	17	22	45	7	15	18	40
New York NY	10	37	8	55	11	24	45	80
Philadelphia PA	8	16	1	25	10	20	46	75
Pittsburgh PA	1	19	0	20	4	29	27	60
Washington DC	14	39	12	65	8	32	45	85
Midwestern Cities								
Chicago IL	8	21	26	55	11	26	27	65
Cincinnati OH	6	23	1	30	4	16	5	25
Cleveland OH	2	23	0	25	8	21	1	30
Detroit MI	7	18	16	40	9	8	43	60
Indianapolis IN	3	7	0	10	4	14	1	20
Kansas City MO	0	4	1	5	1	6	18	25
Louisville KY	1	3	1	5	14	35	6	55
Milwaukee WI	3	22	6	30	7	24	4	35
Minn-St. Paul MN	2	24	4	30	11	15	28	55
Oklahoma City OK	1	9	0	10	1	26	8	35
St. Louis MO	1	14	0	15	12	34	9	55
Southern Cities								
Atlanta GA	2	36	8	45	21	13	31	65
Memphis TN	2	8	0	10	7	22	6	35
Miami FL	7	16	36	60	1	22	47	70
Nashville TN	3	20	2	25	4	9	27	40
Tampa FL	8	7	11	25	6	16	38	60
Southwestern Cities								
Albuquerque NM	1	9	10	20	9	24	2	35
Austin TX	12	43	0	55	10	22	12	45
Corpus Christi TX	1	9	0	10	0	4	0	5
Dallas TX	8	31	15	55	5	24	1	30
Denver CO	6	35	9	50	19	26	6	50
El Paso TX	2	18	0	20	1	4	0	5
Fort Worth TX	6	23	11	40	5	24	1	30
Houston TX	8	28	34	70	5	37	8	50
Phoenix AZ	12	33	15	60	13	36	31	80
Salt Lake City UT	2	13	1	15	8	28	4	40
San Antonio TX	3	26	10	40	3	8	4	15
Western Cities								
Los Angeles CA	4	10	61	75	9	18	23	50
Portland OR	12	22	6	40	11	32	16	60
Sacramento CA	13	31	1	45	8	29	12	50
San Diego CA	9	18	18	45	1	27	1	30
San Fran-Oak CA	8	17	55	80	10	11	39	60
Seattle-Everett WA	18	32	20	70	8	25	21	55

AADT per Lane Ranges:

	Moderate	Heavy	Severe
Freeway & Expressway	15,000-17,500	17,501-20,000	Over 20,000
Principal Arterial Street	5,750-7,000	7,001-8,500	Over 8,500

Source: TTI Analysis and Local Transportation Agency References.

APPENDIX C

FREEWAY AND PRINCIPAL ARTERIAL STREET TRAVEL AND MILEAGE STATISTICS 1982 TO 1988

Table C-1. Summary of Normalized Freeway Travel and Mileage Statistics for 1988

Urbanized Area	Normalized by Population Density[1]							
	VMT Per Person	Rank	VMT Per Sq Mi	Rank	Ln Mi Per 1000 Pers	Rank	Ln Mi Per Sq Mi	Rank
Northeastern Cities								
Baltimore MD	2.03	31	7,310	23	0.18	30	0.63	20
Boston MA	2.84	22	7,820	18	0.19	29	0.52	26
New York NY	0.93	39	4,780	32	0.07	39	0.36	35
Philadelphia PA	1.10	38	4,040	37	0.09	35	0.34	36
Pittsburgh PA	1.57	35	4,000	38	0.20	27	0.51	27
Washington DC	2.12	30	7,760	20	0.13	33	0.49	28
Midwestern Cities								
Chicago IL	1.18	36	4,350	36	0.08	37	0.30	38
Cincinnati OH	4.64	10	10,260	8	0.40	9	0.89	4
Cleveland OH	2.55	27	7,100	24	0.20	27	0.56	24
Detroit MI	1.81	32	5,640	28	0.13	33	0.42	33
Indianapolis IN	3.90	12	8,330	16	0.36	11	0.78	9
Kansas City MO	5.59	7	10,670	5	0.62	6	1.17	1
Louisville KY	3.49	15	7,500	22	0.33	14	0.70	14
Milwaukee WI	2.61	25	5,820	27	0.21	25	0.48	29
Minn-St. Paul MN	4.50	11	8,530	15	0.39	10	0.74	12
Oklahoma City OK	6.38	6	9,190	12	0.68	3	0.98	2
St. Louis MO	3.29	18	8,920	14	0.28	19	0.76	11
Southern Cities								
Atlanta GA	11.23	1	12,940	1	0.81	1	0.93	3
Memphis TN	2.41	28	4,760	33	0.23	23	0.46	30
Miami FL	1.13	37	4,360	35	0.08	37	0.32	37
Nashville TN	8.73	2	9,720	9	0.73	2	0.82	8
Tampa FL	3.38	17	5,170	31	0.29	17	0.44	32
Southwestern Cities								
Albuquerque NM	2.37	29	4,590	34	0.21	25	0.41	34
Austin TX	7.35	4	10,550	7	0.59	7	0.85	7
Corpus Christi TX	3.49	15	5,490	29	0.43	8	0.67	17
Dallas TX	8.45	3	11,480	3	0.63	5	0.86	6
Denver CO	3.87	13	6,770	25	0.32	15	0.55	25
El Paso TX	2.62	24	6,510	26	0.28	19	0.69	16
Fort Worth TX	7.13	5	9,700	10	0.64	4	0.87	5
Houston TX	5.44	8	9,510	11	0.36	11	0.63	20
Phoenix AZ	1.61	34	3,030	39	0.15	31	0.29	39
Salt Lake City UT	3.04	21	5,190	30	0.36	11	0.61	22
San Antonio TX	3.17	20	7,770	19	0.29	17	0.71	13
Western Cities								
Los Angeles CA	1.77	33	9,170	13	0.09	35	0.45	31
Portland OR	3.26	19	7,510	21	0.25	21	0.57	23
Sacramento CA	2.73	23	8,100	17	0.22	24	0.65	18
San Diego CA	3.68	14	11,510	2	0.25	21	0.78	9
San Fran-Oak CA	2.57	26	11,180	4	0.15	31	0.64	19
Seattle-Everett WA	4.66	9	10,580	6	0.31	16	0.70	14
Northeastern Avg.	1.77		5,950		0.14		0.48	
Midwestern Avg.	3.63		7,850		0.34		0.71	
Southern Avg.	5.38		7,390		0.43		0.59	
Southwestern Avg.	4.41		7,330		0.39		0.65	
Western Avg.	3.11		9,680		0.21		0.63	
Total Avg.	3.71		7,630		0.31		0.63	
Maximum Value	11.23		12,940		0.81		1.17	
Minimum Value	0.93		3,030		0.07		0.29	

Note: [1]Ratio values in Tables 3 and 4 divided by population density multiplied by 1000

Source: TTI Analysis and Local Transportation Agency References

Table C-2. Summary of Normalized Principal Arterial Street Travel and Mileage Statistics for 1988

Urbanized Area	Normalized by Population Density[1]							
	VMT Per Person	Rank	VMT Per Sq Mi	Rank	Ln Mi Per 1000 Pers	Rank	Ln Mi Per Sq Mi	Rank
Northeastern Cities								
Baltimore MD	1.34	34	4,810	19	0.25	30	0.91	15
Boston MA	1.61	28	4,430	21	0.34	22	0.93	13
New York NY	0.60	39	3,050	36	0.09	39	0.44	39
Philadelphia PA	1.45	30	5,360	16	0.21	34	0.78	27
Pittsburgh PA	2.26	15	5,760	12	0.38	18	0.95	11
Washington DC	1.69	25	6,180	8	0.20	36	0.75	28
Midwestern Cities								
Chicago IL	0.96	37	3,550	33	0.14	37	0.51	37
Cincinnati OH	1.64	27	3,620	31	0.38	18	0.84	24
Cleveland OH	1.01	36	2,810	37	0.22	33	0.62	33
Detroit MI	1.78	22	5,560	13	0.29	27	0.90	20
Indianapolis IN	1.98	20	4,240	23	0.43	15	0.91	15
Kansas City MO	2.05	18	3,920	27	0.48	14	0.91	15
Louisville KY	1.65	26	3,550	33	0.30	26	0.63	32
Milwaukee WI	1.73	24	3,860	28	0.36	21	0.81	26
Minn-St. Paul MN	1.45	30	2,750	38	0.32	25	0.61	34
Oklahoma City OK	3.32	8	4,780	20	0.63	8	0.91	15
St. Louis MO	2.17	16	5,880	11	0.33	24	0.89	21
Southern Cities								
Atlanta GA	4.78	3	5,510	14	0.73	5	0.84	24
Memphis TN	2.47	12	4,880	18	0.49	13	0.97	10
Miami FL	1.97	21	7,590	3	0.29	27	1.12	7
Nashville TN	8.95	1	9,970	1	1.52	1	1.70	1
Tampa FL	4.00	4	6,110	9	0.61	10	0.94	12
Southwestern Cities								
Albuquerque NM	3.60	6	6,980	5	0.74	3	1.44	4
Austin TX	2.91	10	4,170	25	0.59	11	0.85	23
Corpus Christi TX	3.33	7	5,240	17	0.74	3	1.16	6
Dallas TX	3.08	9	4,180	24	0.64	7	0.87	22
Denver CO	3.85	5	6,740	6	0.68	6	1.18	5
El Paso TX	2.45	13	6,100	10	0.63	8	1.58	2
Fort Worth TX	2.68	11	3,650	30	0.55	12	0.75	28
Houston TX	2.05	18	3,570	32	0.40	16	0.69	31
Phoenix AZ	4.83	2	9,120	2	0.83	2	1.57	3
Salt Lake City UT	1.42	32	2,430	39	0.26	29	0.45	38
San Antonio TX	1.75	23	4,290	22	0.37	20	0.92	14
Western Cities								
Los Angeles CA	1.35	33	7,020	4	0.21	34	1.08	8
Portland OR	1.51	29	3,470	35	0.24	31	0.56	36
Sacramento CA	2.15	17	6,400	7	0.34	22	1.01	9
San Diego CA	1.30	35	4,070	26	0.24	31	0.74	30
San Fran-Oak CA	0.86	38	3,750	29	0.13	38	0.57	35
Seattle-Everett WA	2.38	14	5,430	15	0.40	16	0.91	15
Northeastern Avg.	1.49		4,930		0.24		0.79	
Midwestern Avg.	1.80		4,050		0.35		0.78	
Southern Avg.	4.43		6,810		0.73		1.11	
Southwestern Avg.	2.90		5,130		0.59		1.04	
Western Avg.	1.59		5,020		0.26		0.81	
Total Avg.	2.37		5,000		0.44		0.90	
Maximum Value	8.95		9,970		1.52		1.70	
Minimum Value	0.60		2,430		0.09		0.44	

Note: [1]Ratio values in Tables 6 and 7 divided by population density multiplied by 1000

Source: TTI Analysis and Local Transportation Agency References

Table C-3. Summary of 1982 Relative Mobility Values for Freeways and Expressways

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Congestion Index
Northeastern Cities					
Baltimore MD	10,240	990	5.0	10,400	0.84
Boston MA	15,910	1,410	5.5	11,280	0.90
New York NY	63,170	5,240	5.2	12,060	1.01
Philadelphia PA	12,380	1,250	5.0	9,900	1.00
Pittsburgh PA	5,520	780	4.1	7,120	0.78
Washington DC	16,090	1,240	4.9	12,970	1.07
Midwestern Cities					
Chicago IL	25,460	2,050	5.4	12,450	1.02
Cincinnati OH	8,490	750	5.2	11,310	0.86
Cleveland OH	10,000	960	4.6	10,420	0.80
Detroit MI	20,200	1,480	5.7	13,650	1.13
Indianapolis IN	5,730	670	5.1	8,550	0.71
Kansas City MO	8,900	1,140	4.0	7,840	0.62
Louisville KY	3,920	410	4.3	9,550	0.84
Milwaukee WI	5,600	540	5.3	10,370	0.83
Minn-St. Paul MN	11,200	1,180	4.4	9,490	0.74
Oklahoma City OK	5,830	670	4.9	8,760	0.72
St. Louis MO	12,040	1,210	5.3	9,950	0.83
Southern Cities					
Atlanta GA	15,770	1,370	5.7	11,550	0.89
Memphis TN	3,050	300	5.1	10,170	0.86
Miami FL	5,950	520	5.2	11,550	1.05
Nashville TN	3,250	350	4.3	9,290	0.74
Tampa FL	1,980	190	4.7	10,420	0.94
Southwestern Cities					
Albuquerque NM	1,540	190	4.7	8,080	0.78
Austin TX	2,530	270	5.2	9,550	0.77
Corpus Christi TX	1,300	160	5.2	8,130	0.67
Dallas TX	16,870	1,550	5.3	10,880	0.84
Denver CO	7,900	800	5.1	9,940	0.85
El Paso TX	2,560	330	4.9	7,880	0.63
Fort Worth TX	8,630	910	5.0	9,530	0.76
Houston TX	21,080	1,380	5.9	15,330	1.17
Phoenix AZ	2,850	210	4.8	13,570	1.15
Salt Lake City UT	2,870	400	5.5	7,180	0.63
San Antonio TX	7,600	760	4.9	10,000	0.77
Western Cities					
Los Angeles CA	75,490	4,550	8.1	16,590	1.22
Portland OR	4,740	440	4.9	10,770	0.87
Sacramento CA	5,300	630	6.8	8,410	0.80
San Diego CA	15,080	1,520	7.3	9,920	0.78
San Fran-Oak CA	28,870	2,200	6.7	13,120	1.01
Seattle-Everett WA	12,270	1,010	5.7	12,210	0.95
Northeastern Avg.	20,550	1,830	5.0	10,620	0.93
Midwestern Avg.	10,670	1,000	4.9	10,210	0.83
Southern Avg.	6,000	540	5.0	10,600	0.90
Southwestern Avg.	6,880	630	5.1	10,010	0.82
Western Avg.	23,620	1,720	6.6	11,840	0.94
Total Avg.	12,520	1,080	5.3	10,520	0.87
Maximum Value	75,490	5,240	8.1	16,590	1.22
Minimum Value	1,300	160	4.0	7,120	0.62

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

Source: TTI Analysis and Local Transportation Agency References

Table C-4. Summary of 1982 Relative Mobility Values for Principal Arterial Streets

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-mile	Congestion Index
Northeastern Cities					
Baltimore MD	7,480	1,500	3.8	4,990	0.84
Boston MA	12,760	2,580	2.3	4,940	0.90
New York NY	44,340	6,700	3.4	6,620	1.01
Philadelphia PA	19,000	2,700	2.8	7,040	1.00
Pittsburgh PA	8,860	1,530	2.9	5,810	0.78
Washington DC	12,600	1,950	3.4	6,460	1.07
Midwestern Cities					
Chicago IL	20,910	3,470	3.4	6,030	1.02
Cincinnati OH	3,020	780	3.3	3,900	0.86
Cleveland OH	4,500	1,100	2.9	4,090	0.80
Detroit MI	21,330	3,250	4.3	6,560	1.13
Indianapolis IN	3,770	830	3.6	4,570	0.71
Kansas City MO	3,810	1,020	3.4	3,750	0.62
Louisville KY	2,930	490	3.7	5,970	0.84
Milwaukee WI	4,290	930	3.0	4,610	0.83
Minn-St. Paul MN	4,300	1,110	3.2	3,870	0.74
Oklahoma City OK	2,750	580	3.0	4,780	0.72
St. Louis MO	8,960	1,680	3.0	5,330	0.83
Southern Cities					
Atlanta GA	5,740	1,220	3.4	4,700	0.89
Memphis TN	3,500	670	4.1	5,220	0.86
Miami FL	11,870	1,880	4.2	6,330	1.05
Nashville TN	3,250	790	2.9	4,110	0.74
Tampa FL	3,190	550	3.8	5,850	0.94
Southwestern Cities					
Albuquerque NM	2,860	570	3.5	5,020	0.78
Austin TX	1,600	340	4.0	4,690	0.77
Corpus Christi TX	1,250	310	3.6	4,030	0.67
Dallas TX	6,440	1,560	4.6	4,140	0.84
Denver CO	9,160	1,750	3.6	5,250	0.85
El Paso TX	2,600	760	3.9	3,420	0.63
Fort Worth TX	3,660	790	3.9	4,660	0.76
Houston TX	9,730	1,790	3.8	5,450	1.17
Phoenix AZ	14,930	2,480	3.3	6,020	1.15
Salt Lake City UT	1,460	280	3.1	5,200	0.63
San Antonio TX	3,530	940	3.2	3,750	0.77
Western Cities					
Los Angeles CA	57,150	10,960	3.9	5,210	1.22
Portland OR	2,780	520	3.1	5,390	0.87
Sacramento CA	5,000	830	3.9	6,020	0.80
San Diego CA	6,130	1,430	3.3	4,290	0.78
San Fran-Oak CA	9,690	1,840	3.7	5,280	1.01
Seattle-Everett WA	6,840	1,340	3.2	5,100	0.95
Northeastern Avg.	17,500	2,830	3.1	5,980	0.93
Midwestern Avg.	7,320	1,380	3.3	4,860	0.83
Southern Avg.	5,510	1,020	3.7	5,250	0.90
Southwestern Avg.	5,200	1,050	3.7	4,690	0.82
Western Avg.	14,590	2,820	3.5	5,210	0.94
Total Avg.	9,180	1,690	3.5	5,090	0.87
Maximum Value	57,150	10,960	4.6	7,040	1.22
Minimum Value	1,250	280	2.3	3,420	0.62

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

Source: TTI Analysis and Local Transportation Agency References

Table C-5. Summary of 1983 Relative Mobility Values for Freeway/Expressway

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Congestion Index
Northeastern Cities					
Baltimore MD	10,550	1,030	5.2	10,290	0.84
Boston MA	16,820	1,420	5.5	11,880	0.93
New York NY	64,250	5,320	5.3	12,090	1.02
Philadelphia PA	13,450	1,270	5.0	10,590	1.03
Pittsburgh PA	6,120	850	4.2	7,200	0.76
Washington DC	16,150	1,240	5.0	13,020	1.09
Midwestern Cities					
Chicago IL	25,840	2,060	5.5	12,570	1.02
Cincinnati OH	8,490	790	5.2	10,740	0.83
Cleveland OH	10,220	960	4.6	10,650	0.82
Detroit MI	19,660	1,480	5.7	13,280	1.10
Indianapolis IN	5,260	680	5.1	7,790	0.66
Kansas City MO	8,990	1,160	4.0	7,750	0.62
Louisville KY	4,440	450	4.4	9,860	0.82
Milwaukee WI	5,800	540	5.3	10,740	0.84
Minn-St. Paul MN	12,170	1,180	4.5	10,310	0.79
Oklahoma City OK	5,940	680	4.9	8,800	0.72
St. Louis MO	13,040	1,240	5.3	10,510	0.87
Southern Cities					
Atlanta GA	17,010	1,410	6.0	12,060	0.94
Memphis TN	3,000	330	5.1	9,230	0.80
Miami FL	6,270	520	5.2	12,170	1.09
Nashville TN	3,300	350	4.4	9,430	0.76
Tampa FL	1,950	190	4.7	10,240	0.91
Southwestern Cities					
Albuquerque NM	1,620	190	4.7	8,500	0.83
Austin TX	2,970	280	5.4	10,610	0.84
Corpus Christi TX	1,370	170	5.2	8,300	0.69
Dallas TX	18,400	1,580	5.3	11,650	0.89
Denver CO	8,240	800	5.1	10,360	0.88
El Paso TX	2,690	340	4.9	8,030	0.64
Fort Worth TX	9,230	940	5.2	9,870	0.79
Houston TX	22,560	1,410	6.0	16,000	1.21
Phoenix AZ	2,910	210	4.9	13,860	1.16
Salt Lake City UT	2,980	420	5.5	7,080	0.63
San Antonio TX	7,970	780	4.9	10,280	0.79
Western Cities					
Los Angeles CA	79,340	4,630	8.1	17,140	1.27
Portland OR	5,380	500	4.9	10,750	0.86
Sacramento CA	5,800	630	6.8	9,210	0.84
San Diego CA	16,480	1,550	7.3	10,630	0.83
San Fran-Oak CA	30,000	2,210	6.7	13,570	1.05
Seattle-Everett WA	13,100	1,040	5.7	12,650	0.99
Northeastern Avg.	21,220	1,850	5.0	10,850	0.95
Midwestern Avg.	10,890	1,020	5.0	10,270	0.83
Southern Avg.	6,300	560	5.1	10,620	0.90
Southwestern Avg.	7,360	650	5.2	10,410	0.85
Western Avg.	25,020	1,760	6.6	12,330	0.97
Total Avg.	13,070	1,100	5.3	10,760	0.88
Maximum Value	79,340	5,320	8.1	17,140	1.27
Minimum Value	1,370	170	4.0	7,080	0.62

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

Source: TTI Analysis and Local Transportation Agency References

Table C-6. Summary of 1983 Relative Mobility Values for Principal Arterial Streets

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-mile	Congestion Index
Northeastern Cities					
Baltimore MD	7,780	1,520	3.8	5,140	0.84
Boston MA	12,990	2,600	2.3	5,000	0.93
New York NY	46,050	6,800	3.4	6,770	1.02
Philadelphia PA	19,520	2,760	2.8	7,070	1.03
Pittsburgh PA	8,940	1,590	3.0	5,640	0.76
Washington DC	13,600	1,980	3.5	6,870	1.09
Midwestern Cities					
Chicago IL	21,600	3,590	3.4	6,020	1.02
Cincinnati OH	3,170	780	3.3	4,080	0.83
Cleveland OH	4,530	1,100	2.9	4,110	0.82
Detroit MI	20,910	3,270	4.3	6,390	1.10
Indianapolis IN	3,720	830	3.6	4,480	0.66
Kansas City MO	3,860	1,020	3.4	3,800	0.62
Louisville KY	2,720	500	3.7	5,490	0.82
Milwaukee WI	4,280	940	3.0	4,550	0.84
Minn-St. Paul MN	4,450	1,120	3.2	3,970	0.79
Oklahoma City OK	2,900	610	3.0	4,790	0.72
St. Louis MO	9,290	1,680	3.0	5,530	0.87
Southern Cities					
Atlanta GA	6,540	1,290	3.4	5,070	0.94
Memphis TN	3,400	680	4.1	5,000	0.80
Miami FL	12,300	1,900	4.2	6,470	1.09
Nashville TN	3,400	810	3.0	4,190	0.76
Tampa FL	3,070	550	3.8	5,620	0.91
Southwestern Cities					
Albuquerque NM	3,080	580	3.5	5,360	0.83
Austin TX	1,710	360	4.0	4,750	0.84
Corpus Christi TX	1,300	320	3.6	4,130	0.69
Dallas TX	7,040	1,600	4.6	4,410	0.89
Denver CO	9,400	1,790	3.6	5,270	0.88
El Paso TX	2,710	780	3.9	3,470	0.64
Fort Worth TX	3,850	800	3.9	4,810	0.79
Houston TX	10,350	1,850	3.8	5,610	1.21
Phoenix AZ	14,970	2,490	3.4	6,010	1.16
Salt Lake City UT	1,530	290	3.2	5,260	0.63
San Antonio TX	3,690	970	3.2	3,820	0.79
Western Cities					
Los Angeles CA	60,210	11,100	3.9	5,420	1.27
Portland OR	2,730	520	3.1	5,290	0.86
Sacramento CA	5,200	850	3.9	6,120	0.84
San Diego CA	6,490	1,450	3.3	4,480	0.83
San Fran-Oak CA	10,230	1,850	3.7	5,530	1.05
Seattle-Everett WA	7,320	1,370	3.2	5,360	0.99
Northeastern Avg.	18,150	2,870	3.1	6,080	0.95
Midwestern Avg.	7,400	1,400	3.3	4,840	0.83
Southern Avg.	5,740	1,050	3.7	5,270	0.90
Southwestern Avg.	5,420	1,070	3.7	4,810	0.85
Western Avg.	15,360	2,860	3.5	5,370	0.97
Total Avg.	9,510	1,710	3.5	5,160	0.88
Maximum Value	60,210	11,100	4.6	7,070	1.27
Minimum Value	1,300	290	2.3	3,470	0.62

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

Source: TTI Analysis and Local Transportation Agency References

Table C-7. Summary of 1984 Relative Mobility Values for Freeway/Expressway

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Congestion Index
Northeastern Cities					
Baltimore MD	10,880	1,070	5.4	10,220	0.85
Boston MA	17,300	1,430	5.5	12,140	0.95
New York NY	65,320	5,630	5.5	11,600	0.99
Philadelphia PA	13,640	1,270	5.0	10,740	1.04
Pittsburgh PA	6,460	870	4.2	7,470	0.76
Washington DC	18,070	1,370	5.2	13,170	1.12
Midwestern Cities					
Chicago IL	26,770	2,080	5.5	12,900	1.05
Cincinnati OH	8,660	810	5.3	10,690	0.82
Cleveland OH	10,410	960	4.6	10,840	0.83
Detroit MI	20,760	1,490	5.7	13,930	1.13
Indianapolis IN	6,090	680	5.1	8,960	0.75
Kansas City MO	9,380	1,250	4.1	7,500	0.60
Louisville KY	4,600	470	4.4	9,790	0.81
Milwaukee WI	5,880	550	5.3	10,790	0.87
Minn-St. Paul MN	13,000	1,230	4.5	10,570	0.81
Oklahoma City OK	6,060	680	5.0	8,910	0.75
St. Louis MO	14,410	1,370	5.4	10,520	0.88
Southern Cities					
Atlanta GA	18,110	1,480	6.0	12,270	0.97
Memphis TN	3,020	340	5.1	8,870	0.76
Miami FL	6,470	530	5.3	12,320	1.07
Nashville TN	3,650	380	4.4	9,720	0.83
Tampa FL	2,540	220	4.7	11,550	1.03
Southwestern Cities					
Albuquerque NM	1,710	190	4.7	9,000	0.89
Austin TX	3,300	290	5.4	11,380	0.89
Corpus Christi TX	1,360	170	5.2	8,240	0.69
Dallas TX	19,930	1,620	5.7	12,300	0.94
Denver CO	8,740	800	5.1	10,930	0.93
El Paso TX	2,800	350	5.0	8,120	0.65
Fort Worth TX	9,690	970	5.2	10,040	0.80
Houston TX	24,380	1,480	6.0	16,470	1.25
Phoenix AZ	3,150	280	5.0	11,250	1.10
Salt Lake City UT	3,020	420	5.5	7,190	0.65
San Antonio TX	8,450	790	4.9	10,760	0.82
Western Cities					
Los Angeles CA	83,390	4,680	8.2	17,820	1.32
Portland OR	5,570	510	4.9	10,920	0.88
Sacramento CA	6,480	640	6.9	10,130	0.88
San Diego CA	18,480	1,580	7.3	11,730	0.91
San Fran-Oak CA	32,220	2,210	6.8	14,580	1.12
Seattle-Everett WA	13,920	1,070	5.8	13,070	1.02
Northeastern Avg.	21,940	1,940	5.1	10,890	0.95
Midwestern Avg.	11,460	1,050	5.0	10,490	0.85
Southern Avg.	6,760	590	5.1	10,950	0.93
Southwestern Avg.	7,870	670	5.2	10,520	0.87
Western Avg.	26,670	1,780	6.7	13,040	1.02
Total Avg.	13,800	1,130	5.4	11,010	0.91
Maximum Value	83,390	5,630	8.2	17,820	1.32
Minimum Value	1,360	170	4.1	7,190	0.60

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

Source: TTI Analysis and Local Transportation Agency References

Table C-8. Summary of 1984 Relative Mobility Values for Principal Arterial Streets

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-mile	Congestion Index
Northeastern Cities					
Baltimore MD	8,280	1,540	3.8	5,380	0.85
Boston MA	13,150	2,610	2.3	5,040	0.95
New York NY	46,390	6,800	3.4	6,820	0.99
Philadelphia PA	19,810	2,800	2.8	7,070	1.04
Pittsburgh PA	9,080	1,660	3.0	5,470	0.76
Washington DC	14,800	2,000	3.8	7,400	1.12
Midwestern Cities					
Chicago IL	22,560	3,700	3.5	6,110	1.05
Cincinnati OH	3,230	780	3.3	4,160	0.82
Cleveland OH	4,550	1,100	2.9	4,130	0.83
Detroit MI	21,130	3,300	4.3	6,400	1.13
Indianapolis IN	4,060	840	3.7	4,860	0.75
Kansas City MO	3,910	1,020	3.5	3,830	0.60
Louisville KY	2,650	500	3.7	5,340	0.81
Milwaukee WI	4,660	940	3.0	4,950	0.87
Minn-St. Paul MN	4,650	1,130	3.2	4,120	0.81
Oklahoma City OK	3,330	630	3.0	5,290	0.75
St. Louis MO	9,750	1,710	3.1	5,700	0.88
Southern Cities					
Atlanta GA	7,460	1,340	3.4	5,590	0.97
Memphis TN	3,320	690	4.1	4,800	0.76
Miami FL	12,000	1,930	4.3	6,230	1.07
Nashville TN	4,300	850	3.1	5,050	0.83
Tampa FL	3,660	570	3.7	6,410	1.03
Southwestern Cities					
Albuquerque NM	3,370	590	3.5	5,760	0.89
Austin TX	1,830	380	4.0	4,800	0.89
Corpus Christi TX	1,350	320	3.6	4,220	0.69
Dallas TX	7,640	1,650	4.6	4,630	0.94
Denver CO	10,110	1,790	3.7	5,660	0.93
El Paso TX	2,820	800	3.9	3,530	0.65
Fort Worth TX	4,020	830	3.9	4,870	0.80
Houston TX	10,860	1,920	3.8	5,660	1.25
Phoenix AZ	15,310	2,500	3.4	6,120	1.10
Salt Lake City UT	1,680	300	3.3	5,580	0.65
San Antonio TX	3,920	980	3.2	4,000	0.82
Western Cities					
Los Angeles CA	63,430	11,250	4.0	5,640	1.32
Portland OR	2,800	520	3.2	5,430	0.88
Sacramento CA	5,420	900	4.0	6,020	0.88
San Diego CA	7,090	1,480	3.4	4,790	0.91
San Fran-Oak CA	10,790	1,900	3.8	5,680	1.12
Seattle-Everett WA	7,790	1,410	3.3	5,520	1.02
Northeastern Avg.	18,580	2,900	3.2	6,200	0.95
Midwestern Avg.	7,680	1,420	3.4	4,990	0.85
Southern Avg.	6,150	1,070	3.7	5,620	0.93
Southwestern Avg.	5,720	1,100	3.7	4,980	0.87
Western Avg.	16,220	2,910	3.6	5,510	1.02
Total Avg.	9,920	1,740	3.5	5,340	0.91
Maximum Value	63,430	11,250	4.6	7,400	1.32
Minimum Value	1,350	300	2.3	3,530	0.60

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

Source: TTI Analysis and Local Transportation Agency References

Table C-9. Summary of 1985 Relative Mobility Values for Freeway/Expressway

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Congestion Index
Northeastern Cities					
Baltimore MD	12,170	1,200	5.4	10,140	0.84
Boston MA	18,200	1,450	5.6	12,550	0.98
New York NY	66,060	5,640	5.5	11,710	1.00
Philadelphia PA	13,810	1,290	5.0	10,740	0.90
Pittsburgh PA	6,660	880	4.2	7,560	0.78
Washington DC	19,890	1,390	5.2	14,310	1.20
Midwestern Cities					
Chicago IL	28,670	2,130	4.5	13,460	1.08
Cincinnati OH	8,850	820	5.3	10,790	0.83
Cleveland OH	10,060	960	4.6	10,470	0.81
Detroit MI	21,460	1,550	5.7	13,840	1.12
Indianapolis IN	6,280	690	5.1	9,100	0.76
Kansas City MO	10,190	1,260	4.1	8,090	0.65
Louisville KY	4,450	480	4.4	9,270	0.79
Milwaukee WI	6,070	550	5.3	11,030	0.88
Minn-St. Paul MN	13,690	1,270	4.6	10,780	0.83
Oklahoma City OK	5,980	690	5.0	8,720	0.74
St. Louis MO	14,820	1,420	5.4	10,470	0.89
Southern Cities					
Atlanta GA	19,430	1,520	6.0	12,830	1.02
Memphis TN	3,050	370	5.2	8,360	0.75
Miami FL	7,110	540	5.3	13,170	1.13
Nashville TN	3,920	430	4.5	9,210	0.81
Tampa FL	2,850	260	4.9	10,940	1.00
Southwestern Cities					
Albuquerque NM	1,820	200	4.7	9,330	0.93
Austin TX	4,890	420	5.3	11,640	0.91
Corpus Christi TX	1,400	170	5.2	8,480	0.71
Dallas TX	21,100	1,640	5.7	12,870	0.98
Denver CO	9,050	800	5.1	11,310	0.96
El Paso TX	3,120	350	5.0	9,040	0.70
Fort Worth TX	10,070	980	5.6	10,330	0.82
Houston TX	24,120	1,480	6.0	16,290	1.23
Phoenix AZ	3,530	290	5.1	12,170	1.13
Salt Lake City UT	3,220	420	5.6	7,670	0.68
San Antonio TX	9,080	800	5.0	11,350	0.87
Western Cities					
Los Angeles CA	87,640	4,750	8.2	18,450	1.36
Portland OR	5,930	520	4.9	11,500	0.93
Sacramento CA	6,900	640	6.9	10,780	0.92
San Diego CA	19,650	1,600	7.4	12,320	0.95
San Fran-Oak CA	34,670	2,270	6.8	15,270	1.17
Seattle-Everett WA	14,850	1,100	5.8	13,500	1.05
Northeastern Avg.	22,800	1,970	5.2	11,170	0.95
Midwestern Avg.	11,860	1,070	4.9	10,550	0.85
Southern Avg.	7,270	620	5.2	10,900	0.94
Southwestern Avg.	8,310	690	5.3	10,950	0.90
Western Avg.	28,270	1,810	6.7	13,640	1.06
Total Avg.	14,480	1,160	5.4	11,280	0.93
Maximum Value	87,640	5,640	8.2	18,450	1.36
Minimum Value	1,400	165	4.1	7,560	0.65

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

Source: TTI Analysis and Local Transportation Agency References

Table C-10. Summary of 1985 Relative Mobility Values for Principal Arterial Streets

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-mile	Congestion Index
Northeastern Cities					
Baltimore MD	8,620	1,620	3.8	5,340	0.84
Boston MA	13,490	2,620	2.3	5,150	0.98
New York NY	46,700	6,800	3.4	6,870	1.00
Philadelphia PA	20,410	3,930	2.8	5,190	0.90
Pittsburgh PA	9,450	1,650	3.0	5,720	0.78
Washington DC	15,900	2,110	3.9	7,540	1.20
Midwestern Cities					
Chicago IL	22,870	3,720	3.6	6,150	1.08
Cincinnati OH	3,290	780	3.3	4,220	0.83
Cleveland OH	4,640	1,100	2.9	4,210	0.81
Detroit MI	21,240	3,340	4.4	6,360	1.12
Indianapolis IN	4,100	840	3.7	4,910	0.76
Kansas City MO	4,250	1,030	3.5	4,130	0.65
Louisville KY	2,760	500	3.7	5,510	0.79
Milwaukee WI	4,820	960	3.1	5,020	0.88
Minn-St. Paul MN	4,890	1,140	3.4	4,290	0.83
Oklahoma City OK	3,350	650	3.0	5,190	0.74
St. Louis MO	10,260	1,730	3.1	5,930	0.89
Southern Cities					
Atlanta GA	8,370	1,350	3.4	6,200	1.02
Memphis TN	3,520	720	4.2	4,890	0.75
Miami FL	12,700	1,960	4.3	6,480	1.13
Nashville TN	4,590	880	3.1	5,210	0.81
Tampa FL	3,840	600	3.8	6,450	1.00
Southwestern Cities					
Albuquerque NM	3,600	600	3.5	6,000	0.93
Austin TX	2,000	400	4.0	5,000	0.91
Corpus Christi TX	1,370	320	3.8	4,280	0.71
Dallas TX	7,950	1,680	4.6	4,750	0.98
Denver CO	10,470	1,790	3.7	5,870	0.96
El Paso TX	2,880	800	4.0	3,600	0.70
Fort Worth TX	4,140	840	3.9	4,930	0.82
Houston TX	10,850	1,930	3.9	5,620	1.23
Phoenix AZ	15,710	2,520	3.4	6,230	1.13
Salt Lake City UT	1,800	330	3.4	5,440	0.68
San Antonio TX	4,290	1,020	3.3	4,200	0.87
Western Cities					
Los Angeles CA	66,830	11,400	4.0	5,860	1.36
Portland OR	2,970	520	3.3	5,700	0.93
Sacramento CA	5,650	940	4.0	6,010	0.92
San Diego CA	7,500	1,500	3.4	5,000	0.95
San Fran-Oak CA	11,380	1,940	3.8	5,870	1.17
Seattle-Everett WA	8,060	1,440	3.3	5,600	1.05
Northeastern Avg.	19,090	3,120	3.2	5,970	0.95
Midwestern Avg.	7,860	1,440	3.4	5,080	0.85
Southern Avg.	6,600	1,100	3.8	5,850	0.94
Southwestern Avg.	5,910	1,110	3.8	5,080	0.90
Western Avg.	17,060	2,960	3.6	5,670	1.06
Total Avg.	10,290	1,790	3.6	5,410	0.93
Maximum Value	66,830	11,400	4.6	7,540	1.36
Minimum Value	1,370	320	2.3	3,600	0.65

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

Source: TTI Analysis and Local Transportation Agency References

Table C-11. Summary of 1986 Relative Mobility Values for Freeway/Expressway

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Congestion Index
Northeastern Cities					
Baltimore MD	13,020	1,220	5.4	10,710	0.88
Boston MA	20,060	1,470	5.7	13,650	1.04
New York NY	71,600	5,650	5.5	12,670	1.06
Philadelphia PA	14,130	1,300	5.0	10,870	1.06
Pittsburgh PA	6,900	910	4.2	7,580	0.79
Washington DC	22,410	1,440	5.2	15,520	1.28
Midwestern Cities					
Chicago IL	30,950	2,180	5.6	14,190	1.15
Cincinnati OH	8,910	820	5.3	10,870	0.84
Cleveland OH	10,710	960	4.6	11,150	0.86
Detroit MI	21,670	1,580	5.8	13,720	1.11
Indianapolis IN	6,910	690	5.1	10,010	0.80
Kansas City MO	10,910	1,270	4.2	8,620	0.69
Louisville KY	4,790	500	4.4	9,570	0.80
Milwaukee WI	6,320	550	5.3	11,480	0.90
Minn-St. Paul MN	14,560	1,290	4.7	11,290	0.87
Oklahoma City OK	5,780	690	5.0	8,380	0.71
St. Louis MO	15,620	1,420	5.5	11,000	0.93
Southern Cities					
Atlanta GA	21,530	1,580	6.0	13,630	1.09
Memphis TN	3,110	370	5.2	8,520	0.77
Miami FL	6,980	540	5.3	12,920	1.10
Nashville TN	4,250	430	4.6	10,000	0.86
Tampa FL	2,940	270	4.9	10,890	0.96
Southwestern Cities					
Albuquerque NM	1,930	200	4.7	9,900	0.88
Austin TX	5,300	420	5.5	12,620	0.98
Corpus Christi TX	1,420	170	5.2	8,350	0.71
Dallas TX	22,580	1,650	5.8	13,680	1.04
Denver CO	9,290	820	5.2	11,400	0.97
El Paso TX	3,420	350	5.1	9,910	0.75
Fort Worth TX	10,750	980	5.6	11,030	0.87
Houston TX	24,120	1,510	6.1	15,970	1.21
Phoenix AZ	4,620	310	5.2	14,900	1.20
Salt Lake City UT	3,450	450	5.6	7,750	0.68
San Antonio TX	9,450	810	5.1	11,670	0.90
Western Cities					
Los Angeles CA	92,110	4,800	8.2	19,190	1.42
Portland OR	6,330	530	5.0	12,050	0.97
Sacramento CA	7,400	650	6.9	11,380	0.95
San Diego CA	21,020	1,630	7.4	12,940	1.00
San Fran-Oak CA	36,930	2,290	6.8	16,160	1.24
Seattle-Everett WA	15,500	1,110	5.8	13,960	1.09
Northeastern Avg.	24,680	2,000	5.2	11,830	1.02
Midwestern Avg.	12,460	1,090	5.0	10,930	0.88
Southern Avg.	7,760	640	5.2	11,190	0.96
Southwestern Avg.	8,760	700	5.4	11,560	0.93
Western Avg.	29,880	1,830	6.7	14,280	1.11
Total Avg.	15,380	1,170	5.4	11,800	0.96
Maximum Value	92,110	5,650	8.2	19,190	1.42
Minimum Value	1,420	170	4.2	7,580	0.68

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

Source: TTI Analysis and Local Transportation Agency References

Table C-12. Summary of 1986 Relative Mobility Values for Principal Arterial Streets

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-mile	Congestion Index
Northeastern Cities					
Baltimore MD	8,930	1,640	3.8	5,450	0.88
Boston MA	13,410	2,640	2.3	5,090	1.04
New York NY	47,460	6,820	3.4	6,960	1.06
Philadelphia PA	21,430	2,950	2.8	7,260	1.06
Pittsburgh PA	9,810	1,680	3.0	5,840	0.79
Washington DC	17,400	2,220	4.1	7,840	1.28
Midwestern Cities					
Chicago IL	24,980	3,730	3.6	6,700	1.15
Cincinnati OH	3,240	780	3.3	4,150	0.84
Cleveland OH	4,730	1,100	2.9	4,300	0.86
Detroit MI	21,450	3,400	4.4	6,310	1.11
Indianapolis IN	3,950	840	3.7	4,700	0.80
Kansas City MO	4,390	1,040	3.5	4,240	0.69
Louisville KY	2,740	500	3.7	5,470	0.80
Milwaukee WI	4,700	970	3.3	4,850	0.90
Minn-St. Paul MN	5,100	1,150	3.4	4,430	0.87
Oklahoma City OK	3,310	650	3.1	5,130	0.71
St. Louis MO	10,770	1,730	3.2	6,220	0.93
Southern Cities					
Atlanta GA	9,060	1,370	3.4	6,630	1.09
Memphis TN	3,760	740	4.2	5,120	0.77
Miami FL	12,300	1,980	4.3	6,230	1.10
Nashville TN	4,810	900	3.1	5,340	0.86
Tampa FL	3,650	600	3.8	6,080	0.96
Southwestern Cities					
Albuquerque NM	3,250	620	3.5	5,280	0.88
Austin TX	2,190	410	4.2	5,340	0.98
Corpus Christi TX	1,400	320	3.8	4,380	0.71
Dallas TX	8,230	1,680	4.7	4,900	1.04
Denver CO	10,680	1,800	3.7	5,950	0.97
El Paso TX	2,920	810	4.1	3,620	0.75
Fort Worth TX	4,250	850	3.9	5,000	0.87
Houston TX	10,810	1,960	4.1	5,530	1.21
Phoenix AZ	15,840	2,540	3.5	6,240	1.20
Salt Lake City UT	1,830	340	3.4	5,450	0.68
San Antonio TX	4,590	1,030	3.4	4,450	0.90
Western Cities					
Los Angeles CA	70,410	11,610	4.0	6,060	1.42
Portland OR	3,140	530	3.3	5,980	0.97
Sacramento CA	5,890	970	4.0	6,070	0.95
San Diego CA	7,850	1,530	3.4	5,130	1.00
San Fran-Oak CA	12,000	1,980	3.8	6,080	1.24
Seattle-Everett WA	8,330	1,450	3.3	5,740	1.09
Northeastern Avg.	19,740	2,990	3.2	6,410	1.02
Midwestern Avg.	8,120	1,440	3.5	5,140	0.88
Southern Avg.	6,710	1,120	3.8	5,880	0.96
Southwestern Avg.	6,000	1,120	3.8	5,100	0.93
Western Avg.	17,940	3,010	3.6	5,840	1.11
Total Avg.	10,640	1,790	3.6	5,530	0.96
Maximum Value	70,410	11,610	4.7	7,840	1.42
Minimum Value	1,400	320	2.3	3,620	0.68

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

Source: TTI Analysis and Local Transportation Agency References

Table C-13. Summary of 1987 Relative Mobility Values for Freeway/Expressway

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Congestion Index
Northeastern Cities					
Baltimore MD	13,740	1,240	5.4	11,080	0.90
Boston MA	20,210	1,490	5.8	13,560	1.04
New York NY	73,620	5,790	5.5	12,710	1.06
Philadelphia PA	15,130	1,340	5.1	11,330	1.06
Pittsburgh PA	7,190	940	4.2	7,690	0.79
Washington DC	22,910	1,470	5.2	15,590	1.30
Midwestern Cities					
Chicago IL	30,950	2,190	5.6	14,160	1.15
Cincinnati OH	9,560	850	5.3	11,310	0.87
Cleveland OH	11,190	960	4.6	11,650	0.89
Detroit MI	21,800	1,610	5.8	13,540	1.10
Indianapolis IN	7,640	710	5.1	10,760	0.85
Kansas City MO	11,920	1,330	4.3	8,960	0.71
Louisville KY	5,380	510	4.4	10,550	0.88
Milwaukee WI	6,820	550	5.3	12,400	0.95
Minn-St. Paul MN	15,620	1,390	4.8	11,240	0.87
Oklahoma City OK	6,330	700	5.0	9,040	0.76
St. Louis MO	16,290	1,430	5.5	11,390	0.96
Southern Cities					
Atlanta GA	23,940	1,640	6.1	14,600	1.15
Memphis TN	3,730	380	5.3	9,820	0.84
Miami FL	7,420	560	5.4	13,370	1.14
Nashville TN	5,000	430	4.6	11,630	0.95
Tampa FL	3,300	280	4.9	11,790	1.02
Southwestern Cities					
Albuquerque NM	2,030	200	5.0	10,130	0.91
Austin TX	5,150	420	5.5	12,260	0.96
Corpus Christi TX	1,500	180	5.3	8,330	0.72
Dallas TX	22,100	1,660	5.8	13,310	1.02
Denver CO	9,550	860	5.2	11,170	0.95
El Paso TX	3,200	350	5.2	9,140	0.71
Fort Worth TX	11,000	990	5.7	11,110	0.87
Houston TX	25,800	1,640	6.2	15,730	1.19
Phoenix AZ	4,580	340	5.3	13,470	1.18
Salt Lake City UT	3,810	470	5.6	8,110	0.70
San Antonio TX	8,800	820	5.1	10,800	0.85
Western Cities					
Los Angeles CA	96,890	4,880	8.2	19,850	1.47
Portland OR	6,700	540	5.0	12,410	1.00
Sacramento CA	8,060	660	6.9	12,200	1.00
San Diego CA	23,160	1,640	7.4	14,120	1.08
San Fran-Oak CA	39,580	2,310	6.8	17,170	1.31
Seattle-Everett WA	16,600	1,140	5.8	14,560	1.14
Northeastern Avg.	25,460	2,040	5.2	11,990	1.03
Midwestern Avg.	13,050	1,110	5.1	11,370	0.91
Southern Avg.	8,680	660	5.3	12,240	1.02
Southwestern Avg.	8,870	720	5.4	11,230	0.91
Western Avg.	31,830	1,860	6.7	15,050	1.17
Total Avg.	16,110	1,200	5.5	12,100	0.98
Maximum Value	96,890	5,790	8.2	19,860	1.47
Minimum Value	1,500	180	4.2	7,690	0.70

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

Source: TTI Analysis and Local Transportation Agency References

Table C-14. Summary of 1987 Relative Mobility Values for Principal Arterial Streets

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-mile	Congestion Index
Northeastern Cities					
Baltimore MD	9,020	1,680	3.9	5,370	0.90
Boston MA	13,700	2,680	2.3	5,110	1.04
New York NY	48,490	6,900	3.4	7,030	1.06
Philadelphia PA	22,550	3,220	2.9	7,000	1.06
Pittsburgh PA	9,910	1,700	3.1	5,830	0.79
Washington DC	18,400	2,240	4.1	8,210	1.30
Midwestern Cities					
Chicago IL	24,970	3,740	3.6	6,680	1.15
Cincinnati OH	3,320	790	3.3	4,200	0.87
Cleveland OH	4,840	1,100	2.9	4,400	0.89
Detroit MI	21,550	3,450	4.4	6,240	1.10
Indianapolis IN	4,100	850	3.7	4,850	0.85
Kansas City MO	4,350	1,040	3.5	4,180	0.71
Louisville KY	2,980	510	3.7	5,890	0.88
Milwaukee WI	4,640	980	3.3	4,730	0.95
Minn-St. Paul MN	5,200	1,160	3.4	4,480	0.87
Oklahoma City OK	3,470	660	3.1	5,290	0.76
St. Louis MO	11,220	1,750	3.2	6,430	0.96
Southern Cities					
Atlanta GA	9,350	1,400	3.4	6,700	1.15
Memphis TN	3,930	760	4.3	5,210	0.84
Miami FL	13,000	2,000	4.3	6,500	1.14
Nashville TN	4,920	910	3.1	5,430	0.95
Tampa FL	3,880	610	3.8	6,360	1.02
Southwestern Cities					
Albuquerque NM	3,550	650	3.5	5,460	0.91
Austin TX	2,150	420	4.2	5,180	0.96
Corpus Christi TX	1,490	320	3.8	4,660	0.72
Dallas TX	8,200	1,690	4.7	4,850	1.02
Denver CO	10,600	1,830	3.8	5,790	0.95
El Paso TX	3,000	810	4.2	3,730	0.71
Fort Worth TX	4,250	860	3.9	4,940	0.87
Houston TX	10,500	1,970	4.2	5,330	1.19
Phoenix AZ	16,480	2,570	3.6	6,420	1.18
Salt Lake City UT	1,870	350	3.5	5,410	0.70
San Antonio TX	4,800	1,050	3.4	4,570	0.85
Western Cities					
Los Angeles CA	73,810	11,780	4.0	6,270	1.47
Portland OR	3,200	530	3.3	6,100	1.00
Sacramento CA	6,140	1,000	4.0	6,140	1.00
San Diego CA	8,180	1,560	3.4	5,240	1.08
San Fran-Oak CA	12,670	2,010	3.9	6,320	1.31
Seattle-Everett WA	8,950	1,480	3.3	6,070	1.14
Northeastern Avg.	20,340	3,070	3.3	6,430	1.03
Midwestern Avg.	8,240	1,460	3.5	5,220	0.91
Southern Avg.	7,020	1,130	3.8	6,040	1.02
Southwestern Avg.	6,080	1,140	3.9	5,120	0.91
Western Avg.	18,820	3,060	3.7	6,020	1.17
Total Avg.	10,960	1,820	3.6	5,610	0.98
Maximum Value	73,810	11,780	4.7	8,210	1.47
Minimum Value	1,490	320	2.3	3,730	0.70

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

Source: TTI Analysis and Local Transportation Agency References

Table C-15. Summary of 1988 Relative Mobility Values for Freeway/Expressway

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-Mile	Congestion Index
Northeastern Cities					
Baltimore MD	13,920	1,210	5.4	11,500	0.92
Boston MA	22,720	1,510	5.9	15,040	1.12
New York NY	78,010	5,810	5.5	13,430	1.10
Philadelphia PA	16,680	1,400	5.2	11,910	1.07
Pittsburgh PA	7,380	950	4.3	7,770	0.81
Washington DC	23,600	1,490	5.2	15,850	1.32
Midwestern Cities					
Chicago IL	31,970	2,210	5.6	14,500	1.18
Cincinnati OH	9,750	850	5.3	11,540	0.88
Cleveland OH	12,670	990	4.6	12,800	0.97
Detroit MI	22,020	1,640	5.8	13,430	1.09
Indianapolis IN	7,750	720	5.3	10,760	0.84
Kansas City MO	12,220	1,350	4.4	9,090	0.72
Louisville KY	6,040	570	4.4	10,690	0.87
Milwaukee WI	7,140	590	5.6	12,200	0.94
Minn-St. Paul MN	16,420	1,440	4.9	11,440	0.88
Oklahoma City OK	6,620	710	5.0	9,390	0.78
St. Louis MO	17,390	1,490	5.5	11,710	0.98
Southern Cities					
Atlanta GA	22,970	1,650	6.1	13,920	1.10
Memphis TN	3,950	380	5.4	10,390	0.86
Miami FL	7,890	580	5.4	13,710	1.18
Nashville TN	5,250	440	4.8	11,930	0.99
Tampa FL	3,440	290	4.9	11,860	1.03
Southwestern Cities					
Albuquerque NM	2,230	200	5.0	11,130	0.90
Austin TX	5,220	420	5.6	12,430	0.96
Corpus Christi TX	1,510	190	5.3	8,160	0.70
Dallas TX	22,380	1,680	5.9	13,360	1.02
Denver CO	10,490	860	5.2	12,200	0.99
El Paso TX	3,320	350	5.2	9,490	0.74
Fort Worth TX	11,150	1,000	5.7	11,150	0.87
Houston TX	27,100	1,790	6.2	15,140	1.15
Phoenix AZ	5,550	520	5.6	10,670	1.00
Salt Lake City UT	4,080	480	5.6	8,490	0.72
San Antonio TX	9,050	820	5.2	11,040	0.86
Western Cities					
Los Angeles CA	102,140	4,960	8.2	20,590	1.52
Portland OR	7,100	540	5.0	13,150	1.05
Sacramento CA	8,420	680	6.9	12,470	1.03
San Diego CA	25,040	1,700	7.4	14,770	1.13
San Fran-Oak CA	40,370	2,330	6.8	17,360	1.33
Seattle-Everett WA	17,190	1,140	5.8	15,080	1.17
Northeastern Avg.	27,050	2,060	5.3	12,580	1.06
Midwestern Avg.	13,630	1,140	5.1	11,590	0.92
Southern Avg.	8,700	670	5.3	12,360	1.03
Southwestern Avg.	9,280	760	5.5	11,200	0.90
Western Avg.	33,380	1,890	6.7	15,570	1.21
Total Avg.	16,870	1,230	5.5	12,350	0.99
Maximum Value	102,140	5,810	8.2	20,590	1.52
Minimum Value	1,510	190	4.3	7,770	0.70

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

Source: TTI Analysis and Local Transportation Agency References

Table C-16. Summary of 1988 Relative Mobility Values for Principal Arterial Streets

Urbanized Area	DVMT[1] (1000)	Lane-Miles	Avg. No. Lanes	DVMT/[2] Ln-mile	Congestion Index
Northeastern Cities					
Baltimore MD	9,160	1,740	4.0	5,260	0.92
Boston MA	12,860	2,690	2.3	4,780	1.12
New York NY	49,710	7,110	3.4	6,990	1.10
Philadelphia PA	22,120	3,230	3.0	6,850	1.07
Pittsburgh PA	10,630	1,770	3.1	6,020	0.81
Washington DC	18,800	2,280	4.1	8,250	1.32
Midwestern Cities					
Chicago IL	26,070	3,760	3.6	6,940	1.18
Cincinnati OH	3,440	800	3.3	4,320	0.88
Cleveland OH	5,010	1,110	2.9	4,510	0.97
Detroit MI	21,670	3,520	4.4	6,160	1.09
Indianapolis IN	3,940	850	3.7	4,640	0.84
Kansas City MO	4,490	1,050	3.5	4,300	0.72
Louisville KY	2,860	510	3.7	5,610	0.87
Milwaukee WI	4,730	990	3.4	4,770	0.94
Minn-St. Paul MN	5,300	1,170	3.4	4,530	0.88
Oklahoma City OK	3,450	660	3.1	5,260	0.78
St. Louis MO	11,470	1,750	3.2	6,570	0.98
Southern Cities					
Atlanta GA	9,790	1,490	3.5	6,570	1.10
Memphis TN	4,050	810	4.3	5,030	0.86
Miami FL	13,740	2,020	4.3	6,800	1.18
Nashville TN	5,390	920	3.2	5,890	0.99
Tampa FL	4,070	630	3.8	6,500	1.03
Southwestern Cities					
Albuquerque NM	3,390	700	3.5	4,840	0.90
Austin TX	2,070	420	4.2	4,920	0.96
Corpus Christi TX	1,440	320	3.8	4,500	0.70
Dallas TX	8,150	1,700	4.8	4,810	1.02
Denver CO	10,450	1,840	3.8	5,690	0.99
El Paso TX	3,110	810	4.2	3,860	0.74
Fort Worth TX	4,200	870	4.0	4,860	0.87
Houston TX	10,190	1,980	4.2	5,150	1.15
Phoenix AZ	16,680	2,880	4.0	5,790	1.00
Salt Lake City UT	1,910	350	3.5	5,460	0.72
San Antonio TX	4,990	1,070	3.5	4,660	0.86
Western Cities					
Los Angeles CA	78,240	12,000	4.0	6,520	1.52
Portland OR	3,280	530	3.3	6,250	1.05
Sacramento CA	6,660	1,050	4.0	6,340	1.03
San Diego CA	8,850	1,620	3.4	5,460	1.13
San Fran-Oak CA	13,540	2,050	3.9	6,620	1.33
Seattle-Everett WA	8,820	1,480	3.4	5,980	1.17
Northeastern Avg.	20,550	3,140	3.3	6,360	1.06
Midwestern Avg.	8,400	1,470	3.5	5,240	0.92
Southern Avg.	7,410	1,170	3.8	6,160	1.03
Southwestern Avg.	6,050	1,180	4.0	4,960	0.90
Western Avg.	19,900	3,120	3.7	6,190	1.21
Total Avg.	11,250	1,860	3.7	5,600	0.99
Maximum Value	78,240	12,000	4.8	8,250	1.52
Minimum Value	1,440	320	2.3	3,860	0.70

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

Source: TTI Analysis and Local Transportation Agency References

APPENDIX D

CONGESTION COST ESTIMATE

APPENDIX D
CONGESTION COST ESTIMATE

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

Cost Estimate Constants

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

1. Occupancy -- 1.25 persons per vehicle.
2. 250 working days per year.
3. Average cost of time (9) -- $8.80 per person hour[1].
4. Commercial vehicle operating cost (10) -- $1.75 per mile.
5. Vehicle mix -- 95 percent passenger and 5 percent commercial.
6. Vehicular speeds: Table D-1 (6).

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

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[1]Referenced value of $8.00/hr in 1985 adjusted with the Consumer Price Index to value used for 1988 wage rate.

Table D-1. Congested Daily Vehicle-Miles of Travel by Average Annual Daily Traffic per Lane Volumes

Functional Class	Parameters	Congested DVMT[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

Notes: [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 (5).

Source: TTI Analysis and Houston-Galveston Regional Transportation Study

Cost Estimate Variables

In addition to the derived constants, five urbanized area/state specific variables were identified and used in the congestion cost estimate calculations. These variables are illustrated in Table D-2.

Daily Vehicle-Miles Of Travel

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

Insurance Rates

Auto insurance rates reported in Table D-2 represent the state and urbanized area averages. These rates were compiled by averaging the rates for minimum required automobile coverage in the various areas and states as quoted by three major insurance carriers. The statewide rate is an average of small urbanized areas rate (excluding the study areas and other large urbanized areas). This allowed the calculation of the additional insurance premiums paid by motorists operating vehicles in large urbanized areas.

Fuel Costs

Statewide average fuel cost estimates were obtained from 1988 data published by the American Automobile Association (AAA) (16). These data represent the average reported fuel cost for 1988. Values for different fuel types used in motor vehicles, i.e., diesel and gasoline, did not vary enough to be reported separately. Therefore, an average rate for fuel was used in cost estimate calculations.

Registered Vehicles

The registered vehicle data was obtained from the county Tax Assessor's office in each study area. These data represent the passenger automobiles and light trucks (pick-ups) registered within the study area in 1988.

Population

Population data were obtained from the combination of 1986 U.S. Census Bureau estimates and 1988 population estimates reported in the Federal Highway Administration's Highway Performance Monitoring System (HPMS).

Cost Estimate Calculations

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

Table D-2. 1988 Congestion Cost Estimate Variables

Urbanized Area	Daily VMT Frwy (1000)	Daily VMT Prin.Art.Str. (1000)	Auto Insurance Rates,$	Annual Insurance Difference,$	State Avg Fuel Cost, $	Registered Autos (1000)	Population (1000)	Popn. Per Reg.Veh.
Northeastern Cities								
Baltimore MD	13,920	9,160	910	270	1.16	1,010	1,910	1.89
Boston MA	22,720	12,860	800	110	1.07	1,540	2,910	1.89
New York NY	78,010	49,710	860	430	1.09	5,850	16,320	2.79
Philadelphia PA	16,680	22,120	820	410	1.08	2,720	4,130	1.52
Pittsburgh PA	6,860	10,630	710	300	1.08	1,210	1,850	1.52
Washington DC	23,600	18,800	790	190	1.16	1,640	3,040	1.85
Midwestern Cities								
Chicago IL	31,970	26,070	650	190	1.17	4,030	7,340	1.82
Cincinnati OH	9,750	3,440	400	30	1.13	900	950	1.05
Cleveland OH	12,670	5,010	500	140	1.13	1,480	1,790	1.21
Detroit MI	22,020	21,670	730	230	1.14	2,890	3,900	1.35
Indianapolis IN	7,750	3,940	390	60	1.14	560	930	1.66
Kansas City MO	12,220	4,490	440	50	1.06	680	1,150	1.70
Louisville KY	6,040	2,860	410	80	1.11	460	810	1.76
Milwaukee WI	7,140	4,730	410	80	1.13	520	1,230	2.35
Minn-St. Paul MN	16,420	5,300	500	60	1.19	1,600	1,930	1.20
Oklahoma City OK	6,620	3,450	460	90	1.10	470	720	1.54
St. Louis MO	17,390	11,470	510	120	1.06	950	1,950	2.06
Southern Cities								
Atlanta GA	22,970	9,790	630	90	1.09	1,530	1,780	1.16
Memphis TN	3,950	4,050	540	160	1.12	610	830	1.37
Miami FL	7,890	13,740	1,020	460	1.17	1,350	1,810	1.34
Nashville TN	5,250	5,390	490	110	1.12	500	540	1.09
Tampa FL	3,440	4,070	640	80	1.17	600	670	1.11
Southwestern Cities								
Albuquerque NM	2,230	3,390	420	50	1.13	360	490	1.33
Austin TX	5,220	2,070	470	40	1.14	490	500	1.02
Corpus Christi TX	1,510	1,440	470	40	1.14	220	280	1.23
Dallas TX	22,380	8,150	580	150	1.14	1,600	1,950	1.22
Denver CO	10,490	10,450	570	70	1.20	1,360	1,550	1.14
El Paso TX	3,320	3,110	510	80	1.14	360	510	1.42
Fort Worth TX	11,150	4,200	540	110	1.14	1,020	1,150	1.13
Houston TX	27,100	10,190	630	200	1.14	2,240	2,850	1.27
Phoenix AZ	5,550	16,680	650	50	1.23	1,170	1,830	1.56
Salt Lake City UT	4,080	1,910	380	50	1.17	670	790	1.17
San Antonio TX	9,050	4,990	540	110	1.14	900	1,170	1.30
Western Cities								
Los Angeles CA	102,140	78,240	810	300	1.18	7,790	11,140	1.43
Portland OR	7,100	3,280	480	120	1.05	620	950	1.53
Sacramento CA	8,420	6,660	620	110	1.18	1,250	1,040	0.83
San Diego CA	25,040	8,850	620	110	1.18	1,390	2,180	1.57
San Fran-Oak CA	40,370	13,540	670	160	1.18	3,010	3,610	1.20
Seattle-Everett WA	17,190	8,820	460	70	1.16	1,170	1,630	1.39
Northeastern Avg.	26,960	20,550	820	290	1.11	2,330	5,020	1.91
Midwestern Avg.	13,630	8,400	490	100	1.12	1,320	2,060	1.61
Southern Avg.	8,700	7,410	660	180	1.13	920	1,120	1.21
Southwestern Avg.	9,280	6,050	520	90	1.16	950	1,190	1.25
Western Avg.	33,380	19,900	610	150	1.16	2,540	3,420	1.33
Total Avg.	16,860	11,250	590	140	1.14	1,510	2,360	1.46
Maximum Value	102,140	78,240	1,020	460	1.23	7,790	16,320	2.79
Minimum Value	1,510	1,440	380	30	1.05	220	280	0.83

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

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

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

The congested daily travel values were adjusted by a factor to represent the percentage of travel occurring in the peak period. This factor was calculated using Texas Department of Highways and Public Transportation (TDHPT) 1986 Automatic Traffic Recorder Data (18) for the study areas in Texas. Using these data, the percentage of ADT occurring during the morning and evening peak periods was estimated using these data. These data indicated that a relatively consistent value of 45 percent of total daily traffic occurred during the peak periods. This factor was applied to all the study areas.

Once the DVMT was converted to peak-period congested vehicle-miles of travel (Table D-3), the recurring vehicle-hours of delay were computed (Equation D-1). Recurring delay is caused by the peak facility conditions during normal operations. This value does not include delay resulting from accidents, construction or maintenance operations.

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

This calculation was performed for both freeways and principal arterial streets in a study area; the total recurring vehicle-hours of delay is the sum of the two. The result of these calculations is shown in Table D-4.

Another type of delay encountered by vehicles is incident delay. This is the delay that results from an accident or disabled vehicles. Incident vehicle-hours of delay vary for each area by facility type, i.e., freeway/expressway or arterial street. For the freeway system in individual study areas the ratio of recurring to incident delay reported by Lindley (11) were used. The resulting incident delay was calculated using Equation D-2.

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

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

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

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

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

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

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

Table D-4 shows the results of the freeway and principal arterial street recurring and incident delay calculations.

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

$$\text{Avg. Speed (mph)} = \frac{(\text{Frwy speed}^{**} \times \text{Peak-Period Frwy VMT}) + (\text{Prin.Art. Speed}^{**} \times \text{Peak-Period Prin. Art. Str. VMT})}{\text{Total Peak-Period VMT}} \quad \text{Eq. D-4}$$

**Speeds determined by congestion severity (Table D-1).

Congestion Cost

Three cost components can be associated with congestion: 1) delay cost, 2) fuel cost, and 3) insurance cost. These costs can be directly related to the vehicle-hours of delay, with the exception of the insurance cost. Table D-5 is a summary of the cost calculations for the component congestion cost per each urbanized area.

The average fuel mileage represents the fuel consumption of the vehicles operating in congested conditions. The equation (Equation D-5) is a linear regression applied to a modified version of fuel consumption reported by Raus (19).

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

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

Table D-3. 1988 Congested Daily Vehicle-Miles of Travel

Urbanized Area	Daily Vehicle-Miles of Travel		Percent of Peak-Period[1,2] VMT on Congested Roads		Peak Period Congested DVMT[1,3]		
	Frwy (1000)	Prin.Art.Str. (1000)	Frwy (%)	Prin.Art.Str. (%)	Frwy (1000)	Prin.Art.Str (1000)	Frwy & Prin. Art. St. (1000)
Northeastern Cities							
Baltimore MD	13,920	9,160	25	35	1,570	1,440	3,010
Boston MA	22,720	12,860	45	40	4,600	2,310	6,910
New York NY	78,010	49,710	55	80	19,310	17,900	37,210
Philadelphia PA	16,680	22,120	25	75	1,880	7,460	9,340
Pittsburgh PA	7,380	10,630	20	60	660	2,870	3,530
Washington DC	23,600	18,800	65	85	6,900	7,190	14,090
Midwestern Cities							
Chicago IL	31,970	26,070	55	65	7,910	7,620	15,530
Cincinnati OH	9,750	3,440	30	25	1,320	390	1,710
Cleveland OH	12,670	5,010	25	30	1,430	680	2,110
Detroit MI	22,020	21,670	40	60	3,960	5,850	9,810
Indianapolis IN	7,750	3,940	10	20	350	350	700
Kansas City MO	12,220	4,490	5	25	270	510	780
Louisville KY	6,040	2,860	5	55	140	710	850
Milwaukee WI	7,140	4,730	30	35	960	740	1,700
Minn-St. Paul MN	16,420	5,300	30	55	2,220	1,310	3,530
Oklahoma City OK	6,620	3,450	10	35	300	540	840
St. Louis MO	17,390	11,470	15	55	1,170	2,840	4,010
Southern Cities							
Atlanta GA	22,970	9,790	45	65	4,650	2,860	7,510
Memphis TN	3,950	4,050	10	35	180	640	820
Miami FL	7,890	13,740	60	70	2,130	4,330	6,460
Nashville TN	5,250	5,390	25	40	590	970	1,560
Tampa FL	3,440	4,070	25	60	390	1,100	1,490
Southwestern Cities							
Albuquerque NM	2,230	3,390	20	35	200	530	730
Austin TX	5,220	2,070	55	45	1,290	420	1,710
Corpus Christi TX	1,510	1,440	10	5	70	30	100
Dallas TX	22,380	8,150	55	30	5,540	1,100	6,640
Denver CO	10,490	10,450	50	50	2,360	2,350	4,710
El Paso TX	3,320	3,110	20	5	300	70	370
Fort Worth TX	11,150	4,200	40	30	2,010	570	2,580
Houston TX	27,100	10,190	70	50	8,540	2,290	10,830
Phoenix AZ	5,550	16,680	60	80	1,500	6,000	7,500
Salt Lake City UT	4,080	1,910	15	40	280	340	620
San Antonio TX	9,050	4,990	40	15	1,630	340	1,970
Western Cities							
Los Angeles CA	102,140	78,240	75	50	34,470	17,600	52,070
Portland OR	7,100	3,280	40	60	1,280	890	2,170
Sacramento CA	8,420	6,660	45	50	1,710	1,500	3,210
San Diego CA	25,040	8,850	45	30	5,070	1,190	6,260
San Fran-Oak CA	40,370	13,540	80	60	14,530	3,660	18,190
Seattle-Everett WA	17,190	8,820	70	55	5,410	2,180	7,590
Northeastern Avg.	27,049	20,546	39	63	5,819	6,530	12,349
Midwestern Avg.	13,633	8,401	23	42	1,821	1,958	3,779
Southern Avg.	8,698	7,405	33	54	1,587	1,979	3,566
Southwestern Avg.	9,279	6,051	40	35	2,155	1,277	3,432
Western Avg.	33,375	19,896	59	51	10,412	4,503	14,915
Total Avg.	16,874	11,247	37	46	3,822	2,864	6,686
Maximum Value	102,140	78,240	80	85	34,472	17,896	52,076
Minimum Value	1,510	1,440	5	5	68	32	100

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

Source: TTI Analysis and Local Transportation Agency References

Table D-4. Recurring and Incident Delay Relationships for 1988

Urbanized Area	Peak Period Congested DVMT[1,2] Frwy (1000)	Prin.Art.Str. (1000)	Frwy & Prin. Art. St. (1000)	Ratio of Incident[3] Delay to Recurring Delay Frwy	Prin.Art. Street	Daily Recurring Vehicle-[4] Hours of Delay Frwy	Prin.Art. Street	Total	Daily Incident Vehicle-[4] Hours of Delay Frwy	Prin.Art. Street	Total
ortheastern Cities											
Baltimore MD	1,570	1,440	3,010	2.30	1.10	18,110	12,720	30,830	41,660	13,990	55,650
Boston MA	4,600	2,310	6,910	3.50	1.10	58,790	19,190	77,980	205,760	21,100	226,870
New York NY	19,310	17,900	37,200	2.50	1.10	225,070	159,800	384,870	562,680	175,780	738,460
Philadelphia PA	1,880	7,460	9,340	2.10	1.10	20,430	68,530	88,960	42,900	75,380	118,280
Pittsburgh PA	660	2,870	3,530	2.90	1.10	7,880	25,070	32,950	22,840	27,580	50,420
Washington DC	6,900	7,190	14,090	2.20	1.10	80,540	64,400	144,940	177,180	70,840	248,020
idwestern Cities											
Chicago IL	7,910	7,620	15,540	1.20	1.10	100,060	62,080	162,150	120,080	68,290	188,370
Cincinnati OH	1,320	390	1,700	0.80	1.10	14,880	2,790	17,670	11,910	3,070	14,970
Cleveland OH	1,430	680	2,100	0.70	1.10	16,510	4,170	20,680	11,560	4,590	16,140
Detroit MI	3,960	5,850	9,810	2.20	1.10	49,020	56,130	105,150	107,840	61,740	169,580
Indianapolis IN	350	350	700	1.50	1.10	3,740	2,310	6,060	5,610	2,550	8,160
Kansas City MO	270	510	780	3.10	1.10	3,300	5,030	8,330	10,230	5,530	15,760
Louisville KY	140	710	840	1.10	1.10	1,600	4,530	6,140	1,760	4,990	6,750
Milwaukee WI	960	740	1,710	1.00	1.10	11,640	5,050	16,690	11,640	5,550	17,190
Minn-St. Paul MN	2,220	1,310	3,530	0.90	1.10	26,760	11,040	37,800	24,090	12,140	36,230
Oklahoma City OK	300	540	840	1.10	1.10	3,390	4,390	7,780	3,730	4,820	8,560
St. Louis MO	1,170	2,840	4,010	1.20	1.10	13,580	19,560	33,150	16,300	21,520	37,820
outhern Cities											
Atlanta GA	4,650	2,860	7,510	1.10	1.10	56,930	22,320	79,240	62,620	24,550	87,170
Memphis TN	180	640	820	1.10	1.10	2,020	4,490	6,500	2,220	4,930	7,150
Miami FL	2,130	4,330	6,460	1.50	1.10	27,870	43,250	71,110	41,800	47,570	89,370
Nashville TN	590	970	1,560	1.10	1.10	6,880	9,270	16,150	7,570	10,190	17,760
Tampa FL	390	1,100	1,480	1.50	1.10	4,610	10,380	14,990	6,920	11,420	18,340
outhwestern Cities											
Albuquerque NM	200	530	730	1.10	1.10	2,620	3,300	5,920	2,880	3,630	6,510
Austin TX	1,290	420	1,710	1.10	1.10	14,380	3,060	17,430	15,810	3,360	19,170
Corpus Christi TX	70	30	100	1.10	1.10	780	230	1,000	850	250	1,100
Dallas TX	5,540	1,100	6,640	1.80	1.10	67,090	7,300	74,390	120,750	8,030	128,790
Denver CO	2,360	2,350	4,710	1.00	1.10	28,230	13,950	42,180	28,230	15,340	43,570
El Paso TX	300	70	370	1.10	1.10	3,430	460	3,890	3,770	500	4,270
Fort Worth TX	2,010	570	2,570	1.80	1.10	24,310	3,760	28,070	43,750	4,140	47,890
Houston TX	8,540	2,290	10,830	1.40	1.10	109,260	17,020	126,280	152,960	18,730	171,690
Phoenix AZ	1,500	6,000	7,500	0.40	1.10	17,720	48,690	66,410	7,090	53,560	60,640
Salt Lake City UT	280	340	620	0.60	1.10	3,200	2,280	5,480	1,920	2,500	4,430
San Antonio TX	1,630	340	1,970	1.10	1.10	20,080	2,510	22,590	22,090	2,770	24,850
estern Cities											
Los Angeles CA	34,470	17,600	52,080	1.20	1.10	478,860	146,570	625,430	574,630	161,230	735,860
Portland OR	1,280	890	2,160	2.00	1.10	14,280	6,590	20,870	28,550	7,250	35,800

Table D-4. Recurring and Incident Delay Relationships for 1988 (cont'd.)

Urbanized Area	Peak Period Congested DVMT[1,2] Frwy (1000)	Prin.Art.Str. (1000)	Frwy & Prin. Art. St. (1000)	Ratio of Incident[3] Delay to Recurring Delay Frwy	Prin.Art. Street	Daily Recurring Vehicle-[4] Hours of Delay Frwy	Prin.Art. Street	Total	Daily Incident Vehicle-[4] Hours of Delay Frwy	Prin.Art. Street	Total
Sacramento CA	1,710	1,500	3,200	0.60	1.10	18,640	11,160	29,810	11,190	12,280	23,470
San Diego CA	5,070	1,190	6,260	0.60	1.10	62,180	8,520	70,700	37,310	9,380	46,680
San Fran-Oak CA	14,530	3,660	18,190	1.30	1.10	194,350	33,600	227,950	252,660	36,960	289,610
Seattle-Everett WA	5,410	2,180	7,600	1.40	1.10	63,790	17,720	81,510	89,300	19,490	108,800
Northeastern Avg.	5,819	6,530	12,349	2.58	1.10	68,469	58,283	126,753	175,504	64,112	239,616
Midwestern Avg.	1,821	1,958	3,779	1.35	1.10	22,227	16,099	38,326	29,522	17,709	47,231
Southern Avg.	1,587	1,979	3,566	1.26	1.10	19,661	17,939	37,600	24,226	19,733	43,959
Southwestern Avg.	2,155	1,277	3,432	1.14	1.10	26,462	9,324	35,785	36,374	10,256	46,630
Western Avg.	10,412	4,503	14,915	1.18	1.10	138,683	37,362	176,045	165,606	41,098	206,704
Total Avg.	3,822	2,864	6,686	1.44	1.10	48,123	24,185	72,308	74,170	26,604	100,774
Maximum Value	34,472	17,896	52,076	3.50	1.10	478,861	159,800	625,434	574,633	175,780	738,459
Minimum Value	68	32	100	0.40	1.10	776	227	1,003	854	250	1,104

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

Source: TTI Analysis and Local Transportation Agency References

$$\text{Annual Delay Cost} = \frac{\text{Vehicle-Hrs. of Delay}}{\text{Day}} \times \frac{1.25\text{ person}}{\text{Vehicle}} \times \frac{\$8.80}{\text{Hour}} \times \frac{250\text{ Workdays}}{\text{Year}} \qquad \text{Eq. D-6}$$

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

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

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

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

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

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

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

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

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

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

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

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

Results of Cost Estimate Calculations

Using the methods and equations discussed in the previous sections, the annual cost for each urbanized area was calculated (Table D-5). Reviewing the component costs of delay, fuel, and insurance, it is shown that congestion costs associated with delay make up the majority of annual congestion cost.

Table D-6 illustrates the impacts of the component and total congestion cost in terms of per capita and per registered vehicle.

Table D-7 illustrates the categorical ranking of the urban study areas by annual congestion cost, annual cost per capita, and annual cost per registered vehicle including and excluding insurance costs. It is shown that the elimination of insurance costs from the annual congestion cost did marginally affect the ranking of the top ten urbanized areas. The top 25 urbanized areas, however, were not affected by exclusion of the insurance cost.

Table D-5. Component and Total Congestion Costs By Urbanized Area for 1988

Urbanized Area	Annual Cost Due to Congestion ($Millions)						Total Delay, Fuel &Insurance	Rank
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost	Insurance		
Los Angeles CA	2,060	2,420	350	410	5,240	1,640	6,880	1
New York NY	1,270	2,440	200	380	4,290	1,760	6,040	2
San Fran-Oak CA	760	960	130	160	2,010	340	2,340	3
Chicago IL	530	620	90	100	1,340	540	1,880	4
Washington DC	480	820	80	130	1,510	220	1,730	5
Philadelphia PA	290	380	40	60	770	780	1,550	6
Detroit MI	340	550	50	90	1,030	470	1,510	7
Houston TX	420	570	70	90	1,150	310	1,470	8
Boston MA	260	750	40	120	1,170	120	1,280	9
Miami FL	230	290	40	50	610	430	1,040	10
Dallas TX	250	430	40	70	790	170	960	11
Seattle-Everett WA	270	360	50	60	740	60	800	12
Atlanta GA	260	290	40	50	640	100	730	13
San Diego CA	240	160	40	30	470	110	570	14
Pittsburgh PA	110	160	20	20	310	250	570	14
Baltimore MD	100	180	20	30	330	190	520	16
Phoenix AZ	220	200	40	30	490	40	520	16
Denver CO	140	140	20	20	320	70	400	18
Fort Worth TX	90	160	20	30	300	80	380	19
Minn-St. Paul MN	130	120	20	20	290	70	360	20
St. Louis MO	110	120	20	20	270	80	350	21
Sacramento CA	100	80	20	10	210	100	300	22
Cleveland OH	70	50	10	10	140	140	290	23
Portland OR	70	120	10	20	220	50	270	24
San Antonio TX	80	80	10	10	180	70	250	25
Nashville TN	50	60	10	10	130	40	170	26
Milwaukee WI	60	60	10	10	140	30	160	27
Tampa FL	50	60	10	10	130	30	160	27
Austin TX	60	60	10	10	140	10	160	27
Cincinnati OH	60	50	10	10	130	20	150	30
Memphis TN	20	20	0	0	40	70	120	31
Kansas City MO	30	50	0	10	90	20	110	32
Oklahoma City OK	30	30	0	0	60	30	90	33
Indianapolis IN	20	30	0	0	50	20	80	34
Louisville KY	20	20	0	0	40	30	70	35
Albuquerque NM	20	20	0	0	40	10	60	36
Salt Lake City UT	20	10	0	0	30	20	60	36
El Paso TX	10	10	0	0	20	20	50	38
Corpus Christi TX	0	0	0	0	0	10	20	39
Northeastern Avg.	420	790	70	120	1,390	550	1,950	
Midwestern Avg.	130	160	20	30	330	130	460	
Southern Avg.	120	140	20	20	310	130	440	
Southwestern Avg.	120	160	20	30	320	70	390	
Western Avg.	580	680	100	120	1,480	380	1,860	
Total Avg.	240	330	40	50	660	220	880	
Maximum Value	2,060	2,440	350	410	5,230	1,760	6,870	
Minimum Value	0	0	0	0	10	10	20	

Source: TTI Analysis and Local Transportation Agency References

Table D-6. Estimated Economic Impact of Congestion in 1988

Urbanized Area	Cost Per Registered Vehicle		Cost Per Capita	
	Total Congestion (Dollars)	Delay & Fuel (Dollars)	Total Congestion (Dollars)	Delay & Fuel (Dollars)
Northeastern Cities				
Baltimore MD	520	330	270	170
Boston MA	830	760	440	400
New York NY	1,030	730	370	260
Philadelphia PA	570	280	380	190
Pittsburgh PA	470	260	310	170
Washington DC	1,050	920	570	500
Midwestern Cities				
Chicago IL	470	330	260	180
Cincinnati OH	160	140	150	130
Cleveland OH	200	100	160	80
Detroit MI	520	360	390	270
Indianapolis IN	140	100	80	60
Kansas City MO	170	130	100	80
Louisville KY	160	110	90	60
Milwaukee WI	310	250	130	110
Minn-St. Paul MN	220	180	180	150
Oklahoma City OK	200	130	130	90
St. Louis MO	370	280	180	140
Southern Cities				
Atlanta GA	480	420	410	360
Memphis TN	200	90	140	60
Miami FL	770	450	570	330
Nashville TN	340	260	310	240
Tampa FL	270	210	240	190
Southwestern Cities				
Albuquerque NM	160	130	120	100
Austin TX	320	300	320	290
Corpus Christi TX	60	40	50	30
Dallas TX	600	500	490	410
Denver CO	290	250	260	220
El Paso TX	150	90	100	60
Fort Worth TX	370	290	330	260
Houston TX	660	520	520	410
Phoenix AZ	450	410	290	260
Salt Lake City UT	90	60	80	50
San Antonio TX	280	210	220	160
Western Cities				
Los Angeles CA	880	670	620	470
Portland OR	440	350	280	230
Sacramento CA	240	170	290	200
San Diego CA	410	330	260	210
San Fran-Oak CA	780	670	650	560
Seattle-Everett WA	680	630	490	460
Northeastern Avg.	750	550	390	280
Midwestern Avg.	260	190	170	120
Southern Avg.	410	280	340	240
Southwestern Avg.	310	250	250	200
Western Avg.	570	470	430	350
Total Avg.	420	320	290	220
Maximum Value	1,050	920	650	560
Minimum Value	70	40	50	30

Source: TTI Analysis and Local Transportation Agency References

Table D-7. 1988 Rankings of Urbanized Area by Estimated Economic Impact of Congestion

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

APPENDIX E

POPULATION, LAND AREA, AND DENSITY ESTIMATES

APPENDIX E

POPULATION, LAND AREA, AND DENSITY ESTIMATES

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

Population and Land Area

The most recent HPMS data base currently includes population and land area data from 1982 to 1988. These values are contained in the areawide data within the areawide summary tables. Table E-1 summarizes those data for the 39 urbanized areas considered in this study.

The population and land area, reported in HPMS, are determined by the latest official census (1980) (20) adjusted to current federal-aid urbanized area boundaries. While the HPMS data is updated on an annual basis, Table D-1 indicates that population and land area are not regularly updated. For this reason, the HPMS values were adjusted to reflect urban growth where appropriate.

Adjustments to HPMS Data

HPMS data from 1982 were used as the base year for population and land area adjustments. This was the first year which had data comparable to census estimates. In reviewing the HPMS data (Table E-1) most population and land area values do not change until 1985 or 1987. Using trends set by the 1980 census data and subsequent census estimates, 1985 through 1988 HPMS values were adjusted. The same trends were used to derive estimates for the years, primarily between 1982 and 1985, when no change was indicated in the HPMS data base.

Table E-1. HPMS Population and Land Area Summary Data 1982 to 1988

Urbanized Area	(1982)		(1983)		(1984)		(1985)		(1986)		(1987)		(1988)	
	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)
Northeastern Cities														
Baltimore MD	1,230	410	1,820	490	1,820	520	1,940	520	1,860	520	1,880	530	1,910	530
Boston MA	2,850	910	2,760	1,030	2,760	1,030	2,760	1,030	2,760	1,030	2,850	1,040	2,910	1,060
New York NY	16,660	3,180	16,660	3,150	15,340	3,160	15,340	3,160	15,340	3,160	16,000	3,160	16,320	3,190
Philadelphia PA	4,070	970	4,070	970	4,070	1,100	4,070	1,100	4,070	1,100	4,090	1,120	4,130	1,120
Pittsburgh PA	1,810	980	1,810	980	1,810	710	1,810	710	1,810	710	1,810	720	1,850	730
Washington DC	3,440	820	2,780	740	2,810	740	2,860	740	2,920	820	2,980	820	3,040	830
Midwestern Cities														
Chicago IL	7,080	1,900	7,100	1,960	7,100	1,960	7,100	1,960	7,160	1,960	7,200	1,960	7,340	1,990
Cincinnati OH	1,230	610	1,130	560	1,130	560	1,130	560	1,130	560	930	420	950	430
Cleveland OH	1,980	780	1,750	630	1,750	630	1,750	630	1,750	630	1,750	630	1,790	640
Detroit MI	3,810	1,090	3,810	1,090	3,810	1,090	3,890	1,240	3,890	1,250	3,890	1,250	3,900	1,250
Indianapolis IN	860	420	860	420	860	420	870	420	900	430	930	430	930	440
Kansas City MO	1,100	610	1,100	610	1,100	610	1,130	570	1,140	580	1,140	590	1,150	600
Louisville KY	770	360	780	360	780	360	790	360	790	370	790	370	810	380
Milwaukee WI	1,210	550	1,210	550	1,210	550	1,210	550	1,220	550	1,220	550	1,230	550
Minn-St. Paul MN	1,750	800	1,750	800	1,750	800	1,800	930	1,850	960	1,890	1,000	1,930	1,020
Oklahoma City OK	640	400	640	400	640	400	730	500	740	500	730	500	720	500
St. Louis MO	1,850	650	1,850	700	1,850	700	1,930	700	1,930	700	1,940	710	1,950	720
Southern Cities														
Atlanta GA	1,610	630	1,610	0	1,610	0	1,620	1,500	1,700	1,520	1,770	1,530	1,780	1,540
Memphis TN	810	350	770	30	770	30	780	360	800	380	820	400	830	420
Miami FL	1,730	410	1,720	410	1,750	440	1,780	440	1,780	450	1,790	460	1,810	470
Nashville TN	560	330	520	330	520	330	490	440	500	460	520	470	540	490
Tampa FL	540	350	560	350	570	390	580	390	620	410	650	430	670	440
Southwestern Cities														
Albuquerque NM	450	210	420	210	420	210	460	250	470	250	480	250	490	250
Austin TX	380	200	380	120	380	120	450	330	470	330	480	340	500	350
Corpus Christi TX	250	400	250	400	250	400	260	170	270	180	280	180	280	180
Dallas TX	0	0	0	0	0	0	1,870	1,400	1,890	1,410	1,910	1,420	1,950	1,440
Denver CO	1,350	430	1,350	430	0	0	1,490	860	1,500	870	1,510	880	1,550	890
El Paso TX	450	150	450	190	450	190	460	190	480	190	500	200	510	210
Fort Worth TX	0	0	0	0	0	0	1,100	820	1,120	830	1,130	830	1,150	850
Houston TX	2,410	1,310	2,410	1,550	2,410	1,550	2,420	1,580	2,790	1,600	2,820	1,610	2,850	1,630
Phoenix AZ	1,410	550	1,410	550	1,410	550	1,650	830	1,740	860	1,820	890	1,830	970
Salt Lake City UT	680	360	680	360	680	360	750	370	760	360	770	380	790	460
San Antonio TX	950	350	950	440	950	440	950	450	950	440	1,050	470	1,170	480

Table E-1. HPMS Population and Land Area Summary Data 1982 to 1988 (cont'd.)

Urbanized Area	(1982)		(1983)		(1984)		(1985)		(1986)		(1987)		(1988)	
	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)	Population (1000)	Land Area (Sq Mi)
Western Cities														
Los Angeles CA	9,900	1,830	9,900	1,830	9,900	1,830	10,500	2,000	10,710	2,050	10,920	2,100	11,140	2,150
Portland OR	1,010	350	1,000	350	1,010	350	1,030	380	1,040	400	1,050	410	950	410
Sacramento CA	830	280	830	280	830	280	910	320	960	330	1,000	340	1,040	350
San Diego CA	1,780	610	1,780	610	1,780	610	1,890	650	1,980	670	2,070	680	2,180	700
San Fran-Oak CA	3,330	800	3,330	800	3,330	800	3,350	800	3,440	810	3,520	820	3,610	830
Seattle-Everett WA	1,440	650	1,480	650	1,520	650	1,540	680	1,570	700	1,600	710	1,630	720

Source: FHWA Highway Performance Monitoring System

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

<u>**Population and Land Area Estimates**</u>

Table E-2 illustrates the adjusted population and land area values used in this study. Density values shown in this table were calculated values using the adjusted population and land area values. This table also shows the differences between HPMS, MSA, and city populations and size reported. The population and lane area values used in this study are the values reported as HPMS data.