Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-97/1131-8		

4. Title and Subtitle	5. Report Date
URBAN ROADWAY CONGESTION - 1982 TO 1993 VOLUME 1: ANNUAL REPORT	August 1996
	6. Performing Organization Code
7. Author(s) David L. Schrank and Timothy J. Lomax	8. Performing Organization Report No. Research Report 1131-8, Volume 1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Study No. 0-1131
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Interim: September 1982 - August 1993 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Study Title: Measuring and Monitoring Urban Mobility in Texas

16. Abstract

This research report represents the ninth year of a ten-year research effort focused on quantifying urban mobility. This study contains the facility information for 50 urban areas throughout the country. The database used for this research contains information on vehicle travel, system length, and urban area characteristics from 1982 to 1993. Various federal, state, and local agencies provided the information used to update and verify the primary database. The primary database and original source of most of the information is the Federal Highway Administration's Highway Performance Monitoring System (HPMS).

Researchers combined vehicle travel and system length data to develop Roadway Congestion Index (RCI) values for 50 urban areas including the seven largest in Texas. The RCI values provide an indicator of the relative mobility level within an urban area.

This report includes an analysis of the cost of congestion using travel delay and increased fuel consumption as estimated quantities. The impact of congestion was also estimated by the amount of additional facility capacity required to provide urban mobility. Congestion costs were estimated on an areawide, per eligible driver, and per capita basis.

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

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	86	

Form DOT F 1700.7 (8-72)

URBAN ROADWAY CONGESTION - 1982 TO 1993
VOLUME 1: ANNUAL REPORT

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Research Report 1131-8
Research Study Number 0-1131
Research Study Title: Measuring and Monitoring Urban Mobility in Texas

Sponsored by the
Texas Department of Transportation
In Cooperation with
U.S. Department of Transportation
Federal Highway Administration

August 1996

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IMPLEMENTATION STATEMENT

This report provides information that will assist the Texas Department of Transportation in planning future transportation needs for urban areas in Texas. This report quantifies congestion levels and the economic impact of congestion on urban motorists in seven large cities in Texas. The report also presents data for other large U.S. metropolitan areas to assist in determining mobility trends and the relative performance of Texas' roadway networks. This report is valuable for identifying transportation trends and prioritizing future needs.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. In addition, this report is not intended for construction, bidding, or permit purposes. David L. Schrank and Timothy J. Lomax (Texas Professional Engineer certification number 54597) prepared this research report.

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SUMMARY

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

The level of congestion in an urban area was estimated using procedures developed in previous research (1-4). The Roadway Congestion Index (RCI) combines the daily vehicle-kilometers of travel (VKT) per lane-kilometer for freeways and principal arterial street systems in a ratio comparing the existing value to values identified with congested conditions. Equation S-1 illustrates how the areawide and congested level travel per lane values are combined into the RCI values for each urban area.

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

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

Areawide Mobility

Table S-1 combines the freeway and principal arterial street system daily VKT and daily VKT per lane-kilometer into the 1993 estimated Roadway Congestion Index (RCI). The 10 most congested urban areas in the study are displayed. The RCI values range from 1.54 (Los Angeles) to 1.16 (Atlanta). All of these urban areas have surpassed the RCI value at which undesirable levels of congestion occur (1.0).

Table S-1. 1993 Roadway Congestion Index Value

Urban Area	Freeway/Expressway		Principal Arterial Street		Roadway/[3] Congestion Index	Rank
	Daily VKT[1] (000)	Daily VKT/[2] Ln-Km	Daily VKT[1] (000)	Daily VKT/[2] Ln-Km		
Los Angeles CA	183,460	20,810	133,630	6,610	1.54	1
Washington DC	46,690	17,790	29,620	7,830	1.41	2
San Fran-Oak CA	68,830	17,560	22,860	6,040	1.33	3
Miami FL	15,920	15,450	27,370	7,540	1.32	4
Chicago IL	65,950	15,850	56,350	6,860	1.26	5
Detroit MI	47,500	16,160	41,860	6,050	1.23	6
Seattle-Everett WA	33,330	16,110	15,620	5,970	1.23	6
San Bernardino-Riv CA	24,500	16,280	17,870	5,240	1.21	8
San Diego CA	44,680	15,900	15,540	5,560	1.21	8
Atlanta GA	48,300	15,000	19,320	6,000	1.16	10

Notes: [1] Daily vehicle-kilometers of travel.
[2] Daily vehicle-kilometers of travel per lane-kilometer.
[3] See Equation S-1.

See Table 1 for complete listing of urban areas.
Source: TTI Analysis

Table S-2 displays the 10 urban areas which have experienced the greatest growth in congestion between 1982 and 1993. The RCI values reflect the level of congestion occurring in the urban areas. Salt Lake City experienced a 31 percent increase in congestion during the seven-year period. The congestion increase rate in all cities in the top 10 approached or exceeded two percent per year.

Table S-2. Fastest Congestion Growth Areas

Urban Area	Percent Change 1987-1993	Rank 1987-1993	Year 1982	1987	1991	1992	1993
Salt Lake City UT	31	1	0.63	0.70	0.88	0.90	0.92
Columbus OH	19	2	0.68	0.78	0.91	0.93	0.93
Detroit MI	18	3	1.06	1.04	1.16	1.19	1.23
Cincinnati OH	18	3	0.86	0.87	0.99	1.01	1.03
Miami FL	16	5	1.05	1.14	1.28	1.30	1.32
Charlotte NC	16	5	0.71	0.79	0.89	0.89	0.92
Minn-St. Paul MN	15	7	0.76	0.89	0.96	0.99	1.02
Baltimore MD	14	8	0.84	0.91	1.02	1.04	1.04
Oklahoma City OK	13	9	0.72	0.76	0.81	0.83	0.86
Ft Lauderdale FL	13	9	0.88	0.95	1.03	1.05	1.07

See Table 2 for complete listing of urban areas.

Source: TTI Analysis

The 10 urban areas with the smallest growth in congestion between 1982 and 1993 are shown in Table S-3. Of the top ten, only Jacksonsville and San Francisco-Oakland experienced small increases in congestion levels. Congestion decreases in the other eight urban areas were between zero and one percent per year.

Table S-3. Slowest Congestion Growth Areas

Urban Area	Percent Change 1987-1993	Rank 1987-1993	Year 1982	1987	1991	1992	1993
Phoenix AZ	(8)	1	1.15	1.18	1.08	1.08	1.08
Austin TX	(5)	2	0.84	1.00	0.94	0.95	0.95
Houston TX	(5)	2	1.17	1.19	1.11	1.12	1.13
New Orleans LA	(4)	4	0.98	1.14	1.12	1.10	1.09
Philadelphia PA	(2)	5	1.00	1.06	1.05	1.05	1.04
Norfolk VA	(1)	6	0.79	0.93	0.93	0.92	0.92
Albuquerque NM	0	7	0.78	0.96	0.96	0.95	0.96
St. Louis MO	0	7	0.83	0.96	0.95	0.95	0.96
Jacksonville FL	2	9	0.91	0.94	0.95	0.97	0.96
San Fran-Oak CA	2	9	1.01	1.31	1.34	1.33	1.33

See Table 2 for complete listing of urban areas

Source: TTI Analysis

The 10 urban areas with the highest amount of daily delay are shown in Table S-4. Los Angeles topped this list with over 2.4 million person-hours of delay on a daily basis. New York was the only other urban area with over a million person-hours of daily delay. While Los Angeles tops the list for greatest amount of total delay, it ranks fourth amongst all of the study cities with 65 person-hours of delay annually per eligible driver.

Table S-5 lists the top 10 urban areas based on the amount of fuel wasted annually due to congested travel. Los Angeles tops the list with almost 2.5 billion liters of wasted fuel annually. New York is second with about 2.2 billion liters. Seattle is tenth in this group with about 400 million liters of fuel wasted annually. These 10 areas consume 9.8 billion liters annually due to congestion in their urban areas. Washington, D.C. led this list with about 291 liters of fuel wasted annually per eligible driver.

Table S-6 combines existing freeway and principal arterial street distances with (1989 to 1993) recent annual traffic volume growth rates to produce the number of additional lane-kilometers for both freeway and principal arterial street which would be necessary to avoid increases in areawide congestion. This value illustrates the amount of roadway that would have to be added *every year* to maintain a constant congestion level. The average amount of roadway which was added annually during this time period was also calculated. The annual deficiency in construction of lane-kilometers of freeway and principal arterial streets is shown. Detroit leads this list of cities with a deficiency of 345 lane-kilometers annually between 1989 and 1993 (115 lane-kilometers of freeway and 230 lane-kilometers of principal arterial streets).

Table S-4. Daily and Annual Hours of Delay for 1993

Urban Area	Daily Person-Hours of Delay (000)				Person-Annual Hours of Delay per Capita	Rank[1]	Person-Hours of Annual Delay per Eligible Driver	Rank[1]
	Recurring	Incident	Total	Rank[1]				
Los Angeles CA	1,106	1,295	2,402	1	50	4	65	4
New York NY	750	1,378	2,128	2	31	15	39	17
San Fran-Oak CA	366	462	828	3	43	3	66	3
Washington DC	285	504	789	4	58	1	70	2
Chicago IL	365	423	788	5	26	21	34	20
Detroit MI	253	419	673	6	42	7	57	7
Houston TX	229	309	537	7	46	6	60	5
Boston MA	117	319	437	8	37	12	44	12
Atlanta GA	185	203	388	9	42	7	53	8
Philadelphia PA	162	218	380	10	18	35	23	35

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

See Table 6 for complete listing of urban areas.

Source: TTI Analysis.

Table S-5. Annual Excess Fuel Consumed Due to Traffic Congestion in 1993

Urban Area	Annual Liters of Fuel Wasted (million)				Annual Excess Fuel Consumed per Capita (liters)	Rank[1]	Annual Excess Fuel Consumed per Eligible Driver (liters)	Rank[1]
	Recurring	Incident	Total	Rank[1]				
Los Angeles CA	1,153	1,350	2,503	1	209	5	269	4
New York NY	788	1,447	2,235	2	131	16	165	16
San Fran-Oak CA	390	492	882	3	230	3	282	3
Washington DC	298	526	824	4	242	1	291	1
Chicago IL	380	440	820	5	108	21	140	21
Detroit MI	260	431	691	6	173	9	234	7
Houston TX	245	331	576	7	197	6	257	5
Boston MA	124	339	463	8	156	12	187	12
Atlanta GA	195	214	409	9	176	8	223	9
Seattle-Everett WA	172	229	401	10	214	4	251	6

Notes: [1] Rank value of 1 associated with greatest fuel consumption.

See Table 9 for complete listing of urban areas.

Source: TTI Analysis

Table S-6. Illustration of Annual Capacity Increase Required to Prevent Congestion Growth

Urban Area	Existing (1993) Lane-km		Average Annual VKT Growth (%)[1]	Annual Freeway Lane-km		Annual Prin. Art. Lane-km		Lane-km Deficiency	
	Fwy	Prin. Art.		Needed	Added	Needed	Added	Fwy	Prin. Art.
Detroit MI	2,938	6,923	5.76	169	54	399	169	115	230
New York NY	9,902	12,397	1.71	170	115	213	141	55	72
Kansas City MO	2,479	1,811	5.24	130	74	95	32	56	63
Los Angeles CA	8,815	20,206	1.38	121	143	278	149	-22	129
Baltimore MD	2,206	2,737	3.40	75	56	93	10	19	83
Minn-St. Paul MN	2,471	1,932	5.06	125	34	98	87	91	11
Denver CO	1,594	2,995	3.39	54	52	101	8	2	93
Chicago IL	4,162	8,211	5.05	210	115	415	423	95	-8
Cincinnati OH	1,554	1,328	4.45	69	30	59	12	39	47
Orlando FL	990	1,787	4.33	43	16	77	20	27	57

Note: [1] Average Annual Growth rate of Freeway and Principal Arterial Streets Daily VKT between 1989-1993.

See Table 11 for complete listing of urban areas.

Source: TTI Analysis

The urban areas with the highest annual congestion costs are shown in Table S-7. Delay and fuel costs comprise the total congestion costs. These 10 urban areas have an annual combined congestion cost of over $33 billion. Los Angeles and New York had the highest total congestion costs with values of $8.53 billion and $7.60 billion, respectively. The final urban area in the table, Seattle, had a total congestion cost of $1.35 billion annually.

Table S-7. Component and Total Congestion Costs by Urban Area for 1993

Urban Area	Annual Cost Due to Congestion ($ millions)			Rank
	Delay	Fuel	Total	
Los Angeles CA	7,660	870	8,530	1
New York NY	6,810	790	7,600	2
San Fran-Oak CA	2,670	310	2,980	3
Chicago IL	2,520	280	2,800	4
Washington DC	2,520	270	2,790	5
Detroit MI	2,130	210	2,340	6
Houston TX	1,740	180	1,920	7
Boston MA	1,410	150	1,560	8
Atlanta GA	1,240	120	1,360	9
Seattle-Everett WA	1,210	140	1,350	10

See Table 12 for complete listing of urban areas.

Source: TTI Analysis and Local Transportation Agency Reference

Congestion costs can be used in relation to eligible drivers to show the impact on each potential driver in the urban area. Table S-8 lists the top 10 congestion costs per eligible driver for 1993. San Bernardino ranks first with a cost of $1,090 per driver. Dallas and Houston had costs of $760 and $860 per driver, respectively, or approximately $3.5 per driver per workday.

Table S-8. 1993 Congestion Cost per Eligible Driver

Urban Area	Total Congestion Cost	
	Per Eligible Driver (dollars)	Rank
San Bernardino-Riv. CA	1,090	1
Washington DC	980	2
San Fran-Oak CA	950	3
Los Angeles CA	920	4
Houston TX	860	5
Seattle-Everett WA	840	6
Detroit MI	790	7
Dallas TX	760	8
San Jose CA	750	9
Atlanta GA	740	10

See Table 13 for complete listing of urban areas.

Source: TTI Analysis

Expressing congestion costs on a per capita basis illustrates the congestion "tax" paid by residents (Table S-9). The highest 1993 cost per capita occurred in Washington, D.C. with a cost per capita of $820. San Jose had the smallest cost per capita ($580) of the top 10 urban areas with a cost of just over $2 per capita for each workday.

Table S-9. 1993 Congestion Cost per Capita

Urban Area	Total Congestion Cost	
	Per Capita (dollars)	Rank
Washington DC	820	1
San Bernardino-Riv. CA	790	2
San Fran-Oak CA	780	3
Seattle-Everett WA	720	4
Los Angeles CA	710	5
Houston, TX	660	6
Dallas, TX	600	7
Atlanta GA	590	8
Detroit MI	590	8
San Jose CA	580	10

See Table 13 for complete listing of urban areas.

Source: TTI Analysis

INTRODUCTION

Congestion within the inner city has long been recognized as a severe problem. Congested streets and freeways have forced residents and businesses to relocate in the surrounding suburbs. Relocating to the suburbs, however, proved to be only a temporary solution to metropolitan area congestion problems. Congestion has expanded into the suburbs, with street systems designed for service to residential areas overburdened with traffic headed to large shopping malls and business parks. Urban transportation systems have been required to serve more travel needs between suburbs and fewer trips to or from downtown business districts.

A recent study (5) showed this move to the suburbs has been occurring with the length of work trips increasing in urban areas of all sizes. Between 1983 and 1990, work trip length in urban areas under 1 million increased by 20 percent to 13 kilometers, and by 13 percent to 17 kilometers in urban areas with populations over 1 million. The percentage of the population with a work trip length of greater than 16 kilometers increased from 19 percent of the population in 1983 to 23 percent in 1990 for urban areas under 1 million in population. This increase was also true in urban areas with over 1 million in population, with an increase from 31 percent of the population to 36 percent in 1990.

This same study (5) shows that commute times did not increase significantly as did the length of the commute trip. In urban areas with populations greater than 1 million, the commute times remained virtually unchanged. Overall, the commute times increased by 6 percent between 1983 and 1990. Much of this increase occurred in urban areas under 1 million population and areas classified as not urban with increases in commute times of about 4 percent and 6 percent, respectively.

The decline in urban mobility resulting from congestion has become a major concern not only to the transportation community, but also to the motoring public and business community. The understanding that comes from measuring congestion assists transportation professionals, policy makers, and the general public in communicating problems, developing necessary transportation system improvements, and formulating new policies and programs.

Purpose of Congestion Research

Mobility improvement in most metropolitan areas has meant choosing from a limited set of alternatives including controlling area development, spending large sums of money for personal vehicle and transit facility improvements, or accepting decline in the quality of transportation in the cities and suburbs. Transportation professionals, policy makers, the media, and the general public typically view these options as undesirable. In recent years, cities have encouraged the use of various aspects of travel demand management (TDM). Some of these techniques reduce vehicle travel, thus reducing congestion, while others only modify demand by shifting the time of travel.

Whether cities use more traditional techniques of congestion management or the more recent techniques such as TDM, measuring congestion is still a vital step in understanding the problems of congestion and aiding in the development of effective solutions to the urban mobility problem.

Previous research efforts of this series developed a quantitative procedure to compare traffic volumes and roadway systems. The procedure estimates the mobility levels within an urban area and permits the comparison of roadway networks from year to year and area to area. It is important to note that this research is areawide and does not show direct effects from particular corridors or projects within an urban area. Previous research has determined that approximately 95 percent of trips are contained in private auto and truck trips in an urban area. Thus, this report shows the effects of the vast majority of travel within the urban area. This research does not, however, show the effects of operational improvements, transit, or ridesharing.

Congestion Research Background

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

The methodology primarily uses the Federal Highway Administration's Highway Performance Monitoring System (HPMS) database with supporting information from various state and local agencies (6). The HPMS database is used as a base because of the relative consistency and comprehensive nature. State departments of transportation collect, review, and report the data. Since each state classifies roadways in a slightly different manner, the data are reviewed and adjusted by TTI and then reviewed by state and local agencies familiar with each urban area.

This process was of particular importance with the 1992 HPMS data because many of the urban areas were affected by a U.S. Census realignment. This realignment may have significantly changed the size of the urban area which, in turn, would also cause a change in system length and vehicle travel with resulting changes in the areawide congestion levels. To avoid a stair-step appearance in the data, some historical data may have been changed also to make the realignment a smoother transition that more closely resembles the actual experience for each year. Thus, *some figures which have been reported in past reports may have changed in this report.*

Currently, the database developed for this research contains vehicle travel, population, urban area size, and system length from 1982 to 1993. Vehicle travel and vehicle travel per lane-kilometer are used as the basis of measuring urban congestion levels and comparing areawide roadway systems.

Report Organization/Content

This report is the eighth of a series (3,4) of reports and is the third in the series to utilize the metric system in the analyses. Tables 1 through 15 and the tables in the Appendix of Volume 1 are reprinted in Imperial units in Appendix A of Volume 2. It is important to note that the calculations performed in this report may produce slightly different results between the two systems due to conversions. This research report focuses on 1993 congestion levels and trends displayed by the data from 1982 to 1993. Information on the methodology and the equations utilized to produce the tables, along with detailed yearly summaries of the data are available in Volume 2 of this report.

This report summarizes and discusses urban mobility levels in 50 urban areas throughout the United States. Seven of the areas studied represent the largest urban areas in Texas; the remaining 43 areas are located in 27 states (Figure 1). These 50 areas include nearly all of the urban areas in the United States with populations of 800,000 or more that have a significant amount of congestion.

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

Areawide Congestion

Understanding the reasons for the type and scope of the urban congestion problems is important to transportation planners and policy makers. Quantitative estimates of congestion levels on major roadways allow comparisons of transportation systems and provide a tool to analyze the differences between different transportation systems and urban areas. This section discusses the trends in urban development, travel and system length statistics, and the 1993 Roadway Congestion Index (RCI) values for 50 urban areas included within the study.

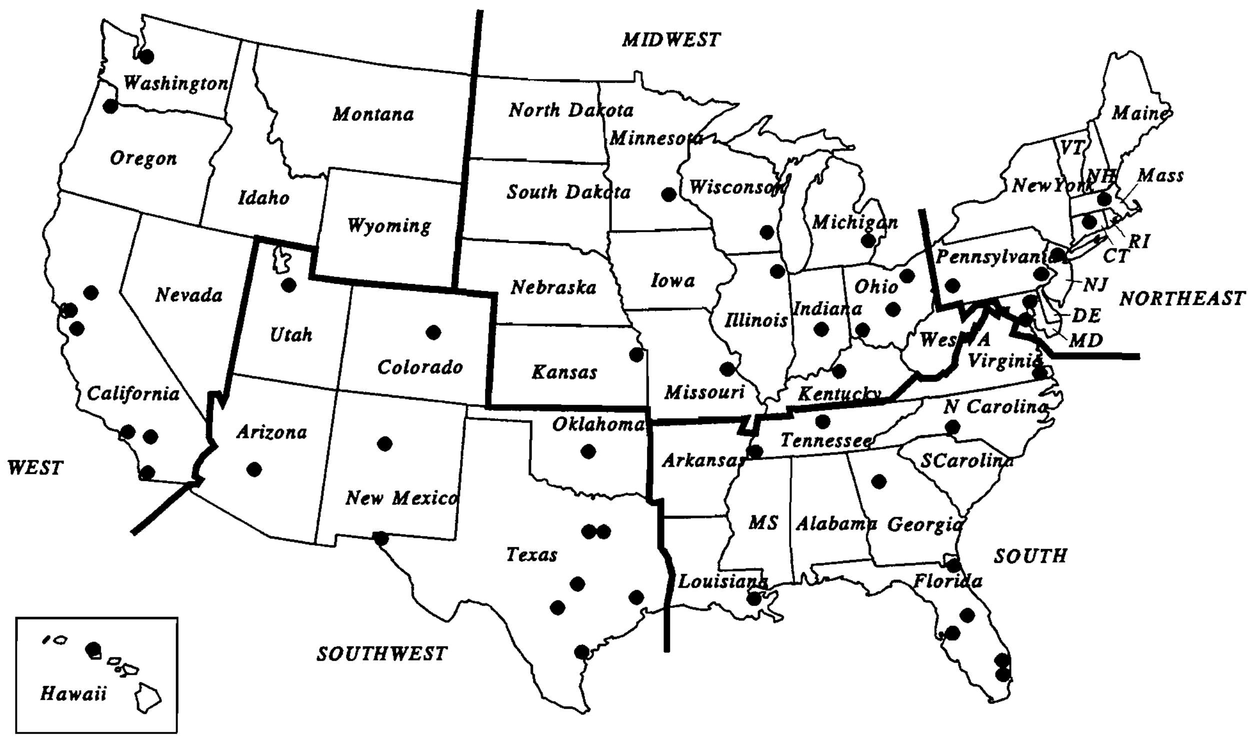

Figure 1. Regional Designations Used in Congestion Summaries

Impacts of Congestion

This section addresses travel delay, the most apparent impact of congestion to the motoring public. Delay may be categorized into two general components—recurring and incident. The impacts of travel delay and the relationship with an urban area's roadway congestion index are analyzed. The amount of excess fuel consumed by vehicles moving slowly in traffic congestion is also estimated.

Cost of Congestion

The economic impact of congestion was estimated for the 50 urban areas studied. Congestion costs have two components—travel delay and wasted fuel. Estimating the costs associated with congestion provides another tool for comparing urban mobility from one area to another. More importantly, congestion cost is another method of tracking changes in congestion levels and their impact on an urbanized area over an extended period of time. Another quantifiable impact of congestion is the additional capacity required to eliminate congestion conditions with only roadway improvements.

AREAWIDE MOBILITY

A 1989 report (7) identified several trends shaping traffic congestion. The interrelated forces impacting the nature and severity of congestion identified in that report include: (1) suburban development, (2) the economy, (3) the labor force, (4) automobile usage, percent of truck traffic, and the highway infrastructure. The following is an example of how these forces interact:

> "Trends in suburban and economic development have supported and generated increased automobile usage and truck traffic. This has resulted in increasing traffic congestion in many metropolitan areas throughout the country" (7).

Trends in Urban Development

Most metropolitan areas have experienced dynamic suburban growth since the 1960s. The prevailing desire to live away from the inner city and yet to be in close enough proximity to enjoy urban amenities encouraged suburban development. This evolutionary process begins with families and then expands to commercial services and jobs. The process shapes traffic congestion in most metropolitan areas by altering the commuting patterns.

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

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

Roadway Congestion Index Values, 1993

Urban roadway congestion levels are estimated using a formula that measures the density of traffic. Average travel volume per lane on freeways and principal arterial streets are estimated using areawide estimates of vehicle-kilometers of travel (VKT) and lane-kilometers of roadway (Ln-Km). The resulting ratios are combined into one value using the amount of travel on each portion of the system. This variable weighting factor allows comparisons between areas such as Phoenix, where principal arterial streets carry twice the amount of travel of freeways, and cities such as Portland, where the ratio is reversed.

The traffic density ratio is divided by a similar ratio that represents congestion for a system with the same mix of freeway and street volume. While it may appear that the travel volume factors on the top and bottom of the equation cancel each other, a sample calculation should satisfy the reader that this is not the case.

Equation 1 illustrates the factors used in the estimate and their combination. The resulting ratio indicates an undesirable level of areawide congestion if a value greater than or equal to 1.0 is obtained.

$$\text{Roadway Congestion Index (RCI)} = \frac{\frac{\text{Freeway}}{\text{VKT/Ln.-Km.}} \times \text{Freeway VKT} + \frac{\text{Prin Art Str}}{\text{VKT/Ln.-Km.}} \times \text{Prin Art Str VKT}}{13{,}000 \times \text{Freeway VKT} + 5{,}000 \times \text{Prin Art Str VKT}} \qquad \text{Eq. 1}$$

The congestion index is a macroscopic measure which does not account for local bottlenecks or variations in travel patterns that affect time of travel or origin-destination combinations. It also does not indicate the improvements such as ramp metering, or of treatments designed to give a travel speed advantage to transit and carpool riders.

1993 Roadway Congestion Index Estimates

Table 1 lists the roadway congestion index values for 1993. Of the 50 urban areas studied, 27 have 1993 RCI values of or exceeding 1.0. RCI values for the 10 most congested urban areas range from 1.54 (Los Angeles) to 1.16 (Atlanta). Sixteen urban areas have estimated RCI values ranging between 0.90 and 0.99, indicating the potential approach of undesirable congestion levels. These areas may not currently experience undesirable levels of congestion; however, traffic growth rates indicate congestion levels could become undesirable within the next few years in many of these cities.

The Western region has the highest average RCI value (1.21), and the Northeastern (1.07) and Southern (1.01) regional averages also exceeded 1.0. The Southwestern and Midwestern regions have average RCI values below 1.0.

Four areas in California ranked in the top 10 including two from the Los Angeles Metropolitan area (also San Bernardino-Riverside). None of the urban areas studied in Texas were included in the 10 most congested areas. Houston (tied at 12th) and Dallas (tied at 17th) were the only urban areas studied in Texas which were in the twenty most congested urban areas. Austin had the next highest rank of the Texas urban areas (tied at 33rd). Florida was the only other state with more than one area in the twenty most congested systems (Miami and Tampa).

Table 1. 1993 Roadway Congestion Index Value

Urban Area	Freeway/Expressway		Principal Arterial Street		Roadway/[3] Congestion Index	Rank
	Daily VKT[1] (000)	Daily VKT/[2] Ln-Km	Daily VKT[1] (000)	Daily VKT/[2] Ln-Km		
Los Angeles CA	183,460	20,810	133,630	6,610	1.54	1
Washington DC	46,690	17,790	29,620	7,830	1.41	2
San Fran-Oak CA	68,830	17,560	22,860	6,040	1.33	3
Miami FL	15,920	15,450	27,370	7,540	1.32	4
Chicago IL	65,950	15,850	56,350	6,860	1.26	5
Detroit MI	47,500	16,160	41,860	6,050	1.23	6
Seattle-Everett WA	33,330	16,110	15,620	5,970	1.23	6
San Bernardino-Riv CA	24,500	16,280	17,870	5,240	1.21	8
San Diego CA	44,680	15,900	15,540	5,560	1.21	8
Atlanta GA	48,300	15,000	19,320	6,000	1.16	10
New York NY	138,460	13,980	88,550	7,140	1.15	11
Honolulu HI	8,860	13,920	3,110	7,880	1.13	12
Houston TX	51,520	14,880	18,350	5,180	1.13	12
Portland OR	13,440	13,920	7,080	6,670	1.11	14
New Orleans LA	8,370	13,510	7,080	6,290	1.09	15
Phoenix AZ	15,780	13,800	29,790	5,520	1.08	16
Boston MA	34,620	14,240	22,540	4,840	1.07	17
Dallas TX	40,090	13,990	14,650	5,080	1.07	17
Denver CO	21,330	13,380	17,870	5,970	1.07	17
Tampa FL	6,360	12,340	7,500	6,470	1.06	20
San Jose CA	26,810	13,650	11,750	5,290	1.05	21
Baltimore MD	28,980	13,140	16,100	5,880	1.04	22
Philadelphia PA	32,520	11,950	34,870	6,580	1.04	22
Sacramento CA	16,550	12,770	12,640	6,280	1.04	22
Cincinnati OH	20,710	13,330	7,080	5,330	1.03	25
Minn-St. Paul MN	32,200	13,030	11,430	5,920	1.02	26
Milwaukee WI	12,620	12,960	9,020	5,000	1.00	27
Cleveland OH	24,100	12,580	9,980	5,410	0.98	28
Ft. Lauderdale FL	13,690	12,500	10,300	5,250	0.98	28
Albuquerque NM	4,410	11,420	7,250	5,450	0.96	30
Jacksonville FL	9,660	12,500	10,060	4,770	0.96	30
St. Louis MO	31,400	11,340	20,450	6,600	0.96	30
Austin TX	10,340	12,110	4,030	5,210	0.95	33
Fort Worth TX	21,090	12,240	7,570	5,000	0.95	33
Columbus OH	15,700	11,820	5,640	5,470	0.93	35
Hartford CT	11,310	11,520	6,100	5,790	0.93	35
Louisville KY	11,270	11,380	5,640	6,030	0.93	35
Memphis TN	8,290	11,320	8,950	5,350	0.93	35
Nashville TN	11,270	11,110	9,020	5,770	0.93	35
Charlotte NC	5,640	11,110	5,190	5,470	0.92	40
Norfolk VA	9,620	10,390	7,890	6,450	0.92	40
Salt Lake City UT	9,760	11,330	4,300	6,140	0.92	40
San Antonio TX	17,230	11,380	9,660	5,310	0.91	43
Indianapolis IN	14,330	11,410	7,250	4,890	0.89	44
Oklahoma City OK	12,400	10,480	7,250	5,630	0.86	45
Orlando FL	10,020	10,120	8,370	4,680	0.82	46
Pittsburgh PA	15,050	8,130	18,520	6,180	0.82	46
Kansas City MO	24,150	9,740	8,860	4,890	0.78	48
El Paso TX	5,960	10,000	5,380	3,880	0.77	49
Corpus Christi TX	3,140	9,290	2,580	4,320	0.75	50
Northeastern Avg	43,950	12,960	30,900	6,320	1.07	
Midwestern Avg	26,030	12,510	15,900	5,670	0.99	
Southern Avg	13,380	12,310	11,010	5,820	1.01	
Southwestern Avg	18,240	12,170	11,040	5,190	0.96	
Western Avg	46,720	15,660	26,680	6,170	1.21	
Texas Avg	21,340	11,990	8,890	4,860	0.93	
Total Avg	27,760	13,020	17,790	5,780	1.04	
Maximum Value	183,460	20,810	133,630	7,880	1.54	
Minimum Value	3,140	8,130	2,580	3,880	0.75	

Notes: [1] Daily vehicle-kilometers of travel.
[2] Daily vehicle-kilometers of travel per lane-kilometer.
[3] See Equation 1.

Source: TTI Analysis.

The limitation of any roadway congestion estimate based on traffic volumes, however, is that only part of the land use transportation system is addressed. As Richardson et al. point out, travel times for work trips have not substantially increased between 1983 to 1990 (8). This reflects the impact of "urban sprawl" as a congestion relief mechanism. As congestion has grown in certain corridors, jobs, residences, or both have relocated to take advantage of less congested roads. Trip lengths and travel speeds can thus both increase as traffic volumes rise due to growth in development. As more development occurs outside the defined urban area, urban area residents make more trips on the roadway system. The long-term sustainability of this growth pattern is being debated, but there is no doubt as to its impact on transportation systems.

Travel time is a very useful congestion measurement. It can be used in multimodal analyses and can illustrate the effect of operational improvements and policy changes designed to make the land use/transportation system function better. Unfortunately, if an analysis focuses only on the work trip, it ignores approximately 50 percent of weekday peak period vehicle trips and 66 percent of weekday vehicle trips. In addition, since 1969, work trips have declined from 36 to 28 percent of total vehicle trips, while family and personal business trips have increased from 31 to 45 percent of total vehicle trips. To suggest that congestion is not increasing because work trip travel times have not substantially changed, is to ignore traffic volumes that are significantly larger than roadway designs envisioned and to discount the effect of three hour peak periods on economic activity in congested travel corridors (8).

Roadway Congestion Index Growth

Table 2 summarizes roadway congestion index values for all 50 urban areas for certain years between 1982 to 1993. During the last seven years, Salt Lake City and Columbus were estimated to have experienced the fastest increase in congestion, while Phoenix, Austin and Houston have experienced the smallest.

Table 2. Roadway Congestion Index Values, 1982 to 1993

Urban Area	Percent Change 1987-1993	Rank	Year							
			1982	1984	1986	1987	1989	1991	1992	1993
Phoenix AZ	(8)	1	1.15	1.10	1.20	1.18	1.03	1.08	1.08	1.08
Austin TX	(5)	2	0.84	0.86	0.94	1.00	0.96	0.94	0.95	0.95
Houston TX	(5)	2	1.17	1.25	1.21	1.19	1.13	1.11	1.12	1.13
New Orleans LA	(4)	4	0.98	1.05	1.09	1.14	1.13	1.12	1.10	1.09
Philadelphia PA	(2)	5	1.00	1.04	1.06	1.06	1.05	1.05	1.05	1.04
Norfolk VA	(1)	6	0.79	0.81	0.90	0.93	0.95	0.93	0.92	0.92
Albuquerque NM	0	7	0.78	0.89	0.96	0.96	0.98	0.96	0.95	0.96
St. Louis MO	0	7	0.83	0.88	0.93	0.96	0.96	0.95	0.95	0.96
Jacksonville FL	2	9	0.91	0.96	0.95	0.94	0.93	0.95	0.97	0.96
San Fran-Oak CA	2	9	1.01	1.12	1.24	1.31	1.36	1.34	1.33	1.33
Boston MA	3	11	0.90	0.95	1.04	1.04	1.09	1.06	1.07	1.07
Corpus Christi TX	4	12	0.67	0.69	0.71	0.72	0.70	0.72	0.74	0.75
Nashville TN	4	12	0.77	0.83	0.86	0.89	0.90	0.90	0.92	0.93
Pittsburgh PA	4	12	0.78	0.76	0.79	0.79	0.82	0.82	0.81	0.82
Sacramento CA	4	12	0.80	0.88	0.95	1.00	1.01	1.04	1.04	1.04
Tampa FL	4	12	0.94	1.03	0.96	1.02	1.03	1.05	1.07	1.06
Atlanta GA	5	17	0.91	0.97	1.09	1.11	1.14	1.16	1.17	1.16
Dallas TX	5	17	0.84	0.94	1.04	1.02	1.02	1.06	1.07	1.07
Indianapolis IN	5	17	0.67	0.75	0.81	0.85	0.86	0.84	0.84	0.89
Los Angeles CA	5	17	1.22	1.32	1.42	1.47	1.54	1.56	1.54	1.54
Milwaukee WI	5	17	0.83	0.87	0.90	0.95	0.97	1.00	1.00	1.00
Orlando FL	6	22	0.72	0.73	0.76	0.77	0.77	0.78	0.80	0.82
San Antonio TX	6	22	0.77	0.82	0.88	0.86	0.87	0.89	0.90	0.91
San Bernardino-Riv CA	6	22	1.11	1.13	1.15	1.14	1.17	1.22	1.22	1.21
San Jose CA	6	22	0.86	0.91	0.97	0.99	1.03	1.08	1.07	1.05
Harftford CT	7	26	0.76	0.86	0.85	0.87	0.89	0.89	0.91	0.93
El Paso TX	8	27	0.63	0.65	0.75	0.71	0.74	0.75	0.76	0.77
Honolulu HI	8	27	0.92	0.95	1.03	1.05	1.07	1.10	1.10	1.13
Louisville KY	8	27	0.78	0.82	0.80	0.86	0.86	0.88	0.90	0.93
New York NY	8	27	1.01	0.99	1.06	1.06	1.12	1.14	1.14	1.15
Seattle-Everett WA	8	27	0.95	1.02	1.09	1.14	1.20	1.20	1.22	1.23
Fort Worth TX	9	32	0.76	0.80	0.87	0.87	0.87	0.92	0.94	0.95
Ft. Lauderdale FL	9	32	0.87	0.86	0.85	0.90	0.92	0.95	0.96	0.98
Washington DC	9	32	1.12	1.11	1.27	1.29	1.33	1.33	1.36	1.41
Chicago IL	10	35	1.02	1.05	1.15	1.15	1.21	1.27	1.28	1.26
Cleveland OH	10	35	0.80	0.83	0.86	0.89	0.96	0.95	0.95	0.98
Kansas City MO	10	35	0.62	0.60	0.68	0.71	0.72	0.75	0.77	0.78
Memphis TN	11	38	0.83	0.79	0.80	0.84	0.90	0.91	0.92	0.93
Portland OR	12	39	0.87	0.88	0.97	0.99	1.07	1.08	1.10	1.11
San Diego CA	12	39	0.78	0.91	1.00	1.08	1.18	1.22	1.22	1.21
Denver CO	13	41	0.88	0.93	0.97	0.95	1.01	1.03	1.05	1.07
Oklahoma City OK	13	41	0.72	0.75	0.76	0.76	0.78	0.81	0.83	0.86
Baltimore MD	14	43	0.84	0.85	0.88	0.91	0.98	1.02	1.04	1.04
Minn-St. Paul MN	15	44	0.76	0.84	0.89	0.89	0.92	0.96	0.99	1.02
Charlotte NC	16	45	0.71	0.76	0.78	0.79	0.82	0.89	0.89	0.92
Miami FL	16	45	1.05	1.10	1.14	1.14	1.25	1.28	1.30	1.32
Cincinnati OH	18	47	0.86	0.82	0.84	0.87	0.94	0.99	1.01	1.03
Detroit MI	18	47	1.06	1.07	1.05	1.04	1.09	1.16	1.19	1.23
Columbus OH	19	49	0.68	0.71	0.75	0.78	0.82	0.91	0.93	0.93
Salt Lake City UT	31	50	0.63	0.65	0.68	0.70	0.81	0.88	0.90	0.92
Northeastern Avg			0.92	0.94	0.99	1.00	1.04	1.04	1.05	1.07
Midwestern Avg			0.80	0.83	0.87	0.89	0.92	0.96	0.97	0.99
Southern Avg			0.86	0.90	0.93	0.95	0.98	0.99	1.00	1.01
Southwestern Avg			0.83	0.87	0.93	0.92	0.92	0.94	0.95	0.96
Western Avg			0.95	1.01	1.09	1.13	1.18	1.20	1.20	1.21
Texas Avg			0.81	0.86	0.91	0.91	0.90	0.91	0.93	0.93
Total Avg			0.86	0.90	0.95	0.97	1.00	1.02	1.03	1.04
Maximum Value			1.22	1.32	1.42	1.47	1.54	1.56	1.54	1.54
Minimum Value			0.62	0.60	0.68	0.70	0.70	0.72	0.74	0.75

Source: TTI Analysis

Figure 2 illustrates trend data for the Texas urban areas studied. This figure graphically shows that all of the Texas urban areas experienced increases in congestion in 1993 except Austin and Dallas. Austin, Fort Worth, and San Antonio are all above the 0.90 level, which means they could reach the 1.00 level in the next few years.

Table 3 compares growth between the congestion level and the daily vehicle-kilometers of travel in each urban area. This table shows some of the dramatic changes in growth rates between the early 1980s and early 1990s. Salt Lake City, for example, was ranked 31st and 20th for its growth in congestion and daily VKT, respectively, between 1982 and 1986, while it is ranked first in both categories for its growth between 1987 and 1993. Slower economic growth and freeway and street expansions funded by increases in fuel tax in the early 1980s have slowed the growth of roadway congestion in Texas relative to most other states.

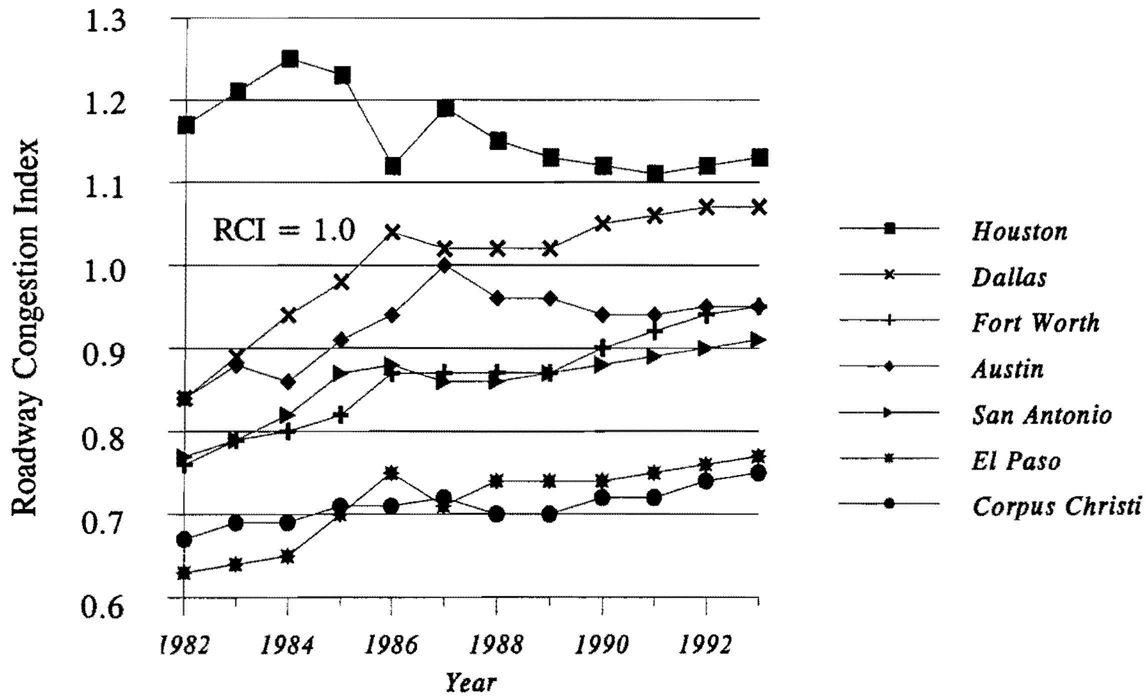

Figure 2. Texas Urban Area Congestion Levels, 1982 - 1993

Table 3. Change in Congestion and VKT, 1982 to 1993

Urban Area	1982 to 1986				1987 to 1993			
	Roadway Congestion Index		Daily Vehicle-Kilometers of Travel		Roadway Congestion Index		Daily Vehicle-Kilometers of Travel	
	Percent Change	Rank	Percent Change	Rank	Percent Change	Rank	Percent Change	Rank
Salt Lake City UT	8	31	22	20	31	1	54	1
Columbus OH	10	26	19	27	19	2	28	14
Cincinnati OH	(2)	48	6	47	18	3	34	4
Detroit MI	(1)	47	4	49	18	3	34	4
Charlotte NC	10	26	21	23	16	5	31	10
Miami FL	9	30	13	37	16	5	32	8
Minn-St. Paul MN	17	9	27	10	15	7	30	11
Baltimore MD	5	38	24	16	14	8	23	22
Denver CO	10	26	14	34	13	9	21	26
Oklahoma City OK	6	34	13	37	13	9	25	20
Portland OR	11	24	26	13	12	11	29	13
San Diego CA	28	1	36	3	12	11	19	32
Memphis TN	(4)	50	13	37	11	13	40	2
Chicago IL	13	16	21	23	10	14	36	3
Cleveland OH	8	31	6	47	10	14	32	8
Kansas City MO	10	26	20	25	10	14	26	18
Fort Worth TX	14	13	22	20	9	17	17	38
Ft. Lauderdale FL	(2)	48	3	50	9	17	27	17
Washington DC	13	16	30	7	9	17	19	32
El Paso TX	19	7	23	18	8	20	14	43
Honolulu HI	12	19	14	34	8	20	28	14
Louisville KY	3	43	15	31	8	20	26	18
New York NY	5	38	11	43	8	20	15	41
Seattle-Everett WA	15	12	25	15	8	20	19	32
Hartford CT	12	19	31	6	7	25	19	32
Orlando FL	6	34	14	34	6	26	24	21
San Antonio TX	14	13	24	16	6	26	21	26
San Bernardino-Riv CA	4	40	11	43	6	26	21	26
San Jose CA	13	16	18	28	6	26	14	43
Atlanta GA	20	6	37	2	5	30	30	11
Dallas TX	24	2	32	5	5	30	12	46
Indianapolis IN	21	5	22	20	5	30	14	43
Los Angeles CA	16	10	23	18	5	30	15	41
Milwaukee WI	8	31	11	43	5	30	17	38
Corpus Christi TX	6	34	11	43	4	35	19	32
Nashville TN	12	19	33	4	4	35	34	4
Pittsburgh PA	1	46	16	30	4	35	22	23
Sacramento CA	19	7	29	8	4	35	28	14
Tampa FL	2	45	27	10	4	35	20	30
Boston MA	16	10	17	29	3	40	5	50
Jacksonville FL	4	40	15	31	2	41	18	37
San Fran-Oak CA	23	3	27	10	2	41	9	49
Albuquerque NM	23	3	29	8	0	43	22	23
St. Louis MO	12	19	26	13	0	43	17	38
Norfolk VA	14	13	20	25	(1)	45	21	26
Philadelphia PA	6	34	13	37	(2)	46	11	47
New Orleans LA	11	24	13	37	(4)	47	10	48
Austin TX	12	19	51	1	(5)	48	22	23
Houston TX	3	43	13	37	(5)	48	20	30
Phoenix AZ	4	40	15	31	(8)	50	34	4

Source: TTI Analysis

TRAVEL DELAY

Travel delay is the most apparent impact of congestion to the motoring public. Analyses of delay have generally been divided into two estimates—recurring and incident. Recurring delay occurs due to normal daily operations when demand for roadway facilities is near or exceeds capacity. The most common example of recurring delay is the increased travel time during peak periods.

Accidents, breakdowns, or other occurrences which temporarily decrease roadway capacity cause incident delay. When congestion levels increase (creating higher RCI values), it is the recurring delay that is being measured. Incident delay is not directly related to or caused by high traffic volume, and incident congestion may be much greater for less congested areas. A severe incident will cause a significant increase in travel delay for an otherwise uncongested area. The estimation of travel delay is discussed in Appendix B of Volume 1.

Table 4 shows the change in congestion levels by region between 1982 and 1993. The largest change in freeway congestion occurred in the Southwestern region with the percent of congested vehicle-kilometers of travel (VKT) climbing from 44 to 54 percent over the twelve-year span. The largest change in principal arterial congestion occurred in the Western region with the percent of congested daily VKT rising from 40 to 55 percent. The percentage of congested daily VKT from all 50 study cities on freeways rose by 8 percentage points (44 to 52 percent) and 9 percentage points (49 to 58 percent) on principal arterial streets for the twelve-year period.

Table 4. Change in Congested Daily Vehicle-Kilometers of Travel and Severity

Region	Year	Freeway				Principal Arterial Street			
		Percent of Daily VKT Congested	Level of Congestion (percent)			Percent of Daily VKT Congested	Level of Congestion (percent)		
			Moderate	Heavy	Severe		Moderate	Heavy	Severe
Northeastern	1982	43	51	19	30	63	26	30	44
	1993	50	26	33	41	72	13	21	66
	change	+7	(25)	+14	+11	+9	(13)	(9)	+22
Midwestern	1982	27	41	31	28	48	33	28	39
	1993	36	26	18	56	54	22	25	53
	change	+9	(15)	(13)	+28	+6	(11)	(3)	+14
Southern	1982	32	54	35	11	46	22	29	49
	1993	41	24	33	43	54	20	21	59
	change	+9	(30)	(2)	+32	+8	(2)	(8)	+10
Southwestern	1982	44	27	16	57	42	43	23	34
	1993	54	19	32	49	49	29	34	37
	change	+10	(8)	+16	(8)	+7	(14)	+11	(3)
Western	1982	60	34	23	43	40	44	37	19
	1993	68	13	15	72	55	18	27	55
	change	+8	(21)	(8)	+29	+15	(26)	(10)	+36
Texas	1982	47	18	15	67	29	35	27	38
	1993	55	19	36	45	37	29	36	35
	change	+8	+1	+21	(22)	+8	(6)	+9	(3)
Total	1982	44	39	23	38	49	33	30	37
	1993	52	20	23	57	58	19	25	56
	change	+8	(19)	0	+19	+9	(14)	(5)	+19

Source: TTI Analysis

The breakdown of congestion on the freeway and principal arterial street systems into levels defined by severity is also shown in Table 4. The Southwestern and Texas regions experienced declines in the percentage of freeway daily VKT experiencing severe congestion. The Northeastern, Southwestern, and Texas regions had increases in heavy congestion on their freeway system. Nationally, severe congestion increased by 19 percentage points. On the principal arterial system, all regions experienced an increase in severe congestion levels except the Southwestern and Texas regions. Nationally, severe congestion levels rose by about 19 percentage points over the twelve year period. Some of this information is shown graphically in the next three figures.

Figure 3 shows the change in congestion levels in the 50 study cities between 1982 and 1993. The average amount of daily VKT experiencing congestion in 1982 on the freeways was 44 percent with 49 percent on the principal arterial street system. These values grew to 52 percent for freeways and expressways and 58 percent for principal arterial streets in 1993.

Figure 4 shows how the levels of congestion have changed during the 1982 to 1993 period on the freeways and expressways in the 50 study cities. In 1982, the congestion levels were 39 percent moderate, 23 percent heavy, and 38 percent severe. The percentage of heavy congestion remained unchanged between the years 1982 and 1993, while the severe congestion rose by 19 percentage points. The breakdown in 1993 was 20 percent moderate, 23 percent heavy, and 57 percent severe.

The change in congestion levels for the principal arterial street system (PAS) for 1982 to 1993 is shown in Figure 5. In 1982, total congestion was comprised of 33 percent moderate, 30 percent heavy, and 37 percent severe. The percentages moved further to the severe side by 1993 with 19 percent moderate, 25 percent heavy, and 56 percent severe.

Table 5 displays the percentage of delay (person-hours) in each of the three congestion levels. Increases in the amount of delay from severe congestion occurred in all regions except Southwestern and Texas. Both of these regions experienced large increases in delay caused by heavy congestion. This information is shown graphically in Figure 6 for all 50 urban areas combined. This graphic shows the large increase in the amount of delay caused by severe congestion on average for the 50 areas.

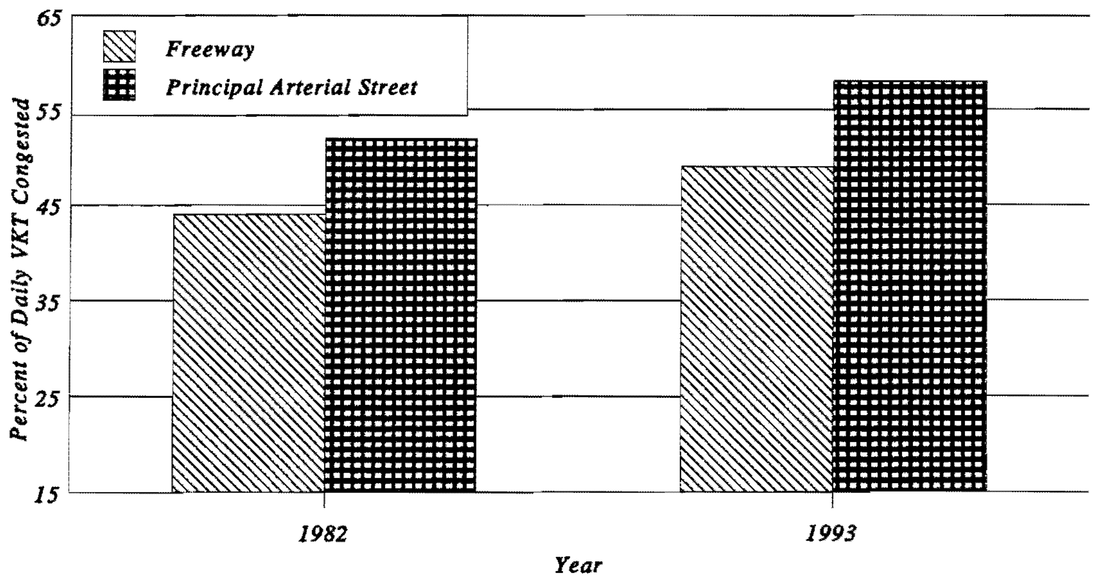

Figure 3. Change in Congestion for 50 Urban Areas, 1982 and 1993

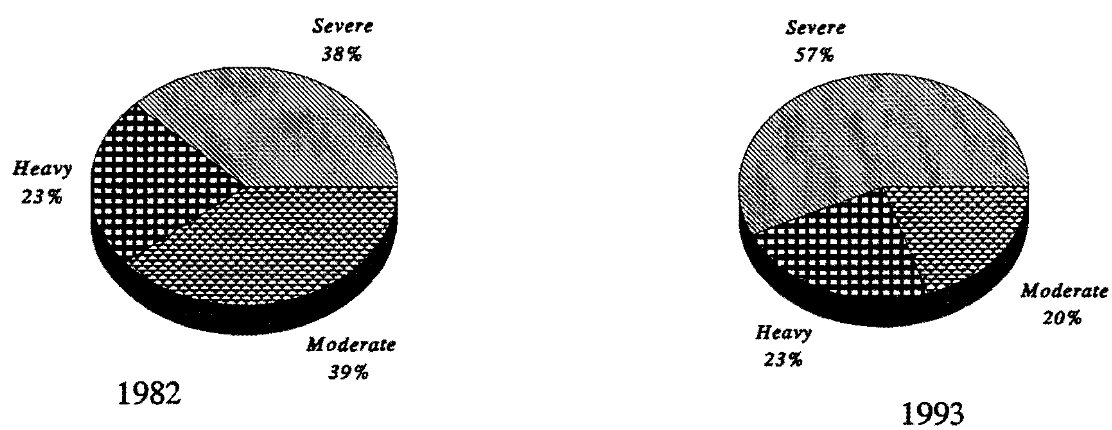

Figure 4. Change in Freeway Congestion Levels for 50 Urban Areas, 1982 and 1993

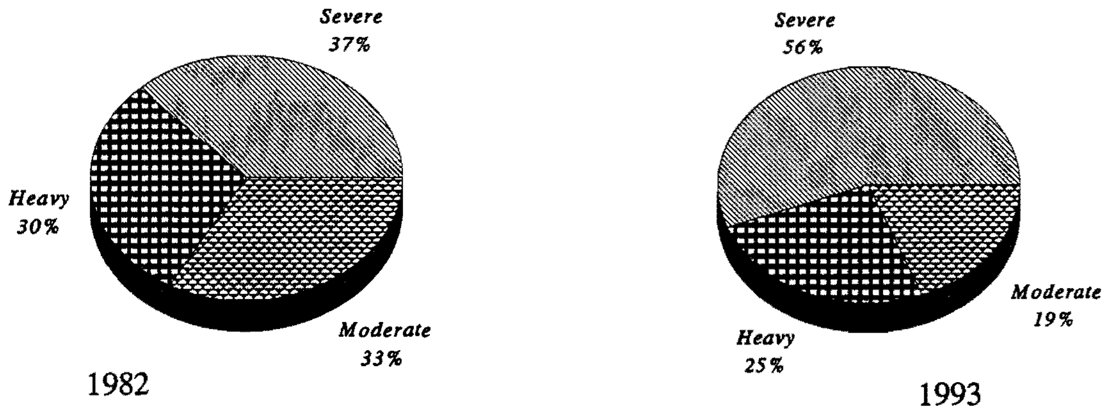

Figure 5. Change in PAS Congestion Levels for 50 Urban Areas, 1982 and 1993

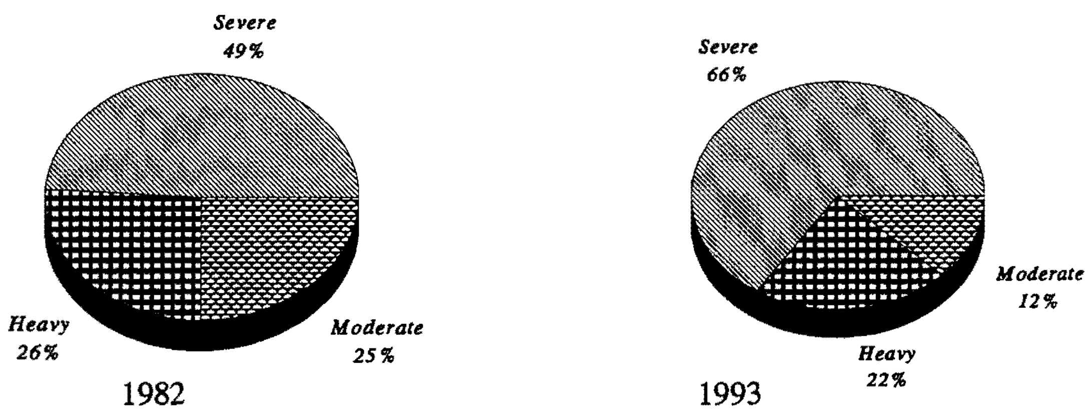

Figure 6. Change in Delay by Congestion Severity, 1982 to 1993

Table 5. Change in Delay within Congestion Categories, 1982 to 1993

Urban Area	Percent of Delay (person-hours) by Congestion Level in 1982			Percent of Delay (person-hours) by Congestion Level in 1993			Change in Percentage Points 1982 to 1993		
	Moderate	Heavy	Severe	Moderate	Heavy	Severe	Moderate	Heavy	Severe
Northeastern Avg	27	25	48	12	25	63	(15)	0	15
Midwestern Avg	26	39	44	15	20	65	(11)	(10)	21
Southern Avg	26	33	41	14	26	60	(12)	(7)	19
Southwestern Avg	22	18	60	15	32	53	(7)	14	(7)
Western Avg	25	27	48	9	16	75	(16)	(11)	27
Texas Avg	14	16	70	14	35	51	0	19	(19)
Total Avg	25	26	49	12	22	66	(13)	(4)	17

Table 6 illustrates the daily and annual delay estimates and rankings. Daily person-hours of delay are presented along with annual delay per person and per eligible driver. A ranking of these values are also shown. Los Angeles topped the list with over 2.4 million person-hours of delay daily. Washington, D.C. had the highest annual delay per capita (58 hours), while San Bernardino-Riverside led the annual delay per eligible driver (76 hours). Thirty-nine of the 50 urban areas have delay per eligible driver of over 20 hours a year or one half of a work week. Sixteen urban areas have over a work week of delay per eligible driver per year. On average, in the 50 areas, about three quarters of a work week is spent in delay per eligible driver. Summary statistics show that the Western and Northeastern regions have the largest average per capita delay, while the Midwestern region has the least. These also show that the Western region had the highest average per eligible driver delay.

The annual delay per person and per eligible driver quantifies the congestion levels independent of urban area size and population. Ranking delay in this manner allows an evaluation similar to the RCI in that it analyzes the effects on individual motorists. Figure 7 illustrates this comparison.

Table 7 gives the annual delay per capita in each urban area for certain years from 1982 to 1993. Twenty-two of the 50 urban areas had at least a 100 percent growth in delay per capita over the twelve-year period. Three of the areas (Hartford, Cleveland, and Cincinnati) had at least a 200 percent delay per capita growth in the same period. Houston, Philadelphia, Tampa, and Phoenix were the only areas that showed less than a 50 percent increase in delay per capita during this same time.

Table 6. Daily Person-Hours of Delay for 1993

Urban Area	Daily Person-Hours of Delay (000)				Annual Person-Hours of Delay per Capita	Rank[1]	Annual Person-Hours of Delay per Eligible Driver	Rank[1]
	Recurring	Incident	Total	Rank[1]				
Northeastern Cities								
Baltimore MD	73	132	205	19	24	22	31	22
Boston MA	117	319	437	8	37	12	44	12
Hartford CT	19	37	56	40	23	23	30	23
New York NY	750	1,378	2,128	2	31	15	39	17
Philadelphia PA	162	218	380	10	18	35	23	35
Pittsburgh PA	64	97	161	21	21	28	26	30
Washington DC	285	504	789	3	58	1	70	2
Midwestern Cities								
Chicago IL	365	423	788	4	26	21	34	20
Cincinnati OH	42	36	78	33	16	40	20	40
Cleveland OH	50	40	89	29	12	43	16	42
Columbus OH	37	31	68	35	17	37	22	36
Detroit MI	253	419	673	6	42	7	57	7
Indianapolis IN	15	20	36	44	9	47	12	47
Kansas City MO	19	41	60	39	12	43	15	44
Louisville KY	20	22	42	43	13	41	16	42
Milwaukee WI	30	32	62	37	13	41	17	41
Minn-St. Paul MN	73	71	144	23	17	37	21	38
Oklahoma City OK	17	19	35	44	11	45	14	45
St. Louis MO	85	97	182	20	23	23	29	24
Southern Cities								
Atlanta GA	185	203	388	9	42	7	53	8
Charlotte NC	23	23	47	41	23	23	28	27
Ft. Lauderdale FL	45	60	105	26	20	32	24	33
Jacksonville FL	37	47	83	32	27	19	35	19
Memphis TN	17	19	36	44	10	46	13	46
Miami FL	139	173	312	13	40	10	51	11
Nashville TN	22	24	46	41	19	33	24	33
New Orleans LA	34	51	85	30	19	33	25	32
Norfolk VA	31	59	90	28	23	23	29	24
Orlando FL	28	37	66	36	18	35	22	36
Tampa FL	29	34	63	37	21	28	27	29
Southwestern Cities								
Albuquerque NM	17	18	35	44	17	37	21	38
Austin TX	35	39	74	34	33	13	41	13
Corpus Christi TX	3	3	6	50	5	50	7	50
Dallas TX	129	217	346	12	41	9	53	8
Denver CO	103	108	211	17	33	13	41	13
El Paso TX	9	10	18	49	8	49	11	49
Fort Worth TX	55	92	147	22	30	17	40	15
Houston TX	229	309	537	7	46	6	60	5
Phoenix AZ	136	112	248	15	30	17	40	15
Salt Lake City UT	18	14	32	48	9	47	12	47
San Antonio TX	47	52	99	27	21	28	28	27
Western Cities								
Honolulu HI	33	52	86	30	31	15	37	18
Los Angeles CA	1,106	1,295	2,402	1	50	4	65	4
Portland OR	44	73	117	24	27	19	34	20
Sacramento CA	56	49	106	25	22	27	29	24
San Bernardino-Riv CA	135	157	292	14	55	2	76	1
San Diego CA	124	86	210	18	21	28	26	30
San Fran-Oak CA	366	462	828	3	54	3	66	3
San Jose CA	113	133	245	16	40	10	52	10
Seattle-Everett WA	162	215	377	11	50	4	59	6
Northeastern Avg	210	384	594		30		38	
Midwestern Avg	84	104	188		18		23	
Southern Avg	54	66	120		24		30	
Southwestern Avg	71	88	159		25		32	
Western Avg	238	280	518		39		49	
Texas Avg	72	103	175		26		34	
Total Avg	120	163	283		26		33	
Maximum Value	1,106	1,378	2,402		58		76	
Minimum Value	3	3	6		5		7	

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

Source: TTI Analysis.

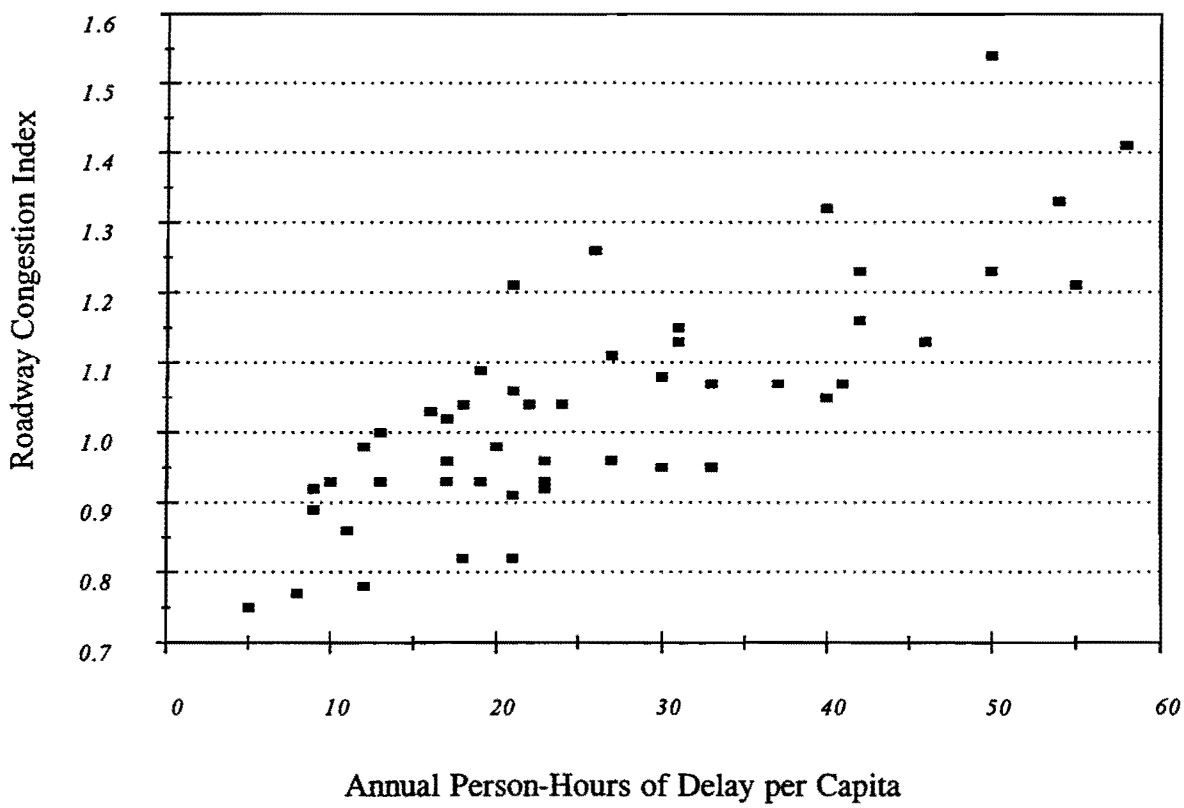

Figure 7. Roadway Congestion Index and Annual Delay per Capita

Table 7. Annual Person-Hours of Delay per Capita, 1982 to 1993

Urban Area	Annual Delay per Capita						Percent Change 1982-1993
	1982	1985	1988	1991	1992	1993	
Northeastern Cities							
Baltimore MD	10	16	17	20	24	24	140
Boston MA	21	26	38	37	38	37	76
Hartford CT	7	10	16	17	19	23	229
New York NY	20	23	26	28	30	31	55
Philadelphia PA	15	18	21	19	18	18	20
Pittsburgh PA	10	14	19	20	20	21	110
Washington DC	34	42	49	53	59	58	71
Midwestern Cities							
Chicago IL	14	19	20	23	26	26	86
Cincinnati OH	5	7	11	12	14	16	220
Cleveland OH	4	5	7	10	11	12	200
Columbus OH	9	9	13	17	18	17	89
Detroit MI	22	23	29	35	38	42	91
Indianapolis IN	3	4	5	6	7	9	200
Kansas City MO	5	6	7	8	11	12	140
Louisville KY	6	7	8	9	11	13	117
Milwaukee WI	7	9	11	12	13	13	86
Minn-St. Paul MN	7	10	15	16	17	17	143
Oklahoma City OK	7	8	10	10	11	11	57
St. Louis MO	15	19	19	21	20	23	53
Southern Cities							
Atlanta GA	22	33	36	35	37	42	91
Charlotte NC	11	16	19	23	22	23	109
Ft. Lauderdale FL	11	13	15	18	19	20	82
Jacksonville FL	16	20	20	23	25	27	69
Memphis TN	5	5	7	9	9	10	100
Miami FL	25	29	35	38	38	40	60
Nashville TN	11	15	24	22	21	19	73
New Orleans LA	11	17	20	19	19	19	73
Norfolk VA	14	20	25	24	24	23	64
Orlando FL	11	13	14	14	15	18	64
Tampa FL	16	21	22	22	22	21	31
Southwestern Cities							
Albuquerque NM	7	10	11	13	14	17	143
Austin TX	20	27	29	27	27	33	65
Corpus Christi TX	2	3	3	4	5	5	150
Dallas TX	28	34	40	41	41	41	46
Denver CO	19	21	23	29	30	33	74
El Paso TX	3	5	6	5	8	8	167
Fort Worth TX	16	20	25	27	27	30	88
Houston TX	38	46	41	43	44	46	21
Phoenix AZ	23	23	28	29	30	30	30
Salt Lake City UT	4	4	5	7	8	9	125
San Antonio TX	10	17	17	17	19	21	110
Western Cities							
Honolulu HI	20	24	25	26	29	31	55
Los Angeles CA	32	42	49	49	50	50	56
Portland OR	13	14	20	22	26	27	108
Sacramento CA	11	15	18	19	19	22	100
San Bernardino-Riv CA	31	40	52	53	55	55	77
San Diego CA	9	14	23	23	22	21	133
San Fran-Oak CA	32	47	55	54	53	54	69
San Jose CA	24	35	42	41	41	40	67
Seattle-Everett WA	22	32	45	47	50	50	127
Northeastern Avg	17	21	27	28	30	30	76
Midwestern Avg	9	11	13	15	16	18	100
Southern Avg	14	18	22	22	23	24	71
Southwestern Avg	16	19	21	22	23	25	56
Western Avg	22	29	36	37	38	39	77
Texas Avg	17	22	23	23	24	26	53
Total Avg	15	19	23	24	25	26	73
Maximum Value	38	47	55	54	59	58	53
Minimum Value	2	3	3	4	5	5	150

Source: TTI Analysis.

The summary statistics show that the Northeastern, Midwestern, and Western regions had at least an 80 percent growth in delay per capita between 1982 and 1993. The Texas cities displayed a 50 percent increase in delay per capita over this period.

The annual delay per eligible driver for certain years from 1982 to 1993 is shown in Table 8. Nineteen of the 50 urban areas experienced at least a 100 percent increase in delay over the twelve year period. Philadelphia, St. Louis, Tampa, Dallas, Houston, Phoenix, and Honolulu were the only areas that experienced less than a 50 percent increase in delay per eligible driver over the period. The Midwestern region had the greatest increase with 100 percent climb, while the Southwestern and Texas regions had the smallest changes with 63 and 50 percent increases, respectively.

One direct effect of congestion is that excess fuel is consumed while vehicles drive in congested traffic conditions. The excess fuel consumed in congestion is estimated in this study from the speeds used in the travel delay estimates. Raus (9) developed an equation for fuel economy that is appropriate for use with areawide speed and travel estimates. Equation 2 is a simple linear relationship between average speed and vehicle fuel efficiency. The speeds for the three congested categories of travel and the uncongested range were used in Equation 2 to estimate fuel economy values for each range. The amount of peak-period travel was combined with the fuel consumption rate for each congested category to estimate the amount of fuel consumed in excess of that which would have been consumed during uncongested travel.

$$\underset{(kilometers\ per\ liter)}{Fuel\ Economy} = 3.74 + 0.11 \underset{(kilometers\ per\ hour)}{Average\ Vehicular\ Speed} \qquad \text{Eq. 2}$$

Table 8. Annual Person-Hours of Delay per Eligible Driver, 1982 to 1993

Urban Area	Annual Delay per Eligible Driver						Percent Change 1982 - 1993
	1982	1985	1988	1991	1992	1993	
Northeastern Cities							
Baltimore MD	13	21	22	26	30	31	138
Boston MA	26	32	46	44	45	44	69
Hartford CT	9	13	21	23	25	30	233
New York NY	25	30	33	36	38	39	56
Philadelphia PA	20	24	27	24	23	23	15
Pittsburgh PA	13	17	24	24	25	26	100
Washington DC	42	51	60	64	70	70	67
Midwestern Cities							
Chicago IL	19	25	26	30	34	34	79
Cincinnati OH	7	9	14	16	18	20	186
Cleveland OH	5	7	10	13	15	16	220
Columbus OH	11	12	17	22	23	22	100
Detroit MI	30	31	40	47	51	57	90
Indianapolis IN	4	5	7	7	8	12	200
Kansas City MO	6	7	10	10	14	15	150
Louisville KY	8	9	10	11	13	16	100
Milwaukee WI	9	12	15	16	17	17	89
Minn-St. Paul MN	9	12	19	20	22	21	133
Oklahoma City OK	9	11	13	12	14	14	56
St. Louis MO	20	24	24	27	26	29	45
Southern Cities							
Atlanta GA	29	43	46	45	47	53	83
Charlotte NC	14	21	24	29	28	28	100
Ft. Lauderdale FL	13	15	19	21	23	24	85
Jacksonville FL	22	26	26	30	32	35	59
Memphis TN	7	7	9	11	12	13	86
Miami FL	30	36	44	49	47	51	70
Nashville TN	14	19	31	28	26	24	71
New Orleans LA	14	23	27	26	25	25	79
Norfolk VA	18	25	32	31	30	29	61
Orlando FL	13	16	17	17	18	22	69
Tampa FL	21	27	27	28	28	27	29
Southwestern Cities							
Albuquerque NM	9	13	15	17	18	21	133
Austin TX	26	35	36	34	34	41	58
Corpus Christi TX	3	3	5	5	7	7	133
Dallas TX	36	44	52	53	53	53	47
Denver CO	24	27	29	36	37	41	71
El Paso TX	5	7	8	7	11	11	120
Fort Worth TX	22	27	33	35	36	40	82
Houston TX	51	60	54	57	57	60	18
Phoenix AZ	30	31	38	38	39	40	33
Salt Lake City UT	5	5	6	9	10	12	140
San Antonio TX	15	23	23	23	25	28	87
Western Cities							
Honolulu HI	25	29	30	31	35	37	48
Los Angeles CA	41	54	63	64	64	65	59
Portland OR	16	17	24	27	32	34	113
Sacramento CA	14	19	23	24	25	29	107
San Bernardino-Riv CA	42	54	72	72	76	76	81
San Diego CA	12	18	29	29	28	26	117
San Fran-Oak CA	39	58	67	66	65	66	69
San Jose CA	33	47	56	54	54	52	58
Seattle-Everett WA	26	38	53	55	59	59	127
Northeastern Avg	21	27	33	34	37	38	81
Midwestern Avg	12	14	17	19	21	23	92
Southern Avg	18	23	27	29	29	30	67
Southwestern Avg	21	25	27	29	30	32	52
Western Avg	28	37	46	47	49	49	75
Texas Avg	23	29	30	31	32	34	48
Total Avg	19	24	29	30	32	33	74
Maximum Value	51	60	72	72	76	76	49
Minimum Value	3	3	5	5	7	7	133

Source: TTI Analysis

Table 9 shows the annual excess fuel consumed in congested travel within the study areas. Los Angeles and New York had the highest fuel consumption with more than 2 billion liters wasted annually in each urban area. Houston ranked seventh with 576 million liters consumed annually due to congestion. To see the effect of this on the individual motorist, the wasted fuel was divided by the population and eligible drivers. Washington, D.C. had the most fuel wasted per capita with about 240 liters. This value shows that each person in Washington, D.C. wastes almost 1 liter of fuel per workday in congested travel. Houston (6th), Dallas (7th), Austin (13th), and Fort Worth (15th) rank in the top fifteen urban areas. The Western region had the highest wasted fuel per capita with 189 liters. All other regions were no higher than 150 liters per capita. The impact on individual drivers has San Bernardino-Riverside with the greatest fuel wasted per driver with 320 liters per year. Washington, D.C. was second with 291 liters per driver. Houston (5th) and Dallas (8th) were the only Texas cities in the top 10. The Western region had the highest average with 239 liters per eligible driver or about 1 wasted liter of fuel per workday. All other regions were under 200 liters per eligible driver.

The annual amount of fuel wasted due to congestion for certain years from 1982 to 1993 is shown in Table 10. Thirty-two of the 50 urban areas experienced at least a 100 percent increase in the amount of wasted fuel. Hartford had the largest increase with 275 percent over the twelve-year period. Houston had the smallest increase with only 48 percent. The summary statistics show that the Midwestern, Western, and Southern regions had the highest average growth over the period. Each experienced at least 100 percent growth.

Table 9. Annual Excess Fuel Consumed Due to Traffic Congestion in 1993

Urban Area	Annual Liters of Fuel Wasted (million)				Annual Excess Fuel Consumed per Capita (liters)	Rank[2]	Annual Excess Fuel Consumed per Eligible Driver (liters)	Rank[2]
	Recurring	Incident	Total	Rank[1]				
Northeastern Cities								
Baltimore MD	77	139	216	19	102	22	130	22
Boston MA	124	339	463	8	156	12	187	12
Hartford CT	20	40	60	40	96	24	127	23
New York NY	788	1,447	2,235	2	131	16	165	16
Philadelphia PA	163	219	382	11	73	36	93	35
Pittsburgh PA	65	98	163	21	86	30	104	32
Washington DC	298	526	824	4	242	1	291	2
Midwestern Cities								
Chicago IL	380	440	820	5	108	21	140	21
Cincinnati OH	46	39	85	33	68	39	87	39
Cleveland OH	54	43	97	28	54	41	71	41
Columbus OH	39	32	71	35	73	36	92	37
Detroit MI	260	431	691	6	173	9	234	7
Indianapolis IN	17	22	39	44	40	47	52	47
Kansas City MO	20	44	64	38	50	44	63	44
Louisville KY	20	22	42	43	52	43	65	43
Milwaukee WI	32	33	65	37	53	42	71	41
Minn-St. Paul MN	78	75	153	23	72	38	91	38
Oklahoma City OK	17	19	36	46	46	45	59	45
St. Louis MO	89	101	190	20	96	24	123	24
Southern Cities								
Atlanta GA	195	214	409	9	176	8	223	9
Charlotte NC	24	24	48	41	94	26	118	27
Ft. Lauderdale FL	48	63	111	25	86	30	103	33
Jacksonville FL	39	49	88	32	113	20	148	19
Memphis TN	18	19	37	45	42	46	54	46
Miami FL	141	175	316	13	163	11	206	11
Nashville TN	23	25	48	41	80	34	101	34
New Orleans LA	36	54	90	31	82	33	107	30
Norfolk VA	33	62	95	29	98	23	122	25
Orlando FL	30	40	70	36	76	35	93	35
Tampa FL	29	34	63	39	85	32	106	31
Southwestern Cities								
Albuquerque NM	17	19	36	46	68	39	87	39
Austin TX	38	42	80	34	141	13	179	13
Corpus Christi TX	3	4	7	50	23	50	32	50
Dallas TX	140	236	376	12	180	7	231	8
Denver CO	108	113	221	18	137	14	171	15
El Paso TX	10	10	20	49	35	49	49	49
Fort Worth TX	59	101	160	22	132	15	174	14
Houston TX	245	331	576	7	197	6	257	5
Phoenix AZ	140	115	255	16	123	18	162	17
Salt Lake City UT	19	15	34	48	39	48	50	48
San Antonio TX	50	55	105	27	88	29	118	27
Western Cities								
Honolulu HI	35	56	91	30	131	16	156	18
Los Angeles CA	1,153	1,350	2,503	1	209	5	269	4
Portland OR	47	77	124	24	115	19	143	20
Sacramento CA	59	52	111	25	92	27	121	26
San Bernardino-Riv CA	142	166	308	14	232	2	320	1
San Diego CA	137	94	231	17	91	28	115	29
San Fran-Oak CA	390	492	882	3	230	3	282	3
San Jose CA	120	141	261	15	171	10	223	9
Seattle-Everett WA	172	229	401	10	214	4	251	6
Northeastern Avg	219	399	618		131		163	
Midwestern Avg	89	110	199		95		123	
Southern Avg	56	69	125		114		144	
Southwestern Avg	76	95	171		134		175	
Western Avg	252	298	550		189		239	
Texas Avg	78	112	190		150		196	
Total Avg	126	172	298		135		171	
Maximum Value	1,153	1,350	2,503		242		320	
Minimum Value	3	4	7		23		32	

Notes: [1] Rank value of 1 associated with greatest fuel consumption.
[2] Rank value of 1 associated with greatest fuel consumption per capita.

Source: TTI Analysis.

Table 10. Annual Wasted Fuel Due to Congestion

Urban Area	Annual Wasted Liters (millions)								Percent Change 1982-1993
	1982	1984	1986	1988	1990	1991	1992	1993	
Hartford CT	16	24	27	40	45	44	49	60	275
Indianapolis IN	11	13	14	22	24	24	27	39	255
Salt Lake City UT	10	12	14	17	20	25	29	34	240
Cleveland OH	30	38	43	58	76	77	88	98	227
San Diego CA	74	106	134	215	230	232	239	231	212
Cincinnati OH	28	32	35	53	59	65	77	85	204
Charlotte NC	16	20	29	34	40	44	46	48	200
Kansas City MO	22	25	28	35	37	37	58	65	195
Baltimore MD	75	105	127	140	167	170	204	216	188
Seattle-Everett WA	139	203	237	316	352	364	392	401	188
El Paso TX	7	7	12	13	13	13	19	20	186
Minn-St. Paul MN	55	70	94	126	137	142	155	153	178
Sacramento CA	40	50	61	77	91	91	97	111	178
Albuquerque NM	13	19	20	23	29	28	30	36	177
Atlanta GA	157	194	268	292	313	319	353	409	161
Orlando FL	28	34	44	47	50	53	57	70	150
Austin TX	33	42	59	64	65	66	67	80	142
Corpus Christi TX	3	3	4	4	4	5	6	7	133
San Antonio TX	45	56	82	84	84	87	95	105	133
San Bernardino-Riv CA	132	165	213	233	268	284	298	307	133
Columbus OH	31	34	40	46	63	65	71	72	132
Ft. Lauderdale FL	48	54	68	78	95	97	105	111	131
Memphis TN	16	17	19	24	27	31	34	37	131
Portland OR	54	56	66	86	95	97	116	124	130
Louisville KY	19	20	23	25	26	28	35	43	126
Nashville TN	22	32	38	54	53	53	52	48	118
Pittsburgh PA	77	96	122	142	149	148	154	163	112
Fort Worth TX	76	98	127	125	133	139	143	160	111
Washington DC	390	474	564	628	700	721	800	824	111
Jacksonville FL	42	51	51	60	74	74	80	87	107
San Jose CA	126	165	212	243	251	262	265	261	107
Norfolk VA	47	57	83	94	99	98	98	95	102
Denver CO	112	143	144	151	178	191	201	221	97
Oklahoma City OK	19	25	26	29	28	30	34	37	95
Chicago IL	424	507	622	613	696	730	809	821	94
Detroit MI	357	385	420	475	539	573	620	691	94
Milwaukee WI	34	42	49	59	62	63	66	66	94
San Fran-Oak CA	454	624	723	841	869	859	858	882	94
Phoenix AZ	133	137	180	210	218	231	245	255	92
Honolulu HI	49	59	61	69	72	74	84	91	86
Miami FL	171	169	203	256	291	293	293	316	85
Los Angeles CA	1,370	1,702	2,081	2,272	2,405	2,425	2,466	2,503	83
Boston MA	255	302	381	471	453	463	472	463	82
New Orleans LA	50	73	83	90	90	89	88	90	80
Tampa FL	36	45	47	58	60	65	65	63	75
Dallas TX	216	272	352	339	359	367	370	376	74
St. Louis MO	118	138	148	152	165	169	167	190	61
New York NY	1,397	1,408	1593	1,818	2,018	2,020	2,154	2,234	60
Philadelphia PA	253	260	315	346	348	355	371	382	51
Houston TX	388	469	496	496	518	537	546	576	48
Northeastern Avg	352	381	447	512	554	560	601	620	76
Midwestern Avg	96	111	129	141	159	167	184	196	104
Southern Avg	58	68	85	99	108	110	115	125	116
Southwestern Avg	94	114	135	139	147	154	159	170	81
Western Avg	271	348	421	484	515	521	535	546	101
Texas Avg	110	135	162	161	168	173	178	189	72
Total Avg	154	183	218	245	265	270	285	297	93
Maximum Value	1,397	1,702	2,081	2,272	2,405	2,425	2,466	2,503	79
Minimum Value	3	3	4	4	4	5	6	7	133

Source: TTI Analysis and Local Transportation Agency References.

COST OF CONGESTION

Another method of assessing impact is to look at economic factors. Travel delay and wasted fuel can be expressed as costs of congestion. This section presents estimates of this cost in each of the study areas and relates these costs to the persons and vehicles in the area. This chapter also reviews the effort required by urban areas to maintain a constant congestion level using additional roadway construction as the only enhancement.

Additional Capacity

The addition of capacity to alleviate congestion is becoming more difficult and less acceptable in many urban areas, but it is among the tools that are used to address congestion problems. As Table 2 indicates, very few urban areas have been able to sustain the level of roadway construction necessary to maintain a slow congestion growth rate on their major roadway system. Table 11 compares the amount of roadway needed each year to maintain the 1993 congestion level based on the recent traffic growth rate and the amount of roadway constructed over the most recent five years.

The estimate of the annual roadway construction needed to address increasing traffic levels is developed by applying the annual traffic growth rate to the amount of freeway and principal arterial streets. The congestion index is a ratio of traffic volume (demand) to facility length (supply). If the RCI is to remain constant (indicating the same congestion level), system supply has to increase by the same percentage as demand.

For example, Salt Lake City would require an additional 48 lane-kilometers of freeway and 39 lane-kilometers of principal arterial streets **every year** to maintain the 1993 congestion level with 5.57 percent annual growth in daily VKT between 1989 and 1993. During this 5 year period, only an average of 10 lane-kilometers of freeway and 32 lane-kilometers of principal arterial street were added annually. This gave Salt Lake City an annual deficit of 38 lane-kilometers of freeway and 7 lane-kilometers of principal arterial streets.

Table 11. Illustration of Annual Capacity Increase Required to Prevent Congestion Growth

Urban Area	Existing (1993) Lane-km		Average Annual VKT Growth (%)[1]	Annual Freeway Lane-km		Annual Prin. Art. Lane-km		Lane-km Deficiency	
	Fwy	Prin. Art.		Needed	Added[2]	Needed	Added[2]	Fwy	Prin. Art
Detroit MI	2,938	6,923	5.76	169	54	399	169	115	230
New York NY	9,902	12,397	1.71	170	115	213	141	55	72
Kansas City MO	2,479	1,811	5.24	130	74	95	32	56	63
Los Angeles CA	8,815	20,206	1.38	121	143	278	149	(22)	129
Baltimore MD	2,206	2,737	3.40	75	56	93	10	19	83
Minn-St. Paul MN	2,471	1,932	5.06	125	34	98	87	91	11
Denver CO	1,594	2,995	3.39	54	52	101	8	2	93
Chicago IL	4,162	8,211	5.05	210	115	415	423	95	(8)
Cincinnati OH	1,554	1,328	4.45	69	30	59	12	39	47
Orlando FL	990	1,787	4.33	43	16	77	20	27	57
Washington DC	2,624	3,784	2.89	76	44	109	60	32	49
Columbus OH	1,328	1,030	4.47	59	14	46	16	45	30
Cleveland OH	1,916	1,843	3.45	66	52	64	12	14	52
Dallas TX	2,866	2,882	2.44	70	36	70	38	34	32
Miami FL	1,030	3,631	3.82	39	24	139	89	15	50
San Antonio TX	1,513	1,819	3.88	59	46	71	20	13	51
Fort Worth TX	1,723	1,513	3.52	61	22	53	30	39	23
Nashville TN	1,014	1,562	5.20	53	60	81	14	(7)	67
Ft. Lauderdale FL	1,095	1,964	4.65	51	36	91	48	15	43
Phoenix AZ	1,143	5,394	4.57	52	42	246	201	10	45
Oklahoma City OK	1,183	1,288	4.07	48	6	52	48	42	4
Salt Lake City UT	861	700	5.57	48	10	39	32	38	7
Houston TX	3,462	3,542	3.35	116	117	119	76	(1)	43
Pittsburgh PA	1,852	2,995	3.02	56	68	90	36	(12)	54
Seattle-Everett WA	2,069	2,616	2.77	57	50	72	40	7	32
Atlanta GA	3,220	3,220	5.34	172	129	172	177	43	(5)
Charlotte NC	507	950	4.72	24	8	45	24	16	21
Louisville KY	990	934	3.86	38	12	36	28	26	8
Memphis TN	733	1,674	6.37	47	30	107	91	17	16
San Diego CA	2,809	2,793	1.19	33	10	33	26	23	7
Philadelphia PA	2,721	5,297	1.52	41	74	80	18	(33)	62
Sacramento CA	1,296	2,013	3.75	49	30	76	68	19	8
Hartford CT	982	1,055	2.46	24	12	26	14	12	12
Indianapolis IN	1,256	1,481	2.79	35	24	41	28	11	13
El Paso TX	596	1,385	2.12	13	8	29	12	5	17
Portland OR	966	1,063	4.16	40	20	44	42	20	2
Honolulu HI	636	394	5.19	33	22	20	10	11	10
Norfolk VA	926	1,224	3.68	34	46	45	14	(12)	31
Austin TX	853	773	5.07	43	42	39	22	1	17
Jacksonville FL	773	2,109	2.86	22	16	60	48	6	12
Corpus Christi TX	338	596	4.58	15	10	27	16	5	11
Milwaukee WI	974	1,803	2.49	24	6	45	48	18	(3)
San Jose CA	1,964	2,222	1.82	36	24	40	38	12	2
Tampa FL	515	1,159	3.15	16	10	37	36	6	1
St. Louis MO	2,769	3,099	1.02	28	14	32	52	14	(20)
San Bernardino-Riv CA	1,505	3,413	3.47	52	22	118	159	30	(41)
Albuquerque NM	386	1,328	2.72	11	10	36	50	1	(14)
New Orleans LA	620	1,127	1.85	11	14	21	32	(3)	(11)
Boston MA	2,431	4,653	0.56	14	(2)	26	74	16	(48)
San Fran-Oak CA	3,920	3,784	0.57	22	34	22	85	(12)	(63)

Notes: [1] Average annual growth rate of freeway and principal arterial streets between 1989 and 1993.
[2] Average lane-kilometers added annually from 1989 to 1993.

The amount of additional capacity required for freeway and principal arterial street systems makes it apparent that the construction of additional roadway as the sole alternative to alleviate congestion is not being used in many urban areas. Regardless of whether the majority of an area's travel is served by the freeway or principal arterial street system, roadway construction must be combined with a range of other improvements and programs to address the needs of severely congested corridors.

Cost Analysis

Many variables are used to analyze congestion cost in this study. Some of these cost variables fluctuate with price trends. The variables—fuel cost, commercial vehicle operating cost, and the average cost of time—are updated annually to reflect the change in these costs. A more detailed discussion of the calculation of cost can be found in Appendix B of Volume 1 of this report. Estimates of vehicle-hours of delay and liters of wasted fuel should be used to analyze congestion trends since congestion costs reflect changes in the price per hour or liter, as well as changes in the transportation situation in an urban area.

The component and total congestion costs for each urban area are shown in Table 12. In 1993, the total cost of congestion for the urban areas studied was approximately $51 billion. This represents a six percent increase in the cost of congestion since 1992 ($48 billion). The increase in the value of time rate was 2.4 percent, and fuel costs averaged about an 8 percent decrease in the 50 study areas. Most of the increase, therefore, was due to the increase in travel delay, which averaged 75 percent for the period spanning 1982 to 1993 (Table 7). Studywide averages indicate that delay accounted for approximately 90 percent of an urban area's congestion cost. The average cost burden placed on urban areas in 1993 due to delay was $910 million, compared to $850 million in 1992.

Fourteen urban areas had total congestion costs exceeding $1 billion. Of the seven urban areas studied in Texas, only two, Houston (7th) and Dallas (12th), ranked in this highest group. Congestion in the Texas urbanized areas resulted in a cost of approximately $4.4 billion, a seven percent increase from 1992 congestion costs.

Table 12. Total Congestion Costs by Urban Area for 1993

Urban Area	Annual Cost Due to Congestion ($ millions)			Rank
	Delay	Fuel	Total	
Los Angeles CA	7,660	870	8,530	1
New York NY	6,810	790	7,600	2
San Fran-Oak CA	2,670	310	2,980	3
Chicago IL	2,520	280	2,800	4
Washington DC	2,520	270	2,790	5
Detroit MI	2,130	210	2,340	6
Houston TX	1,740	180	1,920	7
Boston MA	1,410	150	1,560	8
Atlanta GA	1,240	120	1,360	9
Seattle-Everett WA	1,210	140	1,350	10
Philadelphia PA	1,190	120	1,310	11
Dallas TX	1,130	110	1,240	12
Miami FL	980	110	1,090	13
San Bernardino-Riv CA	930	110	1,040	14
Phoenix AZ	790	90	880	15
San Jose CA	790	90	880	15
San Diego CA	690	80	770	17
Denver CO	670	80	750	18
Baltimore MD	650	80	730	19
St. Louis MO	580	60	640	20
Pittsburgh PA	510	50	560	21
Fort Worth TX	480	50	530	22
Minn-St. Paul MN	470	40	510	23
Portland OR	370	50	420	24
Ft. Lauderdale FL	340	40	380	25
Sacramento CA	340	40	380	25
San Antonio TX	320	40	360	27
Cleveland OH	290	30	320	28
Honolulu HI	290	30	320	28
Norfolk VA	280	30	310	30
Jacksonville FL	270	30	300	31
New Orleans LA	270	30	300	31
Cincinnati OH	260	20	280	33
Austin TX	250	20	270	34
Columbus OH	220	20	240	35
Orlando FL	210	20	230	36
Milwaukee WI	200	20	220	37
Tampa FL	200	20	220	37
Kansas City MO	190	20	210	39
Hartford CT	180	20	200	40
Nashville TN	150	20	170	41
Charlotte NC	140	20	160	42
Louisville KY	130	20	150	43
Indianapolis IN	120	10	130	44
Albuquerque NM	110	20	130	44
Memphis TN	110	20	130	44
Oklahoma City OK	110	20	130	44
Salt Lake City UT	110	10	120	48
El Paso TX	60	10	60	49
Corpus Christi TX	20	0	20	50
Northeastern Avg	1,900	210	2,110	
Midwestern Avg	600	60	660	
Southern Avg	380	40	420	
Southwestern Avg	510	50	560	
Western Avg	1,660	190	1,850	
Texas Avg	570	60	630	
Total Avg	910	100	1,010	
Maximum Value	7,660	870	8,530	
Minimum Value	20	0	20	

Source: TTI Analysis.

Table 13 illustrates the estimated cost of congestion per capita and eligible driver. Viewing congestion costs in relation to population and eligible drivers provides an estimate of the effects of congestion on the individual, which might be thought of as the "congestion tax" on residents of urban areas. San Bernardino-Riverside had the highest per eligible driver cost ($1,090 per driver), while Washington, D.C. had the highest per capita cost ($820 per person). Houston had the highest values of any of the urban areas in Texas in both categories with a per driver cost of $860 and a per capita cost of $660.

The individual relationships of the "congestion tax" estimates to roadway congestion index can be seen in Table 14, which illustrates the rankings of urban areas by the roadway congestion index, annual per capita, and per eligible driver costs. The rankings of the cost estimates are fairly consistent with just thirteen urban areas occupying the top 10 positions in the three categories. The individual cost components should be more closely related to the roadway congestion index values, which is also a measure of the impact of congestion on individuals. When compared with the roadway congestion index rankings, only three urban areas, Chicago, Miami, and San Diego are ranked in the top 10 in the RCI but not in either of the unit cost categories.

Table 15 displays the 1992 and 1993 rankings of the RCI values and the congestion costs per capita. The change during the past year can be seen in the cost and RCI rankings. Fifteen urban areas changed their RCI rankings by more than one position. Of these fifteen, only six moved their overall rankings higher between 1992 and 1993 (Hartford, Cleveland, Detroit, Louisville, Denver, and Charlotte).

Table 13. Estimated Unit Costs of Congestion in 1993

Urban Area	Congestion Cost	
	Per Eligible Driver (dollars)	Per Capita (dollars)
Northeastern Cities		
Baltimore MD	440	350
Boston MA	630	520
Hartford CT	430	330
New York NY	560	450
Philadelphia PA	320	250
Pittsburgh PA	360	290
Washington DC	980	820
Midwestern Cities		
Chicago IL	470	370
Cincinnati OH	290	220
Cleveland OH	240	180
Columbus OH	310	250
Detroit MI	790	590
Indianapolis IN	170	130
Kansas City MO	210	160
Louisville KY	220	180
Milwaukee WI	240	180
Minn-St. Paul MN	300	240
Oklahoma City OK	200	150
St. Louis MO	410	320
Southern Cities		
Atlanta GA	740	590
Charlotte NC	400	320
Ft. Lauderdale FL	350	290
Jacksonville FL	500	380
Memphis TN	180	140
Miami FL	710	560
Nashville TN	340	270
New Orleans LA	360	270
Norfolk VA	410	330
Orlando FL	310	250
Tampa FL	370	290
Southwestern Cities		
Albuquerque NM	300	230
Austin TX	590	470
Corpus Christi TX	110	80
Dallas TX	760	600
Denver CO	580	460
El Paso TX	160	120
Fort Worth TX	580	440
Houston TX	860	660
Phoenix AZ	560	420
Salt Lake City UT	170	130
San Antonio TX	400	290
Western Cities		
Honolulu HI	540	450
Los Angeles CA	920	710
Portland OR	480	390
Sacramento CA	410	310
San Bernardino-Riv CA	1,090	790
San Diego CA	380	300
San Fran-Oak CA	950	780
San Jose CA	750	580
Seattle-Everett WA	840	720
Northeastern Avg	530	430
Midwestern Avg	320	250
Southern Avg	420	340
Southwestern Avg	460	350
Western Avg	710	560
Texas Avg	490	380
Total Avg	470	370
Maximum Value	1,090	820
Minimum Value	110	80

Source: TTI Analysis.

Table 14. 1993 Rankings of Urban Area by Estimated Impact of Congestion

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

Source: TTI Analysis.

Table 15. Congestion Index and Cost Values, 1992 and 1993

Urban Area	Roadway Congestion Index				Congestion Cost per Capita ($)		Annual Congestion Cost ($ millions)	
	1992 Value	1993 Value	1992 Rank	1993 Rank	1992	1993	1992	1993
Northeastern Cities								
Baltimore MD	1.04	1.04	23	22	330	350	680	730
Boston MA	1.07	1.07	17	17	530	520	1,560	1,560
Hartford CT	0.91	0.93	39	35	260	330	160	200
New York NY	1.14	1.15	11	11	420	450	7,170	7,600
Philadelphia PA	1.05	1.04	21	22	250	250	1,260	1,310
Pittsburgh PA	0.81	0.82	46	46	280	290	520	560
Washington DC	1.36	1.41	2	2	820	820	2,680	2,790
Midwestern Cities								
Chicago IL	1.28	1.26	5	5	360	370	2,720	2,800
Cincinnati OH	1.01	1.03	25	25	210	220	250	280
Cleveland OH	0.95	0.98	30	28	160	180	290	320
Columbus OH	0.93	0.93	35	35	250	250	240	240
Detroit MI	1.19	1.23	9	6	520	590	2,080	2,340
Indianapolis IN	0.85	0.89	44	44	90	130	90	130
Kansas City MO	0.77	0.78	48	48	160	160	190	210
Louisville KY	0.90	0.93	40	35	140	180	120	150
Milwaukee WI	1.00	1.00	26	27	180	180	220	220
Minn-St. Paul MN	0.99	1.02	27	26	240	240	510	510
Oklahoma City OK	0.83	0.86	45	45	150	150	110	130
St. Louis MO	0.95	0.96	30	30	280	320	550	640
Southern Cities								
Atlanta GA	1.17	1.16	10	10	510	590	1,160	1,360
Charlotte NC	0.89	0.92	43	40	310	320	150	160
Ft. Lauderdale FL	0.96	0.98	29	28	270	290	350	380
Jacksonville FL	0.97	0.96	28	30	350	380	260	300
Memphis TN	0.92	0.93	36	35	130	140	110	130
Miami FL	1.30	1.32	4	4	510	560	990	1,090
Nashville TN	0.92	0.93	36	35	290	270	170	170
New Orleans LA	1.10	1.09	13	15	260	270	290	300
Norfolk VA	0.92	0.92	36	40	340	330	330	320
Orlando FL	0.80	0.82	47	46	210	250	190	230
Tampa FL	1.07	1.06	17	20	310	290	220	220
Southwestern Cities								
Albuquerque NM	0.95	0.96	30	30	190	230	100	130
Austin TX	0.95	0.95	30	33	390	470	220	270
Corpus Christi TX	0.74	0.75	50	50	70	80	20	20
Dallas TX	1.07	1.07	17	17	580	600	1,210	1,240
Denver CO	1.05	1.07	21	17	420	460	670	750
El Paso TX	0.76	0.77	49	49	110	120	60	60
Fort Worth TX	0.94	0.95	34	33	390	440	460	530
Houston TX	1.12	1.13	12	12	620	660	1,790	1,920
Phoenix AZ	1.08	1.08	16	16	410	420	820	880
Salt Lake City UT	0.90	0.92	40	40	110	130	90	120
San Antonio TX	0.90	0.91	40	43	260	290	310	360
Western Cities								
Honolulu HI	1.10	1.13	13	12	420	450	280	310
Los Angeles CA	1.54	1.54	1	1	700	710	8,250	8,530
Portland OR	1.10	1.11	13	14	360	390	380	420
Sacramento CA	1.04	1.04	23	22	270	310	320	380
San Bernardino-Riv CA	1.22	1.21	6	8	760	790	990	1,040
San Diego CA	1.22	1.21	6	8	320	300	780	770
San Fran-Oak CA	1.33	1.33	3	3	750	780	2,840	2,980
San Jose CA	1.07	1.05	17	21	580	580	880	880
Seattle-Everett WA	1.22	1.23	6	6	710	720	1,300	1,350

Source: TTI Analysis and Local Transportation Agency References.

CONCLUSIONS

This report presents estimates of congestion and the importance of congestion for 50 large and medium cities from 1982 to 1993. The congestion estimates are based on travel volume and roadway capacity in urbanized areas. Given that traffic volume has continued to increase and transportation funding has not kept pace with the rising cost of transportation projects, it should be no surprise that congestion, when measured by vehicle travel per kilometer of roadway, has increased significantly in most major urban areas since 1982. Only a few areas have come close to maintaining a constant congestion level over the period from 1982 to 1993.

The estimate of the amount of roadway construction required to maintain a congestion level or to reduce congestion to acceptable levels (Table 11) also gives little hope for those who think that congestion problems can be solved by the construction of additional freeway and arterial street lanes. The commitment to sustain such a construction program has not been in place in many areas, and the magnitude of the problem suggests that such an approach will not be effective in most of the areas studied. Recent traffic growth rates require the annual addition of 48 lane-kilometers of freeways and principal arterial streets just to maintain a constant congestion level.

A multimodal and multiprogram combination of construction, operation, and demand management improvements is required to improve mobility in most medium and large urban areas. Longer term solutions will focus on communication improvements and better land use/transportation coordination. Funding and environmental concerns will increase pressure on transportation professionals to find solutions to mobility problems.

APPENDIX A

SYSTEM LENGTH AND TRAVEL CHARACTERISTICS

Travel and System Length Statistics

Previous TTI research (3,4) used daily vehicle-kilometers of travel (daily VKT) per lane-kilometer of freeway and principal arterial street as indicators of urban congestion levels. The previous studies established the values of 13,000 daily VKT per freeway lane-kilometer and 5,000 daily VKT per principal arterial street lane-kilometer as the thresholds for undesirable congestion levels. Briefly, when areawide freeway travel volumes exceed an average of 13,000 daily VKT per lane-kilometer, undesirable levels of congestion occur. The corresponding level of service is reached on principal arterial streets when travel volumes average 5,000 daily VKT per lane-kilometer. More information is available on the development of the methodology in Volume 2.

This section presents comparisons of mobility within geographic regions and between individual urban areas using daily VKT per lane-kilometer statistics.

Freeway Travel and Distance Statistics

Table A-1 summarizes areawide freeway operating statistics. The urban areas are ranked according to the primary congestion indicator, daily VKT per lane-kilometer. Twenty-three urbanized areas exceeded the 13,000 daily VKT per lane-kilometer level indicating areawide congested conditions on the freeway systems. Six of these areas have experienced congested freeway systems since 1982. An additional 10 urban areas studied have daily VKT per lane-kilometer values within 10 percent of the 13,000 level. Urban areas with travel demands in this range would only have to experience moderate to slight increases in travel demands over a few years to cause their freeway systems to operate under congested conditions. The summary statistics at the bottom of Table A-1 show average daily VKT per lane-kilometer values by geographic region. Every region, except the Western region (affected by the California cities), has daily VKT per lane-kilometer values below the 13,000 level.

Table A-1. 1993 Freeway System Length and Travel Volume

Urban Area	Daily VKT[1] (000)	Lane-Kilometers	Avg. No. Lanes[2]	Daily VKT/ Lane-Kilometer[3]	Rank[4]
Los Angeles CA	183,460	8,810	8.20	20,810	1
Washington DC	46,690	2,620	5.40	17,790	2
San Fran-Oak CA	68,830	3,920	6.80	17,560	3
San Bernardino-Riv CA	24,500	1,510	7.20	16,280	4
Detroit MI	47,500	2,940	6.00	16,160	5
Seattle-Everett WA	33,330	2,070	6.00	16,110	6
San Diego CA	44,680	2,810	7.60	15,900	7
Chicago IL	65,950	4,160	5.70	15,850	8
Miami FL	15,920	1,030	5.50	15,450	9
Atlanta GA	48,300	3,220	6.40	15,000	10
Houston TX	51,520	3,460	6.40	14,880	11
Boston MA	34,620	2,430	5.90	14,240	12
Dallas TX	40,090	2,870	6.00	13,990	13
New York NY	138,460	9,900	5.70	13,980	14
Honolulu HI	8,860	640	5.30	13,920	15
Portland OR	13,440	970	5.20	13,920	15
Phoenix AZ	15,780	1,140	5.80	13,800	17
San Jose CA	26,810	1,960	6.70	13,650	18
New Orleans LA	8,370	620	5.80	13,510	19
Denver CO	21,330	1,590	5.30	13,380	20
Cincinnati OH	20,710	1,550	5.70	13,330	21
Baltimore MD	28,980	2,210	5.50	13,140	22
Minn-St. Paul MN	32,200	2,470	5.00	13,030	23
Milwaukee WI	12,620	970	5.60	12,960	24
Sacramento CA	16,550	1,300	7.00	12,770	25
Cleveland OH	24,100	1,920	4.90	12,580	26
Ft. Lauderdale FL	13,690	1,090	5.50	12,500	27
Jacksonville FL	9,660	770	4.80	12,500	27
Tampa FL	6,360	520	5.00	12,340	29
Fort Worth TX	21,090	1,720	5.90	12,240	30
Austin TX	10,340	850	5.60	12,110	31
Philadelphia PA	32,520	2,720	5.10	11,950	32
Columbus OH	15,700	1,330	5.90	11,820	33
Hartford CT	11,310	980	5.60	11,520	34
Albuquerque NM	4,410	390	5.10	11,420	35
Indianapolis IN	14,330	1,260	5.50	11,410	36
Louisville KY	11,270	990	4.60	11,380	37
San Antonio TX	17,230	1,510	5.40	11,380	37
St. Louis MO	31,400	2,770	5.70	11,340	39
Salt Lake City UT	9,760	860	5.70	11,330	40
Memphis TN	8,290	730	5.40	11,320	41
Charlotte NC	5,640	510	4.30	11,110	42
Nashville TN	11,270	1,010	4.90	11,110	42
Oklahoma City OK	12,400	1,180	5.20	10,480	44
Norfolk VA	9,620	930	4.70	10,390	45
Orlando FL	10,020	990	5.00	10,120	46
El Paso TX	5,960	600	5.30	10,000	47
Kansas City MO	24,150	2,480	4.60	9,740	48
Corpus Christi TX	3,140	340	5.50	9,290	49
Pittsburgh PA	15,050	1,850	4.30	8,130	50
Northeastern Avg	43,950	3,250	5.36	12,960	
Midwestern Avg	26,030	2,000	5.37	12,510	
Southern Avg	13,380	1,040	5.21	12,310	
Southwestern Avg	18,240	1,390	5.64	12,170	
Western Avg	46,720	2,660	6.67	15,660	
Texas Avg	21,340	1,620	5.73	11,990	
Total Avg	27,760	1,950	5.62	13,020	
Maximum Value	183,460	9,900	8.20	20,810	
Minimum Value	3,140	340	4.30	8,130	

Notes:
[1] Daily vehicle-kilometers of travel.
[2] Average number of lanes.
[3] Daily vehicle-kilometers of travel per lane-kilometer of freeway.
[4] Rank value of 1 associated with most congested condition.

Ranked by daily VKT/lane-kilometer.

Source: TTI Analysis and Local Transportation Agency References.

Principal Arterial Street Travel and System Length Statistics

Table A-2 shows the operating characteristics of the principal arterial street system for each urban area included in this study. As in Table A-1, Table A-2 ranks urban areas by travel per lane-kilometer and contains regional summary statistics. In 1993, 43 of the urban areas studied experienced daily VKT per lane-kilometer levels exceeding 5,000. Of the 50 study areas, 26 have had travel demands exceeding 5,000 daily VKT per lane-kilometer since 1982.

The summary statistics show that all the regional averages, except the Texas average, exceed the 5,000 daily VKT per lane-kilometer level. In contrast to the freeway values, the arterial street statistics indicate more congested operation on the arterial street systems in this study. The regional average travel demand on principal arterial street systems increased between one and two percent from 1992 levels in the Southwestern, Western, and Texas regions. The regional average travel demands showed smaller increases in the Northeastern and Midwestern regions (less than 1 percent), while the Southern region actually showed a very small decrease.

Travel Delay

The recurring and incident hours of delay are shown by congestion level in Tables A-3 and A-4. These two tables give a more detailed look at the delay previously shown in Table 6. The types and severity of delay and facility on which it occurs are shown in these two tables. Table A-3 shows these values for the freeway facilities in the 50 urban areas. This table shows which levels of congestion contain the greatest amount of delay within recurring and incident delay types. Table A-4 shows this same information for the principal arterial street systems in the 50 urban areas.

Table A-2. 1993 Principal Arterial Street System Length and Travel Volume[1]

Urban Area	Daily VKT[1] (000)	Lane-Kilometers	Avg. No. Lanes[2]	Daily VKT/ Lane-Kilometer[3]	Rank[4]
Honolulu HI	3,110	390	3.80	7,880	1
Washington DC	29,620	3,780	4.00	7,830	2
Miami FL	27,370	3,630	4.60	7,540	3
New York NY	88,550	12,400	3.40	7,140	4
Chicago IL	56,350	8,210	3.90	6,860	5
Portland OR	7,080	1,060	3.50	6,670	6
Los Angeles CA	133,630	20,210	4.10	6,610	7
St. Louis MO	20,450	3,100	3.60	6,600	8
Philadelphia PA	34,870	5,300	3.30	6,580	9
Tampa FL	7,500	1,160	3.80	6,470	10
Norfolk VA	7,890	1,220	3.50	6,450	11
New Orleans LA	7,080	1,130	4.20	6,290	12
Sacramento CA	12,640	2,010	4.20	6,280	13
Pittsburgh PA	18,520	2,990	3.20	6,180	14
Salt Lake City UT	4,300	700	4.00	6,140	15
Detroit MI	41,860	6,920	4.50	6,050	16
San Fran-Oak CA	22,860	3,780	4.00	6,040	17
Louisville KY	5,640	930	3.70	6,030	18
Atlanta GA	19,320	3,220	3.80	6,000	19
Denver CO	17,870	2,990	3.90	5,970	20
Seattle-Everett WA	15,620	2,620	3.50	5,970	20
Minn-St. Paul MN	11,430	1,930	3.50	5,920	22
Baltimore MD	16,100	2,740	4.10	5,880	23
Hartford CT	6,100	1,050	3.80	5,790	24
Nashville TN	9,020	1,560	3.50	5,770	25
Oklahoma City OK	7,250	1,290	3.40	5,630	26
San Diego CA	15,540	2,790	3.50	5,560	27
Phoenix AZ	29,790	5,390	4.30	5,520	28
Charlotte NC	5,190	950	3.30	5,470	29
Columbus OH	5,640	1,030	3.50	5,470	29
Albuquerque NM	7,250	1,330	4.00	5,450	31
Cleveland OH	9,980	1,840	3.00	5,410	32
Memphis TN	8,950	1,670	4.60	5,350	33
Cincinnati OH	7,080	1,330	3.50	5,330	34
San Antonio TX	9,660	1,820	3.60	5,310	35
San Jose CA	11,750	2,220	4.20	5,290	36
Ft. Lauderdale FL	10,300	1,960	4.50	5,250	37
San Bernardino-Riv CA	17,870	3,410	4.20	5,240	38
Austin TX	4,030	770	4.20	5,210	39
Houston TX	18,350	3,540	4.50	5,180	40
Dallas TX	14,650	2,880	4.90	5,080	41
Fort Worth TX	7,570	1,510	4.20	5,000	42
Milwaukee WI	9,020	1,800	3.40	5,000	42
Indianapolis IN	7,250	1,480	3.80	4,890	44
Kansas City MO	8,860	1,810	3.60	4,890	44
Boston MA	22,540	4,650	2.50	4,840	46
Jacksonville FL	10,060	2,110	3.90	4,770	47
Orlando FL	8,370	1,790	3.80	4,680	48
Corpus Christi TX	2,580	600	4.10	4,320	49
El Paso TX	5,380	1,380	4.30	3,880	50
Northeastern Avg	30,900	4,700	3.47	6,320	
Midwestern Avg	15,900	2,640	3.62	5,670	
Southern Avg	11,010	1,860	3.95	5,820	
Southwestern Avg	11,040	2,080	4.18	5,190	
Western Avg	26,680	4,280	3.89	6,170	
Texas Avg	8,890	1,790	4.26	4,860	
Total Avg	17,790	2,930	3.84	5,780	
Maximum Value	133,630	20,210	4.90	7,880	
Minimum Value	2,580	390	2.50	3,880	

Notes:
[1] Daily vehicle-kilometers of travel.
[2] Average number of lanes.
[3] Daily vehicle-kilometers of travel per lane-kilometer of freeway.
[4] Rank value of 1 associated with most congested condition. Ranked by daily VKT/lane-kilometer.

Source: TTI Analysis and Local Transportation Agency References

Table A-3. Freeway and Expressway Recurring and Incident Vehicle-Hours of Daily Delay for 1993

Urban Area	Recurring Vehicle-Hours of Delay[1]				Incident Vehicle-Hours of Delay[1]			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	6,900	6,490	21,270	34,660	15,860	14,920	48,920	79,700
Boston MA	8,810	17,180	37,510	63,500	30,840	60,120	131,290	222,250
Hartford CT	1,860	4,240	2,290	8,390	5,020	11,440	6,180	22,640
New York NY	66,600	128,750	120,710	316,060	166,490	321,880	301,760	790,130
Philadelphia PA	6,850	8,060	16,660	31,570	14,390	16,920	34,980	66,290
Pittsburgh PA	1,970	4,140	5,750	11,860	5,730	12,010	16,680	34,420
Washington DC	15,190	24,130	98,840	138,160	33,410	53,090	217,450	303,950
Midwestern Cities								
Chicago IL	19,620	18,490	130,740	168,850	23,550	22,180	156,880	202,610
Cincinnati OH	6,230	12,500	8,110	26,840	4,990	10,000	6,480	21,470
Cleveland OH	10,780	7,680	11,870	30,330	7,540	5,380	8,310	21,230
Columbus OH	920	5,980	13,350	20,250	650	4,190	9,350	14,190
Detroit MI	11,240	8,960	82,010	102,210	24,720	19,720	180,420	224,860
Indianapolis IN	4,110	1,380	1,400	6,890	6,170	2,060	2,090	10,320
Kansas City MO	3,790	1,630	2,870	8,290	11,750	5,060	8,910	25,720
Louisville KY	1,150	800	2,370	4,320	1,260	880	2,600	4,740
Milwaukee WI	2,540	4,860	7,570	14,970	2,540	4,860	7,570	14,970
Minn-St. Paul MN	10,390	3,590	23,360	37,340	9,350	3,230	21,030	33,610
Oklahoma City OK	1,910	1,960	160	4,030	2,100	2,160	170	4,430
St. Louis MO	7,470	11,350	10,290	29,110	8,960	13,620	12,350	34,930
Southern Cities								
Atlanta GA	7,930	27,900	66,330	102,160	8,730	30,690	72,970	112,390
Charlotte NC	2,540	2,030	2,450	7,020	2,040	1,620	1,960	5,620
Ft. Lauderdale FL	4,090	11,330	4,880	20,300	6,130	16,990	7,330	30,450
Jacksonville FL	3,390	6,870	1,710	11,970	5,080	10,300	2,560	17,940
Memphis TN	1,820	1,510	870	4,200	2,000	1,660	960	4,620
Miami FL	6,170	5,160	28,240	39,570	9,250	7,740	42,360	59,350
Nashville TN	3,230	1,990	2,650	7,870	3,550	2,190	2,920	8,660
New Orleans LA	2,270	10,650	2,800	15,720	4,090	19,160	5,040	28,290
Norfolk VA	3,690	7,410	2,730	13,830	9,220	18,520	6,830	34,570
Orlando FL	4,290	2,700	5,860	12,850	6,440	4,050	8,790	19,280
Tampa FL	450	830	4,230	5,510	670	1,250	6,340	8,260
Southwestern Cities								
Albuquerque NM	790	1,030	1,550	3,370	870	1,130	1,710	3,710
Austin TX	4,100	7,340	10,810	22,250	4,510	8,080	11,890	24,480
Corpus Christi TX	940	500	0	1,440	1,030	540	0	1,570
Dallas TX	16,870	28,640	40,010	85,520	30,370	51,560	72,020	153,950
Denver CO	6,360	9,240	33,200	48,800	6,360	9,240	33,200	48,800
El Paso TX	1,750	2,760	640	5,150	1,920	3,030	700	5,650
Fort Worth TX	7,260	12,330	17,220	36,810	13,070	22,190	31,000	66,260
Houston TX	8,840	53,380	89,870	152,090	12,370	74,730	125,820	212,920
Phoenix AZ	5,470	6,250	31,410	43,130	2,190	2,500	12,570	17,260
Salt Lake City UT	1,790	3,570	4,040	9,400	1,080	2,140	2,420	5,640
San Antonio TX	2,880	9,090	16,460	28,430	3,170	10,000	18,110	31,280
Western Cities								
Honolulu HI	2,480	3,490	12,430	18,400	4,470	6,290	22,380	33,140
Los Angeles CA	26,480	23,900	576,430	626,810	31,780	28,680	691,710	752,170
Portland OR	4,050	5,380	11,830	21,260	8,110	10,770	23,670	42,550
Sacramento CA	5,990	12,030	2,280	20,300	3,590	7,220	1,370	12,180
San Bernardino-Riv CA	5,550	12,970	55,690	74,210	6,660	15,570	66,820	89,050
San Diego CA	25,170	25,460	30,940	81,570	15,100	15,270	18,570	48,940
San Fran-Oak CA	20,100	40,060	176,770	236,930	26,120	52,080	229,800	308,000
San Jose CA	6,680	12,390	49,390	68,460	8,010	14,870	59,270	82,150
Seattle-Everett WA	5,460	30,680	63,440	99,580	7,650	42,960	88,810	139,420
Northeastern Avg	15,450	27,570	43,290	86,310	38,820	70,050	108,180	217,050
Midwestern Avg	6,680	6,600	24,510	37,790	8,630	7,780	34,680	51,090
Southern Avg	3,620	7,120	11,160	21,900	5,200	10,380	14,370	29,950
Southwestern Avg	5,190	12,190	22,290	39,670	6,990	16,830	28,130	51,950
Western Avg	11,330	18,490	108,800	138,620	12,390	21,520	133,600	167,510
Texas Avg	6,090	16,290	25,000	47,380	9,490	24,300	37,080	70,870
Total Avg	7,740	13,020	38,890	59,650	12,420	21,530	56,870	90,820
Maximum Value	66,600	128,750	576,430	626,810	166,490	321,880	691,710	790,130
Minimum Value	450	500	0	1,440	650	540	0	1,570

Notes: [1] Delay calculated based on vehicular speed in Table B-1.

Source: TTI Analysis.

Table A-4. Principal Arterial Street Recurring and Incident Vehicle-Hours of Daily Delay for 1993

Urban Area	Recurring Vehicle-Hours of Delay[1]				Incident Vehicle-Hours of Delay[1]			
	Moderate	Heavy	Severe	Total	Moderate	Heavy	Severe	Total
Northeastern Cities								
Baltimore MD	1,620	4,300	17,650	23,570	1,790	4,720	19,420	25,930
Boston MA	4,650	6,330	19,300	30,280	5,120	6,970	21,230	33,320
Hartford CT	1,290	2,530	2,860	6,680	1,420	2,780	3,140	7,340
New York NY	10,390	53,200	220,450	284,040	11,430	58,520	242,500	312,450
Philadelphia PA	5,340	13,600	79,360	98,300	5,880	14,960	87,290	108,130
Pittsburgh PA	7,580	6,730	25,020	39,330	8,330	7,410	27,530	43,270
Washington DC	7,950	18,050	64,030	90,030	8,750	19,850	70,430	99,030
Midwestern Cities								
Chicago IL	14,580	41,580	67,330	123,490	16,030	45,740	74,070	135,840
Cincinnati OH	1,520	1,720	3,350	6,590	1,670	1,890	3,690	7,250
Cleveland OH	1,520	3,990	3,990	9,500	1,670	4,390	4,390	10,450
Columbus OH	1,450	1,530	6,620	9,600	1,590	1,690	7,280	10,560
Detroit MI	7,930	10,910	81,630	100,470	8,720	12,000	89,790	110,510
Indianapolis IN	1,450	1,790	2,110	5,350	1,590	1,970	2,320	5,880
Kansas City MO	1,760	1,710	3,240	6,710	1,930	1,880	3,570	7,380
Louisville KY	1,410	2,850	7,370	11,630	1,550	3,140	8,110	12,800
Milwaukee WI	910	2,640	5,860	9,410	1,000	2,900	6,450	10,350
Minn-St. Paul MN	1,720	2,360	16,940	21,020	1,900	2,590	18,630	23,120
Oklahoma City OK	1,510	3,000	4,920	9,430	1,660	3,300	5,410	10,370
St. Louis MO	8,160	9,630	21,120	38,910	8,980	10,590	23,230	42,800
Southern Cities								
Atlanta GA	4,180	6,150	35,220	45,550	4,590	6,760	38,740	50,090
Charlotte NC	360	2,600	8,790	11,750	400	2,860	9,670	12,930
Ft. Lauderdale FL	3,670	4,890	7,250	15,810	4,040	5,380	7,970	17,390
Jacksonville FL	3,940	3,440	10,140	17,520	4,340	3,780	11,150	19,270
Memphis TN	2,600	2,690	4,050	9,340	2,860	2,960	4,450	10,270
Miami FL	4,560	8,670	58,350	71,580	5,020	9,540	64,190	78,750
Nashville TN	2,140	3,850	3,560	9,550	2,350	4,240	3,920	10,510
New Orleans LA	1,990	3,490	5,950	11,430	2,190	3,840	6,550	12,580
Norfolk VA	930	3,040	7,160	11,130	1,020	3,350	7,880	12,250
Orlando FL	270	1,350	8,060	9,680	290	1,490	8,860	10,640
Tampa FL	1,570	3,440	12,370	17,380	1,730	3,790	13,610	19,130
Southwestern Cities								
Albuquerque NM	2,450	2,640	4,930	10,020	2,690	2,900	5,420	11,010
Austin TX	1,500	2,010	2,570	6,080	1,650	2,210	2,830	6,690
Corpus Christi TX	510	400	0	910	560	440	0	1,000
Dallas TX	4,490	5,840	7,250	17,580	4,940	6,430	7,980	19,350
Denver CO	4,380	6,620	22,860	33,860	4,820	7,280	25,140	37,240
El Paso TX	300	340	1,150	1,790	330	370	1,260	1,960
Fort Worth TX	1,740	2,260	2,810	6,810	1,910	2,490	3,090	7,490
Houston TX	2,690	13,980	14,270	30,940	2,960	15,380	15,700	34,040
Phoenix AZ	11,670	25,200	29,030	65,900	12,830	27,730	31,930	72,490
Salt Lake City UT	2,140	2,000	920	5,060	2,350	2,200	1,010	5,560
San Antonio TX	1,990	2,270	4,890	9,150	2,190	2,490	5,380	10,060
Western Cities								
Honolulu HI	1,230	700	6,120	8,050	1,350	770	6,730	8,850
Los Angeles CA	24,180	66,360	167,680	258,220	26,600	73,000	184,450	284,050
Portland OR	1,710	5,600	6,990	14,300	1,880	6,160	7,680	15,720
Sacramento CA	2,220	5,020	17,620	24,860	2,440	5,520	19,380	27,340
San Bernardino-Riv CA	7,250	9,480	16,790	33,520	7,970	10,430	18,470	36,870
San Diego CA	1,600	10,740	5,520	17,860	1,760	11,810	6,070	19,640
San Fran-Oak CA	2,980	7,600	45,360	55,940	3,280	8,360	49,900	61,540
San Jose CA	3,500	3,600	14,670	21,770	3,850	3,960	16,130	23,940
Seattle-Everett WA	3,670	5,300	20,980	29,950	4,040	5,830	23,080	32,950
Northeastern Avg	5,550	14,960	61,240	81,750	6,100	16,460	67,360	89,920
Midwestern Avg	3,660	6,980	18,710	29,350	4,020	7,670	20,580	32,270
Southern Avg	2,380	3,970	14,630	20,980	2,620	4,360	16,090	23,070
Southwestern Avg	3,080	5,780	8,240	17,100	3,390	6,360	9,070	18,820
Western Avg	5,370	12,710	33,520	51,600	5,910	13,980	36,880	56,770
Texas Avg	1,890	3,870	4,710	10,470	2,080	4,260	5,180	11,520
Total Avg	3,820	8,200	24,130	36,150	4,200	9,020	26,540	39,760
Maximum Value	24,180	66,360	220,450	284,040	26,600	73,000	242,500	312,450
Minimum Value	270	340	0	910	290	370	0	1,000

Notes: [1] Delay calculated based on vehicular speed in Table B-1.

Source: TTI Analysis.

APPENDIX B

ESTIMATION OF CONGESTION COST

Estimation of Congestion Cost

The cost of congestion in each area is estimated using the Highway Performance Monitoring System database and several factors developed from studies of urban travel speeds and traffic volume. This Appendix summarizes the constant values and the variables used to estimate travel delay and fuel consumption costs resulting from traffic congestion.

Cost Estimate Constants

Congestion cost estimates are prepared with the following values held constant for all 50 areas.

- Occupancy—1.25 persons per vehicle. This value is representative of most urban travel during peak travel periods. Occupancy levels are slightly higher near major activity centers and lower in the suburbs.
- Working days per year—250. Weekends and holidays, when congestion levels drop dramatically, are not considered in the conversion from average daily to annual estimates.
- Average cost of time—$10.75 per person-hour (10).[1]

The concept of time valuation used in this study is that people demonstrate a value that they place on time by their actions. Use of a toll facility, frequent lane changing maneuvers, close headway driving, or using residential streets to bypass a congested arterial are behaviors that could lead to accidents or traffic citations, but also may be perceived as time-saving actions. These are the types of characteristics that are included in the value of time used in this study, rather than a wage-based value that might estimate the value to society from time spent in congestion.

- Commercial vehicle operating cost—$1.40 per kilometer (11). The congestion impact on cargo is not measured in this cost component, but on the value of the vehicle and driver.

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[1]Referenced value of $8.00/hr in 1985 adjusted with the Consumer Price Index to value used for 1993 wage rate.

- Vehicle types—95 percent passenger and 5 percent commercial. While the truck percentage is significantly higher in some corridors, this is a good estimate for most urban areas during the peak periods.
- Vehicle Speeds—illustrated in Table B-1. An analysis of traffic volume per lane and peak-period travel speed resulted in the speed estimates used in the delay estimates.

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

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

Functional Class	Parameters	Uncongested	Congested Daily VKT[1,2]		
			Moderate	Heavy	Severe
Freeway/Expressway	ADT/Lane	Under 15,000	15,000 - 17,500	17,501 - 20,000	Over 20,000
	Speed (kph)[3]	97	61	53	48
Principal Arterial Streets	ADT/Lane	Under 5,750	5,750 - 7,000	7,001 - 8,500	Over 8,500
	Speed (kph)[3]	56	45	40	37

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] Represent a "soft" conversion from miles per hour

Source: TTI Analysis and Houston-Galveston Regional Transportation Study (Volume 2, Appendix B) (12)

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 B-2.

Table B-2. 1993 Congestion Cost Estimate Variables

Urban Area	Daily Vehicle Kilometers of Travel		State Average Fuel Cost, ($/liter)	Population (000)	Eligible Drivers (000)
	Freeway (000)	Prin. Art. St. (000)			
Northeastern Cities					
Baltimore MD	28,980	16,100	0.34	2,110	1,660
Boston MA	34,620	22,540	0.33	2,980	2,480
Hartford CT	11,310	6,100	0.36	620	470
New York NY	138,460	88,550	0.35	17,000	13,570
Philadelphia PA	32,520	34,870	0.32	5,200	4,110
Pittsburgh PA	15,050	18,520	0.32	1,900	1,570
Washington DC	46,690	29,620	0.32	3,400	2,830
Midwestern Cities					
Chicago IL	65,950	56,350	0.33	7,600	5,870
Cincinnati OH	20,710	7,080	0.31	1,250	970
Cleveland OH	24,100	9,980	0.31	1,800	1,370
Columbus OH	15,700	5,640	0.31	980	780
Detroit MI	47,500	41,860	0.31	4,000	2,950
Indianapolis IN	14,330	7,250	0.30	960	740
Kansas City MO	24,150	8,860	0.29	1,300	1,020
Louisville KY	11,270	5,640	0.30	820	650
Milwaukee WI	12,620	9,020	0.32	1,230	930
Minn-St. Paul MN	32,200	11,430	0.31	2,120	1,680
Oklahoma City OK	12,400	7,250	0.30	800	620
St. Louis MO	31,400	20,450	0.29	1,990	1,550
Southern Cities					
Atlanta GA	48,300	19,320	0.29	2,320	1,830
Charlotte NC	5,640	5,190	0.31	520	410
Ft. Lauderdale FL	13,690	10,300	0.33	1,300	1,080
Jacksonville FL	9,660	10,060	0.33	770	590
Memphis TN	8,290	8,950	0.31	890	680
Miami FL	15,920	27,370	0.33	1,940	1,530
Nashville TN	11,270	9,020	0.31	600	480
New Orleans LA	8,370	7,080	0.33	1,110	840
Norfolk VA	9,620	7,890	0.31	980	780
Orlando FL	10,020	8,370	0.33	920	750
Tampa FL	6,360	7,500	0.33	740	590
Southwestern Cities					
Albuquerque NM	4,410	7,250	0.34	530	410
Austin TX	10,340	4,030	0.31	570	450
Corpus Christi TX	3,140	2,580	0.31	290	210
Dallas TX	40,090	14,650	0.31	2,090	1,630
Denver CO	21,330	17,870	0.34	1,610	1,290
El Paso TX	5,960	5,380	0.31	570	410
Fort Worth TX	21,090	7,570	0.31	1,210	920
Houston TX	51,520	18,350	0.31	2,930	2,240
Phoenix AZ	15,780	29,790	0.34	2,070	1,570
Salt Lake City UT	9,760	4,300	0.31	880	680
San Antonio TX	17,230	9,660	0.31	1,200	890
Western Cities					
Honolulu HI	8,860	3,110	0.42	690	580
Los Angeles CA	183,460	133,630	0.35	11,950	9,300
Portland OR	13,440	7,080	0.36	1,080	870
Sacramento CA	16,550	12,640	0.35	1,210	920
San Bernardino-Riv CA	24,500	17,870	0.35	1,330	960
San Diego CA	44,680	15,540	0.35	2,530	1,010
San Fran-Oak CA	68,830	22,860	0.35	3,830	3,130
San Jose CA	26,810	11,750	0.35	1,530	1,170
Seattle-Everett WA	33,330	15,620	0.34	1,880	1,600
Northeastern Avg	43,950	30,900	0.33	4,740	3,810
Midwestern Avg	26,030	15,900	0.31	2,070	1,590
Southern Avg	13,380	11,010	0.32	1,100	870
Southwestern Avg	18,240	11,040	0.32	1,270	970
Western Avg	46,720	26,680	0.36	2,890	2,280
Texas Avg	21,340	8,890	0.31	1,270	960
Total Avg	27,760	17,790	0.33	2,200	1,730
Maximum Value	183,460	133,630	0.42	17,000	13,570
Minimum Value	3,140	2,580	0.29	290	210

Source: TTI Analysis and Local Transportation Agency References.

Daily Vehicle-Kilometers of Travel

The daily vehicle-kilometers of travel (VKT) is the average daily traffic (ADT) of a section of roadway multiplied by the length (in kilometers) 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. Daily VKT was estimated for the freeways and principal arterial streets located in each study urbanized area. These estimates originate from the HPMS database and other local transportation data sources and are presented in a previous section of this report.

Fuel Costs

Statewide average fuel cost estimates were obtained from 1993 data published by the American Automobile Association (AAA) (13). These data represent the average reported fuel cost for 1993. 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.

Population

Population data were obtained from the combination of 1990 U.S. Census Bureau estimates and 1993 population estimates reported in the Federal Highway Administration's Highway Performance Monitoring System (HPMS).

Eligible Drivers

The number of eligible drivers for each area was obtained using the population estimate derived above, along with estimates of the percentage of population 16 years of age and older taken from the Statistical Abstract of the United States (14).

Cost Estimate Calculations

The first step in the cost estimate procedure was to convert daily VKT 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-kilometers of travel on congested roadways during each peak period was estimated. This was accomplished by the use of two factors.

Highway Performance Monitoring System (HPMS) data were used to determine the percentage of urbanized area daily VKT 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 ADT per lane values shown in Table B-1.

Using Table B-1 values, the percentage of daily VKT operating in each of the three congested conditions could be calculated for each functional class. These percentages adjust daily VKT to congested daily VKT, 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 the Texas Department of Transportation's (TxDOT) 1986 Automatic Traffic Recorder Data (15) 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. The delay estimates do not include midday, weekend, and special event congestion.

Once the daily VKT was converted to peak-period congested vehicle-kilometers of travel (Table B-3), the recurring vehicle-hours of delay were computed (Equation B-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.

$$\begin{matrix}\textit{Recurring}\\ \textit{Vehicle-Hours of}\\ \textit{Delay per Day}\end{matrix} = \frac{\textit{Peak-Period Congested DVKT}}{\textit{Avg. Peak-Period Speed}} - \frac{\textit{Peak-Period Congested DVKT}}{\textit{Avg. Off-Peak Speed}} \qquad \text{Eq. B-1}$$

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 B-4.

Another type of delay encountered by vehicles is incident delay. This is the delay that results from an accident or disabled vehicle. 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 (16) was used. The resulting incident delay was calculated using Equation B-2.

$$\begin{matrix}\textit{Frwy Incident}\\ \textit{Vehicle-Hours of Delay}\\ \textit{per Day}\end{matrix} = \begin{matrix}\textit{Peak-Period}\\ \textit{Frwy Vehicle-Hours of Delay}\\ \textit{per Day}\end{matrix} \times \begin{matrix}\textit{Frwy}\\ \textit{Incident/Recurring}\\ \textit{Ratio}\end{matrix} \qquad \text{Eq. B-2}$$

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 B-3.

$$\begin{matrix}\textit{Principal Arterial Street Incident}\\ \textit{Vehicle-Hour Delay}\\ \textit{per Day}\end{matrix} = \begin{matrix}\textit{Principal Artrial Street Recurring}\\ \textit{Vehicle-Hour Delay}\\ \textit{per Day}\end{matrix} \times 1.1 \qquad \text{Eq. B-3}$$

Table B-3. 1993 Congested Daily Vehicle-Kilometers of Travel

Urban Area	Daily Vehicle-Kilometers of Travel		Percent of Peak-Period[1,2] VKT on Congested Roads		Peak Period Congested Daily VKT[1,3]		
	Freeway (000)	Prin.Art.St. (000)	Freeway (%)	Prin.Art.St. (%)	Freeway (000)	Prin.Art.St. (000)	Freeway & Prin.Art.St. (000)
Northeastern Cities							
Baltimore MD	28,980	16,100	30	40	3,910	2,900	6,810
Boston MA	34,620	22,540	45	40	7,010	4,060	11,070
Hartford CT	11,310	6,100	20	35	1,020	960	1,980
New York NY	138,460	88,550	60	85	37,380	33,870	71,250
Philadelphia PA	32,520	34,870	25	75	3,660	11,770	15,430
Pittsburgh PA	15,050	18,520	20	65	1,350	5,420	6,770
Washington DC	46,690	29,620	70	85	14,710	11,330	26,040
Midwestern Cities							
Chicago IL	65,950	56,350	60	65	17,810	16,480	34,290
Cincinnati OH	20,710	7,080	35	30	3,260	960	4,220
Cleveland OH	24,100	9,980	35	30	3,800	1,350	5,140
Columbus OH	15,700	5,640	30	50	2,120	1,270	3,390
Detroit MI	47,500	41,860	50	65	10,690	12,240	22,930
Indianapolis IN	14,330	7,250	15	25	970	820	1,780
Kansas City MO	24,150	8,860	10	25	1,090	1,000	2,080
Louisville KY	11,270	5,640	10	60	510	1,520	2,030
Milwaukee WI	12,620	9,020	30	30	1,700	1,220	2,920
Minn-St. Paul MN	32,200	11,430	30	50	4,350	2,570	6,920
Oklahoma City OK	12,400	7,250	10	40	560	1,300	1,860
St. Louis MO	31,400	20,450	25	60	3,530	5,520	9,050
Southern Cities							
Atlanta GA	48,300	19,320	50	65	10,870	5,650	16,520
Charlotte NC	5,640	5,190	35	60	890	1,400	2,290
Ft. Lauderdale FL	13,690	10,300	40	50	2,460	2,320	4,780
Jacksonville FL	9,660	10,060	35	55	1,520	2,490	4,010
Memphis TN	8,290	8,950	15	35	560	1,410	1,970
Miami FL	15,920	27,370	60	70	4,300	8,620	12,920
Nashville TN	11,270	9,020	20	35	1,010	1,420	2,430
New Orleans LA	8,370	7,080	50	50	1,880	1,590	3,480
Norfolk VA	9,620	7,890	40	40	1,730	1,420	3,150
Orlando FL	10,020	8,370	35	30	1,580	1,130	2,710
Tampa FL	6,360	7,500	20	65	570	2,190	2,770
Southwestern Cities							
Albuquerque NM	4,410	7,250	20	45	400	1,470	1,860
Austin TX	10,340	4,030	55	50	2,560	910	3,460
Corpus Christi TX	3,140	2,580	15	15	210	170	390
Dallas TX	40,090	14,650	55	40	9,920	2,640	12,560
Denver CO	21,330	17,870	55	55	5,280	4,420	9,700
El Paso TX	5,960	5,380	25	10	670	240	910
Fort Worth TX	21,090	7,570	45	30	4,270	1,020	5290
Houston TX	51,520	18,350	70	50	16,230	4,130	20,360
Phoenix AZ	15,780	29,790	65	70	4,620	9,380	14,000
Salt Lake City UT	9,760	4,300	25	45	1,100	870	1,970
San Antonio TX	17,230	9,660	40	30	3,100	1,300	4,400
Western Cities							
Honolulu HI	8,860	3,110	50	75	1,990	1,050	3,040
Los Angeles CA	183,460	133,630	75	55	61,920	33,070	94,990
Portland OR	13,440	7,080	40	60	2,420	1,910	4,330
Sacramento CA	16,550	12,640	35	55	2,610	3,130	5,730
San Bernardino-Riv CA	24,500	17,870	70	60	7,720	4,830	12,540
San Diego CA	44,680	15,540	50	35	10,050	2,450	12,500
San Fran-Oak CA	68,830	22,860	80	65	24,780	6,690	31,470
San Jose CA	26,810	11,750	60	55	7,240	2,910	10,150
Seattle-Everett WA	33,330	15,620	70	55	10,500	3,870	14,360
Northeastern Avg	43,950	30,900	39	61	9,860	10,040	19,910
Midwestern Avg	26,030	15,900	28	44	4,200	3,850	8,050
Southern Avg	13,380	11,010	36	50	2,490	2,700	5,180
Southwestern Avg	18,240	11,040	43	40	4,400	2,410	6,810
Western Avg	46,720	26,680	59	57	14,360	6,660	21,010
Texas Avg	21,340	8,890	44	32	5,280	1,490	6,770
Total Avg	27,760	17,790	40	49	6,490	4,650	11,140
Maximum Value	183,460	133,630	80	85	61,920	33,870	94,990
Minimum Value	3,140	2,580	10	10	210	170	390

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

Source: TTI Analysis and Local Transportation Agency References.

Table B-4. Recurring and Incident Delay Relationships for 1993

Urban Area	Peak Period Congested Daily VKT[1]			Ratio of Incident[2] Delay to Recurring Delay		Daily Recurring Vehicle[3] Hours of Delay			Daily Incident Vehicle[3] Hours of Delay		
	Freeway (000)	Prin.Art.St. (000)	Freeway and Prin. Art. St. (000)	Freeway	Prin.Art.St.	Freeway	Hours of Delay Prin.Art.St.	Total	Freeway	Prin.Art.St.	Total
Northeastern Cities											
Baltimore MD	3,910	2,900	6,810	2.3	1.1	34,650	23,570	58,220	79,700	25,930	105,630
Boston MA	7,010	4,060	11,070	3.5	1.1	63,500	30,290	93,780	222,240	33,310	255,560
Hartford CT	1,020	960	1,980	2.7	1.1	8,380	6,680	15,060	22,640	7,340	29,980
New York NY	37,380	33,870	71,250	2.5	1.1	316,050	284,050	600,100	790,140	312,450	1,102,590
Philadelphia PA	3,660	11,770	15,430	2.1	1.1	31,570	98,300	129,870	66,290	108,130	174,430
Pittsburgh PA	1,350	5,420	6,770	2.9	1.1	11,870	39,340	51,200	34,410	43,270	77,680
Washington DC	14,710	11,330	26,040	2.2	1.1	138,160	90,030	228,190	303,950	99,030	402,980
Midwestern Cities											
Chicago IL	17,810	16,480	34,290	1.2	1.1	168,840	123,490	292,340	202,610	135,840	338,450
Cincinnati OH	3,260	960	4,220	0.8	1.1	26,840	6,590	33,430	21,470	7,250	28,720
Cleveland OH	3,800	1,350	5,140	0.7	1.1	30,320	9,500	39,820	21,230	10,450	31,670
Columbus OH	2,120	1,270	3,390	0.7	1.1	20,260	9,600	29,850	14,180	10,560	24,740
Detroit MI	10,690	12,240	22,930	2.2	1.1	102,210	100,460	202,660	224,860	110,500	335,360
Indianapolis IN	970	820	1,780	1.5	1.1	6,880	5,350	12,230	10,330	5,880	16,210
Kansas City MO	1,090	1,000	2,080	3.1	1.1	8,300	6,710	15,010	25,720	7,390	33,110
Louisville KY	510	1,520	2,030	1.1	1.1	4,320	11,630	15,950	4,750	12,790	17,540
Milwaukee WI	1,700	1,220	2,920	1.0	1.1	14,970	9,410	24,380	14,970	10,350	25,320
Minn-St. Paul MN	4,350	2,570	6,920	0.9	1.1	37,340	21,020	58,360	33,610	23,120	56,730
Oklahoma City OK	560	1,300	1,860	1.1	1.1	4,030	9,430	13,460	4,430	10,370	14,800
St. Louis MO	3,530	5,520	9,050	1.2	1.1	29,110	38,910	68,020	34,930	42,800	77,730
Southern Cities											
Atlanta GA	10,870	5,650	16,520	1.1	1.1	102,170	45,550	147,720	112,390	50,100	162,490
Charlotte NC	890	1,400	2,290	0.8	1.1	7,020	11,750	18,770	5,610	12,930	18,540
Ft. Lauderdale FL	2,460	2,320	4,780	1.5	1.1	20,300	15,810	36,110	30,450	17,390	47,840
Jacksonville FL	1,520	2,490	4,010	1.5	1.1	11,960	17,520	29,480	17,950	19,270	37,220
Memphis TN	560	1,410	1,970	1.1	1.1	4,200	9,330	13,530	4,620	10,270	14,890
Miami FL	4,300	8,620	12,920	1.5	1.1	39,560	71,590	111,150	59,340	78,740	138,090
Nashville TN	1,010	1,420	2,430	1.1	1.1	7,860	9,550	17,420	8,650	10,510	19,160
New Orleans LA	1,880	1,590	3,480	1.8	1.1	15,720	11,430	27,150	28,300	12,580	40,870
Norfolk VA	1,730	1,420	3,150	2.5	1.1	13,830	11,130	24,970	34,580	12,250	46,820
Orlando FL	1,580	1,130	2,710	1.5	1.1	12,860	9,680	22,530	19,290	10,640	29,930
Tampa FL	570	2,190	2,770	1.5	1.1	5,510	17,390	22,900	8,260	19,130	27,390

Table B-4. Recurring and Incident Delay Relationships for 1993 (continued)

Urban Area	Peak Period Congested Daily VKT[1]			Ratio of Incident[2] Delay to Recurring Delay		Daily Recurring Vehicle[3] Hours of Delay			Daily Incident Vehicle[3] Hours of Delay		
	Freeway (000)	Prin.Art.St. (000)	Freeway and Prin. Art. St. (000)	Freeway	Prin.Art.St.	Freeway	Hours of Delay Prin.Art.St.	Total	Freeway	Prin.Art.St.	Total
Southwestern Cities											
Albuquerque NM	400	1,470	1,860	1.1	1.1	3,370	10,010	13,380	3,700	11,010	14,710
Austin TX	2,560	910	3,460	1.1	1.1	22,250	6,080	28,330	24,470	6,690	31,160
Corpus Christi TX	210	170	390	1.1	1.1	1,430	920	2,350	1,580	1,010	2,580
Dallas TX	9,920	2,640	12,560	1.8	1.1	85,530	17,580	103,110	153,950	19,340	173,300
Denver CO	5,280	4,420	9,700	1.0	1.1	48,800	33,860	82,660	48,800	37,240	86,040
El Paso TX	670	240	910	1.1	1.1	5,140	1,790	6,930	5,660	1,970	7,630
Fort Worth TX	4,270	1,020	5,290	1.8	1.1	36,810	6,810	43,630	66,260	7,490	73,760
Houston TX	16,230	4,130	20,360	1.4	1.1	152,090	30,940	183,030	212,920	34,040	246,960
Phoenix AZ	4,620	9,380	14,000	0.4	1.1	43,140	65,900	109,040	17,260	72,490	89,750
Salt Lake City UT	1,100	870	1,970	0.6	1.1	9,400	5,060	14,460	5,640	5,570	11,210
San Antonio TX	3,100	1,300	4,400	1.1	1.1	28,440	9,150	37,580	31,280	10,060	41,340
Western Cities											
Honolulu HI	1,990	1,050	3,040	1.8	1.1	18,410	8,050	26,460	33,130	8,860	41,990
Los Angeles CA	61,920	33,070	94,990	1.2	1.1	626,810	258,220	885,030	752,170	284,050	1,036,220
Portland OR	2,420	1,910	4,330	2.0	1.1	21,270	14,290	35,570	42,540	15,720	58,270
Sacramento CA	2,610	3,130	5,730	0.6	1.1	20,300	24,860	45,160	12,180	27,340	39,520
San Bernardino-Riv CA	7,720	4,830	12,540	1.2	1.1	74,210	33,520	107,720	89,050	36,870	125,920
San Diego CA	10,050	2,450	12,500	0.6	1.1	81,580	17,850	99,430	48,950	19,640	68,590
San Fran-Oak CA	24,780	6,690	31,470	1.3	1.1	236,930	55,950	292,870	308,000	61,540	369,550
San Jose CA	7,240	2,910	10,150	1.2	1.1	68,450	21,760	90,220	82,140	23,940	106,090
Seattle-Everett WA	10,500	3,870	14,360	1.4	1.1	99,580	29,950	129,530	139,420	32,950	172,360
Northeastern Avg	9,860	10,040	19,910	2.6	1.1	86,310	81,750	168,060	217,050	89,920	306,980
Midwestern Avg	4,200	3,850	8,050	1.3	1.1	37,780	29,340	67,130	51,090	32,280	83,360
Southern Avg	2,490	2,700	5,180	1.4	1.1	21,910	20,980	42,880	29,950	23,070	53,020
Southwestern Avg	4,400	2,410	6,810	1.1	1.1	39,670	17,100	56,770	51,960	18,810	70,770
Western Avg	14,360	6,660	21,010	1.3	1.1	138,610	51,610	190,220	167,510	56,770	224,280
Texas Avg	5,280	1,490	6,770	1.3	1.1	47,380	10,470	57,850	70,870	11,510	82,390
Total Avg	6,490	4,650	11,140	1.5	1.1	59,650	36,150	95,800	90,820	39,770	130,590
Maximum Value	61,920	33,870	94,990	3.5	1.1	626,810	284,050	885,030	790,140	312,450	1102,590
Minimum Value	210	170	390	0.4	1.1	1,430	920	2,350	1,580	1,010	2,580

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

Source: TTI Analysis and Local Transportation Agency References

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

1. Arterial street 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 traveled way; and

3. Historical data show 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 B-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 economy 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 B-4.

$$\underset{(kph)}{Avg.\ Speed} = \frac{(Frwy speed^{1} x\ Peak\text{-}Period Frwy\ VKT) + (Prin.Art.Speed^{1} x\ Peak\text{-}Period Prin.Art.Str.\ VKT)}{Total\ Peak\text{-}Period\ VKT} \qquad \text{Eq. B-4}$$

[1] Speeds determined by congestion severity (Table B-1).

Congestion Cost

Two cost components can be associated with congestion: delay cost and fuel cost. These costs can be directly related to the vehicle-hours of delay. Table B-5 is a summary of the cost calculations for the component congestion cost per each urbanized area.

The average fuel economy represents the fuel consumption of the vehicles operating in congested conditions. The equation (Equation B-5) is a linear regression applied to a modified version of fuel consumption reported by Raus (9).

$$\underset{(kph)}{\text{Average Fuel Economy}} = 3.74 + 0.11 \ \underset{(kph)}{(\text{Average Vehicular Speed})} \qquad \text{Eq. B-5}$$

Delay Cost

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

$$\begin{matrix}\text{Annual} \\ \text{Delay Cost}\end{matrix} = \frac{\text{Vehicle-Hrs. of Delay}}{\text{Day}} \times \frac{1.25 \text{ person}}{\text{Vehicle}} \times \frac{\$10.75}{\text{Hour}} \times \frac{250 \text{ Workdays}}{\text{Year}} \qquad \text{Eq. B-6}$$

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.

Table B-5. Component and Total Congestion Costs by Urban Area for 1993

Urban Area	Annual Cost Due to Congestion ($ millions)					Rank
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Total	
Los Angeles CA	3,530	4,130	400	470	8,530	1
New York NY	2,400	4,410	280	510	7,600	2
San Fran-Oak CA	1,180	1,490	140	170	2,980	3
Chicago IL	1,170	1,350	130	150	2,800	4
Washington DC	910	1,610	100	170	2,790	5
Detroit MI	800	1,330	80	130	2,340	6
Houston TX	740	1,000	80	100	1,920	7
Boston MA	380	1,030	40	110	1,560	8
Atlanta GA	590	650	60	60	1,360	9
Seattle WA	520	690	60	80	1,350	10
Philadelphia PA	510	680	50	70	1,310	11
Dallas TX	420	710	40	70	1,240	12
Miami FL	440	540	50	60	1,090	13
San Bernardino-Riv CA	430	500	50	60	1,040	14
Phoenix AZ	360	430	40	50	880	15
San Jose CA	430	360	50	40	880	15
San Diego CA	410	280	50	30	770	17
Denver CO	330	340	40	40	750	18
Baltimore MD	230	420	30	50	730	19
St. Louis MO	270	310	30	30	640	20
Pittsburgh PA	200	310	20	30	560	21
Fort Worth TX	180	300	20	30	530	22
Minn-St. Paul MN	240	230	20	20	510	23
Portland OR	140	230	20	30	420	24
Sacramento CA	180	160	20	20	380	25
Ft. Lauderdale FL	150	190	20	20	380	25
San Antonio TX	150	170	20	20	360	27
Cleveland OH	160	130	20	10	320	28
Norfolk VA	100	190	10	20	320	28
Honolulu HI	110	170	10	20	310	30
Jacksonville FL	120	150	10	20	300	31
New Orleans LA	110	160	10	20	300	31
Cincinnati OH	140	120	10	10	280	33
Austin TX	120	130	10	10	270	34
Columbus OH	120	100	10	10	240	35
Orlando FL	90	120	10	10	230	36
Milwaukee WI	100	100	10	10	220	37
Tampa FL	90	110	10	10	220	37
Kansas City MO	60	130	10	10	210	39
Hartford CT	60	120	10	10	200	40
Nashville TN	70	80	10	10	170	41
Charlotte NC	70	70	10	10	160	42
Louisville KY	60	70	10	10	150	43
Indianapolis IN	50	70	0	10	130	44
Albuquerque NM	50	60	10	10	130	44
Memphis TN	50	60	10	10	130	44
Oklahoma City OK	50	60	10	10	130	44
Salt Lake City UT	60	50	10	0	120	48
El Paso TX	30	30	0	0	60	49
Corpus Christi TX	10	10	0	0	20	50
Northeastern Avg	670	1,230	70	140	2,110	
Midwestern Avg	270	330	30	30	660	
Southern Avg	170	210	20	20	420	
Southwestern Avg	230	290	20	30	570	
Western Avg	760	900	90	100	1,850	
Texas Avg	230	330	20	30	630	
Total Avg	380	520	40	60	1,010	
Maximum Value	3,530	4,410	400	510	8,540	
Minimum Value	10	10	0	0	20	

Source: TTI Analysis and Local Transportation Agency References.

Fuel Cost

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

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

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

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 B-9 to determine the yearly fuel cost due to congestion resulting from incident and recurring delay.

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

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

REFERENCES

1 Lomax, Timothy J., Dennis L. Christiansen, and A. V. Fitzgerald. Texas Transportation Institute, "Estimates of Relative Mobility In Major Texas Cities," Research Report 323-1F, 1982.

2 Lomax, Timothy J. Texas Transportation Institute, "Relative Mobility In Texas Cities, 1975 to 1984," Research Report 339-8, 1986.

3 Lomax, Timothy J., Diane L. Bullard, and James W. Hanks, Jr. Texas Transportation Institute, "The Impact Of Declining Mobility In Major Texas and Other U.S. Cities," Research Report 431-1F, 1988.

4 Lomax, Timothy J., Dave Schrank, and Shawn Turner. Texas Transportation Institute, "Urban Roadway Congestion - 1982 to 1992," Research Report 1131-7, September 1995.

5 Vincent, Mary Jayne, et al. 1990 Nationwide Personal Transportation Survey—Urban Travel Patterns, FHWA-PL-94-01B, Comsis Corp., Silver Spring, Maryland, June 1994.

6 Federal Highway Administration. "Highway Performance Monitoring System," 1982 to 1993 Data. FHWA-M 5600.1B, August 1993.

7 United States General Accounting Office. "Traffic Congestion: Trends, Measures, and Effects," Washington, D.C., 1989.

8 Richardson, Harry W., and Peter Gordon. 1990 Nationwide Personal Transportation Survey Databook—Volume 2. FHWA-PL-94-010B, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 1994.

9 Raus, J. "A Method for Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks," FHWA-TS-81-210, April 1981.

10 Chui, Margaret K., and William E. McFarland. "The Value of Travel Time: New Estimates Developed Using a Speed Choice Model," Research Report 396-2F, Texas Transportation Institute, January 1987.

11 "Private Truck Counsel of America Cost Index Survey," Houston Post, July 6, 1987.

12 Morris, D. E., and Michael Ogden. "Houston-Galveston Regional Transportation Study," Texas Transportation Institute, January 1990.

13 American Automobile Association, "Fuel Gauge Report, 1993.

14 Statistical Abstract of the United States 1994. U.S. Department of Commerce, Bureau of the Census 114th Edition, Washington, D.C., 1994.

15 Texas State Department of Highways and Public Transportation. "Permanent Automatic Traffic Recorder Data—1950-1984."

16 Lindley, Jeffrey A. "Quantification of Urban Freeway Congestion and Analysis of Remedial Measures," FHWA-RD-87-052, October 1986.