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URBAN ROADWAY CONGESTION - 1982 TO 1994
VOLUME 1: ANNUAL REPORT

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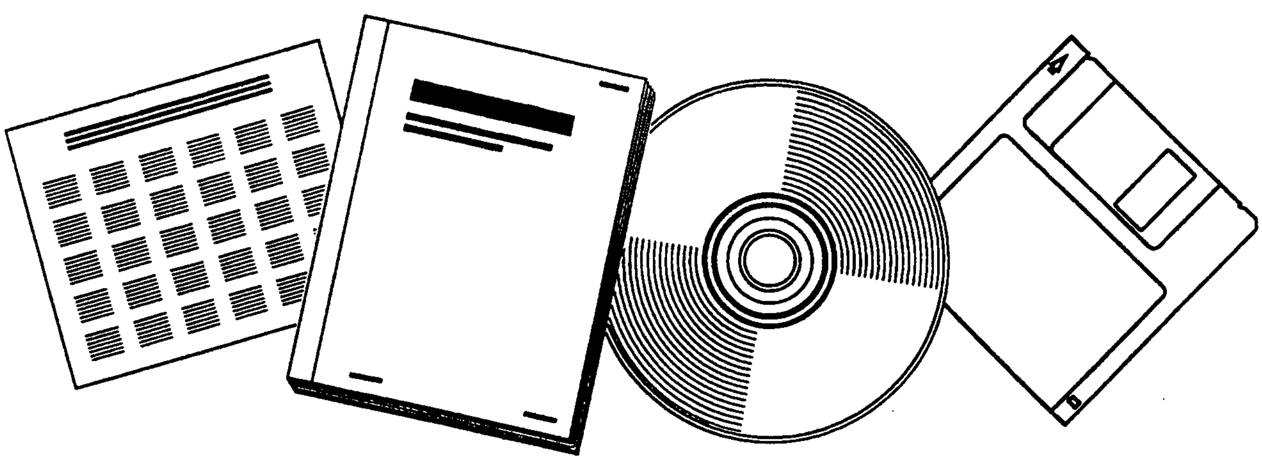

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URBAN ROADWAY CONGESTION—1982 TO 1994
VOLUME 1: ANNUAL REPORT

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Research Report 1131-9, Volume 1
Research Study Number 0-1131
Research Study Title: Measuring and Monitoring Urban Mobility in Texas

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16. Abstract

This research report represents the final year of a 10-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 1994. 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.

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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's 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 of 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 1994 estimated Roadway Congestion Index (RCI). The 10 most congested urban areas in the study are displayed. The RCI values range from 1.52 (Los Angeles) to 1.18 (Atlanta). All of these urban areas have surpassed the RCI value at which undesirable levels of congestion occur (1.0).

Table S-1. 1994 Roadway Congestion Index Value

Urban Area	Freeway/Expressway		Principal Arterial Street		Roadway Congestion Index[3]	Rank
	Daily VKT[1] (000)	Daily VKT[2] Ln-Km	Daily VKT[1] (000)	Daily VKT[2] Ln-Km		
Los Angeles, CA	181,930	20,430	134,270	6,650	1.52	1
Washington, DC	49,310	18,230	29,790	7,770	1.43	2
San Fran-Oak, CA	68,960	17,480	23,670	6,230	1.33	3
Miami, FL	17,030	15,900	27,610	7,310	1.32	4
Chicago, IL	67,820	16,300	59,570	6,880	1.28	5
Seattle-Everett, WA	34,290	16,380	15,900	5,930	1.25	6
Detroit, MI	47,660	16,130	43,500	6,110	1.24	7
San Diego, CA	44,800	15,900	15,780	5,520	1.21	8
San Bernardino-Riv, CA	24,960	16,060	17,950	5,250	1.20	9
Atlanta, GA	53,130	15,350	20,530	6,010	1.18	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 that have experienced the greatest growth in congestion between 1988 and 1994. 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 the top seven cities in this group approached or exceeded two percent per year.

Table S-2. Fastest Congestion Growth Areas

Urban Area	Percent Change 1988-1994	Rank 1988-1994	Year				
			1982	1988	1992	1993	1994
Salt Lake City, UT	31	50	0.63	0.72	0.90	0.92	0.94
Columbus, OH	20	49	0.68	0.79	0.93	0.93	0.95
Cincinnati, OH	19	48	0.86	0.88	1.01	1.03	1.05
Charlotte, NC	17	47	0.71	0.80	0.89	0.92	0.94
Detroit, MI	16	46	1.06	1.07	1.19	1.23	1.24
Minn-St. Paul, MN	16	45	0.76	0.90	0.99	1.02	1.04
Baltimore, MD	15	44	0.84	0.92	1.04	1.04	1.06
Miami, FL	12	43	1.05	1.18	1.30	1.32	1.32
Fort Worth, TX	11	42	0.76	0.87	0.94	0.95	0.97
Kansas City, MO	11	41	0.62	0.72	0.77	0.78	0.80

See Table 2 for complete listing of urban areas.

Source: TTI Analysis

Table S-3 shows the nine urban areas with the smallest growth in congestion between 1988 and 1994. Of the top 10, only Austin and San Bernardino-Riverside experienced a small increase 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 1988-1994	Rank 1988-1994	Year				
			1982	1988	1992	1993	1994
Boston, MA	-4	1	0.90	1.12	1.07	1.07	1.08
Houston, TX	-3	2	1.17	1.15	1.12	1.13	1.12
Philadelphia, PA	-2	3	1.00	1.07	1.05	1.04	1.05
New Orleans, LA	-2	4	0.98	1.13	1.10	1.09	1.11
Norfolk, VA	-1	5	0.79	0.94	0.92	0.92	0.93
Los Angeles, CA	0	6	1.22	1.52	1.54	1.54	1.52
San Fran-Oak, CA	0	6	1.01	1.33	1.33	1.33	1.33
St. Louis, MO	0	6	0.83	0.98	0.95	0.96	0.98
Austin, TX	1	9	0.84	0.96	0.95	0.95	0.97
San Bernardino-Riv, CA	2	10	1.11	1.18	1.22	1.12	1.20

See Table 2 for complete listing of urban areas

Source: TTI Analysis

Table S-4 shows the 10 urban areas with the highest amount of daily delay. Los Angeles topped this list with approximately 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 63 person-hours of delay annually per eligible driver.

Another way of examining the effect of congestion on travel speeds is the areawide speed ratio (ASR). The ASR is a ratio of the network average speeds to the average freeflow speeds on the freeway and principal arterial street networks. The lower the ASR value, the slower the speeds estimated for the areawide roadway system during peak periods. Table S-5 shows the urban areas with lowest ASR values. San Francisco-Oakland has the lowest ASR of 65. This indicates that a driver in San Francisco-Oakland is experiencing peak period driving speeds that are 65 percent of free-flow speeds. All of these 11 areas have ASR values under 75.

Table S-6 lists the top 11 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 2.3 billion liters. Dallas and Seattle-Everett are tied at tenth in this group with about 410 million liters of fuel wasted annually. These 11 areas consume 10.4 billion liters annually due to congestion in their urban areas. San Bernardino-Riverside led this group with about 316 liters of fuel wasted annually per eligible driver.

Table S-7 combines existing freeway and principal arterial street distances with 1990 to 1994 recent annual traffic volume growth rates to produce the number of additional lane-kilometers for both freeway and principal arterial street that 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 that was added annually during this time period was also calculated. Table S-7 shows the annual deficiency in construction of lane-kilometers of freeway and principal arterial streets. Detroit leads this list of cities with a deficiency of 238 lane-kilometers annually between 1990 and 1994 (105 lane-kilometers of freeway and 133 lane-kilometers of principal arterial streets).

Table S-4. Daily and Annual Hours of Delay for 1994

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	1,089	1,275	2,364	1	49	5	63	4
New York, NY	764	1,399	2,162	2	32	14	40	15
San Fran-Oak, CA	367	462	828	3	54	2	65	3
Chicago, IL	383	443	826	4	27	21	35	20
Washington, DC	293	522	815	5	59	1	71	2
Detroit, MI	257	419	677	6	42	9	57	7
Houston, TX	232	313	546	7	46	6	61	5
Boston, MA	122	332	454	8	38	12	46	12
Atlanta, GA	202	222	424	9	44	7	56	8
Seattle-Everett, WA	166	221	387	10	51	4	59	6

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

See Table 3 for complete listing of urban areas.

Source: TTI Analysis.

Table S-5. Areawide Speeds and Congestion Levels for 1994

Urban Area	Roadway Congestion Index	Rank	Areawide Speed Ratio	Rank	Peak Period Speeds (kph)	
					Freeway	Prin. Arterial
San Fran-Oak, CA	1.33	3	65	1	60	44
Los Angeles, CA	1.52	1	69	2	61	47
Washington, DC	1.43	2	69	2	65	42
Houston, TX	1.12	13	70	4	65	48
Seattle-Everett, WA	1.25	6	70	4	65	47
San Bernardino-Riv, CA	1.20	9	72	6	65	47
New York, NY	1.15	11	73	7	71	41
San Jose, CA	1.06	21	74	8	70	47
Austin, TX	0.97	32	75	9	70	48
Chicago, IL	1.28	5	75	9	69	45

See Table 5 for complete listing of urban areas.

Source: TTI Analysis.

Table S-6. Annual Excess Fuel Consumed Due to Traffic Congestion in 1994

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	1,138	1,331	2,469	1	206	5	264	4
New York, NY	802	1,469	2,271	2	134	16	167	15
San Fran-Oak, CA	391	493	884	3	228	3	279	3
Chicago, IL	398	460	858	4	111	21	144	21
Washington, DC	307	546	853	5	248	1	296	2
Detroit, MI	265	432	697	6	174	9	236	8
Houston, TX	250	337	587	7	199	6	261	5
Boston, MA	129	351	480	8	161	12	193	13
Atlanta, GA	213	234	447	9	186	8	235	9
Dallas, TX	155	256	411	10	187	7	239	7
Seattle-Everett, WA	176	235	411	10	215	4	252	6

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

See Table 8 for complete listing of urban areas.

Source: TTI Analysis

Table S-7. Illustration of Annual Capacity Increase Required to Prevent Congestion Growth

Urban Area	Existing (1994) 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	2,954	7,124	4.83	143	38	344	211	105	133
Orlando, FL	1,047	1,932	6.78	71	24	131	52	47	79
New York, NY	10,151	12,478	1.59	162	163	199	76	-1	123
Kansas City, MO	2,520	1,819	5.22	132	83	95	28	49	67
Atlanta, GA	3,462	3,413	7.25	251	177	247	221	74	26
Washington, DC	2,705	3,832	3.27	89	62	125	52	27	73
Nashville, TN	1,079	1,570	6.97	75	72	109	14	3	95
Cincinnati, OH	1,586	1,344	4.44	70	32	60	6	38	54
San Antonio, TX	1,594	1,827	4.93	79	66	90	18	13	72
Minn-St. Paul, MN	2,496	1,996	4.42	110	28	88	97	82	-9

Note: [1] Average Annual Growth Rate of Freeway and Principal Arterial Streets Daily VKT between 1990-1994.

See Table 10 for complete listing of urban areas.

Source: TTI Analysis

Table S-8 shows the urban areas with the highest annual congestion costs. Delay and fuel costs comprise the total congestion costs. These 10 urban areas have an annual combined congestion cost of over $34 billion. Los Angeles and New York had the highest total congestion costs with values of $8.6 billion and $7.9 billion, respectively. The final urban area in the table, Seattle, had a total congestion cost of $1.4 billion annually.

Table S-8. Component and Total Congestion Costs by Urban Area for 1994

Urban Area	Annual Cost Due to Congestion ($ millions)			Rank
	Delay	Fuel	Total	
Los Angeles, CA	7,790	830	8,620	1
New York, NY	7,140	760	7,900	2
San Fran-Oak, CA	2,760	300	3,060	3
Chicago, IL	2,720	280	3,000	4
Washington, DC	2,690	270	2,960	5
Detroit, MI	2,210	210	2,420	6
Houston, TX	1,830	170	2,000	7
Boston, MA	1,500	150	1,650	8
Atlanta, GA	1,400	130	1,530	9
Seattle-Everett, WA	1,280	140	1,420	10

See Table 11 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-9 lists the top 10 congestion costs per eligible driver for 1994. San Bernardino-Riverside ranks first with a cost of $1,100 per driver. Dallas and Houston had costs of $810 and $890 per driver, respectively, or approximately $3.5 per driver per workday.

Table S-9. 1994 Congestion Cost per Eligible Driver

Urban Area	Total Congestion Cost	
	Per Eligible Driver (dollars)	Rank
San Bernardino-Riv, CA	1,100	1
Washington, DC	1,030	2
San Fran-Oak, CA	960	3
Los Angeles, CA	920	4
Houston, TX	890	5
Seattle-Everett, WA	870	6
Detroit, MI	820	7
Dallas, TX	810	8
Atlanta, GA	800	9
Miami, FL	760	10

See Table 12 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-10). The highest 1994 cost per capita occurred in Washington, DC with a cost per capita of $860. Detroit and Miami had the smallest cost per capita ($600) of the top 10 urban areas with a cost of just over $2 per capita for each workday.

Table S-10. 1994 Congestion Cost per Capita

Urban Area	Total Congestion Cost	
	Per Capita (dollars)	Rank
Washington, DC	860	1
San Bernardino-Riv, CA	790	2
San Fran-Oak, CA	790	3
Seattle-Everette, WA	740	4
Los Angeles, CA	720	5
Houston, TX	680	6
Dallas, TX	640	7
Atlanta, GA	640	8
Detroit, MI	600	8
Miami, FL	600	10

See Table 12 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 of 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 of 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 to not only 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 that 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, TTI reviews and adjusts the data, and then state and local agencies familiar with each urban area review the data.

This process was of particular importance with the 1992 HPMS data because a U.S. Census realignment affected many of the urban areas. 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 1994. 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 ninth of a series (3,4) of reports and is the fourth in the series to utilize the metric system in the analyses. Tables 1 through 14 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 1994 congestion levels and trends displayed by the data from 1982 to 1994. Volume 2 of this report contains information on the methodology and the equations utilized to produce the tables, along with detailed yearly summaries of the data.

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 1994 Roadway Congestion Index (RCI) values for 50 urban areas included within the study.

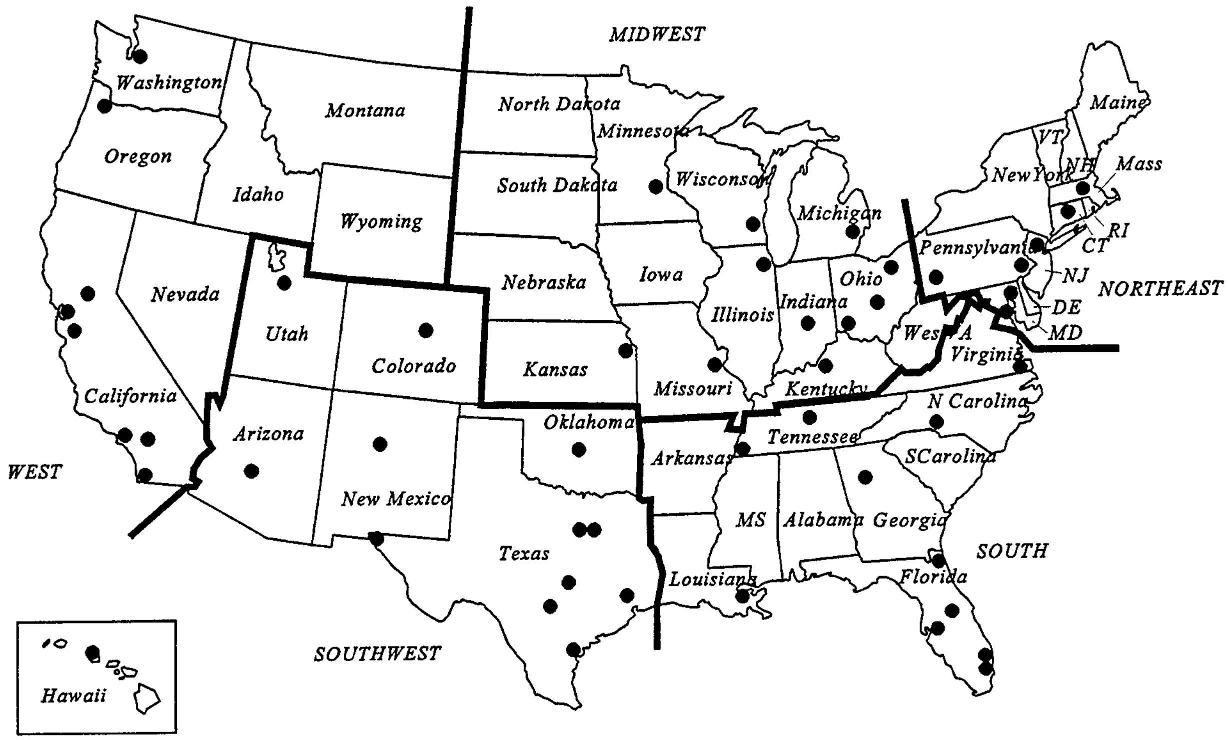

Figure 1. Regional Designations Used in Congestion Summaries

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, 1994

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.

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

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 improvements such as ramp metering or improvement of treatments designed to give a travel speed advantage to transit and carpool riders.

1994 Roadway Congestion Index Estimates

Table 1 lists the roadway congestion index values for 1994. Of the 50 urban areas studied, 28 have 1994 RCI values of or exceeding 1.0. RCI values for the 10 most congested urban areas range from 1.52 (Los Angeles) to 1.18 (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 that 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 (1.08), Midwestern (1.01), and Southern (1.02) regional averages also exceeded 1.0. The Southwestern region has an average RCI value 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 (13th) and Dallas (tied at 16th) were the only urban areas studied in Texas that were in the 20 most congested urban areas. Austin and Fort Worth had the next highest rank of the Texas urban areas (tied at 32nd). Florida was the only other state with more than one area in the twenty most congested systems (Miami and Tampa).

Table 1. 1994 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	181,930	20,430	134,270	6,650	1.52	1
Washington, DC	49,310	18,230	29,790	7,770	1.43	2
San Fran-Oak, CA	68,960	17,480	23,670	6,230	1.33	3
Miami, FL	17,030	15,900	27,610	7,310	1.32	4
Chicago, IL	67,820	16,300	59,570	6,880	1.28	5
Seattle-Everett, WA	34,290	16,380	15,900	5,930	1.25	6
Detroit, MI	47,660	16,130	43,500	6,110	1.24	7
San Diego, CA	44,800	15,900	15,780	5,520	1.21	8
San Bernardino-Riv, CA	24,960	16,060	17,950	5,250	1.20	9
Atlanta, GA	53,130	15,350	20,530	6,010	1.18	10
New York, NY	141,800	13,970	89,680	7,190	1.15	11
Honolulu, HI	9,020	14,000	3,120	7,610	1.13	12
Houston, TX	53,070	14,650	18,900	5,220	1.12	13
New Orleans, LA	8,870	13,280	8,090	6,790	1.11	14
Portland, OR	13,910	13,820	7,570	6,710	1.11	14
Dallas, TX	41,380	14,120	16,950	5,480	1.09	16
Phoenix, AZ	16,740	13,870	29,980	5,560	1.09	16
Boston, MA	35,020	14,310	22,940	4,900	1.08	18
Tampa, FL	7,250	12,860	8,080	6,280	1.07	19
Denver, CO	21,690	13,480	18,110	5,950	1.07	19
Baltimore, MD	30,270	13,570	16,180	5,830	1.06	21
Sacramento, CA	17,110	13,040	12,800	6,260	1.06	21
San Jose, CA	27,170	13,720	11,710	5,270	1.06	21
Philadelphia, PA	33,680	12,090	35,420	6,670	1.05	24
Cincinnati, OH	21,690	13,680	7,120	5,300	1.05	24
Minn-St. Paul, MN	33,330	13,350	11,500	5,760	1.04	26
Cleveland, OH	24,810	12,840	10,100	5,390	1.00	27
Milwaukee, WI	12,560	12,890	9,820	5,170	1.00	27
Ft. Lauderdale, FL	14,970	12,830	10,380	5,120	0.99	29
St. Louis, MO	33,170	11,870	20,490	6,360	0.98	30
Albuquerque, NM	4,700	11,680	7,680	5,610	0.98	30
Jacksonville, FL	10,500	12,540	10,550	4,850	0.97	32
Austin, TX	10,590	12,180	4,700	5,670	0.97	32
Fort Worth, TX	22,280	12,300	9,050	5,430	0.97	32
Nashville, TN	12,480	11,570	9,500	6,050	0.96	35
Columbus, OH	16,380	12,110	5,800	5,540	0.95	36
Louisville, KY	12,240	11,780	5,880	5,790	0.95	36
Charlotte, NC	6,170	11,610	5,300	5,480	0.94	38
Memphis, TN	8,690	11,490	9,290	5,390	0.94	38
Salt Lake City, UT	10,350	11,800	4,590	5,760	0.94	38
Hartford, CT	11,370	11,490	6,150	5,700	0.93	41
Norfolk, VA	9,780	10,470	8,170	6,590	0.93	41
Indianapolis, IN	15,300	11,590	8,450	5,250	0.92	43
San Antonio, TX	18,560	11,640	9,760	5,340	0.92	43
Orlando, FL	10,830	10,350	10,140	5,250	0.86	45
Oklahoma City, OK	12,480	10,470	7,490	5,310	0.85	46
Pittsburgh, PA	15,170	8,050	18,930	6,270	0.83	47
Kansas City, MO	25,160	9,990	9,050	4,970	0.80	48
El Paso, TX	6,150	10,190	5,470	3,890	0.78	49
Corpus Christi, TX	3,470	9,370	2,750	4,500	0.76	50
Northeastern Avg	45,230	13,100	31,300	6,330	1.08	
Midwestern Avg	26,880	12,750	16,560	5,650	1.01	
Southern Avg	14,520	12,570	11,600	5,920	1.02	
Southwestern Avg	19,000	12,300	11,630	5,310	0.97	
Western Avg	46,910	15,650	26,970	6,160	1.21	
Texas Avg	22,210	12,060	9,660	5,080	0.94	
Total Avg	28,600	13,180	18,320	5,820	1.05	
Maximum Value	181,930	20,430	134,270	7,770	1.52	
Minimum Value	3,470	8,050	2,750	3,890	0.76	

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 did not substantially increase between 1983 and 1990 (8). This reflects the impact of "urban sprawl" as a congestion relief mechanism. Urban residents have changed where they work or where the live (or both) in response to growing roadway congestion. These moves initially occur so that travel is on less congested suburban 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 1994. During the last seven years, Salt Lake City and Columbus were estimated to have experienced the largest increase in congestion, while Boston, Houston, Philadelphia, and New Orleans have experienced the smallest. During the span of the entire study, 1982 to 1994, Houston and Phoenix experienced small decreases in congestion. In this same time, San Diego, Salt Lake City, and Columbus have experienced the largest increases in congestion.

Table 2. Roadway Congestion Index Values, 1982 to 1994

Urban Area	Percent Change				Year						
	Short-Term 1988 to 1994		Long-Term 1982 to 1994		1982	1986	1988	1990	1992	1993	1994
	Percent	Rank	Percent	Rank							
Boston, MA	-4	1	20	20	0.90	1.04	1.12	1.06	1.07	1.07	1.08
Houston, TX	-3	2	-4	2	1.17	1.21	1.15	1.12	1.12	1.13	1.12
Philadelphia, PA	-2	3	5	3	1.00	1.06	1.07	1.05	1.05	1.04	1.05
New Orleans, LA	-2	4	13	7	0.98	1.09	1.13	1.12	1.10	1.09	1.11
Norfolk, VA	-1	5	18	15	0.79	0.89	0.94	0.96	0.92	0.92	0.93
Los Angeles, CA	0	6	25	29	1.22	1.42	1.52	1.55	1.54	1.54	1.52
San Fran-Oak, CA	0	6	32	42	1.01	1.24	1.33	1.36	1.33	1.33	1.33
St. Louis, MO	0	6	18	15	0.83	0.93	0.98	0.95	0.95	0.96	0.98
Austin, TX	1	9	15	13	0.84	0.94	0.96	0.94	0.95	0.95	0.97
San Bernardino-Riv, CA	2	10	8	6	1.11	1.15	1.18	1.21	1.22	1.21	1.20
Albuquerque, NM	2	11	26	33	0.78	0.96	0.96	0.98	0.95	0.96	0.98
Jacksonville, FL	2	12	7	5	0.91	0.95	0.95	0.93	0.97	0.96	0.97
Nashville, TN	2	13	25	29	0.77	0.86	0.94	0.89	0.92	0.93	0.96
Pittsburgh, PA	2	14	6	4	0.78	0.79	0.81	0.82	0.81	0.82	0.83
Sacramento, CA	3	15	33	45	0.80	0.95	1.03	1.02	1.04	1.04	1.06
Cleveland, OH	3	16	25	29	0.80	0.86	0.97	0.94	0.95	0.98	1.00
Hartford, CT	3	17	22	22	0.76	0.85	0.90	0.89	0.91	0.93	0.93
Atlanta, GA	4	18	30	40	0.91	1.09	1.14	1.14	1.17	1.16	1.18
Tampa, FL	4	19	14	10	0.94	0.96	1.03	1.05	1.07	1.06	1.07
New York, NY	5	20	14	10	1.01	1.06	1.10	1.14	1.14	1.15	1.15
Phoenix, AZ	5	21	-5	1	1.15	1.20	1.04	1.05	1.08	1.08	1.09
El Paso, TX	5	22	24	28	0.63	0.75	0.74	0.74	0.76	0.77	0.78
Honolulu, HI	6	23	23	26	0.92	1.03	1.07	1.09	1.10	1.13	1.13
San Jose, CA	6	24	23	26	0.86	0.97	1.00	1.05	1.07	1.05	1.06
Milwaukee, WI	6	25	20	20	0.83	0.90	0.94	0.99	1.00	1.00	1.00
Portland, OR	7	26	28	36	0.87	0.97	1.04	1.08	1.10	1.11	1.11
Seattle-Everett, WA	7	27	32	42	0.95	1.09	1.17	1.20	1.22	1.23	1.25
Dallas, TX	7	28	30	40	0.84	1.04	1.02	1.05	1.07	1.07	1.09
San Antonio, TX	7	29	19	18	0.77	0.88	0.86	0.88	0.90	0.91	0.92
San Diego, CA	7	30	55	50	0.78	1.00	1.13	1.22	1.22	1.21	1.21
Denver, CO	8	31	22	22	0.88	0.97	0.99	1.03	1.05	1.07	1.07
Indianapolis, IN	8	32	37	46	0.67	0.81	0.85	0.84	0.85	0.89	0.92
Chicago, IL	8	33	25	29	1.02	1.15	1.18	1.25	1.28	1.26	1.28
Corpus Christi, TX	9	34	13	7	0.67	0.71	0.70	0.72	0.74	0.75	0.76
Oklahoma City, OK	9	35	18	15	0.72	0.76	0.78	0.79	0.83	0.86	0.85
Louisville, KY	9	36	22	22	0.78	0.80	0.87	0.86	0.90	0.93	0.95
Memphis, TN	9	37	13	7	0.83	0.80	0.86	0.89	0.92	0.93	0.94
Washington, DC	10	38	28	36	1.12	1.27	1.30	1.34	1.36	1.41	1.43
Ft. Lauderdale, FL	10	39	14	10	0.87	0.85	0.90	0.94	0.96	0.98	0.99
Orlando, FL	10	40	19	18	0.72	0.76	0.78	0.77	0.80	0.82	0.86
Kansas City, MO	11	41	29	39	0.62	0.68	0.72	0.74	0.77	0.78	0.80
Fort Worth, TX	11	42	28	36	0.76	0.87	0.87	0.90	0.94	0.95	0.97
Miami, FL	12	43	26	33	1.05	1.14	1.18	1.27	1.30	1.32	1.32
Baltimore, MD	15	44	26	33	0.84	0.88	0.92	1.01	1.04	1.04	1.06
Minn-St. Paul, MN	16	45	37	46	0.76	0.89	0.90	0.95	0.99	1.02	1.04
Detroit, MI	16	46	17	14	1.06	1.05	1.07	1.13	1.19	1.23	1.24
Charlotte, NC	17	47	32	42	0.71	0.78	0.80	0.86	0.89	0.92	0.94
Cincinnati, OH	19	48	22	22	0.86	0.84	0.88	0.96	1.01	1.03	1.05
Columbus, OH	20	49	40	48	0.68	0.75	0.79	0.89	0.93	0.93	0.95
Salt Lake City, UT	31	50	49	49	0.63	0.68	0.72	0.85	0.90	0.92	0.94
Northeastern Avg					0.92	0.99	1.03	1.04	1.05	1.07	1.08
Midwestern Avg					0.80	0.87	0.91	0.94	0.97	0.99	1.01
Southern Avg					0.86	0.92	0.97	0.98	1.00	1.01	1.02
Southwestern Avg					0.83	0.93	0.91	0.93	0.95	0.96	0.97
Western Avg					0.95	1.09	1.16	1.20	1.20	1.21	1.21
Texas Avg					0.81	0.91	0.90	0.91	0.93	0.93	0.94
Total Avg					0.86	0.95	0.99	1.01	1.03	1.04	1.05
Maximum Value					1.22	1.42	1.52	1.55	1.54	1.54	1.52
Minimum Value					0.62	0.68	0.70	0.72	0.74	0.75	0.76

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 1994 except Houston. 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.

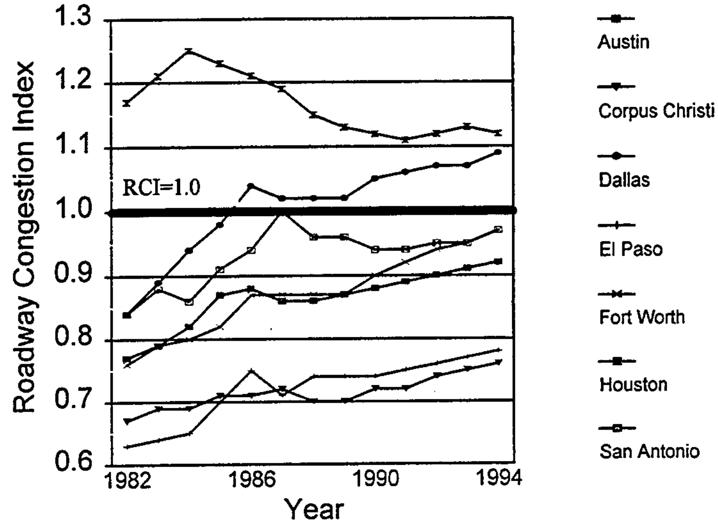

Figure 2. Texas Urban Area Congestion Levels, 1982-1994

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 when travel times are longer during 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. This increased travel time results from the slower speeds associated with congested conditions on the freeways and principal arterial streets.

Accidents, breakdowns, or other occurrences that 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 a much greater percentage of total delay in less congested areas. A severe incident will cause a significant increase in travel delay for an otherwise uncongested area. Appendix B of Volume 1 discussed the estimation of travel delay.

Table 3 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 is also shown. Los Angeles topped the list with almost 2.4 million person-hours of delay daily. Washington, D.C. had the highest annual delay per capita (59 hours), while San Bernardino-Riverside led the annual delay per eligible driver (75 hours). Forty of the 50 urban areas have delay per eligible driver of over 20 hours a year or the equivalent of one-half of a work week. Sixteen urban areas have the equivalent of at least a work week of delay per eligible driver per year. On average, in the 50 areas, over three-quarters of a work week is spent in delay per eligible driver. Summary statistics show that urban areas in 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 delay per eligible driver.

Table 3. Daily and Annual Person-Hours of Delay for 1994

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	74	137	212	18	25	22	31	22
Boston, MA	122	332	454	8	38	12	46	12
Hartford, CT	19	38	57	40	23	25	31	22
New York, NY	764	1,399	2,162	2	32	14	40	15
Philadelphia, PA	160	215	375	12	18	38	23	38
Pittsburgh, PA	68	101	169	22	22	27	27	30
Washington, DC	293	522	815	5	59	1	71	2
Midwestern Cities								
Chicago, IL	383	443	826	4	27	21	35	20
Cincinnati, OH	44	37	81	34	16	40	21	40
Cleveland, OH	54	44	98	28	14	42	18	42
Columbus, OH	38	32	70	36	18	38	22	39
Detroit, MI	257	419	677	6	42	9	57	7
Indianapolis, IN	22	30	52	41	13	44	17	44
Kansas City, MO	20	44	64	39	12	45	16	45
Louisville, KY	24	27	51	42	16	40	19	41
Milwaukee, WI	33	35	68	38	14	42	18	42
Minn-St. Paul, MN	86	83	170	21	20	34	25	35
Oklahoma City, OK	17	19	36	48	11	46	14	47
St. Louis, MO	88	101	188	20	24	23	30	24
Southern Cities								
Atlanta, GA	202	222	424	9	44	7	56	8
Charlotte, NC	23	23	46	44	21	31	27	30
Ft. Lauderdale, FL	49	65	115	25	22	27	26	32
Jacksonville, FL	40	50	90	31	29	18	37	18
Memphis, TN	19	21	41	45	11	46	15	46
Miami, FL	144	180	324	13	42	9	53	10
Nashville, TN	24	26	50	43	20	34	26	32
New Orleans, LA	38	57	94	30	21	31	28	28
Norfolk, VA	34	62	96	29	24	23	30	24
Orlando, FL	32	43	75	35	20	34	24	36
Tampa, FL	31	38	69	37	23	25	28	28
Southwestern Cities								
Albuquerque, NM	19	21	40	46	19	37	24	36
Austin, TX	41	45	85	33	36	13	45	13
Corpus Christi, TX	4	4	8	50	6	50	9	50
Dallas, TX	144	238	381	11	43	8	55	9
Denver, CO	106	110	216	17	32	14	40	15
El Paso, TX	9	10	19	49	8	49	11	49
Fort Worth, TX	60	101	161	23	32	14	43	14
Houston, TX	232	313	546	7	46	6	61	5
Phoenix, AZ	135	110	245	15	29	18	38	17
Salt Lake City, UT	22	17	39	47	11	46	14	47
San Antonio, TX	50	56	106	27	22	27	29	26
Western Cities								
Honolulu, HI	33	53	86	32	31	17	36	19
Los Angeles, CA	1,089	1,275	2,364	1	49	5	63	4
Portland, OR	47	76	123	24	28	20	35	20
Sacramento, CA	59	51	110	26	22	27	29	26
San Bernardino-Riv, CA	134	156	290	14	54	2	75	1
San Diego, CA	125	86	211	19	21	31	26	32
San Fran-Oak, CA	367	462	828	3	54	2	65	3
San Jose, CA	111	131	242	16	39	11	51	11
Seattle-Everett, WA	166	221	387	10	51	4	59	6
Northeastern Avg	214	393	607		31		38	
Midwestern Avg	89	110	249		19		24	
Southern Avg	58	71	129		25		32	
Southwestern Avg	75	94	169		26		34	
Western Avg	236	279	515		39		49	
Texas Avg	78	110	188		28		36	
Total Avg	123	168	291		27		34	
Maximum Value	1,089	1,275	2,364		59		75	
Minimum Value	4	4	8		6		9	

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

Source: TTI Analysis.

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 the comparison of these two congestion assessments.

Table 4 shows the annual delay per eligible driver for several years from 1982 to 1994. Twenty-two of the 50 urban areas experienced at least a 100 percent increase in delay over the 13-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 62 and 57 percent increases, respectively.

The Areawide Speed Ratio (ASR) is another way of examining the effect of congestion on travel speeds. While delay characterizes the amount of time lost, the ASR is a measure of speeds in relation to free-flow travel. The ASR is a ratio of the network average speeds to the average free-flow speed on the freeway and principal arterial street network. Equation 2 shows this relationship. The ASR values are between 0 and 100. The closer the ASR value is to 0, the slower the speeds estimated for the areawide roadway system during the peak periods. For example in Table 5, Los Angeles has an ASR of 69. This indicates that a driver in Los Angeles is experiencing peak period driving speeds that are 69 percent of free-flow speeds. Some drivers are experiencing speeds much less than 69 percent of free-flow but on average, a driver will encounter speeds of about 69 percent of free-flow.

$$\frac{\frac{(\text{Pk Pd Uncongested Fwy DVKT} + \text{Pk Pd Uncongested Prin Art DVKT})}{\text{Total Pk Pd Fwy DVKT} + \text{Total Pk Pd Prin Art DVKT}} \times \begin{matrix}\text{Uncongested Avg Speed}\\ \text{of Fwy and}\\ \text{Prin Art DVKT}\end{matrix} + \frac{(\text{Pk Pd Congested Fwy DVKT} + \text{Pk Pd Congested Prin Art DVKT})}{\text{Total Pk Pd Fwy DVKT} + \text{Total Pk Pd Prin Art DVKT}} \times \begin{matrix}\text{Congested Avg Speed}\\ \text{of Fwy and}\\ \text{Prin Art DVKT}\end{matrix}}{\frac{(\text{Pk Pd Fwy DVKT x Fwy Uncongested Speed}) + (\text{Pk Pd Prin Art DVKT x Prin Art Uncongested Speed})}{\text{Pk Pd Fwy DVKT} + \text{Pk Pd Prin Art DVKT}}} \qquad \text{Eq. 2}$$

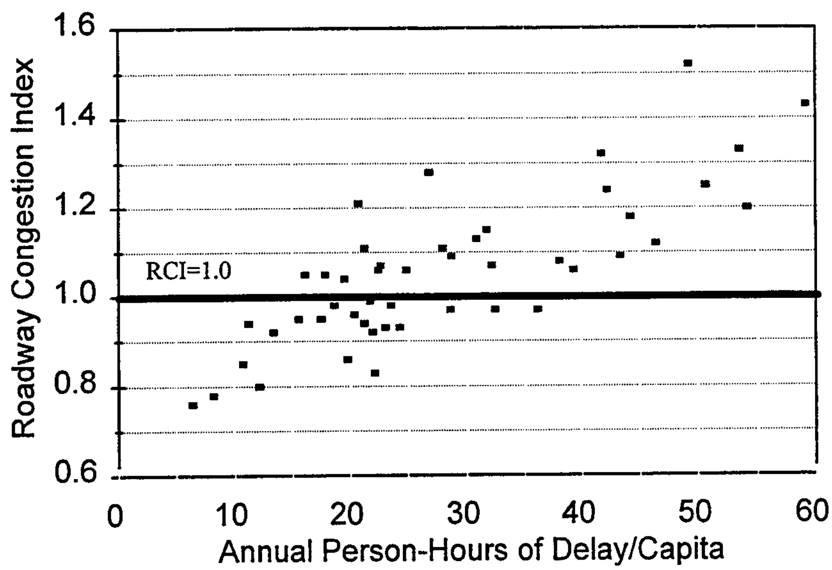

Figure 3. Roadway Congestion Index and Annual Delay per Capita

Table 4. Annual Person-Hours of Delay per Eligible Driver, 1982 to 1994

Urban Area	Annual Delay per Eligible Driver						Percent Change 1982 - 1994
	1982	1986	1990	1992	1993	1994	
Northeastern Cities							
Baltimore, MD	13	21	26	30	31	31	138
Boston, MA	26	40	43	45	44	46	77
Hartford, CT	9	15	23	25	30	31	244
New York, NY	25	31	36	38	39	40	60
Philadelphia, PA	20	25	24	23	23	23	15
Pittsburgh, PA	13	20	24	25	26	27	108
Washington, DC	42	56	66	70	70	71	69
Midwestern Cities							
Chicago, IL	19	28	29	34	34	35	84
Cincinnati, OH	7	9	15	18	20	21	200
Cleveland, OH	5	7	13	15	16	18	260
Columbus, OH	11	14	22	23	22	22	100
Detroit, MI	30	36	44	51	57	57	90
Indianapolis, IN	4	5	7	8	12	17	325
Kansas City, MO	6	8	9	14	15	16	167
Louisville, KY	8	9	10	13	16	19	138
Milwaukee, WI	9	13	16	17	17	18	100
Minn-St. Paul, MN	9	15	20	22	24	25	178
Oklahoma City, OK	9	11	12	14	14	14	56
St. Louis, MO	20	24	26	26	29	30	50
Southern Cities							
Atlanta, GA	29	48	45	47	53	56	93
Charlotte, NC	17	22	26	27	27	27	59
Ft. Lauderdale, FL	13	17	21	23	24	26	100
Jacksonville, FL	22	24	32	32	35	37	68
Memphis, TN	7	8	10	12	13	15	114
Miami, FL	30	35	49	47	51	53	77
Nashville, TN	14	23	28	26	24	26	86
New Orleans, LA	14	25	26	25	25	28	100
Norfolk, VA	18	29	32	30	29	30	67
Orlando, FL	13	18	17	18	22	24	85
Tampa, FL	21	24	26	28	27	28	33
Southwestern Cities							
Albuquerque, NM	9	13	18	17	20	24	167
Austin, TX	26	37	35	34	41	45	73
Corpus Christi, TX	3	4	4	7	7	9	200
Dallas, TX	36	56	54	53	53	55	53
Denver, CO	24	28	33	37	41	40	67
El Paso, TX	5	8	7	11	11	11	120
Fort Worth, TX	22	35	34	36	40	43	95
Houston, TX	51	55	55	57	60	61	20
Phoenix, AZ	30	34	37	39	40	38	27
Salt Lake City, UT	5	6	8	10	12	14	180
San Antonio, TX	15	26	22	25	28	29	93
Western Cities							
Honolulu, HI	25	29	31	35	37	36	44
Los Angeles, CA	41	60	65	64	65	63	54
Portland, OR	16	18	27	32	34	35	119
Sacramento, CA	14	19	26	25	29	29	107
San Bernardino-Riv, CA	42	68	74	76	76	75	79
San Diego, CA	12	19	29	28	26	26	117
San Fran-Oak, CA	39	61	68	65	66	65	67
San Jose, CA	33	50	55	54	52	51	55
Seattle-Everett, WA	26	41	56	59	59	59	127
Northeastern Avg	21	30	35	37	38	38	81
Midwestern Avg	12	15	19	21	23	24	100
Southern Avg	18	25	28	29	30	32	78
Southwestern Avg	21	27	28	30	32	34	62
Western Avg	28	41	48	49	49	49	75
Texas Avg	23	32	30	32	34	36	57
Total Avg	19	27	30	32	33	34	79
Maximum Value	51	68	74	76	76	75	47
Minimum Value	3	4	4	7	7	9	200

Source: TTI Analysis

Table 5. Areawide Speeds and Congestion Levels for 1994

Urban Area	Roadway Congestion Index	Rank	Areawide Speed Ratio	Rank	Peak Period Speeds (kph)	
					Freeway	Prin. Arterial
San Fran-Oak, CA	1.33	3	65	1	60	44
Los Angeles, CA	1.52	1	69	2	61	47
Washington, DC	1.43	2	69	2	65	42
Houston, TX	1.12	13	70	4	65	48
Seattle-Everett, WA	1.25	6	70	4	65	47
San Bernardino-Riv, CA	1.20	9	72	6	65	47
New York, NY	1.15	11	73	7	71	41
San Jose, CA	1.06	21	74	8	70	47
Austin, TX	0.97	32	75	9	70	48
Chicago, IL	1.28	5	75	9	69	45
Miami, FL	1.32	4	75	9	69	44
Phoenix, AZ	1.09	16	76	12	68	45
Atlanta, GA	1.18	10	77	13	74	45
Dallas, TX	1.09	16	77	13	73	49
Denver, CO	1.07	19	77	13	72	47
Honolulu, HI	1.13	12	77	13	74	44
Detroit, MI	1.24	7	78	17	74	44
New Orleans, LA	1.11	14	80	18	75	48
San Diego, CA	1.21	8	80	18	76	50
Boston, MA	1.08	18	81	20	76	49
Fort Worth, TX	0.97	32	81	20	77	50
Portland, OR	1.11	14	82	22	79	46
Ft. Lauderdale, FL	0.99	29	83	23	80	48
Charlotte, NC	0.94	38	84	24	83	46
Minn-St. Paul, MN	1.04	26	84	24	82	46
Philadelphia, PA	1.05	24	84	24	86	43
Sacramento, CA	1.06	21	84	24	82	47
San Antonio, TX	0.92	43	84	24	79	51
Jacksonville, FL	0.97	32	85	29	82	47
Norfolk, VA	0.93	41	85	29	80	50
Cincinnati, OH	1.05	24	86	31	82	51
Cleveland, OH	1.00	27	86	31	82	51
Columbus, OH	0.95	36	86	31	83	48
Tampa, FL	1.07	19	86	31	88	45
Baltimore, MD	1.06	21	87	35	84	49
Orlando, FL	0.86	45	87	35	82	51
Pittsburgh, PA	0.83	47	87	35	88	45
Salt Lake City, UT	0.94	38	87	35	84	50
St. Louis, MO	0.98	30	87	35	86	47
Milwaukee, WI	1.00	27	88	40	84	50
Albuquerque, NM	0.98	30	89	41	87	49
Hartford, CT	0.93	41	91	42	88	51
Louisville, KY	0.95	36	91	42	90	46
Memphis, TN	0.94	38	91	42	89	51
Nashville, TN	0.96	35	91	42	89	51
El Paso, TX	0.78	49	92	46	87	54
Indianapolis, IN	0.92	43	92	46	89	51
Oklahoma City, OK	0.85	46	94	48	93	50
Corpus Christi, TX	0.76	50	95	49	91	54
Kansas City, MO	0.80	48	95	49	93	52
Northeastern Avg	1.08		82		80	46
Midwestern Avg	1.01		87		84	49
Southern Avg	1.02		84		81	48
Southwestern Avg	0.97		82		77	50
Western Avg	1.21		75		70	47
Texas Avg	0.94		82		77	51
Total Avg	1.05		82		79	48
Maximum Value	1.52		95		93	54
Minimum Value	0.76		65		60	41

Source: TTI Analysis.

The ASR provides additional insight into the congestion levels in an urban area, which is not always evident in the RCI (see Table 5). The rankings associated with the RCI and the ASR appear to differ dramatically in some urban areas. The RCI is a macroscopic view of roadway traffic for an urban area. It analyzes total travel and roadway capacity for an area. The RCI does not account for point-specific congestion problems such as capacity bottlenecks or points where demand is funneled into a few corridors. Examples of these locations include points where the number of lanes decrease or tunnels and bridges cross major geographic features. Toll freeways also carry lower than typical traffic volume per lane and can therefore contribute significant reductions in congestion as measured by the roadway congestion index, but not contribute as much benefit to reducing travel delay.

Some urban areas may have the majority of their travel on a small number of roadways, thus creating slow speeds on these roadways. The travel occurring on other roads in the area may be at higher speeds, but it does not account for much of the total travel in the area. In this situation the large amount of travel at the slower speeds would create a lower ASR for the entire area, while the roadway congestion index might show moderate congestion because of the number of roadways carrying relatively low traffic levels.

Table 5 shows a comparison of the roadway congestion index and the areawide speed ratio. Los Angeles leads the list of urban areas with an RCI of 1.52, and it is tied for second with Washington DC with an ASR of 69. San Francisco-Oakland has the lowest ASR at 65. San Francisco-Oakland is a good example of an area with many topographic features that limit the route choices for travelers, creating many natural bottlenecks in the roadway system. These bottlenecks create lower travel speeds and a lower ASR.

Only two urban areas in Texas (Houston and Dallas) ranked in the top 20 RCI values (1.12 and 1.09, respectively), while four urban areas in Texas ranked in the top 20 for the ASR. These four urban areas are Houston (4th), Austin (9th), Dallas (13th), and Fort Worth (20th). The Western region ranked first in both the RCI (1.21) and the ASR (75). The Texas Region had the lowest average RCI (0.94) but ranked second with an ASR of 82.

Table 6 shows the ASR values for several years between 1982 and 1994. The ASR in all but one urban area (Nashville) has decreased in this 13-year span. It has the same ASR (91) in 1994 that it had in 1982. Seattle-Everett has shown the greatest decrease in the ASR between 1982 and 1994 (17 percent). The next three largest decreases occurred in the California urban areas of San Francisco-Oakland, San Bernardino-Riverside, and San Jose. Houston and Corpus Christi experienced the smallest change in the ASR (3 percent decrease) of the Texas cities, while Fort Worth had the largest decrease (8 percent). The Western region showed the largest decrease of about 9 percent. The Texas average decrease was about 5 percent.

Another relationship to explore is between the ASR and hours of delay per capita. As discussed previously, the ASR should be lower as the amount of delay increases. This is not always the case because some cities, such as New York, have a larger segment of the population that is not contributing to the lower speeds on the roadway network because they walk to work or ride transit. They do, however, bring the delay per capita value down when they are included in the calculation. Table 7 shows the comparisons of the two. The first six urban areas listed in the table comprise the top six positions in each category. Washington, DC is first in delay per capita and is second in ASR. San Francisco-Oakland is first in ASR and tied for second in delay per capita. Houston is the highest ranked Texas city in both categories. It is sixth in delay per capita (46 hours) and tied for fourth in ASR (70). Dallas ranks eighth in delay per capita (43 hours) and 13th in ASR (77). Austin is the only other Texas city with a top10 ranking. It is tied for ninth with an ASR of 75. The Western region has the highest delay per capita (39 hours) and the lowest ASR (75).

Table 6. Areawide Speed Ratio 1982 to 1994

Urban Area	Areawide Speed Ratio						% Change 1982-1994
	1982	1986	1990	1992	1993	1994	
Seattle-Everette, WA	84	78	71	71	70	70	-17
San Bernardino-Riv, CA	81	75	73	72	71	72	-11
San Fran-Oak, CA	73	66	65	65	65	65	-11
San Jose, CA	82	75	74	74	74	74	-10
San Diego, CA	88	85	80	80	80	80	-9
Ft. Lauderdale, FL	91	88	84	84	84	83	-9
Phoenix, AZ	83	77	77	76	75	76	-8
Salt Lake City, UT	95	94	93	91	89	87	-8
Denver, CO	84	81	80	78	77	77	-8
Washington, DC	75	73	71	69	69	69	-8
Fort Worth, TX	88	83	83	83	82	81	-8
Minn-St. Paul, MN	91	88	86	86	84	84	-8
Cincinnati, OH	93	92	89	86	86	86	-8
Cleveland, OH	93	91	89	88	86	86	-8
Austin, TX	81	78	78	78	77	75	-7
Atlanta, GA	83	79	79	77	77	77	-7
New Orleans, LA	86	79	80	80	80	80	-7
Boston, MA	87	84	82	81	82	81	-7
Charlotte, NC	90	88	86	84	84	84	-7
Sacramento, CA	90	88	86	87	85	84	-7
Albuquerque, NM	95	93	91	90	90	89	-6
Miami, FL	80	79	75	76	75	75	-6
Detroit, MI	83	82	79	79	77	78	-6
Portland, OR	87	87	84	82	82	82	-6
Jacksonville, FL	90	89	86	86	85	85	-6
Los Angeles, CA	73	68	69	69	69	69	-5
Baltimore, MD	92	90	89	87	87	87	-5
Orlando, FL	92	89	89	89	87	87	-5
Hartford, CT	96	95	93	93	91	91	-5
New York, NY	77	77	74	74	73	73	-5
Indianapolis, IN	97	98	96	96	94	92	-5
Chicago, IL	79	75	76	74	75	75	-5
Dallas, TX	81	77	77	77	78	77	-5
Honolulu, HI	81	79	78	77	77	77	-5
San Antonio, TX	88	84	85	84	84	84	-5
Pittsburgh, PA	91	88	87	87	87	87	-4
Milwaukee, WI	92	89	87	87	88	88	-4
Louisville, KY	95	95	95	94	93	91	-4
Memphis, TN	95	94	94	93	93	91	-4
El Paso, TX	96	94	94	92	92	92	-4
Norfolk, VA	88	83	82	84	84	85	-3
Columbus, OH	89	89	86	86	86	86	-3
Oklahoma City, OK	97	96	95	94	94	94	-3
Corpus Christi, TX	98	97	97	95	95	95	-3
Houston, TX	72	68	70	70	70	70	-3
Philadelphia, PA	86	84	84	84	84	84	-2
St. Louis, MO	89	89	89	89	87	87	-2
Kansas City, MO	97	97	97	95	95	95	-2
Tampa, FL	87	87	85	85	86	86	-1
Nashville, FL	91	92	89	90	91	91	0
Northeastern Avg	86	84	83	82	82	82	-5
Midwestern Avg	91	90	89	88	87	87	-4
Southern Avg	88	86	84	84	84	84	-5
Southwestern Avg	87	84	84	83	83	82	-6
Western Avg	82	78	76	75	75	75	-9
Texas Avg	86	83	83	83	83	82	-5
Total Avg	87	85	84	83	83	82	-6
Maximum Value	98	98	97	96	95	95	-3
Minimum Value	72	66	65	65	65	65	-10

Source: TTI Analysis.

Table 7. Areawide Speeds and Delay per Capita for 1994

Urban Area	Annual Hours of Delay per Capita	Rank	Areawide Speed Ratio	Rank
Washington, DC	59	1	69	2
San Bernardino-Riv, CA	54	2	72	6
San Fran-Oak, CA	54	2	65	1
Seattle-Everett, WA	51	4	70	4
Los Angeles, CA	49	5	69	2
Houston, TX	46	6	70	4
Atlanta, GA	44	7	77	13
Dallas, TX	43	8	77	13
Detroit, MI	42	9	78	17
Miami, FL	42	9	75	9
San Jose, CA	39	11	74	8
Boston, MA	38	12	81	20
Austin, TX	36	13	75	9
Denver, CO	32	14	77	13
Fort Worth, TX	32	14	81	20
New York, NY	32	14	73	7
Honolulu, HI	31	17	77	13
Jacksonville, FL	29	18	85	29
Phoenix, AZ	29	18	76	12
Portland, OR	28	20	82	22
Chicago, IL	27	21	75	9
Baltimore, MD	25	22	87	35
Norfolk, VA	24	23	85	29
St. Louis, MO	24	23	87	35
Hartford, CT	23	25	91	42
Tampa, FL	23	25	86	31
Ft. Lauderdale, FL	22	27	83	23
Pittsburgh, PA	22	27	87	35
Sacramento, CA	22	27	84	24
San Antonio, TX	22	27	84	24
Charlotte, NC	21	31	84	24
New Orleans, LA	21	31	80	18
San Diego, CA	21	31	80	18
Minn-St. Paul, MN	20	34	84	24
Nashville, TN	20	34	91	42
Orlando, FL	20	34	87	35
Albuquerque, NM	19	37	89	41
Columbus, OH	18	38	86	31
Philadelphia, PA	18	38	84	24
Cincinnati, OH	16	40	86	31
Louisville, KY	16	40	91	42
Cleveland, OH	14	42	86	31
Milwaukee, WI	14	42	88	40
Indianapolis, IN	13	44	92	46
Kansas City, MO	12	45	95	49
Memphis, TN	11	46	91	42
Oklahoma City, OK	11	46	94	48
Salt Lake City, UT	11	46	87	35
El Paso, TX	8	49	92	46
Corpus Christi, TX	6	50	95	49
Northeastern Avg	31		82	
Midwestern Avg	19		87	
Southern Avg	25		84	
Southwestern Avg	26		82	
Western Avg	39		75	
Texas Avg	28		82	
Total Avg	27		82	
Maximum Value	59		95	
Minimum Value	6		65	

Source: TTI Analysis.

One direct effect of congestion is that excess fuel is consumed while vehicles drive in congested traffic conditions. This study estimates the excess fuel consumed 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.

$$\underset{(kilometers\ per\ liter)}{Fuel\ Economy} = 3.74 + 0.11 \underset{(kilometers\ per\ hour)}{Average\ Vehicular\ Speed} \qquad \text{Eq. 3}$$

Table 8 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 587 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, DC had the most fuel wasted per capita with about 248 liters. This value shows that each person in Washington, DC wastes almost 1 liter of fuel per workday in congested travel. Houston (6th), Dallas (7th), Austin (13th), and Fort Worth (14th) rank in the top 15 urban areas. The Western region had the highest wasted fuel per capita with 164 liters. All other regions were no higher than 129 liters per capita. The impact on individual drivers has San Bernardino-Riverside with the greatest fuel wasted per driver with 316 liters per year. Washington, DC was second with 296 liters per driver. Houston (5th) and Dallas (7th) were the only Texas cities in the top 10. The Western region had the highest average with 207 liters per eligible driver or about 1 wasted liter of fuel per workday. All other regions were under 200 liters per eligible driver.

Table 8. Annual Excess Fuel Consumed Due to Traffic Congestion in 1994

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	78	144	222	19	105	22	133	22
Boston, MA	129	351	480	8	161	12	193	13
Hartford, CT	20	41	61	40	97	25	130	23
New York, NY	802	1,469	2,271	2	134	16	167	15
Philadelphia, PA	162	217	379	12	72	39	91	39
Pittsburgh, PA	68	102	170	23	89	32	108	33
Washington, DC	307	546	853	5	248	1	296	2
Midwestern Cities								
Chicago, IL	398	460	858	4	111	21	144	21
Cincinnati, OH	48	41	89	34	71	40	91	39
Cleveland, OH	59	47	106	28	59	42	77	42
Columbus, OH	40	33	73	36	74	38	93	38
Detroit, MI	265	432	697	6	174	9	236	8
Indianapolis, IN	24	32	56	41	58	43	75	44
Kansas City, MO	21	47	68	39	52	45	66	45
Louisville, KY	25	28	53	42	64	41	80	41
Milwaukee, WI	35	36	71	37	57	44	77	42
Minn-St. Paul, MN	92	89	181	21	83	35	104	35
Oklahoma City, OK	18	20	38	48	44	48	57	48
St. Louis, MO	92	105	197	20	98	24	127	25
Southern Cities								
Atlanta, GA	213	234	447	9	186	8	235	9
Charlotte, NC	24	24	48	44	89	32	112	31
Ft. Lauderdale, FL	52	69	121	25	92	28	111	32
Jacksonville, FL	42	53	95	31	120	18	154	19
Memphis, TN	20	22	42	45	47	47	62	46
Miami, FL	146	182	328	13	169	10	215	11
Nashville, TN	25	28	53	42	86	34	108	33
New Orleans, LA	40	60	100	30	90	30	118	28
Norfolk, VA	36	66	102	29	104	23	129	24
Orlando, FL	34	45	79	35	83	35	102	36
Tampa, FL	31	38	69	38	90	30	113	30
Southwestern Cities								
Albuquerque, NM	20	22	42	45	77	37	100	37
Austin, TX	44	48	92	32	156	13	196	12
Corpus Christi, TX	4	4	8	50	28	50	37	50
Dallas, TX	155	256	411	10	187	7	239	7
Denver, CO	110	115	225	18	135	15	167	15
El Paso, TX	10	11	21	49	36	49	49	49
Fort Worth, TX	64	109	173	22	139	14	184	14
Houston, TX	250	337	587	7	199	6	261	5
Phoenix, AZ	139	114	253	16	119	19	156	17
Salt Lake City, UT	24	18	42	45	48	46	62	46
San Antonio, TX	54	59	113	27	93	27	124	26
Western Cities								
Honolulu, HI	35	56	91	33	131	17	155	18
Los Angeles, CA	1,138	1,331	2,469	1	206	5	264	4
Portland, OR	49	80	129	24	118	20	147	20
Sacramento, CA	61	53	114	26	94	26	123	27
San Bernardino-Riv, CA	141	165	306	14	229	2	316	1
San Diego, CA	137	95	232	17	91	29	114	29
San Fran-Oak, CA	391	493	884	3	228	3	279	3
San Jose, CA	119	140	259	15	168	11	217	10
Seattle-Everett, WA	176	235	411	10	215	4	252	6
Northeastern Avg	223	408	631		129		160	
Midwestern Avg	94	116	210		79		102	
Southern Avg	60	75	135		105		133	
Southwestern Avg	80	99	179		111		143	
Western Avg	251	296	547		164		207	
Texas Avg	83	118	201		120		156	
Total Avg	130	177	307		114		145	
Maximum Value	1,138	1,469	2,469		248		316	
Minimum Value	4	4	8		28		37	

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 9 shows the annual amount of fuel wasted due to congestion for certain years from 1982 to 1994. Thirty-six of the 50 urban areas experienced at least a 100 percent increase in the amount of wasted fuel. Indianapolis had the largest increase with 409 percent over the 12-year period. Philadelphia had the smallest increase with only 50 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 Wasted Fuel Due to Congestion

Urban Area	Annual Wasted Liters (millions)						Percent Change 1982-1994
	1982	1986	1990	1992	1993	1994	
Indianapolis, IN	11	14	24	27	39	56	409
Salt Lake City, UT	10	14	20	29	34	42	320
Hartford, CT	16	27	45	49	60	61	281
Cleveland, OH	30	43	76	88	98	106	253
Minn-St. Paul, MN	55	94	137	155	170	181	229
Albuquerque, NM	13	20	28	29	34	42	223
Cincinnati, OH	28	35	59	77	85	88	214
San Diego, CA	74	134	230	239	231	232	214
Kansas City, MO	22	28	34	58	65	68	209
El Paso, TX	7	12	13	19	20	21	200
Baltimore, MD	75	127	167	204	216	223	197
Seattle-Everett, WA	139	237	352	392	402	411	196
Sacramento, CA	40	61	91	97	111	115	188
Atlanta, GA	157	268	313	353	409	447	185
Orlando, FL	28	44	50	57	70	79	182
Austin, TX	33	59	65	67	80	92	179
Louisville, KY	19	23	26	35	43	53	179
Memphis, TN	16	19	27	34	37	43	169
Corpus Christi, TX	3	4	4	6	7	8	167
Ft. Lauderdale, FL	48	68	95	105	111	122	154
Charlotte, NC	19	28	38	44	47	48	153
San Antonio, TX	45	82	84	95	105	113	151
Nashville, TN	22	38	53	52	48	53	141
Portland, OR	54	66	95	116	124	130	141
Columbus, OH	31	40	63	71	72	73	135
San Bernardino-Riv, CA	132	213	268	298	307	307	133
Fort Worth, TX	76	127	133	143	160	173	128
Jacksonville, FL	42	51	74	80	87	94	124
Pittsburgh, PA	77	122	149	154	163	170	121
Washington, DC	390	564	700	800	824	853	119
Norfolk, VA	47	82	99	98	95	102	117
Milwaukee, WI	34	49	62	66	66	71	109
San Jose, CA	126	212	251	265	261	258	105
Chicago, IL	424	622	696	809	821	858	102
Denver, CO	112	144	178	201	221	225	101
Oklahoma City, OK	19	26	28	34	37	38	100
New Orleans, LA	50	83	90	88	90	99	98
Detroit, MI	357	420	539	620	691	697	95
San Fran-Oak, CA	454	723	869	858	882	883	94
Miami, FL	171	203	291	293	316	328	92
Tampa, FL	36	47	60	65	63	69	92
Dallas, TX	216	352	359	370	376	411	90
Phoenix, AZ	133	180	218	245	255	253	90
Boston, MA	255	381	453	472	463	479	88
Honolulu, HI	49	61	72	84	91	91	86
Los Angeles, CA	1,370	2,081	2,405	2,466	2,503	2,469	80
St. Louis, MO	118	148	165	167	190	197	67
New York, NY	1,397	1,593	2,018	2,154	2,234	2,271	63
Houston, TX	388	496	518	546	576	586	51
Philadelphia, PA	253	315	348	371	382	379	50
Northeastern Avg	352	447	554	601	620	681	80
Midwestern Avg	96	129	159	184	198	210	116
Southern Avg	58	85	108	115	125	135	133
Southwestern Avg	94	135	147	159	170	179	90
Western Avg	271	421	515	535	546	547	101
Texas Avg	110	162	168	178	189	201	83
Total Avg	154	218	265	285	297	307	98
Maximum Value	1,397	2,081	2,405	2,466	2,503	2,469	409
Minimum Value	3	4	4	6	7	8	50

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 10 compares the amount of roadway needed each year to maintain the 1994 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, Indianapolis would require an additional 64 lane-kilometers of freeway and 78 lane-kilometers of principal arterial streets *every year* to maintain the 1994 congestion level with 4.86 percent annual growth in daily VKT between 1990 and 1994. During this five-year period, only an average of 24 lane-kilometers of freeway and 48 lane-kilometers of principal arterial street were added annually. This gave Indianapolis an annual deficit of 40 lane-kilometers of freeway and 30 lane-kilometers of principal arterial streets.

Table 10. Illustration of Annual Capacity Increase Required to Prevent Congestion Growth

Urban Area	Existing (1994) 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	2,954	7,124	4.83	143	38	344	211	105	133
Orlando, FL	1,047	1,932	6.78	71	24	131	52	47	79
New York, NY	10,151	12,478	1.59	162	163	199	76	-1	123
Kansas City, MO	2,520	1,819	5.22	132	83	95	28	49	67
Atlanta, GA	3,462	3,413	7.25	251	177	247	221	74	26
Washington, DC	2,705	3,832	3.27	89	62	125	52	27	73
Nashville, TN	1,079	1,570	6.97	75	72	109	14	3	95
Cincinnati, OH	1,586	1,344	4.44	70	32	60	6	38	54
San Antonio, TX	1,594	1,827	4.93	79	66	90	18	13	72
Minn-St. Paul, MN	2,496	1,996	4.42	110	28	88	97	82	-9
Baltimore, MD	2,230	2,777	2.99	67	54	83	26	13	57
Indianapolis, IN	1,320	1,610	4.86	64	24	78	48	40	30
Phoenix, AZ	1,208	5,394	3.22	39	50	173	93	-11	80
Denver, CO	1,610	3,043	2.79	45	46	85	16	-1	69
Houston, TX	3,623	3,623	3.43	124	133	124	48	-9	76
Fort Worth, TX	1,811	1,666	4.92	89	42	82	66	47	16
Dallas, TX	2,930	3,091	3.18	93	44	98	85	49	13
Ft. Lauderdale, FL	1,167	2,029	5.13	60	50	104	58	10	46
Seattle-Everett, WA	2,093	2,681	2.68	56	36	72	36	20	36
Cleveland, OH	1,932	1,876	2.44	47	20	46	18	27	28
Memphis, TN	757	1,723	6.85	52	32	118	87	20	31
Philadelphia, PA	2,785	5,313	1.96	55	89	104	20	-34	84
Louisville, KY	1,038	1,014	5.35	56	22	54	44	34	10
Columbus, OH	1,352	1,047	3.13	42	16	33	16	26	17
Pittsburgh, PA	1,884	3,019	2.62	49	68	79	22	-19	57
Los Angeles, CA	8,903	20,206	0.74	66	121	149	58	-55	91
Boston, MA	2,447	4,685	1.33	33	0	62	60	33	2
Austin, TX	869	829	6.07	53	36	50	34	17	16
Jacksonville, FL	837	2,174	3.99	33	28	87	60	5	27
Charlotte, NC	531	966	4.49	24	12	43	26	12	17
Salt Lake City, UT	877	797	5.95	52	14	47	56	38	-9
Miami, FL	1,071	3,775	3.28	35	24	124	109	11	15
St. Louis, MO	2,793	3,220	2.07	58	18	67	81	40	-14
El Paso, TX	604	1,409	2.54	15	10	36	16	5	20
Oklahoma City, OK	1,191	1,409	4.22	50	8	60	78	42	-18
Corpus Christi, TX	370	612	5.87	22	18	36	18	4	18
Sacramento, CA	1,312	2,045	3.42	45	26	70	68	19	2
Hartford, CT	990	1,079	2.23	22	14	24	14	8	10
Honolulu, HI	644	411	5.10	33	24	21	12	9	9
Norfolk, VA	934	1,240	3.55	33	46	44	14	-13	30
Portland, OR	1,006	1,127	4.54	46	28	51	54	18	-3
San Jose, CA	1,980	2,222	1.73	34	28	39	34	6	5
Tampa, FL	564	1,288	4.55	26	20	59	56	6	3
Chicago, IL	4,162	8,654	4.07	169	64	352	449	105	-97
Milwaukee, WI	974	1,900	2.75	27	4	52	70	23	-18
New Orleans, LA	668	1,191	3.87	26	22	46	46	4	0
Albuquerque, NM	403	1,369	3.54	14	12	48	52	2	-4
San Bernardino-Riv, CA	1,554	3,421	1.89	29	28	65	74	1	-9
San Diego, CA	2,818	2,858	0.40	11	10	11	26	1	-15
San Fran-Oak, CA	3,945	3,800	0.42	17	24	16	44	-7	-28

Notes: [1] Average annual growth rate of freeway and principal arterial streets between 1990 and 1994.
[2] Average lane-kilometers added annually from 1990 to 1994.

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. Appendix B of Volume 1 of this report contains a more detailed discussion of the calculation of cost. 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.

Table 11 shows the component and total congestion costs for each urban area. In 1994, the total cost of congestion for the urban areas studied was approximately $53 billion. This represents a four percent increase in the cost of congestion since 1993 ($51 billion). The increase in the value of time rate was 2.4 percent, and average fuel costs averaged about a 4 percent decrease in the 50 study areas. 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 1994 due to delay was $960 million, compared to $910 million in 1993.

Fourteen urban areas had total congestion costs exceeding $1 billion. Of the seven urban areas studied in Texas, only two, Houston (7th) and Dallas (11th), ranked in this highest group. Congestion in the Texas urbanized areas resulted in a cost of approximately $4.8 billion, a nine percent increase from 1993 congestion costs.

Table 11. Total Congestion Costs by Urban Area for 1994

Urban Area	Annual Cost Due to Congestion ($ millions)			Rank
	Delay	Fuel	Total	
Los Angeles, CA	7,790	830	8,620	1
New York, NY	7,140	760	7,900	2
San Fran-Oak, CA	2,760	300	3,060	3
Chicago, IL	2,720	280	3,000	4
Washington, DC	2,690	270	2,960	5
Detroit, MI	2,210	210	2,420	6
Houston, TX	1,830	170	2,000	7
Boston, MA	1,500	150	1,650	8
Atlanta, GA	1,400	130	1,530	9
Seattle-Everett, WA	1,280	140	1,420	10
Dallas, TX	1,280	130	1,410	11
Philadelphia, PA	1,220	120	1,340	12
Miami, FL	1,050	110	1,160	13
San Bernardino-Riv, CA	960	110	1,070	14
San Jose, CA	810	90	900	15
Phoenix, AZ	800	90	890	16
Denver, CO	710	80	790	18
San Diego, CA	710	80	790	18
Baltimore, MD	700	80	780	19
St. Louis, MO	620	60	680	20
Minn-St. Paul, MN	570	60	630	21
Pittsburgh, PA	550	50	600	22
Fort Worth, TX	540	50	590	23
Portland, OR	400	50	450	24
Ft. Lauderdale, FL	380	40	420	25
Sacramento, CA	360	40	400	26
San Antonio, TX	350	40	390	27
Cleveland, OH	330	30	360	28
Norfolk, VA	320	30	350	29
New Orleans, LA	310	30	340	30
Honolulu, HI	290	40	330	32
Jacksonville, FL	300	30	330	32
Austin, TX	290	20	310	33
Cincinnati, OH	280	20	300	34
Orlando, FL	250	20	270	35
Columbus, OH	230	20	250	36
Kansas City, MO	220	20	240	38
Milwaukee, WI	220	.20	240	38
Tampa, FL	220	20	240	38
Hartford, CT	190	20	210	40
Indianapolis, IN	170	20	190	42
Louisville, KY	170	20	190	42
Nashville, TN	170	20	190	42
Charlotte, NC	150	20	170	44
Albuquerque, NM	130	20	150	46
Memphis, TN	130	20	150	46
Salt Lake City, UT	130	20	150	46
Oklahoma City, OK	120	10	130	48
El Paso, TX	60	0	60	49
Corpus Christi, TX	20	0	20	50
Northeastern Avg	2,000	210	2,210	
Midwestern Avg	650	60	710	
Southern Avg	430	40	470	
Southwestern Avg	560	60	620	
Western Avg	1,710	180	1,890	
Texas Avg	620	60	680	
Total Avg	960	100	1,060	
Maximum Value	7,790	830	8,620	
Minimum Value	20	0	20	

Source: TTI Analysis.

Table 12 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 ($1,100 per driver), while Washington, DC had the highest per capita cost ($860 per person). Houston had the highest values of any of the urban areas in Texas in both categories with a per driver cost of $390 and a per capita cost of $680.

Table 13, which illustrates the rankings of urban areas by the roadway congestion index, annual per capita, and per eligible driver costs shows the individual relationships of the "congestion tax" estimates to roadway congestion index. The rankings of the cost estimates are fairly consistent with just 12 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 two urban areas, Chicago and San Diego, are ranked in the top 10 in the RCI but not in either of the unit cost categories.

Table 14 displays the 1993 and 1994 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. Seven urban areas changed their RCI rankings by more than one position. Of these seven, only two moved their overall rankings higher between 1993 and 1994 (Salt Lake City and St. Louis).

Table 12. Estimated Unit Costs of Congestion in 1994

Urban Area	Congestion Cost	
	Per Eligible Driver (dollars)	Per Capita (dollars)
Northeastern Cities		
Baltimore, MD	460	360
Boston, MA	660	550
Hartford, CT	450	340
New York, NY	580	460
Philadelphia, PA	320	250
Pittsburgh, PA	380	310
Washington, DC	1,030	860
Midwestern Cities		
Chicago, IL	500	390
Cincinnati, OH	310	240
Cleveland, OH	260	200
Columbus, OH	320	250
Detroit, MI	820	600
Indianapolis, IN	250	200
Kansas City, MO	230	180
Louisville, KY	280	220
Milwaukee, WI	260	200
Minn-St. Paul, MN	360	290
Oklahoma City, OK	200	150
St. Louis, MO	440	340
Southern Cities		
Atlanta, GA	800	640
Charlotte, NC	380	310
Ft. Lauderdale, FL	380	320
Jacksonville, FL	540	420
Memphis, TN	210	160
Miami, FL	760	600
Nashville, TN	370	300
New Orleans, LA	410	310
Norfolk, VA	440	350
Orlando, FL	350	290
Tampa, FL	400	320
Southwestern Cities		
Albuquerque, NM	350	270
Austin, TX	670	530
Corpus Christi, TX	130	90
Dallas, TX	810	640
Denver, CO	580	470
El Paso, TX	170	120
Fort Worth, TX	630	480
Houston, TX	890	680
Phoenix, AZ	550	420
Salt Lake City, UT	210	160
San Antonio, TX	420	320
Western Cities		
Honolulu, HI	550	470
Los Angeles, CA	920	720
Portland, OR	510	410
Sacramento, CA	430	330
San Bernardino-Riv, CA	1,100	790
San Diego, CA	390	310
San Fran-Oak, CA	960	790
San Jose, CA	750	580
Seattle-Everett, WA	870	740
Northeastern Avg	550	450
Midwestern Avg	350	270
Southern Avg	460	360
Southwestern Avg	490	380
Western Avg	720	570
Texas Avg	530	410
Total Avg	500	390
Maximum Value	1,100	860
Minimum Value	130	90

Source: TTI Analysis.

Table 13. 1994 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	21	22	22
Boston, MA	18	12	13
Hartford, CT	41	24	23
New York, NY	11	17	15
Philadelphia, PA	24	38	38
Pittsburgh, PA	47	30	31
Washington, DC	2	1	2
Midwestern Cities			
Chicago, IL	5	21	21
Cincinnati, OH	24	40	40
Cleveland, OH	27	42	42
Columbus, OH	36	38	38
Detroit, MI	7	9	7
Indianapolis, IN	43	42	44
Kansas City, MO	48	45	45
Louisville, KY	36	41	41
Milwaukee, WI	27	42	42
Minn-St. Paul, MN	26	35	35
Oklahoma City, OK	46	48	48
St. Louis, MO	30	24	24
Southern Cities			
Atlanta, GA	10	7	9
Charlotte, NC	38	30	31
Ft. Lauderdale, FL	29	27	31
Jacksonville, FL	32	18	19
Memphis, TN	38	46	46
Miami, FL	4	9	10
Nashville, TN	35	34	34
New Orleans, LA	14	30	28
Norfolk, VA	41	23	24
Orlando, FL	45	35	36
Tampa, FL	19	27	29
Southwestern Cities			
Albuquerque, NM	30	37	36
Austin, TX	32	13	12
Corpus Christi, TX	50	50	50
Dallas, TX	16	7	8
Denver, CO	19	15	15
El Paso, TX	49	49	49
Fort Worth, TX	32	14	14
Houston, TX	13	6	5
Phoenix, AZ	16	18	17
Salt Lake City, UT	38	46	46
San Antonio, TX	43	27	27
Western Cities			
Honolulu, HI	12	15	17
Los Angeles, CA	1	5	4
Portland, OR	14	20	20
Sacramento, CA	21	26	26
San Bernardino-Riv, CA	9	2	1
San Diego, CA	8	30	30
San Fran-Oak, CA	3	2	3
San Jose, CA	21	11	11
Seattle-Everett, WA	6	4	6

Source: TTI Analysis.

Table 14. Congestion Index and Cost Values, 1993 and 1994

Urban Area	Roadway Congestion Index				Congestion Cost per Capita ($)		Annual Congestion Cost ($ millions)	
	1993 Value	1994 Value	1993 Rank	1994 Rank	1993	1994	1993	1994
Northeastern Cities								
Baltimore, MD	1.04	1.06	22	21	350	360	730	770
Boston, MA	1.07	1.08	17	18	520	550	1,560	1,650
Hartford, CT	0.93	0.93	35	41	330	340	200	210
New York, NY	1.15	1.15	11	11	450	460	7,600	7,900
Philadelphia, PA	1.04	1.05	22	24	250	250	1,320	1,330
Pittsburgh, PA	0.82	0.83	46	47	290	310	560	600
Washington, DC	1.41	1.43	2	2	820	860	2,790	2,960
Midwestern Cities								
Chicago, IL	1.26	1.28	5	5	370	390	2,790	2,990
Cincinnati, OH	1.03	1.05	25	24	220	240	280	300
Cleveland, OH	0.98	1.00	28	27	180	200	320	360
Columbus, OH	0.93	0.95	35	36	250	250	240	250
Detroit, MI	1.23	1.24	6	7	590	600	2,340	2,420
Indianapolis, IN	0.89	0.92	44	43	130	200	130	190
Kansas City, MO	0.78	0.80	48	48	160	180	210	230
Louisville, KY	0.93	0.95	35	36	180	220	140	180
Milwaukee, WI	1.00	1.00	27	27	180	200	220	250
Minn-St. Paul, MN	1.02	1.04	26	26	270	290	570	620
Oklahoma City, OK	0.86	0.85	45	46	150	150	120	130
St. Louis, MO	0.96	0.98	30	30	320	340	640	680
Southern Cities								
Atlanta, GA	1.16	1.18	10	10	590	640	1,360	1,530
Charlotte, NC	0.92	0.94	40	38	310	310	160	170
Ft. Lauderdale, FL	0.98	0.99	28	29	290	320	370	420
Jacksonville, FL	0.96	0.97	30	32	380	420	300	330
Memphis, TN	0.93	0.94	35	38	140	160	120	150
Miami, FL	1.32	1.32	4	4	560	600	1,090	1,160
Nashville, TN	0.93	0.96	35	35	270	300	160	180
New Orleans, LA	1.09	1.11	15	14	270	310	300	340
Norfolk, VA	0.92	0.93	40	41	330	350	320	350
Orlando, FL	0.82	0.86	46	45	250	290	230	270
Tampa, FL	1.06	1.07	20	19	290	320	220	240
Southwestern Cities								
Albuquerque, NM	0.96	0.98	30	30	220	270	120	150
Austin, TX	0.95	0.97	33	32	470	530	270	310
Corpus Christi, TX	0.75	0.76	50	50	80	90	20	30
Dallas, TX	1.07	1.09	17	16	590	640	1,250	1,400
Denver, CO	1.07	1.07	17	19	460	470	750	790
El Paso, TX	0.77	0.78	49	49	120	120	70	70
Fort Worth, TX	0.95	0.97	33	32	440	480	530	590
Houston, TX	1.13	1.12	12	13	660	680	1,920	2,000
Phoenix, AZ	1.08	1.09	16	16	420	420	870	890
Salt Lake City, UT	0.92	0.94	40	38	130	160	110	140
San Antonio, TX	0.91	0.92	43	43	290	320	350	390
Western Cities								
Honolulu, HI	1.13	1.13	12	12	450	470	310	320
Los Angeles, CA	1.54	1.52	1	1	710	720	8,540	8,620
Portland, OR	1.11	1.11	14	14	390	410	420	450
Sacramento, CA	1.04	1.06	22	21	310	330	380	400
San Bernardino-Riv, CA	1.21	1.20	8	9	790	790	1,040	1,070
San Diego, CA	1.21	1.21	8	8	300	310	770	790
San Fran-Oak, CA	1.33	1.33	3	3	780	790	2,980	3,060
San Jose, CA	1.05	1.06	21	21	580	580	880	890
Seattle-Everett, WA	1.23	1.25	6	6	720	740	1,350	1,420

Source: TTI Analysis and Local Transportation Agency References.

CONCLUSIONS

Effects of Congestion

Traffic congestion is a fact of life in most metropolitan areas. It affects both individual travelers and commercial shippers. Commuters consider traffic congestion when they make a decision about where to live. Congestion causes travelers to choose different routes to and from work and shopping. Departure times are adjusted to account for lost time due to heavy traffic conditions. Extra time is often allotted when making a trip to account for the variability in the travel time to reach a destination. All of these factors have a value that ultimately adds to the "price tag" associated with congestion.

Shippers select locations for their warehouses and stores based on several considerations, one of which is accessibility. Traffic congestion also affects inventory decisions. If trucks cannot deliver goods in a reliable fashion, companies may have to retain more inventory than would normally be the case. Companies pass along the costs associated with these decisions to the consumer. So, everyone shares these additional costs; prices reflect the additional cost of moving goods and providing services through and between the cities.

Land use choices also have direct effects on the transportation network. The placement of large suburban activity centers along minor arterial streets designed to carry persons on local trips rather than longer distance commute trips have placed a tremendous strain on much of the suburban roadway networks in many cities. Transit and carpool use in many of these areas is relatively low due to the low density and cheap, available parking.

In addition to population growth, the land area of these urban areas continues to extend further from the traditional city. These increases in population and urban area size continue to have adverse effects on traffic congestion.

Congestion Growth

Table 2 shows that congestion levels have risen an average of more than 22 percent between 1982 and 1994 (just under two percent per year). Many cities have experienced a much greater increase in congestion during this time, including two with greater than three percent per year. Of the 50 cities in the study, only two (Houston and Phoenix) have lower congestion levels in 1994 than in 1982. Table 8 shows the annual hours of delay experienced in traffic by each driver have increased from 19 hours in 1982 to 34 hours in 1994 (79 percent increase). Not one city has seen a decrease in the delay experienced by drivers during this 13 year period.

Despite these increases in congestion, some statistics have shown that travel times to work have remained fairly constant or have dropped slightly in the 1980s and 1990s (5). This is not contradictory to findings of this research study. The shorter work travel times are due to the fact that more homes and jobs are located in the suburbs. This shift in the location of both employees and jobs creates more suburb-to-suburb trips. While these suburban roadways are relatively uncongested in the beginning of the development cycle, they become increasingly congested as the area is more successful in attracting business. More of these "edge cities" are reaching this point in the development cycle.

Figure 4 illustrates the relationship between congestion level (represented by roadway congestion index values) and population. The populations have been divided into four categories: less than 0.9 million, 0.9 million to 1.7 million, 1.7 million to 2.5 million, and greater than 2.5 million. Figure 5 shows the congestion levels generally associated with these four population ranges. A city with a population of about 1.5 million persons would expect to have a congestion level of less than 1.25, well beyond the undesirable congestion threshold of 1.0. In general, as the population of an area increases, congestion levels in the area grow also.

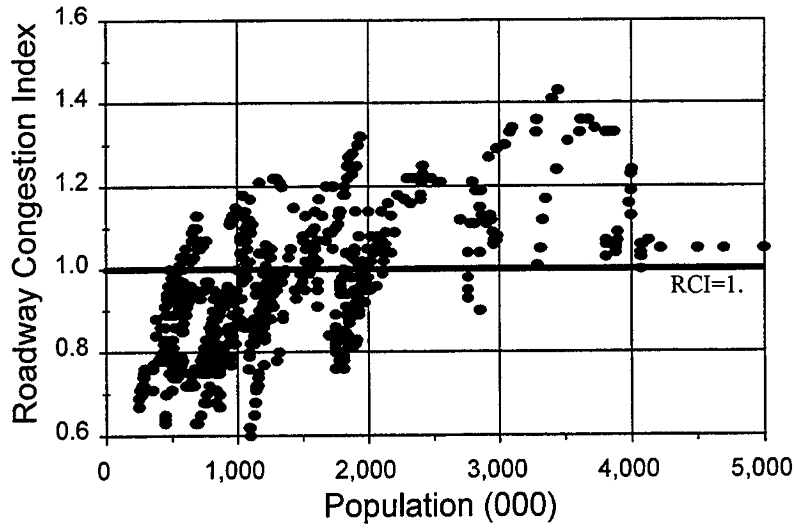

Figure 4. Population and Congestion Level from 1982 to 1994

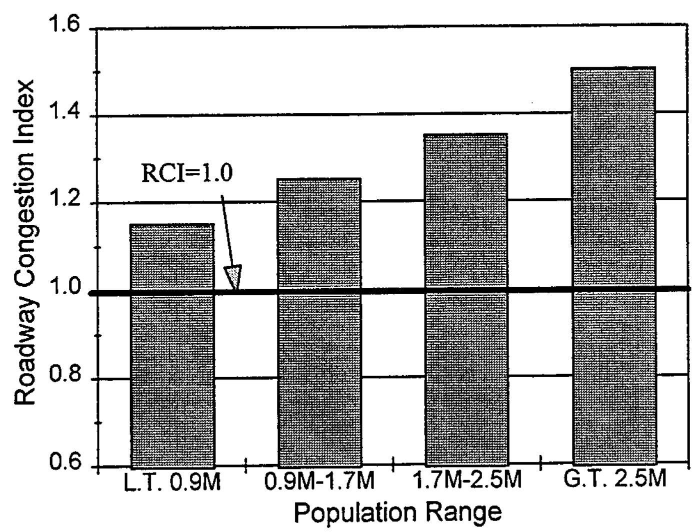

Figure 5. Population Ranges and Congestion Level

Figure 6 shows the relationship that exists between congestion level and population density. The relationship illustrates that the more dense urban areas have higher congestion levels. This graph is simplistic in nature and does not account for many factors that are highly correlated with population density. One such factor is the development age of the each urban area. Many of the northeastern cities were developed long before cities began to rely on the automobile and roadway networks to move people and goods. Some of these urban areas have been able to implement effective transit services, thus helping to keep their congestion levels slightly lower than in some of the more recently developed cities. Another factor is the actual size of the urban area. Some of the areas in the study are very large and require a significant roadway system to handle the mobility needs of the area. In these larger areas, it would be very difficult to handle the urban mobility with transit as the sole means of transportation because of the very large amount of surface area that the transit would have to serve. Because of reasons such as these, little emphasis is placed on the density of urban areas as a predictor of congestion level.

Congestion Solutions

In the past, solutions to congestion involved massive amounts of funding that were put into large-scale construction projects. Adding new roadways and widening older ones was seen as the way to solve the problem. In most cities, this new roadway capacity was quickly filled with additional traffic, and the old problems of congestion returned.

"Edge cities" developed and continue to develop around many of the large metropolitan areas. As these cities grew and attracted more persons and businesses, the problem of traffic congestion would follow. The solutions to these congestion problems became increasingly difficult with limited transit availability as compared to other activity centers in the metropolitan areas. Cheap and available parking in these areas was usually expected and added to the use of personal automobiles to make work commutes.

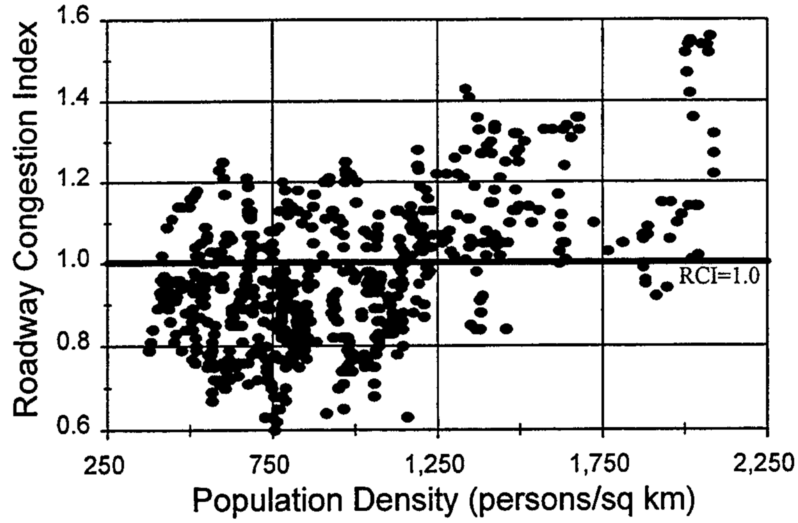

Figure 6. Population Density and Congestion Level from 1982 to 1994

Other trends have had an effect on traffic congestion. These include economic depression and population loss. In the past, when a city experienced economic depression, fewer trips were made on the roadways and traffic congestion reductions were observed. Many times economic depression resulted in a decline in population as persons moved to other cities to find jobs. This caused congestion to increase slowly or even to decrease slightly. Obviously, most business leaders do not consider a recession as an acceptable cure to congestion problems.

Investments to relieve congested roadways are taking some new forms. There will continue to be expenditures to add capacity to either existing roadways or in the construction of new facilities. There are also many projects and programs aimed at managing the existing system better. This is being done with operational improvements, such as intelligent transportation systems, traffic signal coordination, incident detection and response, transportation system management, and many others. In addition to managing the roadway network, more emphasis is being placed on the transit systems to provide commuters with options other than private vehicles for their daily commute. Efforts are also underway with travel demand management projects to attempt to modify driver travel patterns by changing departure times or reducing trip frequency during the most congested travel time. These projects all attempt to relieve congestion by utilizing the existing roadway network and land use patterns.

Another option is an attempt to change land use patterns in ways that will allow for vehicle use reductions. Some of these efforts will be to create more dense or compact development patterns and to infill existing urban land currently unused or underutilized by mixing jobs, shops, and homes. In these efforts to redevelop existing urban lands, there are efforts to make street patterns more conducive to transit, walking, and bicycle use. This will allow for easier and more effective transit service and bring persons closer to their jobs, thus reducing the need for automobiles to reach their work destination.

Many of these policy and program choices reflect an acceptance of congestion. For some combination of funding, public support, environmental, and quality of neighborhood reasons many cities are selecting ways to address or manage rather than eliminate congestion. The broad spectrum of actions, many of which are not directly reflected in the data reported here, and the different congestion goals of urbanized areas should be considered when analyzing the results of this study.

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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-four 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 12 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 (affected by the California cities) and Northeastern regions, has daily VKT per lane-kilometer values below the 13,000 level.

Table A-1. 1994 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	181,930	8,900	8.20	20,430	1
Washington, DC	49,310	2,700	5.40	18,230	2
San Fran-Oak, CA	68,960	3,940	6.80	17,480	3
Seattle-Everett, WA	34,290	2,090	6.00	16,380	4
Chicago, IL	67,820	4,160	5.70	16,300	5
Detroit, MI	47,660	2,950	6.00	16,130	6
San Bernardino-Riv, CA	24,960	1,550	7.20	16,060	7
Miami, FL	17,030	1,070	5.50	15,900	8
San Diego, CA	44,800	2,820	7.60	15,900	8
Atlanta, GA	53,130	3,460	6.40	15,350	10
Houston, TX	53,070	3,620	6.40	14,650	11
Boston, MA	35,020	2,450	5.90	14,310	12
Dallas, TX	41,380	2,930	6.00	14,120	13
Honolulu, HI	9,020	640	5.30	14,000	14
New York, NY	141,800	10,150	5.70	13,970	15
Phoenix, AZ	16,740	1,210	5.80	13,870	16
Portland, OR	13,910	1,010	5.20	13,820	17
San Jose, CA	27,170	1,980	6.70	13,720	18
Cincinnati, OH	21,690	1,590	5.70	13,680	19
Baltimore, MD	30,270	2,230	5.50	13,570	20
Denver, CO	21,690	1,610	5.30	13,480	21
Minn-St. Paul, MN	33,330	2,500	5.00	13,350	22
New Orleans, LA	8,870	670	5.80	13,280	23
Sacramento, CA	17,110	1,310	7.00	13,040	24
Milwaukee, WI	12,560	970	5.60	12,890	25
Tampa, FL	7,250	560	5.00	12,860	26
Cleveland, OH	24,810	1,930	4.90	12,840	27
Ft. Lauderdale, FL	14,970	1,170	5.50	12,830	28
Jacksonville, FL	10,500	840	4.80	12,540	29
Fort Worth, TX	22,280	1,810	5.90	12,300	30
Austin, TX	10,590	870	5.60	12,180	31
Columbus, OH	16,380	1,350	5.90	12,110	32
Philadelphia, PA	33,680	2,790	5.10	12,090	33
St. Louis, MO	33,170	2,790	5.70	11,870	34
Salt Lake City, UT	10,350	880	5.70	11,800	35
Louisville, KY	12,240	1,040	4.60	11,780	36
Albuquerque, NM	4,700	400	5.10	11,680	37
San Antonio, TX	18,560	1,590	5.40	11,640	38
Charlotte, NC	6,170	530	4.30	11,610	39
Indianapolis, IN	15,300	1,320	5.50	11,590	40
Nashville, TN	12,480	1,080	4.90	11,570	41
Hartford, CT	11,370	990	5.60	11,490	42
Memphis, TN	8,690	760	5.40	11,490	42
Norfolk, VA	9,780	930	4.70	10,470	44
Oklahoma City, OK	12,480	1,190	5.20	10,470	44
Orlando, FL	10,830	1,050	5.00	10,350	46
El Paso, TX	6,150	600	5.30	10,190	47
Kansas City, MO	25,160	2,520	4.60	9,990	48
Corpus Christi, TX	3,470	370	5.50	9,370	49
Pittsburgh, PA	15,170	1,880	4.30	8,050	50
Northeastern Avg	45,230	3,310	5.36	13,100	
Midwestern Avg	26,880	2,030	5.37	12,750	
Southern Avg	14,520	1,100	5.21	12,570	
Southwestern Avg	19,000	1,450	5.64	12,300	
Western Avg	46,910	2,690	6.67	15,650	
Texas Avg	22,210	1,690	5.73	12,060	
Total Avg	28,600	2,000	5.62	13,180	
Maximum Value	181,930	10,150	8.20	20,430	
Minimum Value	3,470	370	4.30	8,050	

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 1994, 45 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 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 1993 levels in the Northeastern, Southern, and Southwestern regions. The regional average travel demands showed smaller decreases in the Midwestern and Western regions (less than 1 percent).

Travel Delay

Tables A-3 and A-4 show the recurring and incident hours of delay by congestion level. These two tables give a more detailed look at the delay previously shown in Table 6. These two tables show the types and severity of delay and facility on which it occurs. 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. 1994 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]
Washington, DC	29,790	3,830	4.00	7,770	1
Honolulu, HI	3,120	410	3.80	7,610	2
Miami, FL	27,610	3,780	4.60	7,310	3
New York, NY	89,680	12,480	3.40	7,190	4
Chicago, IL	59,570	8,650	3.90	6,880	5
New Orleans, LA	8,090	1,190	4.20	6,790	6
Portland, OR	7,570	1,130	3.50	6,710	7
Philadelphia, PA	35,420	5,310	3.30	6,670	8
Los Angeles, CA	134,270	20,210	4.10	6,650	9
Norfolk, VA	8,170	1,240	3.50	6,590	10
St. Louis, MO	20,490	3,220	3.60	6,360	11
Tampa, FL	8,080	1,290	3.80	6,280	12
Pittsburgh, PA	18,930	3,020	3.20	6,270	13
Sacramento, CA	12,800	2,040	4.20	6,260	14
San Fran-Oak, CA	23,670	3,800	4.00	6,230	15
Detroit, MI	43,500	7,120	4.50	6,110	16
Nashville, TN	9,500	1,570	3.50	6,050	17
Atlanta, GA	20,530	3,410	3.80	6,010	18
Denver, CO	18,110	3,040	3.90	5,950	19
Seattle-Everett, WA	15,900	2,680	3.50	5,930	20
Baltimore, MD	16,180	2,780	4.10	5,830	21
Louisville, KY	5,880	1,010	3.70	5,790	22
Minn-St. Paul, MN	11,500	2,000	3.50	5,760	23
Salt Lake City, UT	4,590	800	4.00	5,760	23
Hartford, CT	6,150	1,080	3.80	5,700	25
Austin, TX	4,700	830	4.20	5,670	26
Albuquerque, NM	7,680	1,370	4.00	5,610	27
Phoenix, AZ	29,980	5,390	4.30	5,560	28
Columbus, OH	5,800	1,050	3.50	5,540	29
San Diego, CA	15,780	2,860	3.50	5,520	30
Charlotte, NC	5,300	970	3.30	5,480	31
Dallas, TX	16,950	3,090	4.90	5,480	31
Fort Worth, TX	9,050	1,670	4.20	5,430	33
Cleveland, OH	10,100	1,880	3.00	5,390	34
Memphis, TN	9,290	1,720	4.60	5,390	34
San Antonio, TX	9,760	1,830	3.60	5,340	36
Oklahoma City, OK	7,490	1,410	3.40	5,310	37
Cincinnati, OH	7,120	1,340	3.50	5,300	38
San Jose, CA	11,710	2,220	4.20	5,270	39
Indianapolis, IN	8,450	1,610	3.80	5,250	40
Orlando, FL	10,140	1,930	3.80	5,250	40
San Bernardino-Riv, CA	17,950	3,420	4.20	5,250	40
Houston, TX	18,900	3,620	4.50	5,220	43
Milwaukee, WI	9,820	1,900	3.40	5,170	44
Ft. Lauderdale, FL	10,380	2,030	4.50	5,120	45
Kansas City, MO	9,050	1,820	3.60	4,970	46
Boston, MA	22,940	4,690	2.50	4,900	47
Jacksonville, FL	10,550	2,170	3.90	4,850	48
Corpus Christi, TX	2,750	610	4.10	4,500	49
El Paso, TX	5,470	1,410	4.30	3,890	50
Northeastern Avg	31,300	4,740	3.47	6,330	
Midwestern Avg	16,560	2,750	3.62	5,650	
Southern Avg	11,600	1,940	3.95	5,920	
Southwestern Avg	11,630	2,150	4.18	5,310	
Western Avg	26,970	4,310	3.89	6,160	
Texas Avg	9,660	1,870	4.26	5,080	
Total Avg	18,320	3,000	3.84	5,820	
Maximum Value	134,270	20,210	4.90	7,770	
Minimum Value	2,750	410	2.50	3,890	

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 1994

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	5,390	9,930	21,460	36,780	12,410	22,840	49,350	84,600
Boston, MA	9,360	7,340	49,400	66,100	32,770	25,700	172,910	231,380
Hartford, CT	1,710	3,640	3,340	8,690	4,610	9,840	9,020	23,470
New York, NY	77,570	117,960	123,700	319,230	193,920	294,910	309,250	798,080
Philadelphia, PA	8,940	9,080	13,240	31,260	18,780	19,070	27,800	65,650
Pittsburgh, PA	1,960	4,470	5,470	11,900	5,680	12,980	15,870	34,530
Washington, DC	15,970	29,110	100,030	145,110	35,130	64,040	220,070	319,240
Midwestern Cities								
Chicago, IL	15,150	26,170	134,320	175,640	18,180	31,410	161,190	210,780
Cincinnati, OH	6,880	11,990	9,310	28,180	5,500	9,590	7,450	22,540
Cleveland, OH	8,370	9,770	14,640	32,780	5,860	6,840	10,250	22,950
Columbus, OH	1,720	4,690	14,520	20,930	1,210	3,290	10,170	14,670
Detroit, MI	16,510	7,070	75,720	99,300	36,310	15,550	166,580	218,440
Indianapolis, IN	5,030	3,040	2,040	10,110	7,550	4,560	3,060	15,170
Kansas City, MO	3,600	1,830	3,440	8,870	11,150	5,680	10,680	27,510
Louisville, KY	1,260	1,370	4,820	7,450	1,390	1,510	5,310	8,210
Milwaukee, WI	3,460	4,110	6,820	14,390	3,460	4,110	6,820	14,390
Minn-St. Paul, MN	10,120	8,900	26,790	45,810	9,110	8,010	24,110	41,230
Oklahoma City, OK	2,000	1,930	90	4,020	2,190	2,120	100	4,410
St. Louis, MO	6,150	11,940	13,940	32,030	7,380	14,330	16,730	38,440
Southern Cities								
Atlanta, GA	6,470	33,970	72,840	113,280	7,120	37,360	80,130	124,610
Charlotte, NC	3,000	2,500	1,950	7,450	2,400	2,000	1,560	5,960
Ft. Lauderdale, FL	4,430	11,530	6,520	22,480	6,640	17,300	9,790	33,730
Jacksonville, FL	3,560	7,080	2,540	13,180	5,340	10,610	3,810	19,760
Memphis, TN	2,080	3,040	910	6,030	2,290	3,340	1,000	6,630
Miami, FL	4,560	6,890	32,030	43,480	6,840	10,330	48,040	65,210
Nashville, TN	3,160	2,600	3,170	8,930	3,470	2,850	3,480	9,800
New Orleans, LA	1,530	11,720	3,950	17,200	2,750	21,090	7,110	30,950
Norfolk, VA	3,210	7,530	3,710	14,450	8,030	18,830	9,260	36,120
Orlando, FL	3,860	2,410	8,310	14,580	5,790	3,610	12,460	21,860
Tampa, FL	410	750	5,230	6,390	610	1,130	7,840	9,580
Southwestern Cities								
Albuquerque, NM	970	1,620	2,460	5,050	1,070	1,780	2,710	5,560
Austin, TX	3,690	8,660	13,050	25,400	4,060	9,530	14,360	27,950
Corpus Christi, TX	840	210	740	1,790	930	230	820	1,980
Dallas, TX	13,020	31,820	46,130	90,970	23,440	57,270	83,030	163,740
Denver, CO	5,160	14,020	30,350	49,530	5,160	14,020	30,350	49,530
El Paso, TX	1,620	2,640	1,250	5,510	1,780	2,900	1,370	6,050
Fort Worth, TX	5,740	14,020	20,320	40,080	10,330	25,230	36,580	72,140
Houston, TX	15,660	43,210	95,700	154,570	21,930	60,490	133,980	216,400
Phoenix, AZ	7,930	8,760	27,060	43,750	3,170	3,500	10,820	17,490
Salt Lake City, UT	2,190	3,560	6,530	12,280	1,320	2,140	3,920	7,380
San Antonio, TX	2,700	9,230	19,120	31,050	2,970	10,160	21,030	34,160
Western Cities								
Honolulu, HI	2,440	4,690	11,360	18,490	4,400	8,440	20,440	33,280
Los Angeles, CA	26,900	56,760	529,880	613,540	32,280	68,110	635,850	736,240
Portland, OR	3,960	5,380	12,890	22,230	7,920	10,760	25,770	44,450
Sacramento, CA	5,410	11,370	5,020	21,800	3,250	6,820	3,010	13,080
San Bernardino-Riv, CA	6,410	16,480	51,370	74,260	7,690	19,780	61,650	89,120
San Diego, CA	25,630	23,720	32,570	81,920	15,380	14,230	19,540	49,150
San Fran-Oak, CA	21,750	47,170	165,910	234,830	28,280	61,320	215,690	305,290
San Jose, CA	7,990	15,510	44,310	67,810	9,590	18,610	53,180	81,380
Seattle-Everett, WA	5,980	28,010	68,890	102,880	8,370	39,220	96,450	144,040
Northeastern Avg	17,270	25,940	45,240	88,450	43,330	64,200	114,900	222,430
Midwestern Avg	6,690	7,730	25,540	39,960	9,110	8,910	35,200	53,220
Southern Avg	3,300	8,180	12,830	24,310	4,660	11,680	16,770	33,110
Southwestern Avg	5,410	12,520	23,880	41,810	6,920	17,020	30,820	54,760
Western Avg	11,830	23,230	102,470	137,530	13,020	27,480	125,730	166,230
Texas Avg	6,180	15,680	28,050	49,910	9,350	23,690	41,600	74,640
Total Avg	8,070	14,220	38,980	61,270	13,140	22,390	57,630	93,160
Maximum Value	77,570	117,960	529,880	725,410	193,920	294,910	635,850	1,124,680
Minimum Value	410	210	90	710	610	230	100	940

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 1994

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	2,860	2,700	17,230	22,790	3,150	2,970	18,950	25,070
Boston, MA	4,240	6,520	20,600	31,360	4,660	7,170	22,660	34,490
Hartford, CT	1,490	2,300	2,790	6,580	1,640	2,530	3,070	7,240
New York, NY	12,580	32,100	246,910	291,590	13,830	35,310	271,610	320,750
Philadelphia, PA	6,420	20,320	70,050	96,790	7,060	22,350	77,050	106,460
Pittsburgh, PA	6,650	4,630	30,880	42,160	7,310	5,090	33,960	46,360
Washington, DC	9,900	14,810	64,670	89,380	10,890	16,290	71,130	98,310
Midwestern Cities								
Chicago, IL	16,730	37,710	76,210	130,650	18,410	41,480	83,840	143,730
Cincinnati, OH	1,530	1,700	3,430	6,660	1,680	1,870	3,770	7,320
Cleveland, OH	2,230	4,750	3,810	10,790	2,450	5,230	4,190	11,870
Columbus, OH	1,510	2,510	5,570	9,590	1,660	2,760	6,130	10,550
Detroit, MI	5,890	13,270	87,280	106,440	6,480	14,600	96,010	117,090
Indianapolis, IN	1,680	3,200	2,810	7,690	1,850	3,520	3,100	8,470
Kansas City, MO	1,560	1,930	3,580	7,070	1,720	2,120	3,930	7,770
Louisville, KY	1,290	3,580	7,250	12,120	1,420	3,940	7,970	13,330
Milwaukee, WI	990	3,600	7,470	12,060	1,090	3,960	8,220	13,270
Minn-St. Paul, MN	2,040	2,300	18,860	23,200	2,240	2,530	20,750	25,520
Oklahoma City, OK	1,480	3,010	5,380	9,870	1,630	3,310	5,910	10,850
St. Louis, MO	8,890	9,720	19,580	38,190	9,770	10,690	21,540	42,000
Southern Cities								
Atlanta, GA	4,170	7,850	36,230	48,250	4,580	8,630	39,850	53,060
Charlotte, NC	1,170	2,690	7,210	11,070	1,280	2,960	7,930	12,170
Ft. Lauderdale, FL	3,040	4,120	9,750	16,910	3,340	4,530	10,720	18,590
Jacksonville, FL	3,530	5,180	9,860	18,570	3,880	5,700	10,850	20,430
Memphis, TN	2,880	2,730	3,860	9,470	3,170	3,000	4,250	10,420
Miami, FL	4,940	9,380	57,340	71,660	5,430	10,320	63,080	78,830
Nashville, TN	2,080	4,480	3,590	10,150	2,290	4,930	3,950	11,170
New Orleans, LA	2,570	3,150	7,240	12,960	2,830	3,460	7,970	14,260
Norfolk, VA	960	2,630	8,770	12,360	1,060	2,890	9,640	13,590
Orlando, FL	690	1,810	8,780	11,280	760	1,990	9,650	12,400
Tampa, FL	1,800	3,800	13,030	18,630	1,980	4,180	14,330	20,490
Southwestern Cities								
Albuquerque, NM	2,230	5,470	2,570	10,270	2,450	6,010	2,820	11,280
Austin, TX	1,660	2,630	2,840	7,130	1,820	2,890	3,130	7,840
Corpus Christi, TX	490	370	210	1,070	540	400	230	1,170
Dallas, TX	5,230	6,230	12,490	23,950	5,750	6,850	13,740	26,340
Denver, CO	4,460	4,160	26,390	35,010	4,910	4,580	29,030	38,520
El Paso, TX	390	300	1,050	1,740	430	330	1,160	1,920
Fort Worth, TX	2,790	2,590	2,570	7,950	3,070	2,840	2,830	8,740
Houston, TX	3,620	13,490	14,080	31,190	3,980	14,840	15,490	34,310
Phoenix, AZ	13,730	25,700	24,770	64,200	15,100	28,270	27,240	70,610
Salt Lake City, UT	2,130	1,940	1,540	5,610	2,350	2,140	1,700	6,190
San Antonio, TX	1,900	2,340	5,100	9,340	2,090	2,570	5,610	10,270
Western Cities								
Honolulu, HI	1,240	750	6,090	8,080	1,370	830	6,700	8,900
Los Angeles, CA	26,260	63,380	168,220	257,860	28,880	69,720	185,040	283,640
Portland, OR	1,550	6,610	6,970	15,130	1,710	7,270	7,670	16,650
Sacramento, CA	2,420	4,500	18,210	25,130	2,660	4,950	20,040	27,650
San Bernardino-Riv, CA	8,150	9,450	15,200	32,800	8,960	10,400	16,720	36,080
San Diego, CA	1,640	10,300	6,130	18,070	1,800	11,320	6,740	19,860
San Fran-Oak, CA	2,960	6,430	49,010	58,400	3,260	7,070	53,910	64,240
San Jose, CA	3,750	4,470	12,970	21,190	4,120	4,920	14,270	23,310
Seattle-Everett, WA	3,620	7,560	18,760	29,940	3,990	8,320	20,640	32,950
Northeastern Avg	6,300	11,910	64,730	82,940	6,930	13,100	71,200	91,230
Midwestern Avg	3,820	7,270	20,100	31,190	4,200	8,000	22,110	34,310
Southern Avg	2,530	4,350	15,060	21,940	2,780	4,780	16,570	24,130
Southwestern Avg	3,510	5,930	8,510	17,950	3,860	6,520	9,360	19,740
Western Avg	5,730	12,610	33,510	51,850	6,300	13,870	36,860	57,030
Texas Avg	2,300	3,990	5,480	11,770	2,530	4,390	6,030	12,950
Total Avg	4,160	7,940	25,100	37,200	4,580	8,740	27,610	40,930
Maximum Value	26,260	63,380	246,910	336,550	28,880	69,720	271,610	370,210
Minimum Value	390	300	210	900	430	330	230	990

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—$11.00 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. Using a toll facility, making 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 that 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—$1.46 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 1994 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. Table B-2 illustrates these variables.

Table B-2. 1994 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	30,270	16,180	0.32	2,130	1,680
Boston, MA	35,020	22,940	0.31	2,990	2,490
Hartford, CT	11,370	6,150	0.35	630	470
New York, NY	141,800	89,680	0.33	17,010	13,590
Philadelphia, PA	33,680	35,420	0.31	5,250	4,160
Pittsburgh, PA	15,170	18,930	0.31	1,910	1,580
Washington, DC	49,310	29,790	0.32	3,450	2,880
Midwestern Cities					
Chicago, IL	67,820	59,570	0.32	7,700	5,970
Cincinnati, OH	21,690	7,120	0.31	1,260	970
Cleveland, OH	24,810	10,100	0.31	1,810	1,380
Columbus, OH	16,380	5,800	0.31	1,000	790
Detroit, MI	47,660	43,500	0.29	4,010	2,950
Indianapolis, IN	15,300	8,450	0.29	970	750
Kansas City, MO	25,160	9,050	0.28	1,320	1,030
Louisville, KY	12,240	5,880	0.29	830	660
Milwaukee, WI	12,560	9,820	0.31	1,240	930
Minn-St. Paul, MN	33,330	11,500	0.31	2,180	1,730
Oklahoma City, OK	12,480	7,490	0.28	850	660
St. Louis, MO	33,170	20,490	0.28	2,000	1,550
Southern Cities					
Atlanta, GA	53,130	20,530	0.28	2,400	1,900
Charlotte, NC	6,170	5,300	0.30	540	430
Ft. Lauderdale, FL	14,970	10,380	0.32	1,320	1,100
Jacksonville, FL	10,500	10,550	0.32	790	610
Memphis, TN	8,690	9,290	0.30	910	690
Miami, FL	17,030	27,610	0.32	1,940	1,530
Nashville, TN	12,480	9,500	0.30	620	490
New Orleans, LA	8,870	8,090	0.31	1,110	840
Norfolk, VA	9,780	8,170	0.30	990	790
Orlando, FL	10,830	10,140	0.32	950	780
Tampa, FL	7,250	8,080	0.32	760	610
Southwestern Cities					
Albuquerque, NM	4,700	7,680	0.33	540	420
Austin, TX	10,590	4,700	0.30	590	470
Corpus Christi, TX	3,470	2,750	0.30	300	220
Dallas, TX	41,380	16,950	0.30	2,200	1,720
Denver, CO	21,690	18,110	0.33	1,680	1,350
El Paso, TX	6,150	5,470	0.30	580	420
Fort Worth, TX	22,280	9,050	0.30	1,240	940
Houston, TX	53,070	18,900	0.30	2,940	2,250
Phoenix, AZ	16,740	29,980	0.34	2,130	1,620
Salt Lake City, UT	10,350	4,590	0.31	880	680
San Antonio, TX	18,560	9,760	0.30	1,210	910
Western Cities					
Honolulu, HI	9,020	3,120	0.43	700	590
Los Angeles, CA	181,930	134,270	0.34	12,000	9,350
Portland, OR	13,910	7,570	0.35	1,100	880
Sacramento, CA	17,110	12,800	0.34	1,220	930
San Bernardino-Riv, CA	24,960	17,950	0.34	1,340	970
San Diego, CA	44,800	15,780	0.34	2,550	2,030
San Fran-Oak, CA	68,960	23,670	0.34	3,870	3,170
San Jose, CA	27,170	11,710	0.34	1,540	1,190
Seattle-Everett, WA	34,290	15,900	0.33	1,910	1,630
Northeastern Avg	45,230	31,300	0.32	4,770	3,840
Midwestern Avg	26,880	16,560	0.30	2,100	1,610
Southern Avg	14,520	11,600	0.31	1,120	890
Southwestern Avg	19,000	11,630	0.31	1,300	1,000
Western Avg	46,910	26,970	0.35	2,910	2,300
Texas Avg	22,210	9,660	0.30	1,290	990
Total Avg	28,600	18,320	0.31	2,230	1,750
Maximum Value	181,930	134,270	0.43	17,010	13,590
Minimum Value	3,470	2,750	0.28	300	220

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 1994 data published by the American Automobile Association (AAA) (13). These data represent the average reported fuel cost for 1994. 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 1994 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 were 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. The ADT per lane values shown in Table B-1 define congested conditions for these facilities.

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. 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). The peak facility conditions during normal operations cause recurring delay. 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. Table B-4 shows the result of these calculations.

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. 1994 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	30,270	16,180	30	40	4,090	2,910	7,000
Boston, MA	35,020	22,940	45	40	7,090	4,130	11,220
Hartford, CT	11,370	6,150	20	35	1,020	970	1,990
New York, NY	141,800	89,680	60	85	38,290	34,300	72,590
Philadelphia, PA	33,680	35,420	25	75	3,790	11,950	15,740
Pittsburgh, PA	15,170	18,930	20	65	1,360	5,540	6,900
Washington, DC	49,310	29,790	70	85	15,530	11,390	26,920
Midwestern Cities							
Chicago, IL	67,820	59,570	60	65	18,310	17,420	35,740
Cincinnati, OH	21,690	7,120	35	30	3,420	960	4,380
Cleveland, OH	24,810	10,100	35	35	3,910	1,590	5,500
Columbus, OH	16,380	5,800	30	50	2,210	1,300	3,520
Detroit, MI	47,660	43,500	50	65	10,720	12,720	23,450
Indianapolis, IN	15,300	8,450	20	30	1,380	1,140	2,520
Kansas City, MO	25,160	9,050	10	25	1,130	1,020	2,150
Louisville, KY	12,240	5,880	15	60	830	1,590	2,410
Milwaukee, WI	12,560	9,820	30	35	1,700	1,550	3,240
Minn-St. Paul, MN	33,330	11,500	35	55	5,250	2,850	8,090
Oklahoma City, OK	12,480	7,490	10	40	560	1,350	1,910
St. Louis, MO	33,170	20,490	25	60	3,730	5,530	9,260
Southern Cities							
Atlanta, GA	53,130	20,530	50	65	11,950	6,000	17,960
Charlotte, NC	6,170	5,300	35	60	970	1,430	2,400
Ft. Lauderdale, FL	14,970	10,380	40	50	2,700	2,340	5,030
Jacksonville, FL	10,500	10,550	35	55	1,650	2,610	4,260
Memphis, TN	8,690	9,290	20	35	780	1,460	2,250
Miami, FL	17,030	27,610	60	70	4,600	8,700	13,290
Nashville, TN	12,480	9,500	20	35	1,120	1,500	2,620
New Orleans, LA	8,870	8,090	50	50	2,000	1,820	3,820
Norfolk, VA	9,780	8,170	40	40	1,760	1,470	3,230
Orlando, FL	10,830	10,140	35	30	1,710	1,370	3,070
Tampa, FL	7,250	8,080	20	65	650	2,360	3,020
Southwestern Cities							
Albuquerque, NM	4,700	7,680	25	45	530	1,560	2,080
Austin, TX	10,590	4,700	60	50	2,860	1,060	3,920
Corpus Christi, TX	3,470	2,750	15	15	230	190	420
Dallas, TX	41,380	16,950	55	45	10,240	3,430	13,670
Denver, CO	21,690	18,110	55	55	5,370	4,480	9,850
El Paso, TX	6,150	5,470	25	10	690	250	940
Fort Worth, TX	22,280	9,050	45	35	4,510	1,430	5,940
Houston, TX	53,070	18,900	70	50	16,720	4,250	20,970
Phoenix, AZ	16,740	29,980	65	70	4,900	9,440	14,340
Salt Lake City, UT	10,350	4,590	30	45	1,400	930	2,330
San Antonio, TX	18,560	9,760	40	30	3,340	1,320	4,660
Western Cities							
Honolulu, HI	9,020	3,120	50	75	2,030	1,050	3,080
Los Angeles, CA	181,930	134,270	75	55	61,400	33,230	94,630
Portland, OR	13,910	7,570	40	60	2,500	2,040	4,550
Sacramento, CA	17,110	12,800	35	55	2,700	3,170	5,860
San Bernardino-Riv, CA	24,960	17,950	70	60	7,860	4,850	12,710
San Diego, CA	44,800	15,780	50	35	10,080	2,490	12,560
San Fran-Oak, CA	68,960	23,670	80	65	24,830	6,920	31,750
San Jose, CA	27,170	11,710	60	55	7,340	2,900	10,230
Seattle-Everett, WA	34,290	15,900	70	55	10,800	3,930	14,740
Northeastern Avg	45,230	31,300	39	61	10,170	10,170	20,340
Midwestern Avg	26,880	16,560	30	46	4,430	4,090	8,510
Southern Avg	14,520	11,600	37	50	2,720	2,820	5,540
Southwestern Avg	19,000	11,630	44	41	4,620	2,580	7,190
Western Avg	46,910	26,970	59	57	14,390	6,730	21,120
Texas Avg	22,210	9,660	44	34	5,510	1,700	7,220
Total Avg	28,600	18,320	41	50	6,690	4,800	11,490
Maximum Value	181,930	134,270	80	85	61,400	34,300	94,630
Minimum Value	3,470	2,750	10	10	230	190	420

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 1994

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	4,090	2,910	7,000	2.30	1.10	36,790	22,790	59,580	84,610	25,070	109,680
Boston, MA	7,090	4,130	11,220	3.50	1.10	66,110	31,360	97,460	231,380	34,490	265,870
Hartford, CT	1,020	970	1,990	2.70	1.10	8,690	6,590	15,280	23,470	7,240	30,710
New York, NY	38,290	34,300	72,590	2.50	1.10	319,230	291,590	610,820	798,080	320,750	1118,820
Philadelphia, PA	3,790	11,950	15,740	2.10	1.10	31,260	96,790	128,050	65,660	106,470	172,120
Pittsburgh, PA	1,360	5,540	6,900	2.90	1.10	11,910	42,150	54,060	34,530	46,370	80,900
Washington, DC	15,530	11,390	26,920	2.20	1.10	145,110	89,370	234,490	319,250	98,310	417,560
Midwestern Cities											
Chicago, IL	18,310	17,420	35,740	1.20	1.10	175,650	130,660	306,300	210,780	143,720	354,500
Cincinnati, OH	3,420	960	4,380	0.80	1.10	28,180	6,660	34,840	22,550	7,320	29,870
Cleveland, OH	3,910	1,590	5,500	0.70	1.10	32,770	10,790	43,560	22,940	11,870	34,810
Columbus, OH	2,210	1,300	3,520	0.70	1.10	20,940	9,590	30,530	14,660	10,550	25,200
Detroit, MI	10,720	12,720	23,450	2.20	1.10	99,290	106,430	205,730	218,440	117,080	335,520
Indianapolis, IN	1,380	1,140	2,520	1.50	1.10	10,120	7,700	17,820	15,170	8,470	23,650
Kansas City, MO	1,130	1,020	2,150	3.10	1.10	8,870	7,070	15,940	27,500	7,770	35,280
Louisville, KY	830	1,590	2,410	1.10	1.10	7,460	12,120	19,570	8,200	13,330	21,530
Milwaukee, WI	1,700	1,550	3,240	1.00	1.10	14,380	12,070	26,450	14,380	13,280	27,650
Minn-St. Paul, MN	5,250	2,850	8,090	0.90	1.10	45,810	23,200	69,010	41,230	25,520	66,740
Oklahoma City, OK	560	1,350	1,910	1.10	1.10	4,010	9,870	13,880	4,410	10,860	15,270
St. Louis, MO	3,730	5,530	9,260	1.20	1.10	32,040	38,180	70,220	38,440	42,000	80,450
Southern Cities											
Atlanta, GA	11,950	6,000	17,960	1.10	1.10	113,280	48,240	161,530	124,610	53,070	177,680
Charlotte, NC	970	1,430	2,400	0.80	1.10	7,460	11,070	18,520	5,960	12,170	18,140
Ft. Lauderdale, FL	2,700	2,340	5,030	1.50	1.10	22,480	16,910	39,390	33,730	18,600	52,330
Jacksonville, FL	1,650	2,610	4,260	1.50	1.10	13,180	18,580	31,750	19,760	20,430	40,200
Memphis, TN	780	1,460	2,250	1.10	1.10	6,030	9,470	15,500	6,630	10,420	17,050
Miami, FL	4,600	8,700	13,290	1.50	1.10	43,470	71,660	115,130	65,210	78,830	144,030
Nashville, TN	1,120	1,500	2,620	1.10	1.10	8,920	10,160	19,070	9,810	11,170	20,980
New Orleans, LA	2,000	1,820	3,820	1.80	1.10	17,200	12,970	30,160	30,960	14,260	45,220
Norfolk, VA	1,760	1,470	3,230	2.50	1.10	14,450	12,360	26,810	36,130	13,590	49,720
Orlando, FL	1,710	1,370	3,070	1.50	1.10	14,580	11,280	25,860	21,870	12,410	34,270
Tampa, FL	650	2,360	3,020	1.50	1.10	6,390	18,620	25,010	9,590	20,490	30,070

Table B-4. Recurring and Incident Delay Relationships for 1994 (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	530	1,560	2,080	1.10	1.10	5,040	10,260	15,300	5,550	11,280	16,830
Austin, TX	2,860	1,060	3,920	1.10	1.10	25,400	7,130	32,530	27,940	7,840	35,780
Corpus Christi, TX	230	190	420	1.10	1.10	1,800	1,060	2,860	1,980	1,170	3,150
Dallas, TX	10,240	3,430	13,670	1.80	1.10	90,970	23,940	114,910	163,740	26,340	190,080
Denver, CO	5,370	4,480	9,850	1.00	1.10	49,520	35,010	84,540	49,520	38,520	88,040
El Paso, TX	690	250	940	1.10	1.10	5,500	1,740	7,240	6,050	1,920	7,970
Fort Worth, TX	4,510	1,430	5,940	1.80	1.10	40,080	7,950	48,030	72,140	8,750	80,890
Houston, TX	16,720	4,250	20,970	1.40	1.10	154,570	31,190	185,750	216,390	34,300	250,700
Phoenix, AZ	4,900	9,440	14,340	0.40	1.10	43,750	64,190	107,940	17,500	70,610	88,110
Salt Lake City, UT	1,400	930	2,330	0.60	1.10	12,290	5,620	17,910	7,370	6,180	13,560
San Antonio, TX	3,340	1,320	4,660	1.10	1.10	31,060	9,340	40,390	34,160	10,270	44,430
Western Cities											
Honolulu, HI	2,030	1,050	3,080	1.80	1.10	18,490	8,090	26,570	33,280	8,890	42,170
Los Angeles, CA	61,400	33,230	94,630	1.20	1.10	613,530	257,850	871,380	736,240	283,640	1,019,870
Portland, OR	2,500	2,040	4,550	2.00	1.10	22,230	15,130	37,360	44,450	16,650	61,100
Sacramento, CA	2,700	3,170	5,860	0.60	1.10	21,810	25,140	46,940	13,080	27,650	40,730
San Bernardino-Riv, CA	7,860	4,850	12,710	1.20	1.10	74,270	32,800	107,060	89,120	36,080	125,200
San Diego, CA	10,080	2,490	12,560	0.60	1.10	81,920	18,060	99,990	49,150	19,870	69,020
San Fran-Oak, CA	24,830	6,920	31,750	1.30	1.10	234,840	58,400	293,230	305,290	64,240	369,520
San Jose, CA	7,340	2,900	10,230	1.20	1.10	67,810	21,190	89,000	81,370	23,310	104,680
Seattle-Everett, WA	10,800	3,930	14,740	1.40	1.10	102,890	29,950	132,830	144,040	32,940	176,980
Northeastern Avg	10,170	10,170	20,340	2.60	1.10	88,440	82,950	171,390	222,420	91,240	313,670
Midwestern Avg	4,430	4,090	8,510	1.30	1.10	39,960	31,190	71,150	53,230	34,310	87,540
Southern Avg	2,720	2,820	5,540	1.50	1.10	24,310	21,940	46,250	33,110	24,130	57,240
Southwestern Avg	4,620	2,580	7,190	1.10	1.10	41,820	17,950	59,760	54,760	19,740	74,500
Western Avg	14,390	6,730	21,120	1.30	1.10	137,530	51,840	189,380	166,230	57,030	223,250
Texas Avg	5,510	1,700	7,220	1.30	1.10	49,910	11,760	61,670	74,630	12,940	87,570
Total Avg	6,690	4,800	11,490	1.50	1.10	61,280	37,210	98,480	93,170	40,930	134,090
Maximum Value	61,400	34,300	94,630	3.50	1.10	613,530	291,590	871,380	798,080	320,750	1,118,820
Minimum Value	230	190	420	0.40	1.10	1,800	1,060	2,860	1,980	1,170	3,150

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.

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

[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).

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

Delay Cost

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

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

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 1994

Urban Area	Annual Cost Due to Congestion ($ millions)					Rank
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Total	
Los Angeles, CA	3,590	4,200	380	450	8,620	1
New York, NY	2,520	4,620	270	490	7,900	2
San Fran-Oak, CA	1,220	1,540	130	170	3,060	3
Chicago, IL	1,260	1,460	130	150	3,000	4
Washington, DC	970	1,720	100	170	2,960	5
Detroit, MI	840	1,370	80	130	2,420	6
Houston, TX	780	1,050	70	100	2,000	7
Boston, MA	400	1,100	40	110	1,650	8
Atlanta, GA	670	730	60	70	1,530	9
Seattle-Everett, WA	550	730	60	80	1,420	10
Dallas, TX	480	800	50	80	1,410	11
Philadelphia, PA	520	700	50	70	1,340	12
Miami, FL	470	580	50	60	1,160	13
San Bernardino-Riv, CA	440	520	50	60	1,070	14
Phoenix, AZ	440	360	50	40	890	16
San Jose, CA	370	440	40	50	900	16
Denver, CO	350	360	40	40	790	18
San Diego, CA	420	290	50	30	790	18
Baltimore, MD	250	450	30	50	780	19
St. Louis, MO	290	330	30	30	680	20
Minn-St. Paul, MN	290	280	30	30	630	21
Pittsburgh, PA	220	330	20	30	600	22
Fort Worth, TX	200	340	20	30	590	23
Portland, OR	150	250	20	30	450	24
Ft. Lauderdale, FL	160	220	20	20	420	25
Sacramento, CA	190	170	20	20	400	26
San Antonio, TX	170	180	20	20	390	27
Cleveland, OH	180	150	20	10	360	28
Norfolk, VA	110	210	10	20	350	29
New Orleans, LA	120	190	10	20	340	30
Jacksonville, FL	130	170	10	20	330	31
Honolulu, HI	110	180	20	20	330	32
Austin, TX	140	150	10	10	310	33
Cincinnati, OH	150	130	10	10	300	34
Orlando, FL	110	140	10	10	270	35
Columbus, OH	130	100	10	10	250	37
Milwaukee, WI	110	110	10	10	240	37
Tampa, FL	100	120	10	10	240	38
Kansas City, MO	70	150	10	10	240	39
Hartford, CT	60	130	10	10	210	40
Indianapolis, IN	70	100	10	10	190	41
Louisville, KY	80	90	10	10	190	43
Nashville, TN	80	90	10	10	190	43
Charlotte, NC	80	70	10	10	170	44
Albuquerque, NM	60	70	10	10	150	46
Memphis, TN	60	70	10	10	150	46
Salt Lake City, UT	70	60	10	10	150	47
Oklahoma City, OK	60	60	0	10	130	48
El Paso, TX	30	30	0	0	60	49
Corpus Christi, TX	10	10	0	0	20	50
Northeastern Avg	710	1,290	70	130	2,200	
Midwestern Avg	290	360	30	30	710	
Southern Avg	190	240	20	20	470	
Southwestern Avg	250	310	20	30	610	
Western Avg	780	920	80	100	1,880	
Texas Avg	260	370	20	40	690	
Total Avg	410	550	40	60	1,060	
Maximum Value	3,590	4,620	380	490	9,080	
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.

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

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

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.

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

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.

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