Roadway Congestion in Major Urban Areas: 1982 to 1988

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The results of the third year of analysis of a 6-year research effort focused on quantifying urban mobility are described. Roadway information is provided for 39 urban areas representing a geographic cross section throughout the country. The data base used for this research contains vehicle travel, urban area information, facility mileage, and vehicle travel per lane-mile information. Various federal, state, and local information sources were used to develop and update the data base with the primary source being the FHWA's Highway Performance Monitoring System. Vehicle-miles of travel (VMT) and lane-mile data were used to develop roadway congestion index values for the 7 largest Texas and 32 other U.S. urban areas. These index values serve as indicators of the relative mobility level within an urban area. An analysis of the cost of congestion was performed using travel delay, increased fuel consumption, and increased automobile insurance premiums as the economic analysis factors. Congestion costs were estimated on urban-areawide, per-registered-vehicle, and per-capita bases. The 39 urban areas were categorized in five geographic regions: northeastern, midwestern, southern, southwestern, and western. Comparing the amount of VMT served by freeway and principal arterial street systems and roadway congestion index values, it was concluded that the amount of urban area VMT served by freeway and principal arterial street systems indicated which system urban areas relied on for mobility. Analyses indicated that the Northwestern and Southern regions tended to rely equally on both systems, whereas the remaining regions had a greater reliance on their freeway systems. A comparison of regional roadway congestion index values indicated that the northeastern area was the only region with increasing congestion growth rate. The largest decrease in congestion growth rate was exemplified by the Southwestern region. In 1988, the total annual cost of congestion exceeded $34 billion. The average annual congestion cost, studywide, was approximately $880 million; however, 10 of the urban areas had annual costs exceeding $1 billion. The largest contribution (65 percent) to congestion costs may be directly attributed to travel delay.

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

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

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

Existing data are taken from federal, state, and local agencies to develop planning level estimates of mobility on the freeway and principal arterial street systems in 39 urban areas. Currently, the data base developed for this research contains vehicle travel, travel per lane-mile, population, urban area size, and facility mileage from 1982 to 1988.

Urban mobility is characterized by urban travel volume and capacity statistics. The relative level of mobility can be estimated by the roadway congestion index (RCI). RCI values are based on the major indicators of daily vehicle-miles of travel (DVMT) per lane-mile for freeways and principal arterial streets. Combining the freeway and principal arterial street DVMT per lane-mile into an RCI value provides a quantitative method for estimating the urban areawide mobility. An RCI value $\geqq 1.0$ indicates an undesirable level of congestion.

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

URBAN AREAWIDE CONGESTION MEASUREMENT AND COST METHODOLOGY DEVELOPMENT

Previous research (*1–4*) on area wide mobility levels in Texas and other U.S. cities resulted in methodologies for comparing roadway congestion levels and the costs associated with congestion. The methodologies, outlined in the following sec-

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tions, use generally available data from federal, state, and local agencies.

Measurement of Areawide Urban Congestion

This methodology uses the major indicators of DVMT per lane-mile for freeways and principal arterial streets combined in an RCI for estimating and ranking the relative areawide mobility. An RCI value of 1.0 or greater indicates an undesirable areawide congestion level. This methodology has some limitations induced by population densities, development and land use patterns, and overall urban area mobility characteristics.

Methodology

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

$$RCI = \frac{\left(\frac{\text{Freeway}}{\text{VMT/ln-mi}} \times \frac{\text{Freeway}}{\text{VMT}}\right) + \left(\frac{\text{Principal Arterial Street}}{\text{VMT/ln-mi}} \times \frac{\text{Principal Arterial Street}}{\text{VMT}}\right)}{\left(13{,}000 \times \frac{\text{Freeway}}{\text{VMT}}\right) + \left(5{,}000 \times \frac{\text{Principal Arterial Street}}{\text{VMT}}\right)} \quad (1)$$

The two constant values, 13,000 and 5,000, are the results of the TTI research. It was found that when areawide freeway travel volumes reached 13,000 DVMT per lane-mile, congested conditions [level of service (LOS) D] are estimated to occur. The corresponding LOS value for principal arterial street travel volumes is represented by a system average of 5,000 DVMT per lane-mile.

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

The urban areawide congestion methodology also uses a relationship between average daily traffic (ADT) per lane and average travel speed. This relationship was developed using travel time and ADT data for freeways and principal arterial streets in Houston, Texas (*6*), to obtain better estimates of travel delay. Peak-period speeds were established for the various ADT per lane ranges (Table 1).

The percentage of the total DVMT operating under moderate, heavy, and severe conditions was estimated for each urban area. The travel delay was estimated applying the speeds. This procedure provides a better estimate of travel delay within individual urban areas because the operating characteristics of the freeway and principal arterial street systems are defined in a more disaggregate form.

Limitations of Roadway Congestion Estimates

The RCI is intended to be an urban area value, representing the entire area and not site-specific locations. This index is based on areawide freeway and principal arterial street travel. Therefore, if a large percentage of these systems have good operational characteristics, the effects of point or specific facility congestion may be underestimated by this analysis. It should also be noted that the RCI and its methodology were developed for urban areas similar to those in Texas. Urban areas in the northeast and midwestern states have different roadway and development patterns. The RCI methodology also does not include considerations of traffic signal system operations, freeway designs, freeway system configuration,

TABLE 1 SPEED RELATIONSHIPS WITH ADT PER LANE VOLUMES

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

Note: [1]Assumes congested freeway operation when ADT/Lane exceeds 15,000.
[2]Assumes congested principal arterial street operations when ADT/lane exceeds 5,750.
[3]Values represent weighted average (6).

Source: TTI Analysis and Houston-Galveston Regional Transportation Study arterial street continuity, HOV lanes, or the role of transit. Although these factors have a definite impact on urban congestion, much more detailed urban area information is required than presently is available through regional data bases.

Congestion Cost Methodology

This methodology outlines the procedure used to evaluate the impact of congestion in a specific urban area. The procedure had two basic input units. These units were daily DVMT and population. Table 2 presents a summary of the basic data for each urban area analyzed. The DVMT data were obtained from the HPMS (*5*) and various state and local agencies. The population data were estimated from HPMS and U.S. Census Bureau estimates.

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

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

The congested daily travel values were adjusted by a factor to represent the percentage of travel occurring in the peak period. This factor was calculated using Texas State Department of Highways and Public Transportation (SDHPT) 1986 Automatic Traffic Recorder Data (*8*) for the study areas in Texas. Using these data, the percentage of ADT occurring during the morning and evening peak periods was estimated using these data. These data indicated that a relatively consistent value of 45 percent of total daily traffic occurred during the peak periods. This factor was applied to all the study areas.

Once the DVMT was converted to peak-period congested VMT (Table 3), the recurring vehicle-hours of delay were computed from Equation 2. Recurring delay is caused by the peak facility conditions during normal operations, excluding delay resulting from accidents, construction, or maintenance operations.

$$\begin{pmatrix}\text{Recurring}\\ \text{Vehicle-Hours of}\\ \text{Delay Per Day}\end{pmatrix} = \left(\frac{\text{Peak-Period Congested DVMT}}{\text{Average Peak-Period Speed}}\right) - \left(\frac{\text{Peak-Period Congested DVMT}}{\text{Average Off-Peak Speed}}\right) \quad (2)$$

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

TABLE 2 SUMMARY OF 1988 DVMT VALUES AND POPULATION FOR CONGESTION COST ESTIMATES

Urban Area	Daily Vehicle-Miles of Travel (1000) Freeway/ Expressway	Principal Arterial Street	Freeway and Arterial	Population (1000)
Boston MA	22,720	12,860	35,580	2,910
New York NY	78,010	49,710	127,720	16,320
Philadelphia PA	16,680	22,120	38,790	4,130
Washington DC	23,600	18,800	42,400	3,040
Chicago IL	31,970	26,070	58,030	7,340
Detroit MI	22,020	21,670	43,690	3,900
Atlanta GA	22,970	9,790	32,750	1,780
Miami FL	7,890	13,740	21,630	1,810
Nashville TN	5,250	5,390	10,640	540
Tampa FL	3,440	4,070	7,510	670
Dallas TX	22,380	8,150	30,530	1,950
Denver CO	10,490	10,450	20,940	1,550
Houston TX	27,100	10,190	37,290	2,850
Phoenix AZ	5,550	16,680	22,230	1,830
Los Angeles CA	102,140	78,240	180,380	11,140
Portland OR	7,100	3,280	10,380	950
Sacramento CA	8,420	6,660	15,080	1,040
San Diego CA	25,040	8,850	33,880	2,180
San Fran-Oak CA	40,370	13,540	53,910	3,610
Seattle-Everett WA	17,190	8,820	26,010	1,630

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

TABLE 3 1988 CONGESTED DVMT

Urban Area	Daily Vehicle-Miles of Travel		Percent of Peak-Period[1,2] VMT on Congested Roads		Peak Period Congested DVMT[1,3]		
	Frwy (1000)	Prin.Art.Str. (1000)	Frwy (%)	Prin.Art.Str. (%)	Frwy (1000)	Prin.Art.Str (1000)	Frwy & Prin. Art. St. (1000)
Boston MA	22,720	12,860	45	40	4,600	2,310	6,910
New York NY	78,010	49,710	55	80	19,310	17,900	37,210
Philadelphia PA	16,680	22,120	25	75	1,880	7,460	9,340
Washington DC	23,600	18,800	65	85	6,900	7,190	14,090
Chicago IL	31,970	26,070	55	65	7,910	7,620	15,530
Detroit MI	22,020	21,670	40	60	3,960	5,850	9,810
Atlanta GA	22,970	9,790	45	65	4,650	2,860	7,510
Miami FL	7,890	13,740	60	70	2,130	4,330	6,460
Nashville TN	5,250	5,390	25	40	590	970	1,560
Tampa FL	3,440	4,070	25	60	390	1,100	1,490
Dallas TX	22,380	8,150	55	30	5,540	1,100	6,640
Denver CO	10,490	10,450	50	50	2,360	2,350	4,710
Houston TX	27,100	10,190	70	50	8,540	2,290	10,830
Phoenix AZ	5,550	16,680	60	80	1,500	6,000	7,500
Los Angeles CA	102,140	78,240	75	50	34,470	17,600	52,070
Portland OR	7,100	3,280	40	60	1,280	890	2,170
Sacramento CA	8,420	6,660	45	50	1,710	1,500	3,210
San Diego CA	25,040	8,850	45	30	5,070	1,190	6,260
San Fran-Oak CA	40,370	13,540	80	60	14,530	3,660	18,190
Seattle-Everett WA	17,190	8,820	70	55	5,410	2,180	7,590

Notes: [1]Daily vehicle-miles of travel
[2]Represents the percentage of daily vehicle-miles of travel on each roadway system during the peak period operating on congested conditions
[3]Daily vehicle-miles of travel multiplied by peak-period vehicle travel and percent of congested DVMT
Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

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 3.

$$\begin{pmatrix}\text{Principal Arterial Street Incident}\\ \text{Vehicle-Hour Delay}\\ \text{Per Day}\end{pmatrix} = \begin{pmatrix}\text{Principal Arterial Street Recurring}\\ \text{Vehicle-Hour Delay}\\ \text{Per Day}\end{pmatrix} \times 1.1 \qquad (3)$$

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

1. Arterial street systems designs are more consistent from city to city than freeway design.
2. The side streets, drives, median openings, and other appurtenances associated with arterial streets allow numerous opportunities to remove incidents from the traveled way.
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 4 presents the results of the freeway and principal arterial street recurring and incident delay calculations.

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

$$\text{Average Speed (mph)} = \left[\begin{pmatrix}\text{Freeway}\\ \text{Speed}\end{pmatrix} \times \begin{pmatrix}\text{Peak-Period}\\ \text{Freeway VMT}\end{pmatrix} + \begin{pmatrix}\text{Principal}\\ \text{Arterial}\\ \text{Speed}\end{pmatrix} \times \begin{pmatrix}\text{Peak-Period}\\ \text{Principal}\\ \text{Arterial}\\ \text{Street VMT}\end{pmatrix}\right] \div \text{Total Peak-Period VMT} \qquad (4)$$

In this equation, freeway speed and principal arterial speed are determined by congestion severity (Table 1).

Economic Impact Estimates

The economic impact of congestion was estimated by three cost components: traffic delay, excess fuel, and increased vehicle insurance premiums. Traffic delay and excess fuel costs were estimated for incident and recurring events encountered by motorists. For the purpose of this study, recurring conges-

TABLE 4 RECURRING AND INCIDENT DELAY RELATIONSHIPS FOR 1988

Urban Area	Peak Period Congested DVMT[1,2]			Ratio of Incident[3] Delay to Recurring Delay		Daily Recurring Vehicle-[4] Hours of Delay			Daily Incident Vehicle-[4] Hours of Delay		
	Frwy (1000)	Prin.Art.Str. (1000)	Frwy & Prin. Art. St. (1000)	Frwy	Prin.Art. Street	Frwy	Prin.Art. Street	Total	Frwy	Prin.Art. Street	Total
Boston MA	4,600	2,310	6,910	3.50	1.10	58,790	19,190	77,980	205,760	21,100	226,870
New York NY	19,310	17,900	37,200	2.50	1.10	225,070	159,800	384,870	562,680	175,780	738,460
Philadelphia PA	1,880	7,460	9,340	2.10	1.10	20,430	68,530	88,960	42,900	75,380	118,280
Washington DC	6,900	7,190	14,090	2.20	1.10	80,540	64,400	144,940	177,180	70,840	248,020
Chicago IL	7,910	7,620	15,540	1.20	1.10	100,060	62,080	162,150	120,080	68,290	188,370
Detroit MI	3,960	5,850	9,810	2.20	1.10	49,020	56,130	105,150	107,840	61,740	169,580
Atlanta GA	4,650	2,860	7,510	1.10	1.10	56,930	22,320	79,240	62,620	24,550	87,170
Miami FL	2,130	4,330	6,460	1.50	1.10	27,870	43,250	71,110	41,800	47,570	89,370
Nashville TN	590	970	1,560	1.10	1.10	6,880	9,270	16,150	7,570	10,190	17,760
Tampa FL	390	1,100	1,480	1.50	1.10	4,610	10,380	14,990	6,920	11,420	18,340
Dallas TX	5,540	1,100	6,640	1.80	1.10	67,090	7,300	74,390	120,750	8,030	128,790
Denver CO	2,360	2,350	4,710	1.00	1.10	28,230	13,950	42,180	28,230	15,340	43,570
Houston TX	8,540	2,290	10,830	1.40	1.10	109,260	17,020	126,280	152,960	18,730	171,690
Phoenix AZ	1,500	6,000	7,500	0.40	1.10	17,720	48,690	66,410	7,090	53,560	60,640
Los Angeles CA	34,470	17,600	52,080	1.20	1.10	478,860	146,570	625,430	574,630	161,230	735,860
Portland OR	1,280	890	2,160	2.00	1.10	14,280	6,590	20,870	28,550	7,250	35,800
Sacramento CA	1,710	1,500	3,200	0.60	1.10	18,640	11,160	29,810	11,190	12,280	23,470
San Diego CA	5,070	1,190	6,260	0.60	1.10	62,180	8,520	70,700	37,310	9,380	46,680
San Fran-Oak CA	14,530	3,660	18,190	1.30	1.10	194,350	33,600	227,950	252,660	36,960	289,610
Seattle-Everett WA	5,410	2,180	7,600	1.40	1.10	63,790	17,720	81,510	89,300	19,490	108,800

Notes: [1]Daily vehicle-miles of travel
[2]Represents the percentage of Daily Vehicle-Miles of travel on each roadway system during the peak period operating in congested conditions
[3]Percentage of Incident Delay related to Recurring Delay
[4]Facility delays as calculated by type and urban area
Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

tion was defined as congestion resulting from normal daily facility operations. Incident congestion occurs as a result of an accident, vehicle breakdown, or any other event not typically encountered during normal operations.

Study Constants

The congestion cost analysis and calculations used six independent variables. The following constant values were used in the calculations for each urban area studied.

1. Average vehicle occupancy, 1.25 persons;
2. Working days per year, 250;
3. Average cost of time (*10*), $8.80 per person-hour;
4. Commercial vehicle operations cost (*11*), $1.75 per mile;
5. Vehicle mix, 95 percent passenger and 5 percent commercial; and
6. Vehicular speeds, as presented in Table 1.

These variables do not account for individual variation between urban areas. However, the areawide approach of this research allows the use of these average values describing average cost of time, vehicle mix, and vehicular speeds. The intent of this research is to develop a method to measure and compare urban mobility using existing and readily available data. Without question, urban area roadway congestion index values may be improved by specific area values not readily available to the general transportation community.

Urban Area Variables

Five area-specific variables were also used in the congestion cost estimate. These variables are presented in Table 5.

1. Daily vehicle-miles of travel (DVMT), the average daily traffic (ADT) of a section of roadway multiplied by the length (in miles) of that roadway section.
2. Insurance rates, the difference between the urban average, excluding large metropolitan areas, and the average premium paid within a specific urban area.
3. Fuel cost, the state average fuel cost per gallon for 1988 (*12*).
4. Registered vehicles, the number of registered vehicles are reported by local agencies.
5. Population, estimated using 1988 U.S. Census Bureau estimates and 1988 HPMS data (*13*).

Congestion Cost

Three cost components can be associated with congestion (a) delay cost, (b) fuel cost, and (c) insurance cost. These costs can be directly related to the vehicle-hours of delay, with the exception of the insurance cost. Table 5 presents the cost calculations for the component congestion cost per each urban area.

The average fuel mileage represents the fuel consumption of the vehicles operating in congested conditions. Equation 6 is a linear regression applied to a modified version of fuel consumption reported by Raus (*13*).

$$\text{Average Fuel Mileage (mpg)} = 8.8 + 0.25\,(\text{Average Vehicular Speed}) \quad (5)$$

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

TABLE 5 1988 CONGESTION COST ESTIMATE VARIABLES

Urban Area	Daily VMT Frwy (1000)	Daily VMT Prin.Art.Str. (1000)	Auto Insurance Rates,$	Annual Insurance Difference,$	State Avg Fuel Cost, $	Registered Autos (1000)	Population (1000)	Popn. Per Reg.Veh.
Boston MA	22,720	12,860	800	110	1.07	1,540	2,910	1.89
New York NY	78,010	49,710	860	430	1.09	5,850	16,320	2.79
Philadelphia PA	16,680	22,120	820	410	1.08	2,720	4,130	1.52
Washington DC	23,600	18,800	790	190	1.16	1,640	3,040	1.85
Chicago IL	31,970	26,070	650	190	1.17	4,030	7,340	1.82
Detroit MI	22,020	21,670	730	230	1.14	2,890	3,900	1.35
Atlanta GA	22,970	9,790	630	90	1.09	1,530	1,780	1.16
Miami FL	7,890	13,740	1,020	460	1.17	1,350	1,810	1.34
Nashville TN	5,250	5,390	490	110	1.12	500	540	1.09
Tampa FL	3,440	4,070	640	80	1.17	600	670	1.11
Dallas TX	22,380	8,150	580	150	1.14	1,600	1,950	1.22
Denver CO	10,490	10,450	570	70	1.20	1,360	1,550	1.14
Houston TX	27,100	10,190	630	200	1.14	2,240	2,850	1.27
Phoenix AZ	5,550	16,680	650	50	1.23	1,170	1,830	1.56
Los Angeles CA	102,140	78,240	810	300	1.18	7,790	11,140	1.43
Portland OR	7,100	3,280	480	120	1.05	620	950	1.53
Sacramento CA	8,420	6,660	620	110	1.18	1,250	1,040	0.83
San Diego CA	25,040	8,850	620	110	1.18	1,390	2,180	1.57
San Fran-Oak CA	40,370	13,540	670	160	1.18	3,010	3,610	1.20
Seattle-Everett WA	17,190	8,820	460	70	1.16	1,170	1,630	1.39

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

$$\text{Annual Delay Cost} = \frac{\text{Vehicle-Hr of Delay}}{\text{Day}} \times \frac{1.25 \text{ person}}{\text{Vehicle}} \times \frac{\$8.80}{\text{Hour}} \times \frac{250 \text{ Workdays}}{\text{Year}} \quad (6)$$

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 both from incident and recurring delays.

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

$$\text{Passenger Fuel Cost} = \frac{\frac{\text{Vehicle-hr of Delay}}{\text{Day}} \times 95\% \times \text{Average Speed} \times \text{Average Urban Area Fuel Cost}}{\text{Average Fuel Mileage}} \quad (7)$$

$$\text{Commercial Fuel Cost} = \frac{\frac{\text{Vehicle-hr of Delay}}{\text{Day}} \times 5\% \times \text{Average Speed} \times \text{Average Urban Area Fuel Cost}}{\text{Average Fuel Mileage}} \quad (8)$$

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

$$\text{Average Urban Area Fuel Cost} = (\text{Passenger Fuel Cost} + \text{Commercial Fuel Cost}) \times \frac{250 \text{ Days}}{\text{Year}} \quad (9)$$

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

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

$$\text{"Excess" Insurance Cost per year} = \left[\left(\begin{matrix}\text{Study Area}\\ \text{Rate}\end{matrix}\right) - \left(\begin{matrix}\text{Average State}\\ \text{Rate}\end{matrix}\right)\right] \times 0.70 \times \begin{matrix}\text{Number of}\\ \text{Registered}\\ \text{Vehicles}\end{matrix} \quad (10)$$

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

RESULTS OF URBAN AREA CONGESTION AND CONGESTION COST ANALYSES

The statistics, in this section, are the result of TTI's analyses of the data base compiled for the 39 urban areas from 1982 to 1988 included in this study. Mobility within these regions, as well as within individual urban areas, was compared on the base of DVMT per lane-mile and congestion cost.

1988 Urban Congestion

Urban area freeway and principal arterial street system travel volume and travel volume per lane-mile are presented in Table 6. Combining these statistics (Equation 1) results in the 1988 estimated RCI value. An RCI value of 1.0 or greater indicates an undesirable areawide congestion level.

Of the 39 urban areas studied, 18 have RCI values equal to or greater than 1.0. The 10 most congested urban areas have RCI values ranging from 1.52 (Los Angeles) to 1.10 (New York and Atlanta). Eight urban areas have roadway congestion index values between 0.99 and 0.90. Cities in this range could reach undesirable congestion levels in the near future. Urban areas in the western region had the highest average RCI value, whereas the southwestern region experienced the lowest (Figure 1).

Traffic Congestion Growth, 1982 to 1988

The RCI values for each urban area from 1982 to 1988 are presented in Table 7. From 1982 to 1988, San Diego, Nashville, and San Francisco–Oakland were estimated to have the fastest congestion growth rate, whereas Phoenix, Detroit, and Houston experienced the lowest.

The annual percent change in RCI value for the 11 most congested urban areas in 1988 is shown in Figure 2. This figure illustrates the change for the entire study period (1982 to 1988), an intermediate period (1985 to 1988), and the most recent percent change (1987 to 1988). Los Angeles and Atlanta data indicate that the congestion growth rate has declined in recent years. Conversely, Boston has experienced an increasing congestion growth rate for all years included in this study. Houston is the only urban area in the top 11 that has shown a consistent decreasing congestion growth rate for these time periods.

The summary statistics indicate that all regions have experienced annual increases in average RCI values during the study period with the exception of the southwestern region (Figure 3). This region had approximately a 1 percent decrease in the average regional RCI value from 1987 to 1988.

Figure 3 shows RCI changes during the same time periods as Figure 2. The northeast was the only region with increasing congestion growth rates. The urban areas in Texas account

TABLE 6 1988 RCI VALUES

Urban Area	Freeway/Expressway		Principal Arterial Street		Roadway[3] Congestion Index	Rank
	DVMT[1] (1000)	DVMT/[2] Ln-Mile	DVMT[1] (1000)	DVMT/[2] Ln-Mile		
Los Angeles CA	102,140	20,590	78,240	6,520	1.52	1
San Fran-Oak CA	40,370	17,360	13,540	6,620	1.33	2
Washington DC	23,600	15,850	18,800	8,250	1.32	3
Chicago IL	31,970	14,500	26,070	6,940	1.18	4
Miami FL	7,890	13,710	13,740	6,800	1.18	4
Seattle-Everett WA	17,190	15,080	8,820	5,980	1.17	6
Houston TX	27,100	15,140	10,190	5,150	1.15	7
San Diego CA	25,040	14,770	8,850	5,460	1.13	8
Boston MA	22,720	15,040	12,860	4,780	1.12	9
New York NY	78,010	13,430	49,710	6,990	1.10	10
Atlanta GA	22,970	13,920	9,790	6,570	1.10	10
Detroit MI	22,020	13,430	21,670	6,160	1.09	12
Philadelphia PA	16,680	11,910	22,120	6,850	1.07	13
Portland OR	7,100	13,150	3,280	6,250	1.05	14
Tampa FL	3,440	11,860	4,070	6,500	1.03	15
Sacramento CA	8,420	12,470	6,660	6,340	1.03	15
Dallas TX	22,380	13,360	8,150	4,810	1.02	17
Phoenix AZ	5,550	10,670	16,680	5,790	1.00	18
Nashville TN	5,250	11,930	5,390	5,890	0.99	19
Denver CO	10,490	12,200	10,450	5,690	0.99	19

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

Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: Equation 1 and Tables 2 and 5

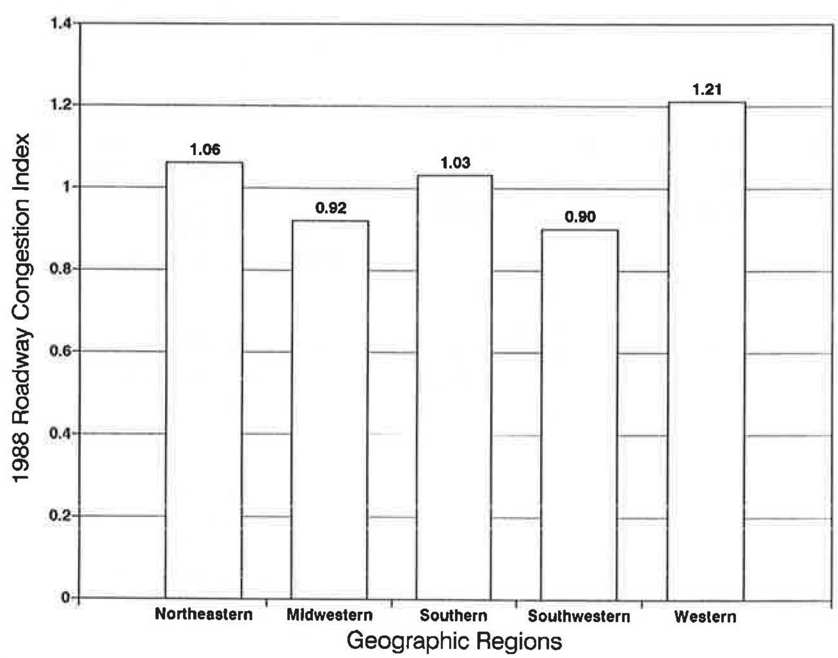

FIGURE 1 1988 roadway congestion index.

TABLE 7 RCI VALUES, 1982 TO 1988

Urban Area	Year 1982	1983	1984	1985	1986	1987	1988	Percent Change 1982 to 1988
Phoenix AZ	1.15	1.16	1.10	1.13	1.20	1.18	1.00	-13
Detroit MI	1.13	1.10	1.13	1.12	1.11	1.10	1.09	-4
Houston TX	1.17	1.21	1.25	1.23	1.21	1.19	1.15	-2
Philadelphia PA	1.00	1.03	1.04	0.90	1.06	1.06	1.07	7
New York NY	1.01	1.02	0.99	1.00	1.06	1.06	1.10	9
Tampa FL	0.94	0.91	1.03	1.00	0.96	1.02	1.03	10
Miami FL	1.05	1.09	1.07	1.13	1.10	1.14	1.18	12
Chicago IL	1.02	1.02	1.05	1.08	1.15	1.15	1.18	16
Denver CO	0.85	0.88	0.93	0.96	0.97	0.95	0.99	16
Dallas TX	0.84	0.89	0.94	0.98	1.04	1.02	1.02	21
Portland OR	0.87	0.86	0.88	0.93	0.97	1.00	1.05	21
Washington DC	1.07	1.09	1.12	1.20	1.28	1.30	1.32	23
Seattle-Everett WA	0.95	0.99	1.02	1.05	1.09	1.14	1.17	23
Boston MA	0.90	0.93	0.95	0.98	1.04	1.04	1.12	24
Atlanta GA	0.89	0.94	0.97	1.02	1.09	1.15	1.10	24
Los Angeles CA	1.22	1.27	1.32	1.36	1.42	1.47	1.52	25
Sacramento CA	0.80	0.84	0.88	0.92	0.95	1.00	1.03	29
San Fran-Oak CA	1.01	1.05	1.12	1.17	1.24	1.31	1.33	32
Nashville TN	0.74	0.76	0.83	0.81	0.86	0.95	0.99	34
San Diego CA	0.78	0.83	0.91	0.95	1.00	1.08	1.13	45

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: Equation 1 and TTI Data Base 1982-1988

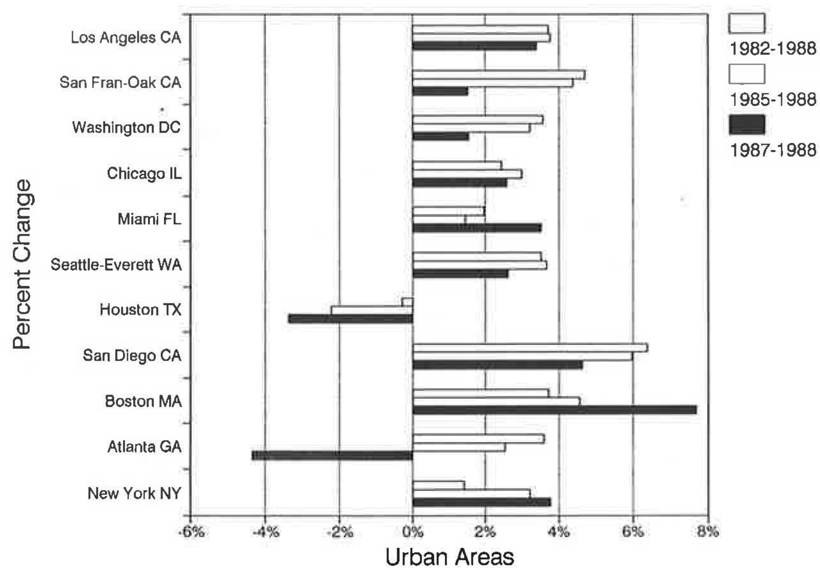

FIGURE 2 Annual percent change of RCI value for the 11 most congested urban areas.

for much of the decrease in the growth rate in the southwest. Between 1987 and 1988, however, Phoenix had the largest decrease in congestion growth at a rate of 15 percent. The graph indicates the other three regions are all experiencing decreasing congestion growth rates. The southern region has the highest increase of those regions from 1987 to 1988.

Cost Estimate Calculations

Using the methods and equations discussed in the previous section, the annual cost for each urban area was calculated (Table 8). Reviewing the component costs of delay, fuel, and insurance, it is shown that congestion costs associated with delay make up the majority of annual congestion cost.

Table 9 presents the impacts of the component and total congestion cost per capita and per registered vehicle. Table 10 presents the categorical ranking of the urban study areas by annual congestion cost, annual cost per capita, and annual cost per registered vehicle, including and excluding insurance costs. Elimination of insurance costs from the annual congestion cost did marginally affect the ranking of the top 10 urban areas. The remaining 15 in the top 25 urban areas, however, were not affected by exclusion of the insurance cost.

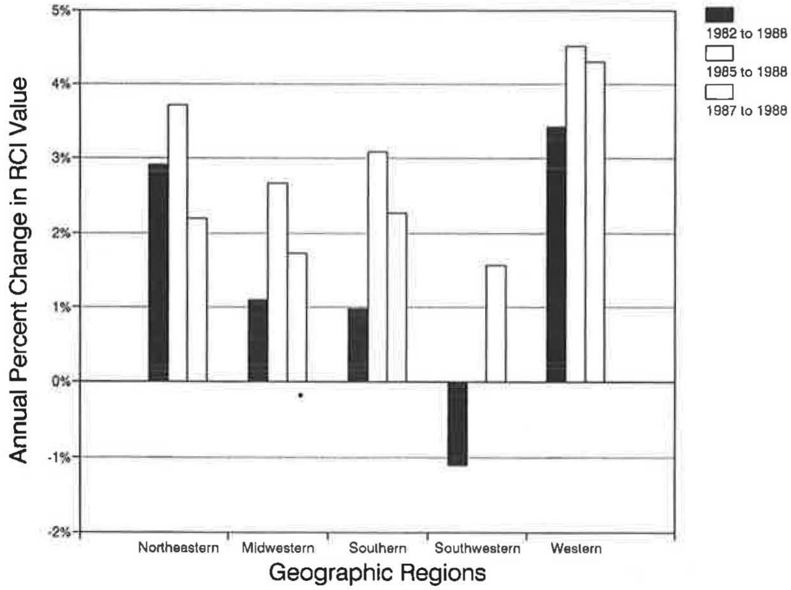

FIGURE 3 Annual percent change in RCI values by geographic region.

TABLE 8 COMPONENT AND TOTAL CONGESTION COSTS BY URBAN AREA FOR 1988

Urban Area	Annual Cost Due to Congestion ($Millions)							Rank
	Recurring Delay	Incident Delay	Recurring Fuel	Incident Fuel	Delay&Fuel Cost	Insurance	Total Delay, Fuel &Insurance	
Los Angeles CA	2,060	2,420	350	410	5,240	1,640	6,880	1
New York NY	1,270	2,440	200	380	4,290	1,760	6,040	2
San Fran-Oak CA	760	960	130	160	2,010	340	2,340	3
Chicago IL	530	620	90	100	1,340	540	1,880	4
Washington DC	480	820	80	130	1,510	220	1,730	5
Philadelphia PA	290	380	40	60	770	780	1,550	6
Detroit MI	340	550	50	90	1,030	470	1,510	7
Houston TX	420	570	70	90	1,150	310	1,470	8
Boston MA	260	750	40	120	1,170	120	1,280	9
Miami FL	230	290	40	50	610	430	1,040	10
Dallas TX	250	430	40	70	790	170	960	11
Seattle-Everett WA	270	360	50	60	740	60	800	12
Atlanta GA	260	290	40	50	640	100	730	13
San Diego CA	240	160	40	30	470	110	570	14
Phoenix AZ	220	200	40	30	490	40	520	16
Denver CO	140	140	20	20	320	70	400	18
Sacramento CA	100	80	20	10	210	100	300	22
Portland OR	70	120	10	20	220	50	270	24
Nashville TN	50	60	10	10	130	40	170	26
Tampa FL	50	60	10	10	130	30	160	27

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

TABLE 9 ESTIMATED ECONOMIC IMPACT OF CONGESTION IN 1988

Urban Area	Cost Per Registered Vehicle		Cost Per Capita	
	Total Congestion (Dollars)	Delay & Fuel (Dollars)	Total Congestion (Dollars)	Delay & Fuel (Dollars)
Boston MA	830	760	440	400
New York NY	1,030	730	370	260
Philadelphia PA	570	280	380	190
Pittsburgh PA	470	260	310	170
Washington DC	1,050	920	570	500
Chicago IL	470	330	260	180
Detroit MI	520	360	390	270
Atlanta GA	480	420	410	360
Miami FL	770	450	570	330
Nashville TN	340	260	310	240
Tampa FL	270	210	240	190
Dallas TX	600	500	490	410
Denver CO	290	250	260	220
Houston TX	660	520	520	410
Phoenix AZ	450	410	290	260
Los Angeles CA	880	670	620	470
Portland OR	440	350	280	230
Sacramento CA	240	170	290	200
San Diego CA	410	330	260	210
San Fran-Oak CA	780	670	650	560
Seattle-Everett WA	680	630	490	460

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis and Local Transportation Agency References

TABLE 10 1988 RANKINGS OF URBAN AREA BY ESTIMATED ECONOMIC IMPACT OF CONGESTION

Urban Area	Areawide Cost		Cost Per Capita		Cost Per Registered Vehicle	
	Total Congestion	Delay&Fuel	Total Congestion	Delay&Fuel	Total Congestion	Delay&Fuel
Boston MA	9	6	8	7	4	2
New York NY	2	2	12	12	2	3
Philadelphia PA	6	10	11	20	10	19
Washington DC	5	4	3	2	1	1
Chicago IL	4	5	21	22	14	14
Detroit MI	7	8	10	11	11	12
Atlanta GA	13	12	9	8	13	10
Miami FL	10	13	3	9	6	9
Nashville TN	26	27	15	15	21	21
Tampa FL	27	27	24	20	26	25
Dallas TX	11	9	6	5	9	8
Denver CO	18	16	21	17	24	23
Houston TX	8	6	5	5	8	7
Phoenix AZ	16	14	17	12	16	11
Los Angeles CA	1	1	2	3	3	4
Portland OR	24	22	19	16	17	13
Sacramento CA	22	23	17	19	27	28
San Diego CA	14	15	21	18	18	14
San Fran-Oak CA	3	3	1	1	5	4
Seattle-Everett WA	12	11	6	4	7	6

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

CONCLUSIONS

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

Urban Area Mobility

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

Comparing the amounts of VMT served by the freeway and principal arterial street systems indicates which system urban areas rely on for mobility. Figure 4 graphically shows the percent of the total travel volume served by urban area freeway and principal arterial street systems. The northeastern and southern regions tend to rely on both systems equally, whereas the remaining three regions are more freeway oriented.

Table 7 summarizes RCI values from 1982 to 1988. Of the 39 urban areas included in this study, 3 have lower 1988 RCI values than were estimated for 1982 (Phoenix, Detroit, and Houston). Trends in congestion growth rates for the individual regions are shown in Figure 3. The Northeastern area was the only region with increasing congestion growing rates. The largest decrease in the congestion growth rate is in the Southwestern region, with Texas congestion levels being the major contributing factor in the decline.

Economic Impact of Congestion

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

- Travel delay caused by congested roadways and incidents,
- Increased fuel consumption, and
- Increased insurance premiums.

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

The total annual cost of congestion exceeded $34 billion in 1988. Ten of the urban areas studied were estimated to have annual congestion costs exceeding $1 billion. The average annual cost for 39 urban areas was approximately $880 million, with 65 percent being attributed to travel delay. Table 11 presents the estimated economic impact of congestion per capita and per registered vehicle. These values represent the congestion cost paid by urban area residents and motorists.

Table 11 presents the comparison between ranking urban areas by the RCI, cost per capita, and per registered vehicle. The comparison between the RCI and cost per capita ranks indicates the effect of urban population. Chicago and New York are both removed from the top 10 by virtue of their large urban area populations that dilute the cost of congestion. Comparing the cost per registered vehicle value to the RCI,

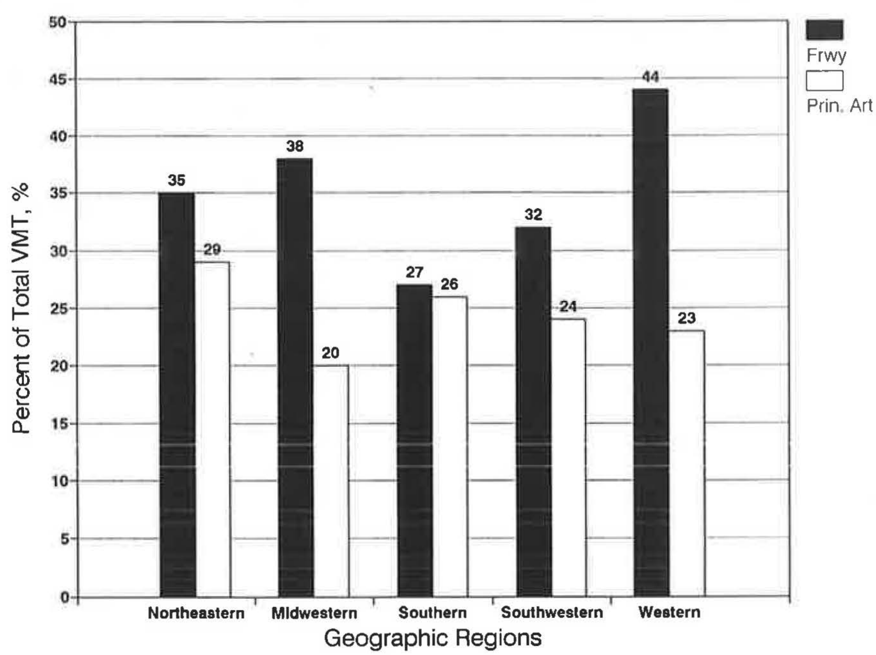

FIGURE 4 Facility travel volume by geographic region.

TABLE 11 1988 URBAN AREA RANKINGS BY RCI AND COST PER CAPITA

Urban Area	Roadway Congestion Index	Rank	Congestion Cost Per Capita (Dollars)	Rank	Congestion Cost Per Vehicle (Dollars)	Rank
Los Angeles CA	1.52	1	620	2	880	3
San Fran-Oak CA	1.33	2	650	1	780	5
Washington DC	1.32	3	570	3	1,050	1
Chicago IL	1.18	4	260	21	470	14
Miami FL	1.18	4	570	3	770	6
Seattle-Everett WA	1.17	6	490	6	680	7
Houston TX	1.15	7	520	5	660	8
San Diego CA	1.13	8	260	21	410	18
Boston MA	1.12	9	440	8	830	4
New York NY	1.10	10	370	12	1,030	2
Atlanta GA	1.10	10	410	9	480	13
Detroit MI	1.09	12	390	10	520	11
Philadelphia PA	1.07	13	380	11	570	10
Portland OR	1.05	14	290	19	440	17
Tampa FL	1.03	15	240	24	270	26
Sacramento CA	1.03	15	290	17	240	27
Dallas TX	1.02	17	490	6	600	9
Phoenix AZ	1.00	18	290	17	450	16
Nashville TN	0.99	19	310	15	340	21
Denver CO	0.99	19	260	21	290	24

Note: Table illustrates the 20 most congested urban areas. Complete listing of 39 urban areas studied contained in (7).

Source: TTI Analysis

New York is ranked second. This ranking represents the effect of the lower vehicle ownership rates within the area. In general, ranking urban areas by congestion cost per capita and per registered vehicle corresponds to ranking areas by RCI values.

The material in this paper is an overview of *Roadway Congestion in Major Urban Areas 1982 to 1988*, Research Report 1131-3 (7). The methodology used in this research provides an areawide rather than site-specific urban mobility analysis. Analyses and data are intended to estimate the effects and level of congestion within an urban area, not as a basis for project selection or funding allocations.

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