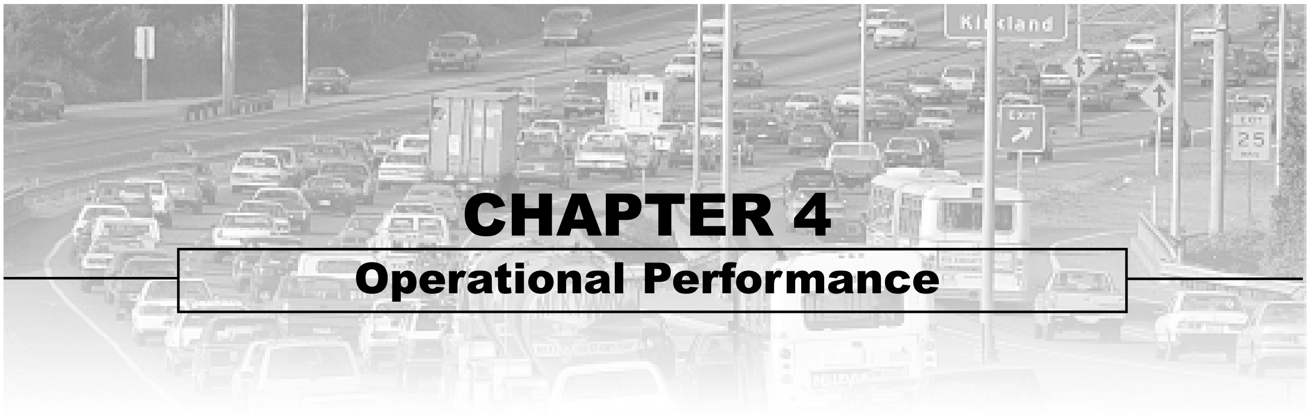


CHAPTER 4
Operational Performance

Introduction

This chapter describes operational performance of the highway and transit infrastructure. Operational performance reflects the quality of service provided by transportation systems. It shows how well each system accommodates travel demand.

The chapter begins with a Summary section highlighting the key highway and transit statistics discussed later in this chapter, and comparing them with the values from the last report. Where the 1995 data have been revised, this is reflected in the summary table.

The highway section of this chapter begins by briefly discussing the costs of congestion. It examines the impact of congestion on highway users and on the entire American economy. The section then describes how congestion, an easy concept to understand, is actually problematic to measure. Because there is no single indicator for congestion, Chapter 4 looks at three measures: daily delay; and Daily Vehicle-Miles Traveled per lane; and Volume Service Flow (V/SF).

The highway section concludes by examining statistics from the Texas Transportation Institute's annual report on urban roadway congestion. These provide a good snapshot of congestion problems in 70 metropolitan areas throughout the United States.

The transit section of this chapter describes how to measure transit operational performance. It describes characteristics from the National Transit Database and passenger survey information.

Summary

Exhibit 4-1 highlights the key highway and transit statistics discussed in this chapter, and compares them with the values from the last report. The first data column contains the values reported in the 1997 C&P report, which were based on 1995 data. Where the 1995 data have been revised, updated values are shown in the second column. The third column contains comparable values, based on 1997 data.

Exhibit 4-1

Comparison of Operational Performance Statistics with those in the 1997 C&P Report

Statistic	1995 Data		
	1997 Report	Revised	1997 Data
Daily Vehicle-Miles Traveled (DVMT) per Lane-Mile on Rural Interstates	4,640	---	4,952
Daily Vehicle-Miles Traveled (DVMT) per Lane-Mile on Rural Other Principal Arterials	2,410	---	2,522
Daily Vehicle-Miles Traveled (DVMT) per Lane-Mile on Urban Interstates	13,110	---	13,696
Daily Vehicle-Miles Traveled (DVMT) per Lane-Mile on Urban Other Freeways and Expressways	10,300	---	10,620
Daily Vehicle-Miles Traveled (DVMT) per Lane-Mile on Urban Other Principal Arterials	5,650	---	5,768
Percent of Congested Travel on Urban Principal Arterial Highways (V/SF>=.8)	41.1%	40.9%	40.2%
Daily Delay (Hours per Thousand Vehicle Miles Traveled) on all Highways	not reported	9.348	8.973
Passenger-Mile Weighted Average Speed by Rail (miles per hour)	26.6	---	26.1
Passenger-Mile Weighted Average Speed by Non-Rail (miles per hour)	13.7	---	13.8

To examine highway operational performance, this chapter looks at daily travel per lane-mile, peak-hour volume/service flow ratio, and daily delay.

DVMT per lane-mile is the most basic measure, since it is a count-based metric. This measure increased at a faster annual rate on the Interstates than any other segments of the highway system between 1987 and 1997. DVMT per lane-mile increased at an annual rate of 3.40 percent on rural Interstates and by 2.00 percent on urban Interstates. Increased travel has not yet saturated rural highways to the degree it has impacted urban highways, so it has not resulted in similar congestion patterns.

Another way to examine highway congestion is to determine the percentage of peak-hour urban traffic that operates at a volume service flow (V/SF) threshold of 0.80 or higher. Between 1993 and 1997, congestion increased somewhat on urban Interstates while decreasing on other freeways and expressways and other principal arterials. The proportion of peak-hour travel exceeding the 0.80 threshold on urban Interstates increased slightly from 52.6 to 53.3 percent. On all urban principal arterials, it was 40.2 percent in 1997, down from 40.9 percent in 1995. Overall the congestion trends seem to have flattened over the past several years.

Daily delay is a more recently adopted measure of congestion, and is an attempt to use a measure that is readily observed by the traveling public. However, the delay values used in this report are modeled values, not directly observed values. Delay is expressed in terms of hours per thousand vehicle-miles traveled. Between 1993 and 1997, the greatest delay has been on "other principal arterial" highways in urbanized areas with more than 200,000 residents. These are higher-level roads that are accommodating significant metropolitan growth; the delay on these roads includes that caused by stop signs and traffic signals.

There are essentially two ways to examine transit performance. One approach is to use operating data from the National Transit Database to derive average operating speeds and vehicle utilization. For example, passenger-mile weighted average speed decreased slightly between 1995 and 1997, from 20.4 to 20.3 miles per hour. Another approach is to use passenger survey data that identifies travel times, waiting times, and seating conditions upon boarding. For example, the basic mobility group is more dependent on transit and has a higher tolerance for delay (12.1 minutes) and unreliability (13.6 minutes) than the other two groups. People with an automobile alternative, using transit to avoid traffic congestion, have average wait times of 7.3 minutes, with 9.3 minutes in variation. Similarly, *above poverty* households without cars experience wait times that are a little longer than those experienced by households with cars. They also experience a similar reliability factor.

Highway Operational Performance

Operational performance is defined by how well highways accommodate travel demand. Congestion, therefore, is an indicator of poor operational performance. Recent newspaper stories about "road rage" highlight the escalating problem of congestion in the United States. Congestion may contribute to a sense of frustration and hostility on highways, but it also has more specific measurable costs for American drivers. The Texas Transportation Institute's (TTI) *1999 Urban Roadway Congestion Annual Report* estimates that in the 68 urban areas studied in 1997, drivers experienced 4.3 billion hours of delay and wasted 6.7 billion gallons of fuel. Total congestion cost for these areas, including wasted fuel and time, was estimated to be about $72 billion in 1997. Almost 60 percent of that cost was experienced in the 10 metropolitan areas with the most congestion. Exhibit 4-2 shows the 20 urban areas with the highest congestion costs, according to TTI.

Exhibit 4-2

Total Congestion Costs by Urban Area, 1997

	Annual Cost Due to Congestion ($ Millions)			
Urban Area	Delay	Fuel	Total	Rank
Los Angeles, CA	10,855	1,550	12,405	1
New York, NY-Northeastern NJ	7,835	1,050	8,885	2
Chicago, IL-Northwestern IN	3,915	485	4,400	3
Washington, DC-MD-VA	3,190	370	3,560	4
Detroit, MI	2,820	325	3,145	5
San Francisco-Oakland, CA	2,670	395	3,065	6
Boston, MA	2,330	305	2,635	7
Atlanta, GA	2,050	220	2,270	8
Houston, TX	1,980	230	2,210	9
Philadelphia, PA-NJ	1,630	195	1,825	10
Seattle-Everett, WA	1,585	220	1,805	11
Dallas, TX	1,535	180	1,715	12
Miami-Hialeah, FL	1,355	160	1,515	13
Baltimore, MD	1,185	145	1,330	14
St. Louis, MO-IL	1,180	130	1,310	15
San Diego, CA	1,100	165	1,265	16
Denver, CO	930	120	1,050	17
Phoenix, AZ	925	125	1,050	18
Minneapolis-St. Paul, MN	915	115	1,030	19
San Jose, CA	835	120	955	20

Source: Texas Transportation Institute, 1999 Annual Mobility Report.

Congestion has an adverse impact on the American economy, which values speed, reliability, and efficiency. Transportation is a critical link in the production process for many businesses, and firms are forced to spend money on wasted fuel and drivers' salaries that might otherwise be invested in research and development, firm expansion, and other activities. The problem is of particular concern to firms involved in logistics and distribution. As just-in-time delivery increases, firms need an integrated transportation network that allows for the reliable, predictable shipment of goods. Congestion, then, is a major hurdle for businesses in the developing economy.

> **Q. What is the Federal Highway Administration view of the reports produced by the Texas Transportation Institute on Urban Roadway Congestion?**
>
> **A.** The Texas Transportation Institute has studied congestion in a number of cities in the Nation annually since 1982. This is the most significant continuing study being done on congestion in the United States. In order to attain the substantial achievements of this study, TTI has used a straight-forward, simple procedure to define congestion and to estimate the costs of congestion to the public. The TTI studies have provided usable measures of congestion in a large number of metropolitan areas in the Nation, combining measures of congestion delay, incident delay, and fuel consumption. FHWA commends TTI for its contribution to the knowledge base of congestion and believes that the results are useful as measures of the trends of congestion and its costs in the metropolitan areas. Future research may provide the means to further refine this type of study.

Measuring Traffic Congestion

While congestion is conceptually easy to understand, it has no widely accepted definition. This is because the perception of what constitutes congestion varies from place to place. What may be considered congestion in a city of 300,000 may be greatly different than perceived traffic conditions in a city with 3 million people, based on varying history and expectations. Because of this, transportation professionals examine congestion from several perspectives.

Three key aspects of congestion are its severity, extent, and duration. The **severity** of congestion refers to the magnitude of the problem, as measured by the average overall travel speed, travel time delay, or the length of queues behind bottlenecks. The **extent** of congestion is defined by the geographic area (the portion of the population or portion of total travel affected). The **duration** of congestion is the lenth of time that the traffic flow is congested, often referred to as the “peak period” of traffic flow.

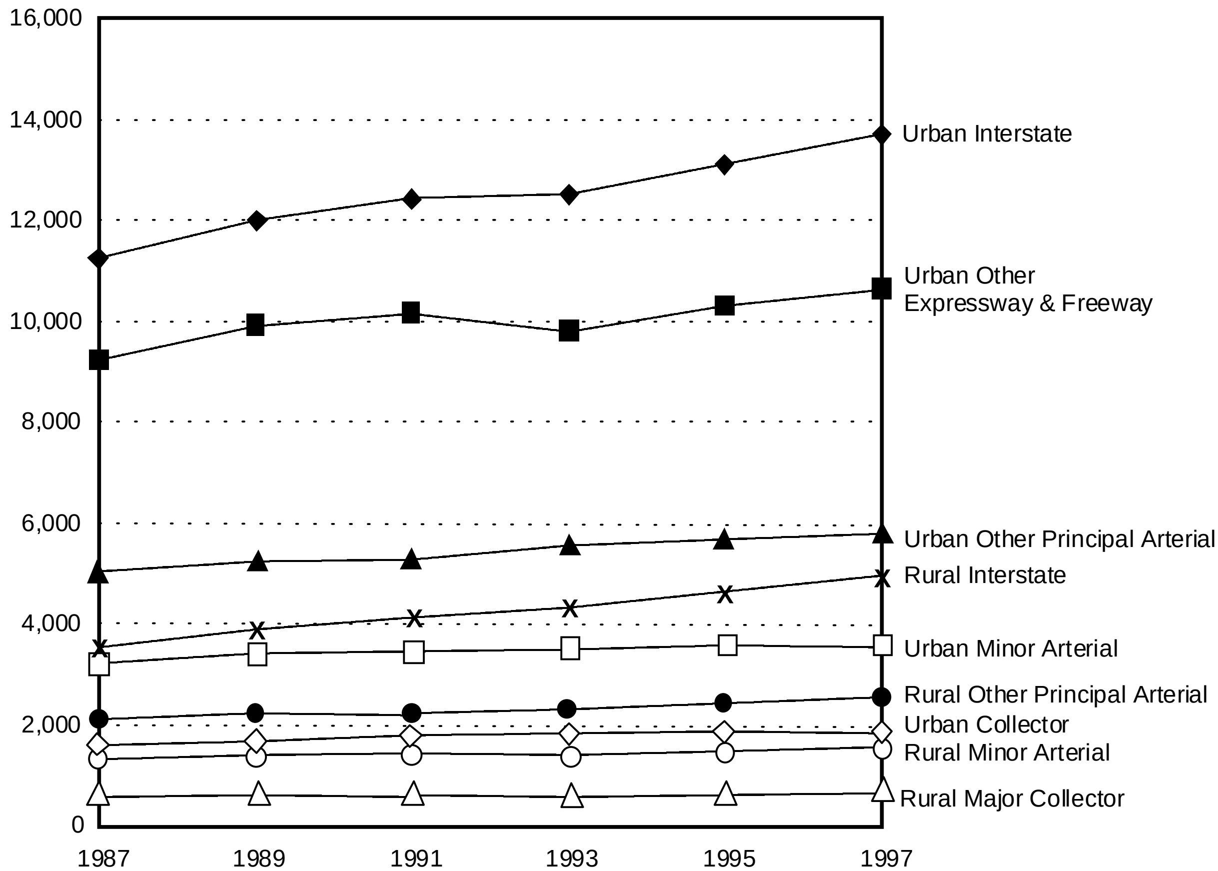
Daily vehicle-miles of travel (DVMT) per lane-mile is the most basic measure of how much travel is being accommodated on our highway systems since it is a count-based metric. It is based on actual counts of traffic, not on calculations which are in turn based on actual data. The traditional congestion measure in this report has been volume service flow (V/SF), the ratio of the volume of traffic using a road in the peak travel hour to the capacity or service flow of that road. V/SF is limited because it only addresses peak-hour and disregards the duration of congestion. As travel volume grows on a given highway section, after a certain point peak-hour congestion tends to stabilize even as total hours of congestion continue to increase. Focusing only on the V/SF measure alone can lead to erroneous conclusions about highway operating performance. This report adds a new indicator of congestion, delay. Delay incorporates the effects of congestion throughout the day, not only during the peak hour of travel.

DVMT per Lane-Mile

The volume of travel per lane-mile has increased over the past 10 years on every functional highway system for which data are collected . For urban Interstate the rate of increase from 1987 to 1997 is 2.0 percent, and for rural Interstate the rate of increase is 3.4 percent. DVMT per Lane-Mile for each system is shown in Exhibit 4-3. Whatever other measure is used to estimate congestion or its effects, there is no doubt that the density of traffic is increasing, especially on the higher functional systems.

Exhibit 4-3

DVMT per Lane-Mile, 1987-1997



Jurisdiction	1987	1989	1991	1993	1995	1997	Annual Rate of Change 1987-1997
Rural							
Interstate	3,530	3,880	4,120	4,310	4,640	4,952	3.40%
Other Principal Arterial	2,090	2,210	2,220	2,310	2,410	2,522	1.90%
Minor Arterial	1,300	1,390	1,440	1,390	1,470	1,556	1.80%
Major Collector	540	580	600	560	590	632	1.60%
Urban							
Interstate	11,230	11,990	12,420	12,520	13,110	13,696	2.00%
Other Expressway & Freeway	9,240	9,910	10,140	9,770	10,300	10,620	1.40%
Other Principal Arterial	5,010	5,240	5,280	5,540	5,650	5,768	1.40%
Minor Arterial	3,220	3,420	3,460	3,490	3,560	3,567	1.00%
Collector	1,600	1,650	1,780	1,830	1,880	1,832	1.40%

Source: June 1999 HPMS.

V/SF Ratio

Volume/service flow (also known as the volume/capacity ratio) is a measure of the severity of congestion. The V/SF is the ratio between the volume of traffic actually using a highway during the peak hour and the theoretical capacity of the highway to accommodate traffic. The higher the ratio, the more congested the facility.

Congestion reported in this chapter is based on a threshold value of 0.80. This typically represents Level of Service (LOS) D, as described in Exhibit 4-4. This volume of traffic is 80 percent of the maximum that can be accommodated on a highway, but freedom to maneuver is noticeably limited and incidents result in substantial delays. Higher V/SF ratios represent more severe congestion, escalating into a breakdown in traffic flow at LOS F. Procedures for calculating the V/SF ratio are described in the Transportation Research Board's *Highway Capacity Manual* (HCM). It should be noted that this measure of congestion is still a subjective issue, even with engineering standards.

Exhibit 4-4

Description of Levels of Service

Level of Service	Description
A	LOS A generally describes free-flow operations. Average operating speeds at the free-flow level generally prevail. Vehicles are almost completely unimpeded in their ability to maneuver within the traffic stream. The effects of incidents are easily absorbed.
B	LOS B also represents reasonably free flow, and speeds at the free-flow level are generally maintained. The ability to maneuver within the traffic stream is only slightly restricted, and the general level of physical and psychological comfort provided to drivers is still high. The effects of minor incidents are still easily absorbed, although local deterioration in service may be more severe than for LOS A.
C	LOS C provides for flow with speeds still at or near the free-flow speed of the freeway. Freedom to maneuver within the traffic stream is noticeably restricted at LOS C. Minor incidents may still be absorbed, but the local deterioration in service will be substantial. The driver experiences a noticeable increase in tension.
D	LOS D is the level at which speeds begin to decline slightly with increasing flows. Freedom to maneuver within the traffic stream is more noticeably limited, and the driver experiences reduced physical and psychological comfort levels. Even minor incidents can be expected to create queuing.
E	LOS E describes operation at or near capacity. Operations are volatile, because there are virtually no usable gaps in the traffic stream. Any disruption can cause the following vehicles to give way, which can establish a disruption wave that propogates throughout the upstream traffic flow. The traffic stream has no ability to dissipate even the most minor disruptions, and any incident can be expected to produce a serious breakdown with extensive queuing. The level of physical and psychological comfort afforded the driver is extremely poor.
F	LOS F describes breakdowns in vehicular flow. Such conditions generally exist with queues forming breakdown points. Such breakdowns occur because of traffic incidents, recurring points of congestion, or peak-hour flow demand exceeding the capacity of the location.

Source: Highway Capacity Manual, 1994.

Exhibit 4-5 describes the percentage of peak-hour urban traffic that operates at a V/SF threshold of 0.80 or higher. The severity of congestion was somewhat greater on urban Interstates in 1997 than in 1993, increasing from 52.6 to 53.3 percent of all peak-hour traffic operating under congested conditions. For the same period peak-hour congestion was declining on other freeways and expressways until 1997, when it increased to 45.7 percent. Meanwhile, congestion severity decreased on other urban principal arterials between 1993 and 1997. Further years of estimating congestion may provide a clearer picture of the long-term trends in congestion.

Exhibit 4-5

Percent of Congested Travel on Urban Principal Arterial Highways, 1993-1997
Peak-hour travel with V/SF >= 0.80 based on 1994 Highway Capacity Manual

Year	All Urban Principal Arterial Highways	Urban Interstate Highways	Urban Other Freeways and Expressways	Urban Other Principal Arterials
1993	42.4%	52.6%	48.3%	31.4%
1994	41.0%	51.5%	46.3%	29.9%
1995	40.9%	51.6%	44.7%	30.1%
1996	40.3%	54.0%	44.8%	26.6%
1997	40.2%	53.3%	45.7%	26.5%

Source: June 1999 HPMS.

Delay

The *Federal Highway Administration 1998 National Strategic Plan* established a target of reducing delays on Federal-aid highways by 20 percent in 10 years, in terms of hours of delay per 1000 VMT. The delay values used in this report are modeled rather than measured. Currently we have no efficient way to measure delay directly. (See "Future Research," on page 4-12.) Delay is calculated as the difference between estimated actual travel speed and free-flow travel speed. Note that the delay calculations are in terms of vehicle-hours of delay, so that one hour of delay affects the same number of vehicles in one location as another. To the extent that vehicle occupancy differs from place to place, the number of people affected by one vehicle hour of delay may differ.

Delay is a new measure relative to the other two measures used in this report. How well it tracks perceived congestion remains to be seen. Several more years of use will be needed to determine the validity of the procedures used to calculate the value and the credibility of the results.

Exhibit 4-6 shows trends in delay since 1993. **For each of the four types of areas shown, delay in 1997 was greater than in 1993**. Delay increased from 8.27 to 9.35 hours between 1993 and 1995, but declined to 8.97 hours in 1997. Most urban highways have experienced less delay since 1995. Delay on Urban Interstates has fallen below 1993 levels. As shown in Exhibit 4-7, there is far more delay on Urban Interstates in the areas with more than 200,000 population than in the smaller urban areas or in rural areas.

The greatest delay occurs on urban other principal arterials, in urbanized areas with more than 200,000 residents. These are higher-level roads that are accommodating metropolitan growth. As shown in Exhibit 4-8, delay on these routes was 50 percent greater than delay on the same functional system in small urban areas under 50,000 population.

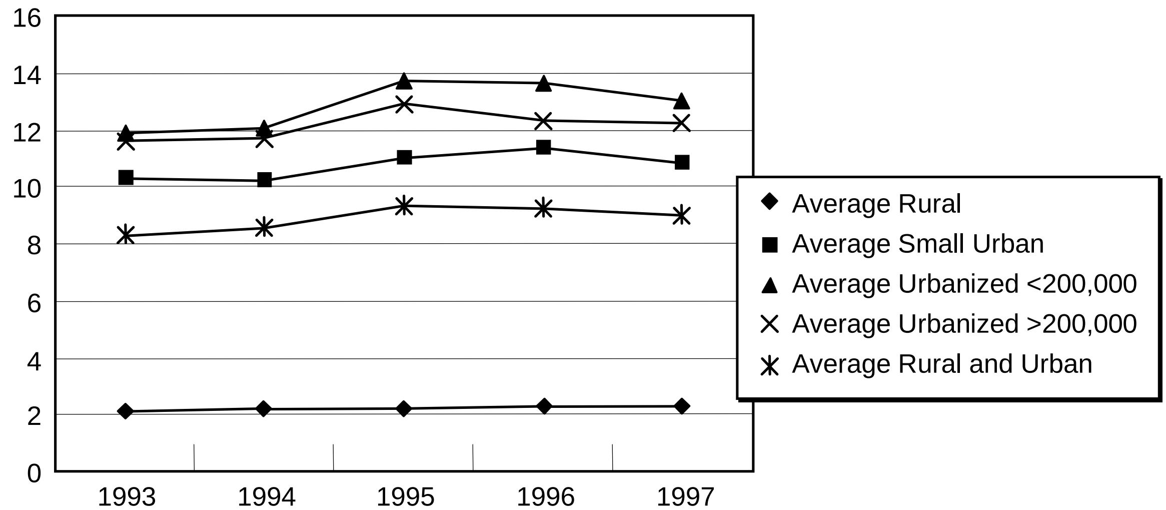
Despite the overall decline in delay observed since 1995, rural delay continues to increase. Every rural functional system had higher average delay in 1997 than in 1995.

Congestion in Metropolitan Areas

The Texas Transportation Institute (TTI) annually estimates congestion costs for travelers in many urbanized areas. The latest TTI study evaluates travel conditions and operations of arterial networks in 68 urbanized areas from 1982 to 1997. The TTI estimates are not directly based on HCM

Exhibit 4-6

Daily Delay, 1993-1997 (Hours per Thousand Vehicle Miles Traveled)



	1993	1994	1995	1996	1997
Rural					
Interstate	0.537	0.591	0.412	0.418	0.463
Other Principal Arterial	1.921	2.094	2.235	2.228	2.259
Minor Arterial	2.548	2.553	2.681	2.926	3.004
Major Collector	3.389	3.694	3.491	3.581	3.666
Average Rural	**2.074**	**2.186**	**2.204**	**2.249**	**2.313**
Small Urban					
Interstate	0.613	0.588	0.473	0.471	0.496
Other Freeways & Expressways	2.579	2.585	2.705	3.129	2.751
Other Principal Arterial	9.548	9.891	11.023	11.025	10.717
Minor Arterial	11.708	11.733	12.654	13.517	12.827
Collector	13.159	12.404	13.419	13.319	12.721
Average Small Urban	**10.268**	**10.160**	**11.020**	**11.316**	**10.772**
Urbanized <200,000					
Interstate	1.394	1.534	0.962	0.913	0.909
Other Freeways & Expressways	3.481	3.341	2.790	3.062	2.949
Other Principal Arterial	14.630	14.756	16.914	16.588	15.987
Minor Arterial	13.423	13.283	15.304	15.909	14.555
Collector	12.484	12.776	14.075	13.419	13.355
Average Urbanized <200,000	**11.891**	**12.062**	**13.720**	**13.614**	**13.027**
Urbanized >200,000					
Interstate	3.175	3.051	2.213	2.413	2.533
Other Freeways & Expressways	4.277	4.408	3.929	3.963	3.833
Other Principal Arterial	15.963	16.047	17.648	16.387	16.091
Minor Arterial	14.449	14.338	16.734	15.755	15.576
Collector	12.702	12.621	14.628	14.657	14.210
Average Urbanized >200,000	**11.593**	**11.694**	**12.938**	**12.329**	**12.176**
Average Rural and Urban	**8.268**	**8.517**	**9.348**	**9.223**	**8.973**

procedures, but assume that a given traffic volume per lane everyday (depending on the facility type) defines the threshold of congestion. TTI then incorporates an estimate of the cost of delay caused by incidents and an allowance for increased fuel consumption. Unlike methodology in the HCM, TTI reports do not account for changes in driver behavior over time. Continuing research supports changes in the HCM procedures which recognizes that drivers today are willing to drive closer together with less space between vehicles and at higher speeds than was the case 15 years ago. Thus, a highway facility with the same traffic volume that it accommodated 15 years ago will be reported as having less congestion today than formerly, using the latest HCM procedures. HCM procedures, however, do not account for delay caused by incidents, which in many cities may be a large portion of the total delay to traffic.

Exhibit 4-7

Daily Delay on Interstate Highways in 1997
(Hours per Thousand Vehicle Miles Traveled)

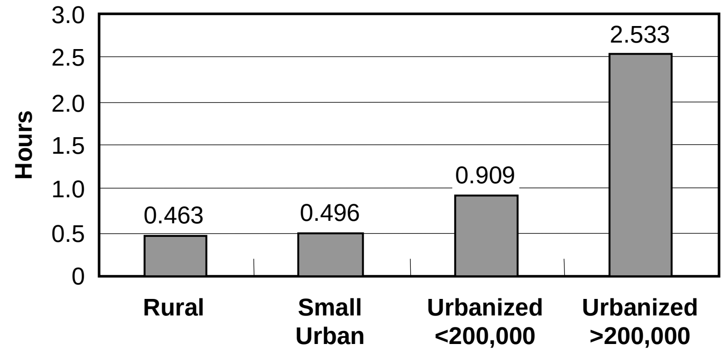
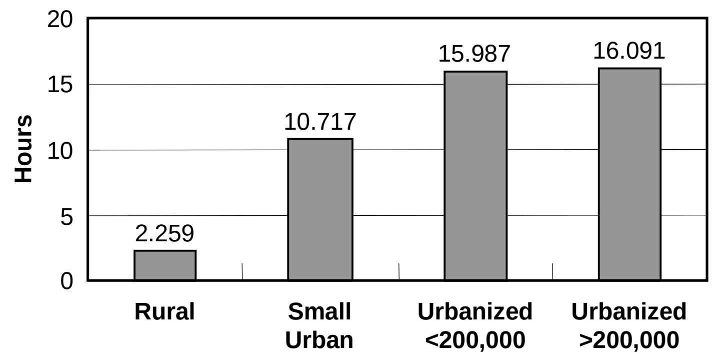


Exhibit 4-8

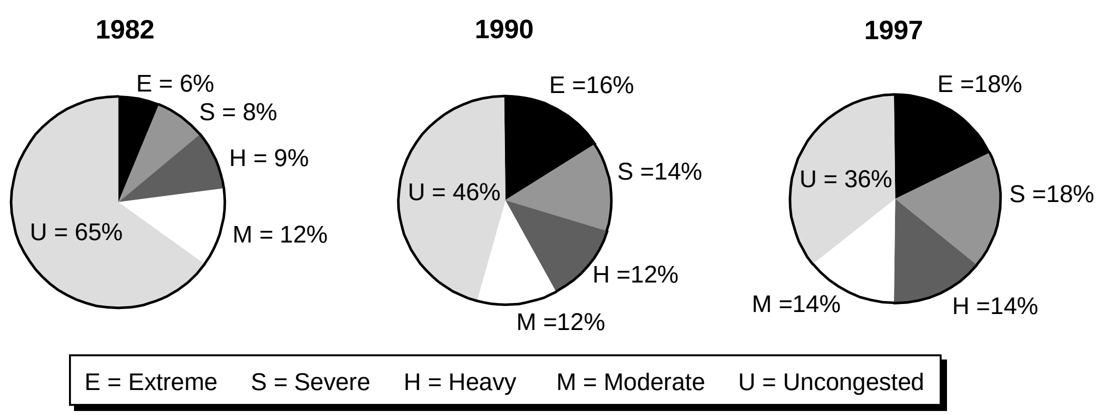
Daily Delay on Other Principal Arterials in 1997
(Hours per Thousand Vehicle Miles Traveled)



According to TTI, the percentage of travel in congested conditions (moderate to extreme) almost doubled, rising from 35 percent in 1982 to 64 percent in 1997. Looking at this from another perspective, about two-thirds of urban travel in 1982 was in uncongested conditions. This has dropped to about one-third of travel by 1997. These statistics are described in Exhibit 4-9.

Exhibit 4-9

Growth of Congested Travel, 1982-1997



The heart of the TTI mobility report is a travel rate index (TRI). Urban mobility levels are estimated using a ratio of travel time during the peak period to that experienced during free-flow travel. The estimates are developed from travel information on freeways and arterial highways. The travel time ratios on each system are combined into a single value using the amount of travel on each portion of the system.   This variable weighting factor allows comparisons between cities like Phoenix, AZ, where principal arterials carry about 50 percent more traffic than freeways, and Portland, OR, where the ratio is reversed.

The estimated peak-period travel rate—in minutes per mile—is divided by the travel rate at the speed limit to identify the time penalty due to congestion. A travel rate index of 1.3 indicates a 30 percent time penalty during the peak—a 20-minute trip becomes a 26-minute trip. The average travel rate index for the 69 urban areas studied by TTI is 1.29. Of the 68 areas, 34 have TRI values in excess of 1.2 and 8 more are within 0.03 of exceeding this level.

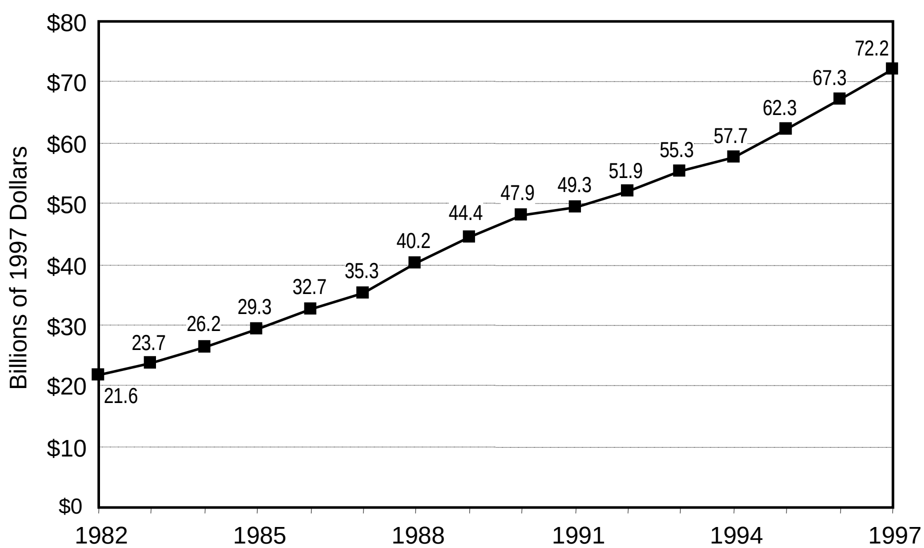
Q. **How many metropolitan areas have experienced increased congestion since 1996?**

A. According to the Texas Transportation Institute, 46 of 68 urban areas studied showed decreased mobility between 1996 and 1997. Eight areas showed improved mobility.

TTI has estimated the cost of congestion from 1982 to 1997, normalizing the values to the same number of metropolitan areas and to 1997 dollars. This cost, by their estimation, has risen from $21 billion to $72 billion for this 16-year period. This trend is shown is Exhibit 4-10.

Exhibit 4-10

Cost of Congestion 1982-1997 in Constant 1997 Dollars



Source: Texas Transportation Institute, 1999 Annual Mobility Report.

Reducing Congestion

The U.S. Department of Transportation is committed to improving the highway system's operational performance. However, solving the congestion problem requires more than adding capacity. The U.S. Department of Transportation is involved with its State and local partners on a variety of techniques to reduce congestion. These include:

- Adding capacity through new and expanded highways;
- Reducing the number of vehicles by promoting transit;
- Increasing the number of passengers in each vehicle through incentive programs;
- Changing when vehicles use the highway, which reduces the load on the highway system at peak-travel time;
- Using the Intelligent Transportation System (ITS) to more efficiently direct traffic; and
- Providing better land use patterns by more efficiently locating employment centers, shopping, and residential neighborhoods.

Future Research

Measurement of congestion is still a difficult problem. Substantial research has supported the use of delay as the definitive measure of congestion, and delay is certainly important. It exacts a substantial cost from the traveler and consequently from the consumer. However, it does not tell the complete story. Moreover, we currently have no direct measure of delay that is inexpensive and reliable to collect. Reliability is another important characteristic of any transportation system, one that industry in particular requires for efficient production. If a given trip requires one hour on day one and one and a half hours on day two, an industry that is increasingly relying on "just in time" delivery suffers. It cannot plan effectively for variable trip times. Additional research is needed to determine what measures should be used to describe congestion and what data will be required to supply these measures.

Transit Operational Performance

Transit system performance can be measured in a variety of ways. One approach is to use operating data from the National Transit Database (NTD). Two nationwide performance measures that can be calculated from the NTD are average operating speeds and vehicle utilization rates, which are used as inputs to the Performance Enhancement Module of the Transit Economic Requirements Model (TERM). Where operating speeds are especially low or vehicle utilization rates are especially high, TERM calls for new investment in those areas to improve nationwide performance. The TERM is discussed in greater detail in Appendix I.

Another approach is to use passenger survey data describing the characteristics of a particular trip. The data source for this approach is the 1995 Nationwide Passenger Transportation Survey (NPTS). Survey observations are for individual transit trips, and include data on travel times, waiting times, and seating conditions upon boarding. These performance measures can be calculated for transit trips by public policy function (See Chapter 2).

Operating Speeds

Average speeds for transit systems are presented for both rail and non-rail modes in Exhibit 4-11. Vehicle speeds are calculated by dividing vehicle revenue miles by vehicle revenue hours, yielding a measure of miles per hour. These are calculated for each operator and mode. The average speeds are then obtained by weighting operator-mode speeds by passenger miles. This weighting allows for a better measure of the speed at which the average transit passenger in the U.S. travels.

The average speed for transit passengers was 20.3 miles per hour (mph) in 1997. This represents an increase of 1.0 mph since 1987, but it is down slightly since 1995. Rail speeds, which are substantially higher than non-rail speeds, were also higher in 1997 (at 26.1 mph) than they were a decade prior, but have decreased slightly since 1995. Non-rail speeds showed a slight increase to 13.8 mph since 1987, but have remained virtually unchanged for the last nine years.

Q. **Why did average rail speeds fall between 1995 and 1997?**

A. Much of the decrease in weighted-average speeds during that period can be attributed to the substantial rise in passenger miles in the New York City subway system, which has a lower operating speed (18.3 mph) than the average for all rail systems (which include commuter rail).

Exhibit 4-11

Passenger-Mile Weighted Average Speed by Transit Mode, 1987-1997

	Rail	Non-Rail	Total
1987	23.7	13.2	19.3
1988	24.4	13.8	19.1
1989	24.3	13.5	19.1
1990	24.8	13.4	19.2
1991	27.6	13.4	20.4
1992	27.0	13.5	20.3
1993	26.3	13.7	19.9
1994	26.7	13.8	20.4
1995	26.6	13.7	20.4
1996	26.0	13.8	20.4
1997	26.1	13.8	20.3

Source: National Transit Database.

Vehicle Utilization

Vehicle utilization is measured as annual passenger miles of travel per capacity-equivalent vehicle operated in maximum service. It incorporates both vehicle operating intensity (the number of miles a vehicle is driven per year) and passenger usage intensity (the number of passengers per vehicle). Exhibit 4-12 shows vehicle utilization for the five highest-PMT modes for 1987 through 1997. Rail modes (heavy rail, light rail, and commuter rail) show much higher utilization rates than do the non-rail modes (bus and demand response), with annual utilization rates over 600,000 passenger miles per vehicle for each of the rail modes.

The trend shows that bus utilization was lower in 1997 than in the late 1980s, but rose slightly in the last two years. Heavy rail utilization fell in the early 1990s, but has now recovered and surpassed the level of 1987. Commuter rail and demand response modes have seen their utilization rates increase over the last decade. Light rail has shown by far the largest increase in vehicle utilization, up 6.8 percent annually since 1987.

Exhibit 4-12

Vehicle Utilization
Annual Percentage Miles Per Capacity-Equivalent Vehicle by Mode (Thousands)

	Bus	Heavy Rail	Commuter Rail	Light Rail	Demand Response
1987	415.8	689.7	741.9	330.9	156.6
1988	432.2	657.7	766.1	415.9	162.1
1989	421.9	689.7	796.8	474.8	164.4
1990	421.5	654.6	773.3	427.8	163.9
1991	421.4	616.1	841.4	408.1	162.4
1992	398.9	625.0	842.6	438.6	170.9
1993	394.3	595.1	745.6	455.4	172.7
1994	393.3	613.7	835.7	540.3	146.9
1995	390.7	630.6	849.1	575.7	154.8
1996	392.4	675.4	863.6	607.5	152.6
1997	400.6	696.3	814.7	637.6	170.1
Annual Rate of Change 1987-97	-0.4%	0.1%	0.9%	6.8%	0.8%

Source: National Transit Database.

Waiting Times and Reliability

Two important measures of transit performance to the user are the length of time that the user must wait at a transit stop for a transit vehicle to arrive, and the reliability of those waiting times. Studies of travel behavior have found that transit passengers find waiting time to be even more onerous than in-vehicle travel time. Thus, an important measure of transit service is the amount of time that passengers must spend waiting to continue on their journey. Reliability, as measured by the variation in waiting times, is also an important measure of performance. As expected waiting times become more uncertain, transit passengers are less able to rely on transit to deliver them to their destinations at their desired arrival time.

Exhibit 4-13 shows the difference in wait times and reliability across the three niches. The basic mobility group is more “dependent” on transit and has a higher tolerance for delay (12.1 minutes) and

Exhibit 4-13

Waiting Times and Reliability

	Average Waiting Time (minutes)	Variation in Waiting Time*
Basic Mobility	12.1	13.6
Location Efficiency	8.9	8.8
Congestion Relief	7.3	9.3

*standard deviation in waiting time.

Source: FTA analysis of 1995 NPTS Database.

unreliability (13.6 minutes) than the other two groups. People with an automobile alternative, using transit to avoid traffic congestion, have average wait times of 7.3 minutes, with 9.3 minutes in variation. Similarly, *above-poverty* households without cars experience wait times that are slightly longer than those experienced by households with cars. They also experience a similar degree of reliability. These observations are consistent with the professional literature, which indicates that higher-income individuals generally place a greater value on their time, as their opportunity cost of not being at work is higher. Thus, passengers who use transit for its location benefits or to avoid traffic congestion are more likely than others to use it only if the system is reliable and minimizes schedule delay.

Seating Conditions

Exhibit 4-14 shows the degree of crowding in transit vehicles, according to the function transit is performing, as measured by the proportion of passengers who are unable to find a seat upon boarding. Transit vehicles are crowded (i.e., transit seating capacity is periodically insufficient) in all three market niches for more than ¼ of riders. Basic mobility passengers experience slightly more crowding than others, while passengers who look to transit as an alternative to their cars experience the least. This relative "equality" of crowding reflects transit's perennial need to serve each of its three constituencies in a balanced way with the limited resources it has available, in this case by allocating capacity such that similar proportions of passengers in each niche are forced to stand at the beginning of their trip.

Exhibit 4-14

Seating Conditions

	Seat Unavailable Upon Boarding
Basic Mobility	29.7%
Location Efficiency	26.3%
Congestion Relief	25.0%

Source: 1995 NPTS Database.