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Report to the Chairman, Subcommittee on Transportation and Related Agencies, Committee on Appropriations, U.S. Senate

November 1989

TRAFFIC CONGESTION

Trends, Measures, and Effects

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Program Evaluation and
Methodology Division

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November 30, 1989

The Honorable Frank R. Lautenberg
Chairman, Subcommittee on Transportation and Related Agencies
Committee on Appropriations
United States Senate

Dear Mr. Chairman:

In response to your letter of May 11, 1989, we are submitting this report entitled Traffic Congestion: Trends, Measures, and Effects. This study focuses on the forces that affect the problem, the severity of the problem, and the effects of traffic congestion on the economy, environment, and human stress. The present report is intended as a companion to our study entitled Traffic Congestion: Federal Efforts to Improve Mobility (GAO/PEMD-90-2). We hope that our work provides the subcommittee with useful information as it considers policies for improving freeway and roadway mobility.

As agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution of it until 30 days from the date of the report. We will then send copies to interested congressional committees and the Department of Transportation, and we will make copies available to others upon request.

If you have any questions or would like additional information, please call me at (202) 275-1854 or Dr. Michael J. Wargo, Director of Program Evaluation in Physical Systems Areas, at (202) 275-3092. Other major contributors to this report are listed in appendix III.

Sincerely yours,

Carl E. Wisler

Carl E. Wisler
Director of Planning and Reporting

Executive Summary

Purpose

Many transportation experts believe that the efficient movement of people and commerce is being threatened by escalating traffic delays from congested conditions. Moreover, some believe that traffic congestion could become the number one problem within surface transportation by the 1990's and into the 21st century. One important issue facing the Congress is the extent to which traffic congestion in large and small metropolitan areas warrants specific federal attention.

To understand more about the nature of traffic congestion, its measurement, and its effects, GAO initiated a study under the sponsorship of the Subcommittee on Transportation and Related Agencies of the Senate Committee on Appropriations. GAO set out to determine the evidence pertaining to the following questions:

- What forces affect the traffic congestion problem and how have they shaped its nature and severity?
- How is traffic congestion measured and how credible are the estimates of urban freeway delay developed by the Federal Highway Administration (FHWA)?
- What effects of traffic congestion have been measured?

By answering these questions, GAO provides the Congress with an overview of the traffic congestion problem. This resource document is a companion to a GAO report that profiles federal efforts to improve freeway mobility. (See GAO/PEMD-90-2.)

Background

The traffic congestion problem, including its commonly associated effects, such as wasted time and fuel, slowed economic productivity, diminished air quality, and higher stress levels, appears to be endemic to most metropolitan areas. There is little doubt that traffic delays occur repeatedly at certain times and locations and also occur randomly from accidents, road construction, and weather conditions. And because the level of congestion is relative to where people drive, increasing traffic delays have been perceived as a major problem by not only urban residents but suburban and some rural residents as well.

Although it is recognized that the traffic congestion problem is escalating, transportation officials differ over how it should be measured and its magnitude. The results of one national study, receiving much professional and public attention, were based on a computer model for forecasting urban freeway delay using the Highway Performance Monitoring System data base. In this study, FHWA estimated that between 1985 and

2005, freeway delay will increase 436 percent, barring changes in highway capacity and driving behavior (or time of travel and vehicle use).

Results in Brief

Trends in major societal forces have shaped the nature and severity of traffic congestion. Shifts in the employment base, the availability and use of private vehicles, and expansion of the labor force, for example, have expanded the location and occurrence of congested road conditions. Traffic congestion has thus become a metropolitanwide problem encompassing suburban as well as urban jurisdictions. (See pages 15-34.)

While traffic congestion is measured in many ways, no standard approach is universally accepted. Transportation agencies use a variety of interrelated measures to characterize congested traffic flow, such as higher traffic density and slower speeds, and these measures can differ on what constitutes an unacceptable level of traffic flow for the capacity of a given road. For all measures, however, the level of traffic congestion increases as the volume of traffic reaches the capacity of the road to carry vehicles efficiently and safely. (See pages 35-49.)

A recent FHWA staff study on congestion represents a significant advance toward quantifying urban freeway delay nationwide. However, by using various combinations of alternative assumptions regarding the threshold of congestion and capacity improvements, the forecast of freeway delay for 2005 in this study could be reduced by about 32 percent below the agency's forecast. Even so, congestion levels would still increase nearly 300 percent over 1985 levels, barring changes in drivers' behavior or the introduction of advanced technology to reduce congestion. (See pages 50-60.)

GAO found limited empirical investigation of the effects of traffic congestion, although some relationships between congestion and higher business costs, poorer air quality, and behavioral change are generally thought to hold. Some studies have been conducted for each potential area, but it is difficult to separate the effect of traffic congestion from other factors that affect the environment, the economy, and human stress. (See pages 61-68.)

GAO's Analysis

Trends

From a review of the literature, GAO identified six forces that shape traffic congestion. Trends in suburban development, the economy, the labor force, automobile use, truck traffic, and the highway infrastructure have tended to spread traffic congestion out across metropolitan areas and have increased both predictable and random delays. Congested traffic conditions are no longer confined to central cities but increasingly occur in suburban and even outlying rural areas. In addition, random interruptions in traffic flow may be a greater source of delay than recurring congestion during peak periods of traffic flow.

Measurement Approaches

Through an extensive literature review and interviews with transportation officials in various metropolitan areas, GAO found that federal, state, and local transportation agencies use various traffic flow measures to estimate the service level of a given facility such as a freeway. GAO identified six interrelated measures that characterize the traffic flow conditions: traffic density, average travel speed, maximum service flow rate, the ratio of traffic volume to facility capacity, average daily traffic volume, and daily vehicle miles of travel.

National Congestion Study Review

FHWA's urban freeway delay model has been used to estimate present and future levels of congestion nationally and to rank 37 of the largest metropolitan areas by the severity of their congestion problems. GAO's review uncovered five areas in which the assumptions made could threaten the accuracy and thus the credibility of the forecasts that were based on this model. GAO noted that the model's omission of capacity improvements, limitations in the Highway Performance Monitoring System data base, and other factors raise questions about the forecasts and comparisons between cities. For example, supplemental analyses, using alternative assumptions specified by GAO, showed that the model was quite sensitive to changes in freeway capacity.

Potential Effect Areas

The information available on potential environmental, economic, and human stress effects is limited but does provide a framework for understanding their nature. Beyond the FHWA urban freeway congestion study, GAO was unable to identify studies that measured the effects of traffic congestion nationwide. In the FHWA staff study, economic effects were quantified by attributing dollar values to the time and fuel wasted in traffic delays. Some information is available about the health and environmental effects of motor vehicle emissions, and laboratory tests have shown that motor vehicles emit high levels of some pollutants under conditions associated with traffic congestion, such as slow speeds and idling. Also, some studies have linked traffic congestion with physiological and behavioral changes.

Recommendation

This study documents important efforts by FHWA to provide information on traffic congestion through the use and analysis of Highway Performance Monitoring System data. Estimates of traffic congestion help inform federal and state transportation agencies as well as the Congress on the present and potential severity of this problem. GAO's review of FHWA's model for estimating urban freeway delay suggests that while the agency is taking aggressive steps to assess the present and future magnitude of traffic congestion, additional attention to this area is warranted.

GAO recommends that the secretary of Transportation direct the administrator of FHWA to review and, where appropriate, modify the collection, use, and analysis of traffic congestion data to ensure that accurate statistics on congestion are available for policy decisions regarding freeway mobility. Careful review and refinement of these data sources could lead to valuable improvements in the quality of the information available to transportation policymakers as they seek effective approaches for improving freeway mobility.

Agency Comments

In the Department of Transportation's response to a draft of this report, it generally agreed with GAO's recommendation but cautioned that studies by its staff may not be representative of, or have potential effect on, department or FHWA policy. The studies cited in GAO's report are, however, considered by the department to be important resource documents that both quantify congestion and assess the relative effectiveness of various ways to reduce the problem. GAO made changes in the final report where appropriate, based on technical points identified by the department. (See pages 72-73.)

Contents

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Abbreviations

ADT	Average daily traffic
DVMT	Daily vehicle miles of travel
FHWA	Federal Highway Administration
GAO	General Accounting Office
HPMS	Highway Performance Monitoring System
OTA	Office of Technology Assessment
SMSA	Standard metropolitan statistical area
V/C	Volume to capacity

Chapter 1

Introduction

Many transportation experts believe that the efficient movement of people and commerce is threatened by the physical deterioration of the highway system and escalating traffic delays caused by congested conditions. For example, the National Council on Public Works Improvement recently found that the quality of the U.S. infrastructure, particularly its highways and mass transit systems, is barely adequate to fulfill current requirements and insufficient to meet the demands of future economic growth and development.[1] In addition, some watchful observers believe that traffic congestion could become the number one transportation problem of the 1990's and remain so into the 21st century unless effective action is taken.[2]

FHWA officials, industry representatives, and the news media have emphasized the growing severity of the traffic congestion problem. For example, FHWA stated in a 1987 report that current "trends have generated travel demands that are exceeding not only the supply that is available at a reasonable level of service, but the very capacity of the transportation system itself."[3] There is little doubt that traffic delays occur in specific locations at recurring intervals in most cities and that delays can occur throughout the day across some metropolitan areas. And because the level of congestion is relative to where people drive, increasing traffic delays have been perceived as a major problem by urban, suburban, and some rural residents.

Traffic congestion, and its effects on economic productivity, air quality, and stress, appears to be endemic to many metropolitan areas in the United States and in other countries.[4] FHWA estimates that metropolitan traffic congestion is severe in areas greater than 2 million population and starts becoming a serious problem in metropolitan areas of over

[1]National Council on Public Works Improvement, Fragile Foundations: A Report on America's Public Works (Washington, D.C.: 1988), pp. 1 and 6.

[2]Robert Cervero, Suburban Gridlock (Brunswick, N.J.: Rutgers University Press, 1986).

[3]Federal Highway Administration, The Future National Highway Program 1991 and Beyond: Urban and Suburban Highway Congestion, working paper 10 (Washington, D.C.: December 1987), p. 77. This paper is part of a series of 19 papers prepared by senior FHWA managers to provide input to federal policies regarding the future federal highway program.

[4]A metropolitan area is basically defined by the U.S. Bureau of the Census as a standard metropolitan statistical area (SMSA). The Bureau also discusses such areas in terms of consolidated metropolitan statistical areas and their subsets, metropolitan statistical areas. These terms refer to statistical aggregations of counties around major cities that embrace most commuter traffic. The urbanized area within the SMSA is not a political boundary but is defined as the area within which the average population density exceeds 1,000 persons per square mile.

250,000 population.[5] However, according to FHWA, small urban areas as well as suburban and rural areas have been experiencing higher rates of congestion growth than large central cities. For example, FHWA estimates that between 1983 and 1985, freeway delay from congestion grew by approximately 39.5 percent in central cities, compared to 66.4 percent in outlying areas and 90.9 percent in rural areas.[6]

Controversial Projections

While transportation experts generally agree that traffic congestion is an escalating problem, estimates of its magnitude are controversial. In support of its growing severity, an FHWA study showed an increasing trend in the proportion of urban freeways that are congested during peak travel hours, from 54 percent of the roads in 1983 to 65 percent in 1987.[7] Another staff study estimated that if no improvements are made to highway capacity by 2005, vehicle delay will increase about 436 percent over the 1985 level, or 8.8 percent a year.[8] In addition, FHWA staff believe that in the next 20 years, a much larger increase in freeway congestion will continue to occur in suburban and rural areas than in central city areas.

Others believe, however, that the 2005 forecast of future urban freeway congestion may misrepresent the severity of the problem for a number of reasons, including the omission of any new highway construction in the congestion model that was used. And in any case, some transportation experts claim that drivers will generally tolerate some level of delay, adapting when and where possible. Although FHWA staff readily accept these criticisms, their congestion forecasts are the ones most often cited in the transportation literature and news media.

Defining Congestion

The term "congestion" has been defined by transportation professionals as a condition in which the number of vehicles attempting to use a roadway at any given time exceeds the ability of the roadway to carry the

[5] Federal Highway Administration, Urban Traffic Congestion: A Perspective to Year 2020 (San Francisco, Calif.: September 1987), p. 1-7.

[6] FHWA, The Future National Highway Program 1991 and Beyond, p. 25.

[7] Federal Highway Administration, The Status of the Nation's Highways and Bridges: Conditions and Performance and Highway Bridge Replacement and Rehabilitation Program 1989 (Washington, D.C.: 1989), p 1-6.

[8] FHWA, The Future National Highway Program 1991 and Beyond, p. 21. According to FHWA, freeway congestion will increase 300 percent in urban areas of over 1 million population and more than 1,000 percent in lesser-populated areas.

load at generally accepted service levels.[9] A facility's service level is described in terms of the operating conditions within a traffic stream, such as the average travel speed, and the perceptions of motorists regarding maneuverability and comfort. Congestion has also been defined as the additional daily travel time arising from reduced speed caused by traffic surges. Federal, state, and local transportation agencies use a variety of measures to describe the flow of traffic. A key consideration in all the measures is the specification of what constitutes an acceptable level of service or traffic flow.

Traffic delays are described by whether they are recurring or nonrecurring. Recurring traffic congestion means predictable times when traffic volumes exceed the design capacities of the roadways and when the geometric design of the roadway does not allow a normal traffic flow. Peak periods of traffic flow commonly occur during the morning and evening rush hours; however, experiences in some metropolitan areas, such as Houston, Los Angeles, and New York, show that traffic delays can occur throughout the day. The problem of recurring traffic congestion is exacerbated by random events, such as accidents, construction activity, and weather conditions, that produce nonrecurring traffic delays.

Even though recurring traffic congestion garners much attention, nonrecurring congestion may actually be a more serious problem. For example, a traffic study of metropolitan Los Angeles noted that 57 percent of the delays were from nonrecurring congestion. It has been estimated that every minute during which an incident that disrupts traffic flow is not responded to causes 5 minutes of delay for motorists.[10]

Objective, Scope, and Methodology

Although state and local governments are primarily responsible for mitigating the causes of traffic congestion, federal funds, programs, and requirements influence most aspects of surface transportation management.[11] The system of interstate, primary, secondary, and urban roads that receive federal aid handles 80 percent of all travel in the nation.

[9] Morris Rothenberg, "Urban Congestion in the United States: What Does the Future Hold?" Strategies to Alleviate Traffic Congestion, proceedings of ITE's 1987 national conference (Washington, D.C.: 1988), p. 374.

[10] Allen Cook, T. H. Maze, and Rong-Shyang Ju, "Techniques for Managing Freeway Traffic Congestion," Transportation Quarterly, 41:4 (1987), 520.

[11] Federal programs to assist local governments in alleviating traffic congestion are discussed in a forthcoming companion GAO report (Traffic Congestion: Federal Efforts to Improve Mobility (GAO/PEMD-90-2).

With the expected completion of the interstate freeway system in the next few years, reauthorizing a Highway Trust Fund after 1991 is being evaluated, as is the federal role in surface transportation.[12] As a result, a number of transportation organizations are developing policy positions to influence federal actions in this regard, including options to address the traffic congestion problem.

Objective

This study is one of a series of reports on freeway mobility requested by Senator Frank Lautenberg, Chairman of the Subcommittee on Transportation and Related Agencies of the Senate Committee on Appropriations. The objective of this report was to examine the evidence that exists regarding the nature and severity of traffic congestion. More specifically, we intended to answer the following evaluation questions:

- What forces affect the traffic congestion problem, and how have they shaped its nature and severity?
- How is traffic congestion measured, and how credible are the estimates of urban freeway delay developed by FHWA?
- What effects of traffic congestion have been measured?

By answering these questions, we hope to have provided the Congress with a framework for discussing traffic congestion and its effects. In conjunction with our companion report profiling federal efforts to address this problem, this resource document should help form a foundation for assessing federal efforts to improve freeway mobility.

Scope and Methodology

This report relies primarily on a synthesis of testimonial and documentary information pertaining to traffic congestion and its potential effects. We collected and reviewed more than 200 documents between August 1988 and January 1989. The data collection approach included computer literature searches, phone interviews, and site visits to selected metropolitan areas. The computer literature search involved our accessing various data retrieval systems, identifying relevant articles on traffic congestion, and collecting this information for further

[12]The Highway Trust Fund was created by the Highway Revenue Act of 1956, a companion to the Federal-Aid Highway Act of 1956, which launched the construction of the National Interstate and Defense Highway System. Most of the trust fund, which receives tax revenue from users of the highway system, is dedicated to construction.

analysis.[13] We searched these systems for metropolitan newspaper coverage of local traffic congestion problems and empirical studies of the potential environmental, economic, and social effects of congestion.

We developed data collection instruments to collect information about the nature and severity of traffic congestion, how it is measured, and its potential effects from representatives of transportation-related organizations located in 12 congested metropolitan areas.[14] We refined the instruments before conducting phone interviews with 40 representatives from federal, state, and local agencies, as well as experts in academia and private industry. In addition, we conducted personal interviews with more than 35 cognizant officials in 4 of the metropolitan areas that we visited.[15] The areas we selected for phone and personal interviewing varied geographically and by the severity of their traffic congestion problems.

We reviewed and synthesized the information we collected by using various evaluation techniques.[16] Our synthesis of published material involved (1) identifying major forces that affect traffic congestion and determining how these have shaped the problem, (2) identifying how traffic congestion is measured, and (3) reviewing what is known about the potential effects of traffic congestion. We summarized the responses to our phone and personal interviews by metropolitan area and compared them by questions. We also generated frequencies to identify response patterns in these data.

In addition, we conducted a methodological review of an FHWA urban freeway congestion model, because of its uniqueness and potential effect

[13]The primary data retrieval systems we examined included DIALOG, SCORPIO, VU/TEXT, DATATIME, and LEXIS-NEXIS. For some of the data retrieval systems, we looked at several subdirectories. Our search of these systems generally covered citations over the last 5 years.

[14]The 12 metropolitan areas were Phoenix, Arizona; Los Angeles, California; Denver, Colorado; Washington, D.C.; Miami, Florida; Tampa, Florida; Atlanta, Georgia; Detroit, Michigan; Dallas, Texas; Houston, Texas; New York, New York; and Seattle, Washington.

[15]Between August and October 1988, we visited Los Angeles, California; Denver, Colorado; Washington, D.C.; and Detroit, Michigan.

[16]Our synthesis relied on techniques discussed in GAO, Designing Evaluations, methodology transfer paper 4 (Washington, D.C.: 1984), and The Evaluation Synthesis, Institute for Program Evaluation methods paper I (Washington, D.C.: 1983).

on transportation policy.[17] To assist us in our review, we asked four transportation experts to examine the model based on our review criteria. Collectively, the four reviewers had experience in national and local transportation planning and operations and in traffic congestion quantification techniques and methodologies and knowledge of the data base used in the model. The criteria we developed to guide their reviews included a standardized list of questions pertaining to theoretical, operational, data, and policy issues related to this model. We analyzed their responses and incorporated their reviews into our analysis of this model. Appendix I names the experts and lists our review criteria.

Finally, we reviewed the results of public opinion polls pertaining to traffic congestion that we found in a computerized search of 26 metropolitan newspapers, national polling organizations, and professional publications. We found traffic congestion cited as a major problem in a number of communities experiencing high growth rates. However, as expected, the level of concern about traffic congestion, as identified in a limited number of pertinent national, state, and regional polls, decreased in importance compared to other broader concerns. For example, while traffic congestion is the major concern in some communities, it has not been identified as a prominant concern in national polls.

Strengths and Limitations

In conducting our research, we used multiple approaches to collect and analyze information on the nature and severity of the traffic congestion problem to ensure the adequate coverage of the subject and the representation of various points of view. For example, our use of several data retrieval systems and interviews with a broad spectrum of knowledgeable individuals allowed us to collect an extensive array of documents for further analysis. We also had recognized transportation experts assist in our review of the FHWA urban freeway delay model. We obtained additional estimates of future levels of traffic delay from FHWA, based on running the agency's computer program with the same data but changing the assumptions regarding the measurement of traffic delays and growth in freeway capacity. We did not, however, independently test the validity of FHWA's model or its data.

[17]The methodology and results of the FHWA congestion study using the model are in three documents: FHWA, The Future National Highway Program 1991 and Beyond; Jeffrey Lindley, A Methodology for Quantifying Urban Freeway Congestion (Washington, D.C.: Federal Highway Administration, 1987), and "Urban Freeway Congestion: Quantification of the Problem and Effectiveness of Potential Solutions," ITE Journal, 57:1 (January 1987), 27-32.

Some constraints, however, limited the scope of our data collection and the extent of the review. For example, from necessity, we concentrated our literature search on studies regarding the direct effects of traffic congestion rather than the broader effects that transportation networks have on the environment, the economy, and human stress. We were also limited in our ability to independently verify the accuracy of the trend data cited for the forces shaping traffic congestion. And since much of the trend data come from the 1980 census reports and a few midcensus surveys, they indicate the direction of change but not current conditions.

Our work was performed in accordance with generally accepted government auditing standards. The Department of Transportation provided written comments on a draft of this report. These comments are presented and evaluated in chapter 6 and are included in appendix II.

Trends Shaping the Traffic Congestion Problem

Trends in a number of interrelated forces have shaped the traffic congestion problem. From our review of the literature, we identified six major forces: (1) suburban development, (2) the economy, (3) the labor force, (4) automobile use, (5) truck traffic, and (6) the highway infrastructure. As these forces are not mutually exclusive, they have tended to interact in ways that have changed the nature and severity of traffic congestion. For example, trends in suburban and economic development have fostered the growth of automobile usage and truck traffic, in turn increasing traffic congestion in many metropolitan areas.

Suburban Development Trends

The prevailing desire to live away from central cities yet still be close to urban amenities has led to suburban development, an evolutionary process that involved first families, then commercial services, and finally jobs. Trends in the population and employment migration to suburban locations within large and small metropolitan areas have affected traffic congestion by reshaping the commuting patterns of many workers.

Population Migration

The U.S. population has increasingly migrated to metropolitan areas across the country, particularly the suburban locations in these areas. In 1950, 29 percent of the U.S. population lived in 14 metropolitan areas of over a million in population. By 1980, almost half the population, 108 million people, lived in 35 metropolitan areas of over a million in population, and one third lived in areas of over 2.5 million. Since 1950, 86 percent of this growth has been in suburban locations, which grew at an annual rate of 1.25 percent from 1980 to 1983, about three times the rate of growth of the core areas surrounding the central business districts. By 1986, 77 percent of the U.S. population lived in urban counties that are defined by the Bureau of Census as standard metropolitan statistical areas.

While metropolitan populations are increasing, so are the populations of counties adjacent to metropolitan counties. According to an Office of Technology Assessment (OTA) report, in the 1960's all regions of the United States exhibited more-rapid metropolitan growth than nonmetropolitan growth, and much of the nonmetropolitan movement came from population increases in counties adjacent to metropolitan areas.[1] However, during the 1970's, nonmetropolitan counties actually grew more

[1] Office of Technology Assessment, Technology and the American Economic Transition: Choices for the Future, OTA-TET-283 (Washington, D.C.: U.S. Government Printing Office, 1988), p. 196. According to the Bureau of the Census, nonmetropolitan counties are classified by the tendency of their populations to commute to counties within standardized metropolitan statistical areas.

rapidly than their metropolitan counterparts in all regions except the South. Table 2.1 depicts population growth percentages by metropolitan and nonmetropolitan counties for 1960-70 and 1970-80.

Table 2.1: Population Growth by Region[a]

County population change	Northeast	North Central	South	West	Total
1960-70					
Metropolitan	10.0%	13.1%	22.2%	28.4%	**17.1%**
Nonmetropolitan					
Adjacent to metro area	10.0	4.4	4.3	13.3	**6.2**
Not adjacent to metro area	3.5	−0.9	0.8	5.0	**1.0**
Total	**8.4%**	**2.0%**	**2.6%**	**9.0%**	**3.9%**
Total	**9.8%**	**9.6%**	**14.3%**	**24.2%**	**13.4%**
1970-80					
Metropolitan	−1.8%	2.6%	21.5%	22.1%	**10.0%**
Nonmetropolitan					
Adjacent to metro area	13.1	8.6	19.6	34.4	**16.7**
Not adjacent to metro area	11.8	6.0	14.7	28.8	**13.8**
Total	**12.8%**	**7.4%**	**17.3%**	**31.6%**	**15.4%**
Total	**0.2%**	**4.0%**	**20.0%**	**23.9%**	**11.4%**

[a]Metropolitan and nonmetropolitan populations are based on 1980 boundaries.

Source: Larry Long and Diana DeAre, "The Economic Population Growth in Nonmetropolitan Settings," in Office of Technology Assessment, Technology and the American Economic Transition: Choices for the Future, OTA-TET-283 (Washington, D.C.: 1988), p. 198.

Employment Migration

Nationwide, there has been a dramatic increase in the number of jobs in suburban locations in virtually every metropolitan area. For a number of reasons, including lower land costs, more amenities, and closer proximity to workers, employment opportunities have expanded into suburban areas. In 1960, about 14 million jobs were in suburban areas, or about 35 percent of all metropolitan jobs. By 1980, the number of jobs in the suburbs had more than doubled to about 33 million, representing nearly half of all metropolitan jobs. According to Alan Pisarski in a 1987 report on American commuting patterns, suburban areas now have about 60 percent of all metropolitan workers and are experiencing about 67 percent of the total job growth.[2] Table 2.2 shows the national and regional distribution of workers within metropolitan areas in 1980.

[2]Alan Pisarski, Commuting in America: A National Report on Commuting Patterns and Trends (Westport, Conn.: Eno Foundation for Transportation, Inc., 1987), p. 4.

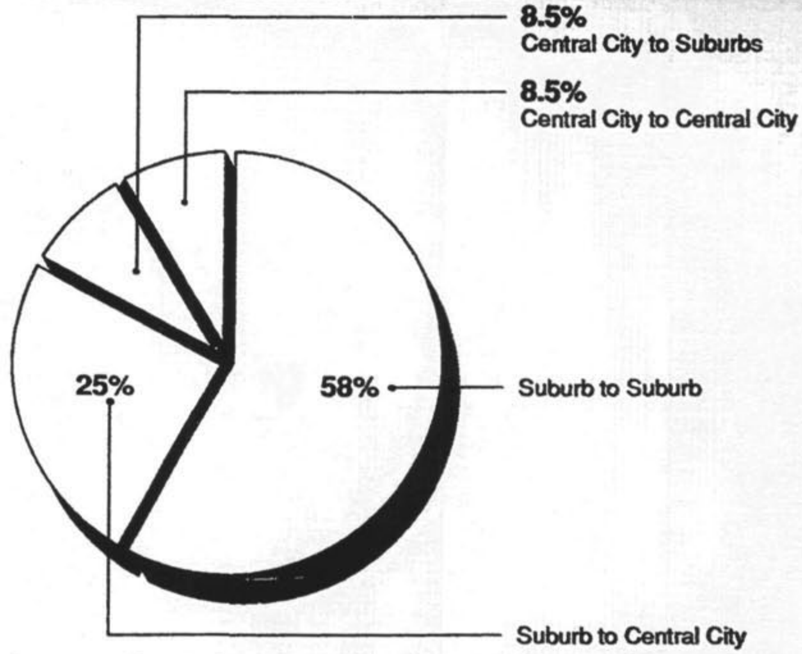
Table 2.2: Distribution of Workers Within Metropolitan Areas in 1980

Area	Percent of workers in metropolitan areas	Difference from national	Percent of metropolitan workers in suburbs	Difference from national
National	77%	0	61%	0
Northeast	86	+9	64	+3
North Central	73	−4	62	+1
South	70	−7	58	−3
West	85	+8	61	0

Source: Alan Pisarski, Commuting in America: A National Report on Commuting Patterns and Trends (Westport, Conn.: Eno Foundation for Transportation, Inc., 1987), p. 30.

Suburban population expansion ushered in the traditional suburb-to-central-city commuting pattern along radial roads and mass transit lines. In turn, the subsequent migration of jobs to suburban locations altered commuting patterns and made them more suburban. Between 1960 and 1980, intersuburban traffic movement became the dominant commuter pattern, increasing from 28 percent to 38 percent of all commuter trips. During this period, intercity travel decreased from 46 percent to 30 percent of all commuter trips, and the suburb-to-central-city work-trip pattern increased slightly from 16 percent to 19 percent of all commuter traffic. Trends in the distribution of commuter traffic, however, varied among metropolitan areas. For example, a more significant shift in commuting patterns occurred in metropolitan areas of over 1 million commuters than for areas of fewer commuters. Figure 2.1 displays the distribution of growth in commuter traffic between 1960 and 1980.

Figure 2.1: Distribution of Growth in Commuter Traffic 1960-80



Source: Alan Pisarski, Commuting in America: A National Report on Commuting Patterns and Trends (Westport, Conn.: Eno Foundation for Transportation, Inc., 1987), p. 43.

Little is known about travel between metropolitan and nonmetropolitan counties. Pisarski noted that from 5 percent to 15 percent of the workers commuted to metropolitan areas in more than 700 of 2,400 nonmetropolitan counties in 1980.[3] While these trips added to the metropolitan traffic flows at different stages in the commute, it is difficult to quantify their effect on metropolitan traffic congestion. By traversing suburban areas, they added to the suburb-to-suburb commuting pattern and, depending on the eventual destination of these trips, they added to traffic's moving downtown, between cities, and from the center city to other suburban locations.

Economic Trends

Economic trends, including changes in employment base, economic growth and distribution, methods of production and communication, and the amount of discretionary travel have changed the distribution of goods, services, and travel patterns. These trends have affected the location and occurrence of metropolitan traffic congestion.

[3] Pisarski, Commuting in America, p. 47.

Shift in Employment Base

According to a 1987 FHWA study, while the magnitude of the national shift from a manufacturing to service- and knowledge-based economies may be disputed, the shift is clearly occurring in many localities.[4] Further, experts believe that this sector has been and will continue to be the primary area of job expansion, unless there are major technological advances in manufacturing industries. For example, the Bureau of Labor Statistics projects that more than half the 20 million new jobs expected to be created in the U.S. economy by 2000 will be in service industries, particularly health care and business services.[5]

Jobs in service industries have tended to concentrate in exurban locations within large metropolitan areas. Exurban areas have been defined as independent "urban villages" on the outskirts of major cities. They are usually comprised of office, retail, housing, and entertainment areas such as occur in Southfield outside Detroit and Tysons Corner outside Washington, D.C.[6] Traffic congestion has increased in these areas because of the concentration of activities and the general lack of transportation infrastructure.

Economic Growth and Distribution

The domestic and international growth of complex production and distribution networks is reshaping the location of America's economic activities and is also affecting the patterns of commodity movement. These changes are tending to concentrate wealth and economic activities in certain locations, especially in regions that surround major coastal cities.[7] According to a 1987 FHWA report, the growth of international trade will affect the total demand for freight transportation, and it will shift the dominant movement of goods from between domestic areas to across international borders.[8] Table 2.3 shows that the predominant areas of growth are in cities on or near the east and west coasts and in the Southwest.

[4]Federal Highway Administration, The Future Highway Program 1991 and Beyond: Changing Demographics and Economic Base, working paper no. 1 (Washington, D.C.: December 1987), p. 20. According to this report, the shift to services has been largely relative, not absolute.

[5]Congressional Research Service, The Cities, vol. 9, no. 10 (Washington, D.C.: November-December 1988), p. 7.

[6]Christopher Leinberger and Charles Lockwood, "How Business Is Reshaping America," The Atlantic Monthly, October 1986, p. 43.

[7]OTA, Technology and the American Economic Transition, p. 190.

[8]FHWA, The Future Highway Program 1991 and Beyond, p. 22.

Table 2.3: Major U.S. Metropolitan Population Growth

Largest population gains 1970-86	Statistical area	Population (in millions)	Annual percent
Los Angeles-Anaheim-Riverside, California	CMSA[a]	3.094	1.70%
Houston-Galveston-Brazoria, Texas[b]	CMSA	1.465	3.28
Dallas-Fort Worth, Texas	CMSA	1.303	2.79
San Francisco-Oakland-San Jose, California	CMSA	1.125	1.34
Miami-Fort Lauderdale, Florida	CMSA	1.024	2.75
Phoenix, Arizona	MSA[c]	0.929	4.28
Atlanta, Georgia	MSA	0.877	2.65
San Diego, California	MSA	0.843	3.06
Tampa-St. Petersburg-Clearwater, Florida	MSA	0.808	3.49
Denver-Boulder, Colorado[b]	CMSA	0.609	2.53
Washington, D.C.-Md.-Va.	MSA	0.523	1.00
Seattle-Tacoma, Washington	CMSA	0.448	1.37
Orlando, Florida[b]	MSA	0.445	4.37
Sacramento, California	MSA	0.443	2.66
West Palm Beach-Boca Raton-Delray Beach, Florida	MSA	0.407	4.95

[a]Bureau of the Census designated consolidated metropolitan statistical area.

[b]Metropolitan areas that would drop off the list of largest population gains if only the growth rate for the last year were considered.

[c]Bureau of the Census designated metropolitan statistical area.

Source: Office of Technology Assessment, Technology and the American Economic Transition: Choices for the Future (Washington, D.C.: 1988), p. 192.

Methods of Production and Communication

Changes in production methods and communication have decentralized operations and increased reliance on trucks and private vehicles. In manufacturing, it is recognized that the emergence of relatively small batch production, "just-in-time" inventory systems, and the growth of tightly linked networks supplying goods to retail outlets have encouraged the decentralization of activities. These new methods of production tend to favor trucks over slower and less flexible transportation.

Telecommunication advances and the nature of work have also made the location of office buildings less dependent on proximity to clients and supporting services. Although this change has made it easier for businesses to branch out and away from central-city locations, the dispersal of office space has fragmented commuting patterns, necessitating a greater reliance on private vehicles for the work commute. However, improved telecommunication links between the home and the office may alter the frequency and timing of the work commute for a portion of the labor force. Home-based and satellite-center telecommuting are work options that may help reduce commuter traffic by allowing employees to work at home and at centers close to where they live.

Discretionary Travel

The amount of discretionary travel available to Americans is affected by the amount of disposable income and time that they can allocate to this form of travel, as well as by demographic factors. In general, the decline of both disposable income and available free time for most Americans reduces the duration of discretionary travel. However, the growing population of elderly and childless couples, which typically have more money and time for travel, has fostered discretionary travel. In both cases, these trends tend to increase travel near the home.

Disposable income has declined for most Americans, but the amount of available free time appears to have the greater effect on the characteristics of discretionary travel. According to an OTA report, time constraints on personal travel and family vacations, more than reduced disposable income, have altered the travel behavior of many families.[9] For example, in order to fit into increasingly complex personal schedules, many households are now looking for short-term recreation in close proximity to the home, in lieu of the traditional "2 weeks at the beach." This situation may change somewhat, however, if Americans begin enjoying increases in vacation and holiday travel, as some observers predict.[10]

Demographic factors also affect discretionary travel. The decline in family size will mean that fewer young people will be around to support recreational markets. However, according to the OTA study, an increase in discretionary travel by greater elderly and childless family populations are expected to offset the effect of these changes in family composition. For example, as people reach retirement age, their transportation needs change—they no longer commute to work, but they have more time to travel, go shopping, and visit family. In addition, the increase in

[9] OTA, Technology and the American Economic Transition, p. 75. According to OTA, average household income declined between 1977 and 1984 for all but the top 10 percent of American families.

[10] Elizabeth Deakin, "Transportation in California: Problems and Policy Options Through the Year 2000," University of California at Berkeley, Department of City and Regional Planning, and the Institute of Transportation Studies, Berkeley, California, 1987, p. 10.

the number of shorter and more-intensive weekend and holiday vacations has magnified travel on roads linking metropolitan areas with nearby resort locations.

The factors previously mentioned and others have increased family, business, social, and recreational travel as a percentage of all personal travel. Changes in the nature of discretionary travel tend to increase metropolitan traffic flow throughout the day and the demands on facilities connecting major population centers with resort areas.

Labor Force Trends

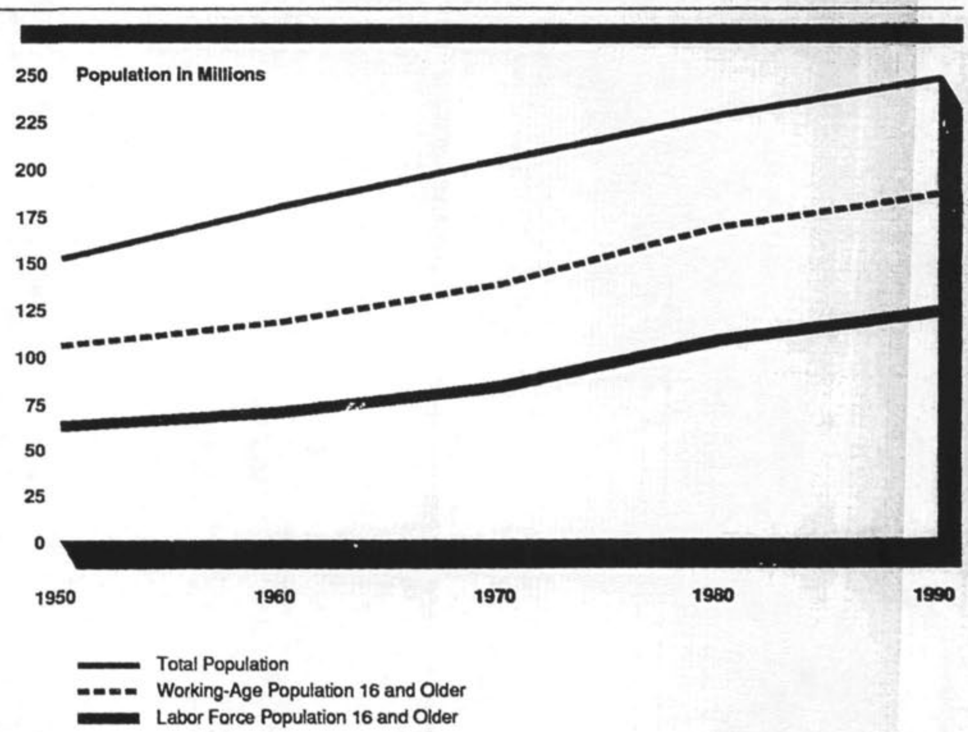
Increases in the number of jobs and of workers in the labor force also affect traffic congestion. Labor force expansion has increased the number of workers and the number of work-trip commuters in both fast- and slow-growing metropolitan areas. Two demographic trends that have had major effects on the rapid growth of the labor force are the growth in the working-age population and an unprecedented number of women entering the labor force.

Labor Force Participation

The traditional relationship between total population growth and the growth of the working-age group (16 years of age and older) has changed in the last decade, as has the relationship between growth in the working-age population and the growth of the labor force. Between 1940 and 1960, total population growth exceeded growth in the working-age population and the labor force. However, because of the entrance of the post-World War II "baby boomers" into the working-age group, the growth of this population and the total labor force exceeded total population growth between 1960 and 1988. More than twice as many people entered the working-age group between 1970 and 1980 as entered between 1950 and 1960.

Figure 2.2 illustrates growth trends in these three populations from 1950 to 1990 (estimated). Although the lines appear similar, the percentage change between decades for the working-age population and the labor force is much greater than the fairly consistent growth rate of the total population. For example, while working-age population increased 36 percent and the labor force grew 43 percent between 1960 and 1988, total population increased only 27 percent.

Figure 2.2: Trends in Population and Labor Force Growth[a]



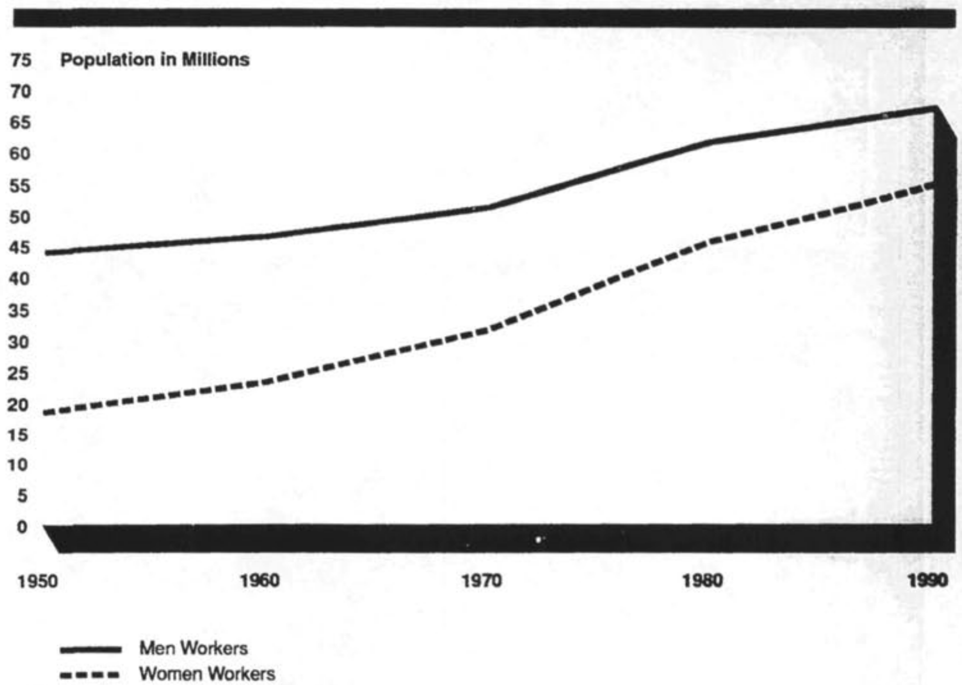
[a]Data for 1990 were extrapolated from 1988 estimates.

Source: The Bureau of the Census and the Bureau of Labor Statistics, Washington, D.C., 1989.

Women Entering the Labor Force

A major explanation for the large leap in the proportion of the working-age group actually entering the labor force is the extraordinary number of women taking jobs outside the home. In 1950, about one third of working-age women were employed, representing about 30 percent of the labor force. By 1988, almost two thirds were employed, constituting more than 45 percent of the labor force. Since 1950, the growth rate of women in the labor force exceeded that of men, although men still outnumber women. According to Pisarski, of the 50 million new entries between 1950 and 1985, 30 million were women. Figure 2.3 shows the share of men and women workers in the labor force from 1950 to 1990 (estimated).

Figure 2.3: Trends in Shares of the Labor Force by Gender[a]



[a]Data for 1990 were extrapolated from 1988 estimates.

Source: Bureau of Labor Statistics, Washington, D.C., 1989.

There is some prospect of a smaller labor force, as the "baby boom" generation ages, even though the rate of women participating in the force is expected to climb. According to a Congressional Research Service report, America's prospect of imminent long-term labor scarcity means that opportunities in all sectors for "marginal" workers will be greatly improved, especially for those who can be trained for work in a "high-tech" economy.[11] The Congressional Research Service concluded that if labor scarcity requires employers to seek out underused labor resources, the "reverse commute" of inner-city residents to jobs in the suburbs and surrounding areas may become even more common than today.

Automobile Use Trends

Our review of the transportation literature identified two automobile trends that have affected the level of traffic congestion. Both the growth in vehicle availability and an increased use of private vehicles

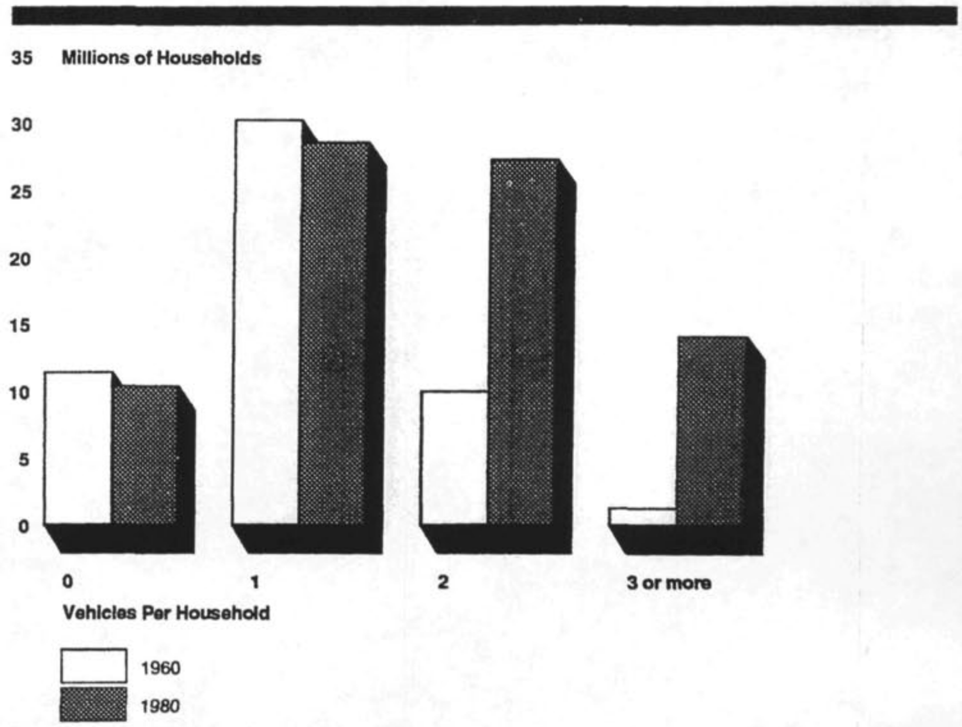
[11]Congressional Research Service, The Cities, p. 25.

over other modes of surface transportation have dramatically increased the number of vehicles using the transportation system.

Vehicle Availability

A trend in automobile use is reflected in an increase in vehicles available per worker and per household. Between 1960 and 1980, the average number of vehicles per worker grew at almost triple the rate of growth of the labor force. By 1980, the number of vehicles available per worker in the labor force averaged 1.34. In addition, according to Pisarski, vehicle ownership, as a characteristic of American households, grew 60 percent from 1960 to 1980. The number of vehicles per household increased from 1.03 in 1960 to 1.61 in 1980. In 1980, more than 50 percent of the households had 2 or more vehicles and only 13 percent did not have a vehicle, down from about 22 percent in 1960. Figure 2.4 depicts the dramatic growth in vehicle availability between 1960 and 1980.

Figure 2.4: Change in Vehicle Availability by Household



Source: Alan Pisarski, Commuting in America: A National Report on Commuting Patterns and Trends (Westport, Conn.: Eno Foundation for Transportation, Inc., 1987), p. 33.

The Use of Private Vehicles

Between 1960 and 1980, the use of private vehicles for the work commute nearly doubled, from 43 million users to 83 million users. Pisarski notes that since the labor force grew by 50 percent during that 20-year period, only half the growth of private vehicle usage can be attributed to growth in the number of commuters—the other half was from a shift of commuters from other modes of transportation to private vehicles.[12] It has been estimated that between 1970 and 1980, the use of public transit for the work commute fell from 8.9 percent to 6.4 percent among all commuters, while personal vehicle use increased from 80.2 percent to 85.7 percent of all commuting modes.[13]

Some transportation experts contend that our preference for private vehicles is an expression of American individualism and a practical means for achieving physical and social mobility. Americans are conditioned to demand freedom of mobility, a freedom that is enhanced by the psychological aspect of driving one's own car. The "personalization" of transportation services has increased to a point at which two thirds of all trips (and 86 percent of all commuting trips) are made alone.[14]

Truck Traffic Trends

Our research uncovered several trends that contribute to the involvement of trucks in metropolitan traffic congestion. The greater use of trucks, their increased size and weight, and the growth of heavy-truck accidents are all factors adding to increased traffic delays in many metropolitan areas.

Level of Truck Traffic

Changes in inventory policies and a phenomenal growth in imports of manufacturer and consumer goods have increased the use of trucks to carry freight. The "just-in-time" inventory policies of many manufacturers have accelerated the demand for speedy, direct truck service. As a result, some transportation officials claim that many urban interstate highways have become local arterials and manufacturing lines. Container traffic, originating at coastal ports, has also grown dramatically because of an increase in the need to import goods to points across the country.

[12] Pisarski, Commuting in America, p. 7.

[13] OTA, Technology and the American Economic Transition, p. 120.

[14] OTA, Technology and the American Economic Transition, p. 115.

Regulatory reform and new markets were forces behind a dramatic growth in the number of trucking firms entering the industry. Regulatory change in the rules governing entry, pricing, and services in the trucking industry, as provided for in the Motor Carrier Act of 1980, allowed this industry to capitalize on its speed, flexibility, and cost-effectiveness to enhance its already dominant share of the freight market.[15] In 1986, the trucking industry received approximately 77 percent of all freight transportation revenues in this country.[16] Between 1980 and 1986, the number of federally regulated trucking companies, which does not include private companies, increased 66 percent alone.[17] Although the number of trucking companies has increased significantly since 1980, the actual number of commercial and private truck-tractor registrations declined from 1.4 million in 1980 to 1.1 million in 1986, with only a slight increase in the registration of private and commercial trailers.[18]

Another reason behind the proliferation of trucking firms was railroad deregulation. According to an OTA report, the Railroad Revitalization and Recovery Act of 1976 and the Staggers Rail Act of 1980 liberalized merger policies and made it easier for railroads to demonstrate unprofitability in a line.[19] The railroads, faced with shifting markets and increased competition from trucks, began abandoning some lines and consolidating others, thereby allowing trucks to fill in the service gap.

Although the number of trucking firms has increased, growth in the number of miles traveled by trucks and in their size are the most significant factors behind the effect of trucks on metropolitan traffic congestion. Based on an increase of 100 percent in the number of freight miles traveled per ton and a 60-percent increase in the movement of freight by ton between 1950 and 1983, it has been estimated that the average haul

[15] OTA, Technology and the American Economic Transition, p. 233. According to OTA, the number of trucking firms increased from 18,000 to 30,000 between 1980 and 1983. However, because average profits for the industry have fallen below traditional levels from an increase in competition, the number of firms has grown smaller in recent years.

[16] 1986 American Trucking Association data as used in Office of Technology Assessment, Gearing Up for Safety: Motor Carrier Safety in a Competitive Environment, OTA-SET-382 (Washington, D.C.: U.S. Government Printing Office, 1988), p. 3.

[17] Transportation 2020 Program, Beyond Gridlock: The Future of Mobility as the Public Sees It (Washington, D.C.: June 1988), p. 29.

[18] OTA, Gearing Up for Safety, p. 31.

[19] OTA, Technology and the American Economic Transition, p. 233.

length per ton increased 30 percent.[20] Most heavy commercial trucks travel close to 100,000 miles per year and dominate commercial interstate traffic. According to one study, these combination trucks presently account for 10 to 12 percent of total urban freeway traffic.[21]

The Size and Weight of Trucks

According to an OTA report, trucks have become significantly bigger and heavier since deregulation, primarily in response to federal legislation requiring the states to allow longer, wider trailers and heavier gross weights.[22] The report concludes that because many of the roads have not been upgraded in design and capacity, the wider trailers and heavier-gross-weight trucks are more difficult to handle than smaller trucks. Handling today's trucks safely through turns, in passing lanes, and on ramps has become difficult for even skilled and experienced drivers, particularly during urban peak-period traffic congestion.

Heavy-Truck Accident Rate

The difficulty of maneuvering heavy trucks (over 26,000 pounds in gross vehicle weight) through urban traffic has tended to increase the likelihood of accidents. According to OTA, although the number of accidents involving passenger cars has declined, the number involving heavy trucks increased a total of 15 percent between 1981 and 1986, reaching an estimated total of 278,322 accidents nationwide.[23]

The rate of accidents of heavy trucks is also increasing faster than the growth in total truck miles traveled. Studies have shown that the rate of heavy-truck accidents increased roughly 40-percent faster than the increase in total truck miles traveled and that most of these accidents occur between 6 a.m. and 6 p.m. on the urban roads.[24] Poor lighting conditions, driver fatigue, and deficient truck maintenance are some of the reasons given for a greater number of fatal accidents at night. Figures 2.5 and 2.6 (on pages 29 and 30) portray these data.

[20] OTA, Technology and the American Economic Transition, p. 231.

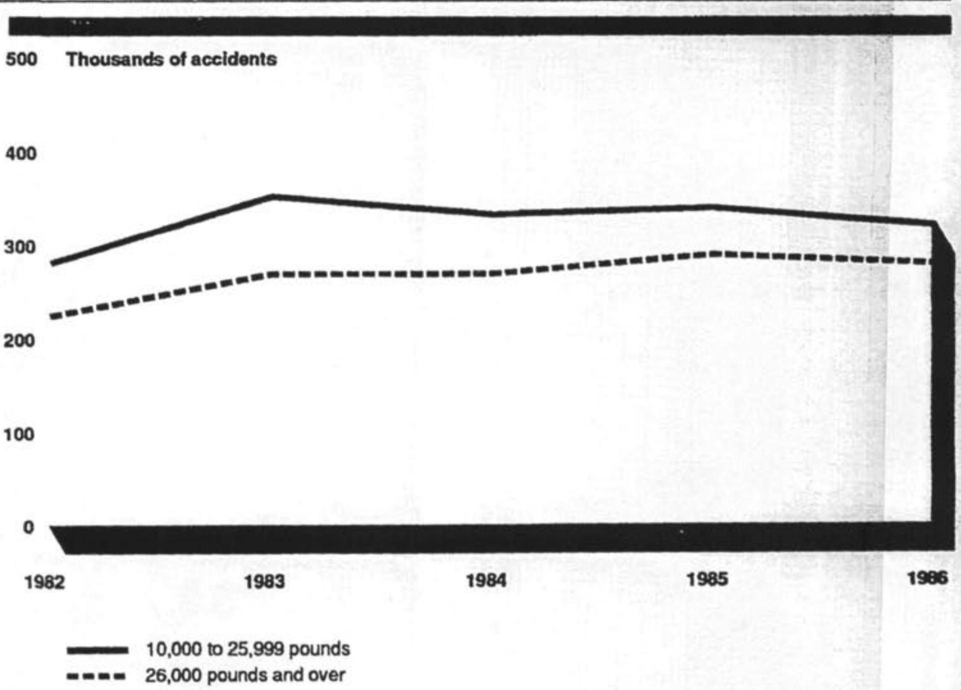
[21] Federal Highway Administration, Urban Traffic Congestion: A Perspective to Year 2020 (San Francisco, Calif.: September 1987), p. 1-8.

[22] OTA, Gearing Up for Safety, p. 3.

[23] OTA, Gearing Up for Safety, pp. 5 and 85. According to OTA, existing heavy-truck data and information resources have deficiencies that limit their reliability. In addition, OTA noted that cooperative federal and state efforts, under the Motor Carrier Safety Assistance Program, may have played a role in the slight drop in the number of heavy-truck accidents that occurred in 1986.

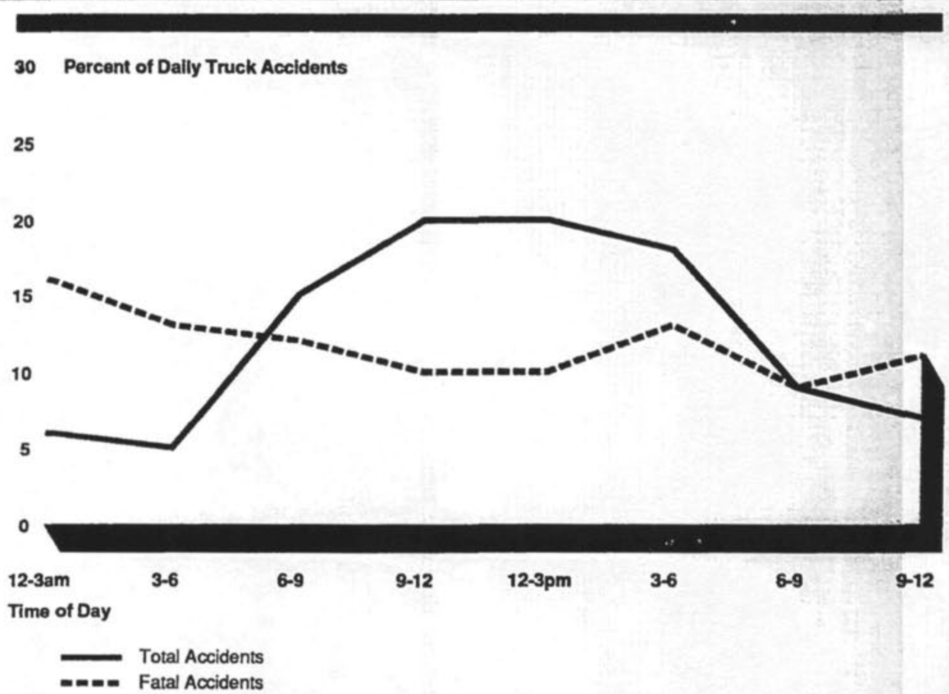
[24] OTA, Technology and the American Economic Transition, p. 406, and Gearing Up for Safety, p. 103.

Figure 2.5: Truck Accidents by Truck Weight



Source: Office of Technology Assessment, Gearing Up for Safety: Motor Carrier Safety in a Competitive Environment, OTA-SET-382 (Washington, D.C.: U.S. Government Printing Office, September 1988). Based on National Accident Sampling System data.

Figure 2.6: Combination-Truck Accidents by Time of Day[a]



[a]The figure shows the percentage of all accidents and all fatal accidents that occur at each time interval. As a percentage of the total for each category, more fatal accidents occur in the morning and late at night than would be expected from the number of accidents, including nonfatal accidents.

Source: Office of Technology Assessment, Gearing Up for Safety: Motor Carrier Safety in a Competitive Environment, OTA-SET-382 (Washington, D.C.: U.S. Government Printing Office, September 1988).

Highway Infrastructure Trends

Demand for new highways, accompanying the population and employment migration to the suburbs and beyond, has not been met by an increase in new construction. While the overall number of vehicle miles traveled between 1960 and 1987 increased at around 3.7 percent per year, or about 168 percent, the number of new highway miles increased by only about 9 percent.[25] In addition, demand for intersuburban traffic movement and a greater number of highway access points have changed the intended use of interstates through many metropolitan areas. Since highway capacity has not met growing demands, the duration and location of traffic congestion have increased, as well as the number of accidents.

Reasons for the decline in new highway construction during the last 20 years include reduced funding for construction projects, the rising costs

[25]National Council on Public Works Improvement, Fragile Foundations: A Report on America's Public Works (Washington, D.C.: 1988), p. 133.

of construction, heightened environmental concern, and public resistance to building more highways. For example, revenues from gasoline taxes, which support highway maintenance and construction, have declined relative to the increase in the number of cars because of an absolute decline in fuel consumption, caused in turn by higher prices and more fuel-efficient motor vehicles. Increases in the price of petroleum-based products have also increased construction costs, in terms of operating and materials costs, such as for asphalt.[26]

According to the National Council on Public Works Improvement, "we have worn through the cushion of excess capacity built into earlier investments without making commensurate investments of our own."[27] It has been estimated that $162 billion in capital improvements will be required over a 20-year period to keep up with increasing demand.[28] Even though the amount of funding available for highway maintenance and new construction began increasing in the mid-1980's, the supply of highways is still expected to lag behind demand. One reason for this lag has been the cost of improving urban freeways. According to FHWA, some states have indicated that their larger metropolitan areas cannot rely exclusively on traditional highway construction as a solution to the traffic congestion problem because of the excessive cost of obtaining rights-of-way.[29]

Figure 2.7 compares vehicle miles traveled with capital investments in highways and bridges between 1951 and 1987. While growth in vehicle miles traveled increased at a fairly steady rate during this period, capital highway investment, as adjusted for inflation, fluctuated. Until about 1966, it appears that capital investment paralleled the growth of vehicle miles traveled. However, during the 1970's, these investments declined precipitously and continued declining until around 1984, when they began increasing once again. Between 1984 and 1987, capital investment increased 31.5 percent.

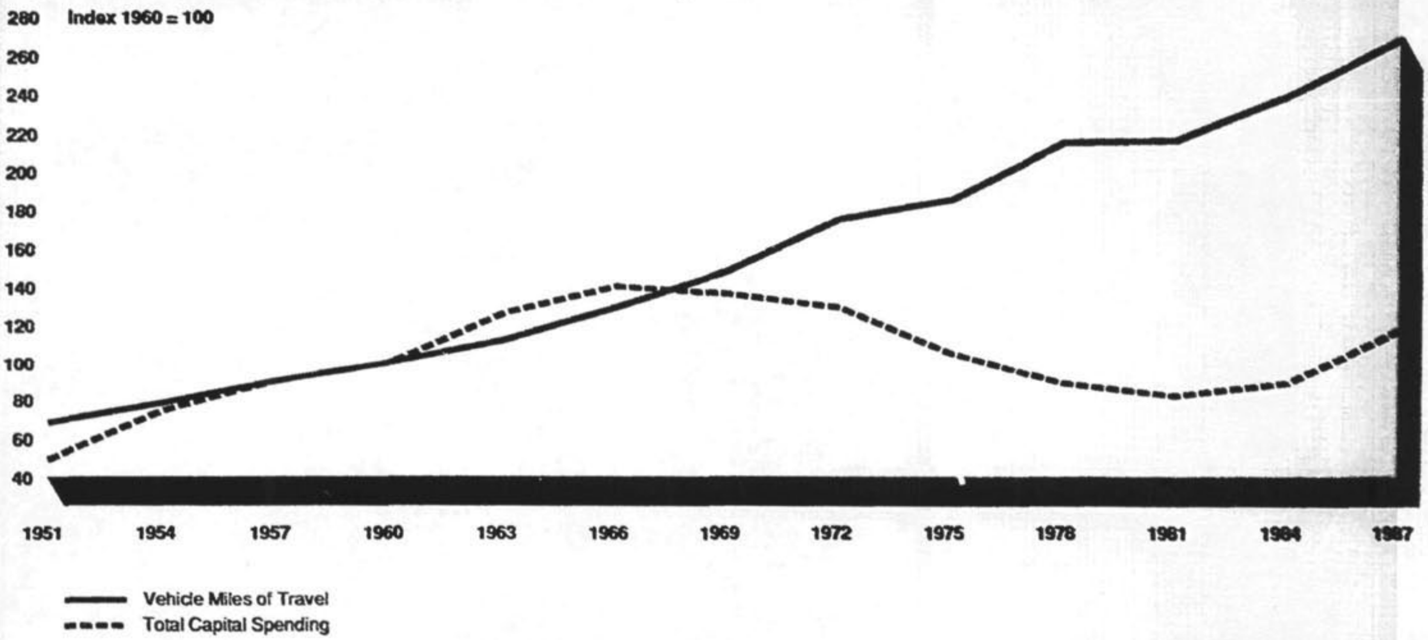
[26]Daniel Nagin and Kant Rao, "Addressing the Highway Funding Crisis: A Review of Alternative Petroleum-Related Taxes," in Strategies to Alleviate Traffic Congestion, proceedings of ITE's 1987 National Conference (Washington, D.C.: Institute of Transportation Engineers, 1988), pp. 644-45.

[27]National Council on Public Works Improvement, Fragile Foundations, p. 1.

[28]Morris J. Rothenberg, "Urban Congestion in the United States: What Does the Future Hold?" p. 387, in Strategies to Alleviate Traffic Congestion, proceedings of ITE's 1987 National Conference (Washington, D.C.: Institute of Transportation Engineers, 1988).

[29]Federal Highway Administration, The Status of the Nation's Highways and Bridges: Conditions and Performance and Highway Bridge Replacement and Rehabilitation Program 1989 (Washington, D.C.: 1989), p. I-8.

Figure 2.7: Vehicle Miles Traveled by Capital Investment in Highways[a]



[a]Capital investment in highways was adjusted for inflation using appropriate structural and gross national product deflators.

Source: National Council on Public Works Improvement, Fragile Foundations: A Report on America's Public Works (Washington, D.C., 1988), p. 139. Updated data were obtained from Apogee Research, Bethesda, Maryland.

Implications for Traffic Congestion

Traffic congestion does not occur uniformly across metropolitan areas; it is a metropolitan and regional phenomenon that can occur in many locations and on various types of roads. Traffic congestion, both recurring and nonrecurring, is common in the central business district and on links between suburban locations and the core area, and it is increasing on roads between suburban locations and between nonmetropolitan and metropolitan counties. Both sources of congestion add to traffic delay; however, nonrecurring congestion may be a more serious problem. Because metropolitan traffic congestion can exist on urban highways, access roads, county roads, and local arterials around suburban business centers, it has become an interjurisdictional problem.

The six forces shaping traffic congestion have tended to spread traffic out across metropolitan areas and to increase both predictable and random delays. Although the measurable effects of these forces on traffic congestion are difficult to quantify, we believe that they have changed its nature and severity. In effect, they have made traffic congestion a metropolitanwide problem by expanding the traditional locations and occurrences of congestion.

Suburban Development

The migration of population to suburban areas, followed by employment opportunities, has placed a new set of demands on streets and highways that often exceed their intended capacity. For example, the beltways around many cities are clogged with commuters moving between suburban areas, and delays are increasing on some rural roads leading to suburban office parks. Lack of highway capacity to serve these new demands, along with limited alternatives to private vehicle use in suburban and exurban areas, has resulted in increasing traffic delays around many metropolitan areas.

Economic Development

The decentralization of office locations to urban villages has necessitated the greater use of private vehicles and the movement of lighter freight loads by truck. In addition, changes in production methods and communication and more discretionary travel have tended to increase the number of vehicle trips made each day. However, the severity of local traffic congestion also depends somewhat on the robustness of a local economy. Metropolitan areas along the coasts, with economies thriving from increased international trade, tend to have more traffic-related problems than cities in economic recession.

Labor Force

The expansion of the labor force, as a result of a larger working-age population and greater participation of women in the work force, has affected the number of commuters and their travel patterns. More commuters have strained the transportation infrastructure, resulting in longer periods of recurring traffic congestion. More women in the labor force and the growth of part-time employment have tended to fragment travel patterns and increase the level of traffic throughout the day. Studies reveal that the trip patterns of women differ from those of men in that women tend to make more "chained" trips, involving travel, for example, to child care centers or shopping areas before and after work.[30] The frequency of trips is also increased by the growth of part-time employment, particularly for women. Although these latter changes in

[30] OTA, Technology and the American Economic Transition, p. 118, and Deakin, "Transportation in California," p. 9.

the labor force may lessen recurring traffic congestion, they tend to increase traffic flows throughout the metropolitan area.[31]

Automobile Use

When changes in workers' access to private vehicles are taken into account, along with America's increasing passion for "personalized" transportation, the dramatic increase in the use of private vehicles for work commuting is not surprising. A greater availability and use of private vehicles and a decline in the use of alternative modes of commuting simply mean higher traffic volumes. And without commensurate increases in highway capacity, increasing traffic volumes will continue to exacerbate traffic congestion in all metropolitan areas, irrespective of their rates of population growth.

Truck Traffic

The increasing number and size of trucks in our metropolitan areas have added to recurring congestion problems by occupying more road space and taking longer to accelerate in slow-moving traffic. In addition, the concentration of heavy-truck accidents during peak periods of traffic congestion has aggravated nonrecurring congestion in terms of growth and severity. However, it is still unclear how much truck-related delay contributes to the overall traffic congestion problem.

Highway Infrastructure

Until the late 1970's, the nation's highway system contained enough excess capacity to accommodate moderate increases in use. However, since then the substantial growth in traffic volume, combined with little new highway construction, has used up the excess capacity. The inability of the highway infrastructure to handle current demand has increased both recurring and nonrecurring traffic congestion, particularly in suburban areas. As more vehicles occupy relatively stable road capacities, recurring traffic congestion becomes more severe and the frequency of incidents increases. When this is translated into delay, increases in traffic congestion are significant.

[31] American Association of State Highway and Transportation Officials, "Growing Urban/Suburban Congestion," draft discussion paper, Washington, D.C., 1988, p. 11.

Measures of Traffic Congestion

In order to obtain a better understanding of the severity of the traffic congestion problem in metropolitan areas across the country, we reviewed the various ways it is measured. We found that the point or threshold at which traffic flow on a given facility starts to become congested can be defined by a number of interrelated measures. Although there is no universally accepted way to measure traffic congestion, different measures are used to explain various dimensions of the problem.

According to the 1985 Highway Capacity Manual, two concepts are involved in the analysis of traffic flow: capacity and level of service.[1] The capacity of a facility is defined as the maximum hourly rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given period of time under prevailing road, traffic, and control conditions. It is usually expressed as vehicles per hour.[2] The preferred time period for capacity analysis is a 15-minute interval, which is considered the shortest period of consistent traffic flow.[3] The 1985 manual recommends that a value of 2,000 vehicles per hour per lane be used as the average capacity of a freeway section under ideal conditions—that is, flat terrain, no lateral obstructions or trucks, clear weather, and so on.

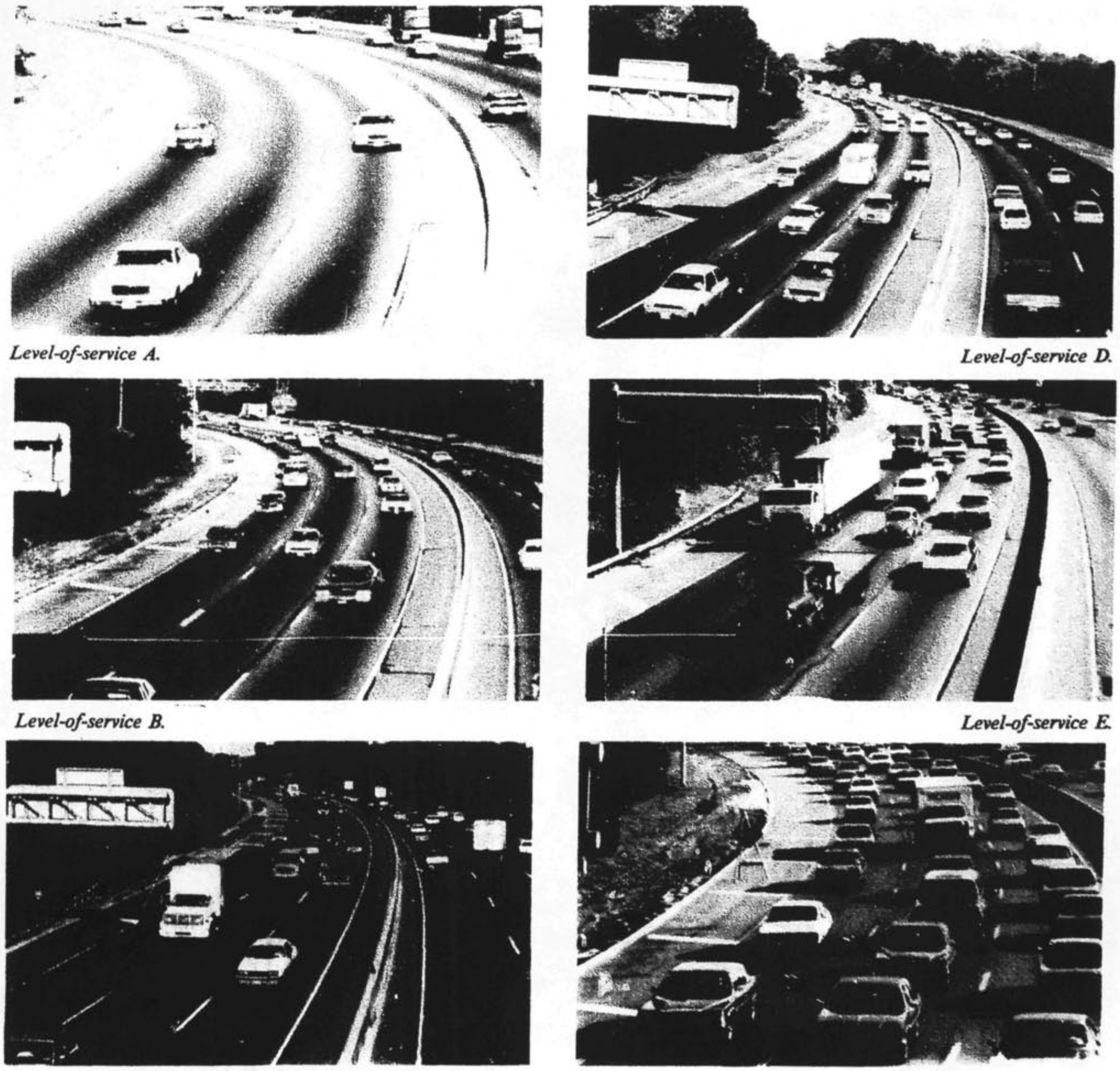
Knowing facility capacity alone provides limited information, because any freeway or street begins to operate poorly at or near the roadway's capacity to carry traffic efficiently and safely. Therefore, a range of operating conditions, or levels of service, has been developed in order to describe the different traffic flow conditions that may exist on a given facility. The 1985 manual defines six levels of service using an ordinal scale A to F, with level-of-service A representing the best operating conditions of free-flowing traffic and level-of-service F the worst condition, or a breakdown in traffic flow. Each level of service describes the operating conditions of the traffic stream in terms such as speed and travel

[1] Transportation Research Board, Highway Capacity Manual, special report 209 (Washington, D.C.: National Research Council, 1985), p. 1-3. Transportation professionals consider this manual a standard for conducting capacity and other transportation analyses.

[2] According to the Highway Capacity Manual, road conditions refer to the geometric characteristics of the road, such as number of lanes; traffic conditions refer to the distribution of vehicle types and directional flow; and control conditions refer to the types and specific design of control devices and traffic regulations present on a given facility. A section is typically a mile of lane or road.

[3] Prior to 1985 revisions to the Highway Capacity Manual, the preferred time interval for capacity analysis was 1 hour. However, because traffic volumes can vary significantly within an hour, a shorter interval is now suggested for this analysis in order to isolate these variations.

Figure 3.1: Levels of Service for a Basic Freeway Segment



Level-of-service A.

Level-of-service B.

Level-of-service C.

Level-of-service D.

Level-of-service E.

Level-of-service F.

Source: Transportation Research Board, Highway Capacity Manual (Washington, D.C.: National Research Council, 1985), p. 3-9.

time, freedom to maneuver, traffic interruptions, comfort and convenience, and safety. Figure 3.1 show the proximity between vehicles that can be expected on a freeway segment at the six levels of service.

Prior to 1985 revisions to the 1965 Highway Capacity Manual, the designated service level for a lane or road section was primarily measured by the average travel speed of vehicles crossing the section and the section's volume-to-capacity (V/C) ratio. Since 1985, a wider range of measures of traffic flow has been used to define levels of service. The operational state of a given traffic stream is now defined by its traffic density, average travel speed, and service flow rate. Traffic density has been emphasized because it more directly relates to the maneuverability of vehicles in the traffic stream, which by definition is an important consideration in determining the service level of a particular facility. Although current standards emphasize density as the primary measure for determining a facility's service level, many state and local transportation officials still use the more traditional V/C measure.

The 1985 manual defines density, speed, and flow rate in the following ways. Traffic density is defined as the number of vehicles occupying a lane or road section averaged over time and usually expressed as passenger cars per mile per lane (pc/mi/ln).[4] Because the direct measurement of density is difficult, it is generally computed by dividing the rate of traffic flow on a section by the average travel speed of vehicles crossing the section, which is more easily measured.

Speed is generally defined as how fast a vehicle is going in miles per hour (mph). Since vehicles tend to operate at various speeds in the traffic stream, an average travel speed is typically computed by dividing the length of a lane or road section by the average time it takes a vehicle to traverse the section.

A flow rate is a volume measure that enumerates the vehicles passing a point on a lane or road during a designated time interval (usually 15 minutes). A rate of flow is found by dividing the number of vehicles observed in a period of less than an hour by the time (in hours) over which they are observed.

The range of potentially congested facilities in metropolitan areas is wide, including interstates and noninterstate freeways, arterials,

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[4]Because a traffic stream contains trucks, buses, and recreation vehicles, passenger car equivalents are determined for each type of vehicle for the traffic and road conditions under study.

collectors, local streets, and signalized intersections. For this discussion, we concentrate on uninterrupted flow facilities, such as freeways, with a design speed of 70 mph. In addition, we focus on peak-hour traffic volumes because they have the highest capacity requirements. For example, a road section that experiences level-of-service E for only 15 minutes in an hour is rated at level-of-service E. Peak-hour traffic volumes, however, may change from day to day, or from season to season. While urban routes generally show little variation in the peak hours of traffic—the majority of users are daily commuters—rural and recreational routes show wide variations in peak-hour volumes, depending on the weekend and season.

Methods of Measurement

Each level of service for a given facility has boundaries based on measures of traffic flow. The measure of traffic flow for a basic freeway section is primarily based on traffic density. At each level of service, the 1985 Highway Capacity Manual specifies values for traffic densities, average travel speeds, maximum service flow rates, and V/C ratios that can be expected under ideal conditions for freeways constructed for different design speeds. In addition to these measures of traffic flow, we identified two others: average daily traffic volume (ADT) per lane and daily vehicles miles of travel (DVMT) per mile per lane. Table 3.1 lists operating conditions or measures that are associated with the six levels of service. In the table, the values represent boundaries between service levels.

Table 3.1: Measures of Traffic Flow for Basic Freeway Sections[a]

Level of service	Density[b]	Speed[c]	MSF[d]	V/C[e]	ADT[f]	DVMT[g]
A	12	60	700	0.35	[h]	[h]
B	20	57	1,100	0.54	13,000	11,500
C	30	54	1,550	0.77	15,000	13,000
D	42	46	1,850	0.93	17,000	15,000
E	67	30	2,000	1.00	18,500	17,000
F	[i]	[i]	[i]	[i]	[i]	[i]

[a]Figures are for a design speed of 70 mph.

[b]Traffic density in passenger cars per mile per lane.

[c]Average travel speed in miles per hour.

[d]Maximum service flow rate in passenger cars per hour per lane; all values have been rounded to the nearest 50 passenger cars per hour.

[e]The ratio of traffic volume to facility capacity.

[f]Average daily traffic volume per lane.

[g]Daily vehicle miles of travel per mile per lane.

[h]No values given at this level of service.

[i]Highly variable, unstable conditions.

Source: Transportation Research Board, Highway Capacity Manual, special report no. 209 (Washington, D.C.: National Research Council, 1985), p. 3-8, and Timothy Lomax, The Texas A&M University System, Texas Transportation Institute, College Station, Texas.

Traffic Congestion Thresholds

From our literature review and interviews, we found that freeways operating at the boundary of levels-of-service C and D through level-of-service F are considered nearing a congested state or are congested. According to the 1985 manual, a basic freeway section that is rated at level-of-service C is considered to be operating at stable traffic flows of over 54 mph. However, a small increase in flow at even this service level is expected to cause substantial deterioration in service quality. The boundary values for levels of service D and E describe unstable traffic flows approaching the operating capacity of a lane or road section. At these service levels, average travel speeds can drop to 46 mph and 30 mph, respectively. Finally, level-of-service F describes the breakdown of traffic flow. This condition exists when lines form behind the breakdown point, causing significant traffic delay. A significant proportion of the total freeway delay occurs at level-of-service F.

Transportation agencies across the country use a variety of methods to measure traffic congestion. As these measures are interrelated, the magnitude of the problem primarily depends on the level of service that an agency uses as its threshold of traffic congestion. The following discussion illustrates how these measures have been used to describe congested traffic conditions.

Traffic Density

Values ranging from 12 to 67 passenger cars per mile per lane are used to represent maximum allowable densities for corresponding service levels. Traffic density is computed by dividing the rate of traffic flow by the average travel speed exhibited on a given lane or road section. For example, as density increases from zero, the rate of traffic flow also increases, because more vehicles are on the roadway, but vehicle speeds will begin to decline because of the interaction of vehicles in the traffic stream. As density continues to increase toward the capacity of the facility, the ability to maneuver in traffic is reduced, because the gaps between vehicles are shortened. Near capacity, average travel speeds decline precipitously, and the formation of upstream lines and breakdowns in flow becomes almost unavoidable. According to the 1985 manual, the level-of-service E density boundary of 67 pc/mi/ln has been generally found to be the "critical density" at which congestion most often occurs.

Average Travel Speed

The speed at which a vehicle operates in the traffic stream is typically determined by calculating either average travel speed or average running speed. For most purposes, average travel speed is used; it is based on the travel time observed over a known length of freeway. For uninterrupted facilities, average speed and running speed are equal, except for facilities operating at level-of-service F. Peak-hour running speeds of 35 mph to 54 mph have been used as traffic congestion thresholds on freeways. For example, on the freeways in Los Angeles, the city uses an average travel speed of 35 mph or less as an indicator of significant traffic congestion. FHWA has used an average travel speed of 54 mph as an indication that a freeway section, regardless of its location, is approaching a congested state.

Maximum Service Flow

The maximum service flow rate is the highest 15-minute rate of traffic flow that can be accommodated on a freeway under ideal conditions, while maintaining operating characteristics such as speed for a given level of service. Maximum service flow rates are expressed as passenger cars per hour per lane (pc/ph/pl). Because service flow rates are maximums for each level of service, except level-of-service F, they also define flow boundaries between service levels. Maximum service flow rates for freeways range from 700 to 2,000 pc/ph/pl. The American Association of State Highway and Transportation Officials recommends that urban freeways not operate with volumes higher than 1,500 to 1,700 pc/ph/pl and rural freeways no higher than 1,000 to 1,200.

FHWA presently uses a facility's maximum service flow rate (formally capacity) to derive a ratio of volume to service flow for determining the level of congestion on roadways. The volume-service flow ratio expresses the relationship between the number of vehicles traversing a point or section of roadway over a given period of time and the maximum hourly rate at which vehicles can reasonably be expected to traverse a uniform section of roadway during this time period. These ratios essentially correspond to the V/C ratios in table 3.1. FHWA presently uses a volume-service flow ratio of 0.80 as a threshold of traffic congestion.[5]

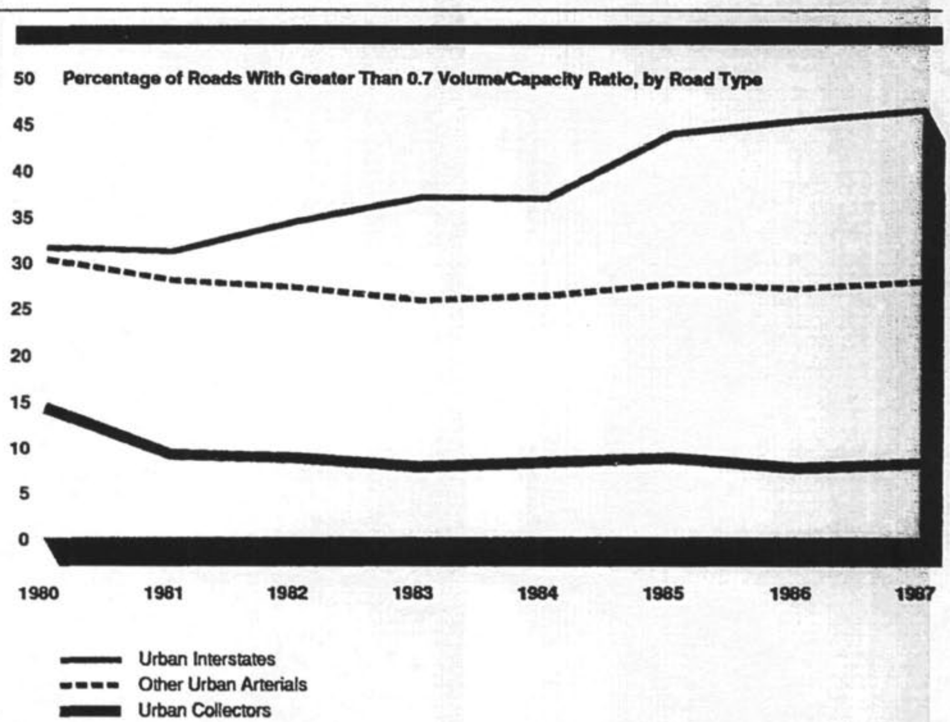
Volume-to-Capacity Ratio

The V/C ratio is probably the most frequently used measure of traffic congestion. The V/C ratio is calculated by dividing the volume of traffic on a road by the capacity of the road to carry traffic. Ratios ranging from 0.70 to 1.00 have been used as indicators of congested traffic flow conditions. For example, an FHWA staff study used a V/C ratio of 0.77 as a congestion indicator for freeways, based on studies that show a breakdown of traffic flow at this threshold.[6] Other transportation agencies use a V/C ratio closer to 1.00 as their congestion threshold. Figure 3.2 illustrates the use of the V/C ratio to compare levels of congestion by road type between 1980 and 1987. Parenthetically, FHWA's shift to a volume-service flow ratio approach in 1986 may somewhat alter the 1986 and 1987 points in figure 3.2.

[5] FHWA, The Status of the Nation's Highways and Bridges: Conditions and Performance and Highway Bridge Replacement and Rehabilitation Program 1989 (Washington, D.C.: 1989), p. III-4.

[6] FHWA, The Future National Highway Program 1991 and Beyond: Urban and Suburban Highway Congestion, working paper no. 1 (Washington, D.C.: December 1987), p. 7.

Figure 3.2: Congestion on U.S. Urban Roads[a]



[a]Since FHWA shifted away from using volume-to-capacity ratios to volume-service ratios in 1986, some of the values for 1986 and 1987 may differ slightly from those shown here.

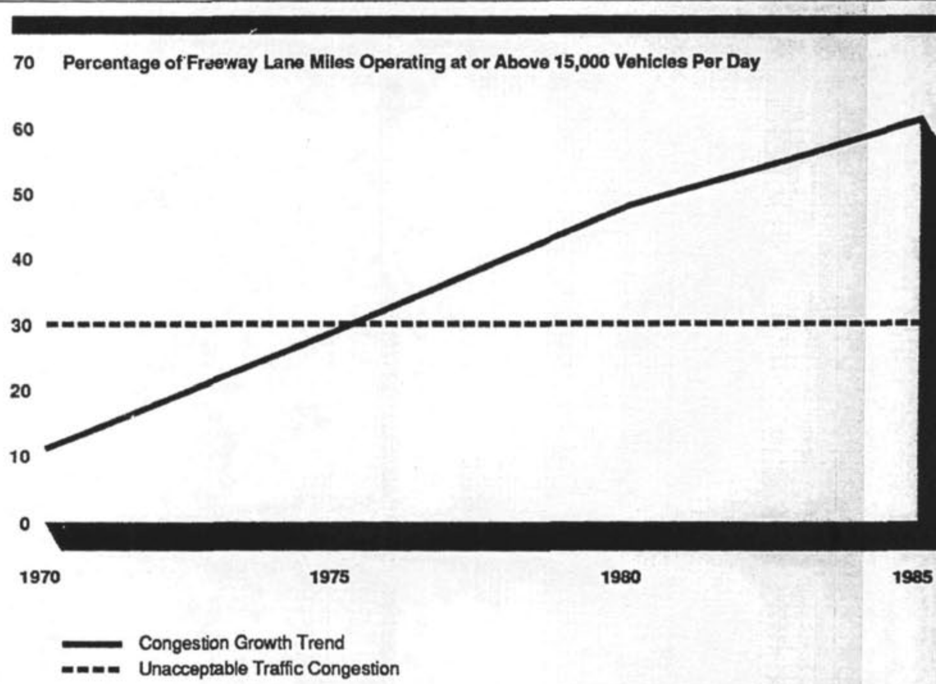
Source: Highway statistics reports for 1980-87 prepared by the Federal Highway Administration, Washington, D.C., 1988.

Average Daily Traffic Volume

Average daily traffic volume requires an enumeration of the vehicles that pass over a given lane or road section in a given time period. These data are easily obtained and most transportation organizations have established methods for collecting them. For an example of its use in determining the extent of freeway congestion, the Texas Transportation Institute chose an average daily traffic volume threshold of 15,000 vehicles per lane. We were told by an institute staff person that FHWA uses 13,000 ADT per lane as a planning tool in determining when a facility is close enough to being congested that mitigation approaches should be initiated. The 15,000 ADT is interpreted to represent the boundary between levels-of-service C and D.

Figure 3.3 illustrates how this method is used to quantify the growth of traffic congestion in metropolitan Houston, Texas. According to one study, the traffic flow in this metropolitan area between 1976 and 1977 became unacceptable in terms of operating efficiency and safety.[7] At this time, it was estimated that 30 percent of Houston's freeway lane-mile sections were operating near the 15,000 ADT threshold. The authors of the study conclude that the 30-percent figure and the 15,000 ADT threshold can be used as surrogate measures for unacceptable congestion on the entire freeway system.

Figure 3.3: Houston's Congestion Growth Trend[a]



[a]Unacceptable levels of traffic congestion begin once 30 percent of the freeway lane miles are operating at or above 15,000 vehicles per day.

Source: Timothy Lomax, Diane Bullard, and James Hanks, "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," draft research report 431-1F, The Texas A&M University System, Texas Transportation Institute, College Station, Texas, August 1988, p. 9.

Daily Vehicle Miles of Travel

Another way to characterize systemwide traffic congestion is by measuring the daily vehicle miles of travel per mile per lane. This systemwide measure is derived by averaging total miles traveled by all vehicles during a day across all road sections. Values for DVMT are lower than values for ADT volume because they are averages based on all road

[7]Timothy Lomax, Diane Bullard, and James Hanks, "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," draft research report 431-1F, The Texas A&M University System, Texas Transportation Institute, College Station, Texas, August 1988.

sections in a study area, which includes both congested and uncongested road sections. Table 3.2 shows how this measure is used to quantify relative levels of traffic congestion in 7 Texas cities and 22 other cities of similar character, excluding cities such as New York and Boston, which have higher population densities and transit ridership rates.[8] In this table, freeway systems in metropolitan areas that have more than 13,000 DVMT per mile per lane are considered nearing a congested state. This threshold of congestion also represents the boundary between levels-of-service C and D.

[8]Other ways in which daily vehicle miles of travel are used to compare the level of congestion across metropolitan areas are by per capita, per 1,000 persons, and per square miles of urban area. The Texas Transportation Institute found that changing measures altered the relative ranking of metropolitan areas according to the severity of their traffic congestion problems.

Table 3.2: Daily Vehicle Miles of Metropolitan Travel

Metropolitan area	DVMT[a]	Rank[b]
Los Angeles, California	17,945	1
San Francisco-Oakland, California	16,285	2
Houston, Texas	15,970	3
Atlanta, Georgia	14,795	4
Phoenix, Arizona	14,665	5
Seattle-Everett, Washington	13,965	6
Dallas, Texas	13,765	7
San Diego, California	12,935	8
Miami, Florida	12,905	9
Austin, Texas	12,620	10
Denver, Colorado	12,470	11
Minneapolis-St. Paul, Minnesota	12,235	12
Portland, Oregon	12,045	13
San Antonio, Texas	11,800	14
Milwaukee, Wisconsin	11,375	15
St. Louis, Missouri	11,320	16
Sacramento, California	11,135	17
Fort Worth, Texas	11,000	18
Tampa, Florida	10,890	19
Nashville, Tennessee	10,625	20
El Paso, Texas	9,910	21
Albuquerque, New Mexico	9,650	22
Louisville, Kentucky	9,475	23
Salt Lake City, Utah	9,080	24
Memphis, Tennessee	8,520	25
Indianapolis, Indiana	8,405	26
Oklahoma City, Oklahoma	8,375	27
Corpus Christi, Texas	8,350	28
Kansas City, Missouri	7,735	29

[a]Daily vehicle miles of travel per mile per lane. A study area such as a county or metropolitan area is considered congested when there are 13,000 DVMT on its freeway system.

[b]As this study assessed freeway traffic flow conditions in only selected metropolitan areas dominated by Texas cities, it did not present a ranking of all U.S. metropolitan areas.

Source: Timothy Lomax, Diane Bullard, and James Hanks, "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," draft research report 431-1F, The Texas A&M University System, Texas Transportation Institute, College Station, Texas, August 1988.

Traffic Delay Measurement

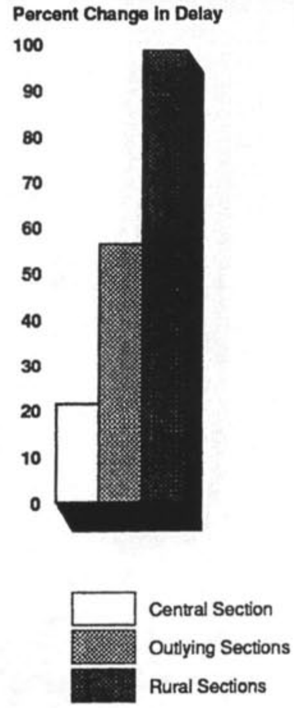
An important consideration in the measurement of traffic congestion is the delay experienced by motorists. Because delay can be considered both an effect and a measure of traffic congestion, we have separated its discussion from the other measures.[9] The 1985 Highway Capacity Manual defines delay as the additional time experienced by a driver beyond what would reasonably be desired for a given trip. An FHWA staff study, for example, calculated annual vehicle delay nationwide by comparing the average travel speed exhibited per sample freeway section to an ideal travel speed when free traffic flow is assumed (at 55 mph or faster). The difference between average travel speed and free flow speed on a given freeway section yields average delay per vehicle. Multiplying this figure by traffic volume for all sections yields a number for total vehicle delay per day. Annual delay is then computed by multiplying this figure by 260 days.[10]

FHWA notes, however, that because the threshold used to indicate the beginning of traffic congestion varies among transportation agencies, the total hours of vehicle delay may not equal the number of congested traffic hours in some metropolitan areas. For example, the California Department of Transportation does not consider traffic to be seriously congested unless it is moving slower than 35 mph for 15 minutes or longer—that is, 19 mph slower than the average travel speed used in one FHWA staff study. Figure 3.4 shows the estimates that FHWA made of the percentage change in delay between 1983 and 1985 for urban and suburban freeways.

[9] In chapter 5, we discuss some of the potential consequences of traffic delay in terms of its environmental, economic, and social effects.

[10] Although FHWA uses 260 days in its computation, others have used fewer days, taking into consideration holidays that fall during the work week.

Figure 3.4: 1983-85 Percentage Change in Urban and Suburban Freeway Delay[a]



[a]A central section is the core of an urban area, dominated by commercial activities, residential development, and fringe businesses. Outlying sections combine business districts and residential areas that are geographically separated from the central business district. Rural sections represent the outermost portions of the urban area and are comprised of residential and farming land uses.

Source: Federal Highway Administration, The Future National Highway Program 1990 and Beyond: Urban and Suburban Highway Congestion, working paper no. 10 (Washington, D.C.: December 1987), p. 22.

The Application of Traffic Flow Measures

For general transportation planning purposes, local governments, metropolitan planning organizations, state departments of transportation, and FHWA assess road conditions, including the flow of traffic, in order to set priorities for improvements and to justify special projects.[11] For example, most of the jurisdictions we contacted through phone interviews tracked the conditions of their roads, including relative levels of traffic congestion for project planning purposes, and most used a variety of

[11]Metropolitan planning organizations provide local input into federal-aid highway and transit programs. They are federally funded to collect data and analyze policies, projects, and programs. Federal statutes require that no transportation project in an urban area (over 50,000 population) will receive federal funds unless it is compatible with the comprehensive transportation plan developed by local officials acting through metropolitan planning organizations in cooperation with the state.

methods to measure traffic flow. FHWA also measures traffic congestion for project planning purposes; however, the majority of its measurements are taken for program and policy purposes.

The only standardized data source to measure traffic conditions and to estimate future levels of congestion across metropolitan areas is FHWA's Highway Performance Monitoring System (HPMS) data base. The HPMS data base consists of detailed data on road geometry and traffic flow and other types of information provided by state highway agencies for a national sample of road sections.[12] Although FHWA requests that each state provide certain types of data, the states are given some latitude in their sampling approach.

FHWA calculates national highway needs estimates from the HPMS data base. A model is used to analyze these data to determine the present condition of the nation's highways and to estimate future highway capital investment needs. Within this effort, FHWA uses these data to estimate congestion levels on federal-aid roads. In figure 3.2, FHWA showed that over a 7-year period, the percentage of all urban interstate miles that were considered to be congested increased from 31.5 to 46.7. Congestion on other urban arterials and collectors during this period, however, appears to have remained fairly stable since 1981.

We identified two studies that also used HPMS data to assess congestion problems across metropolitan areas. One study, conducted by Texas Transportation Institute researchers and already discussed in this chapter, relied on a systemwide measure of daily vehicle miles of travel per mile per lane to compare traffic congestion levels across selected metropolitan areas.[13] As shown in table 3.2, of the 29 metropolitan areas that were compared in 1986, 7 had unacceptable levels of congestion. In addition, these researchers found that between 1982 and 1986, all but two metropolitan areas showed increases in traffic congestion, based on their congestion index values, ranging from 1 percent to 29 percent and averaging 12 percent across all areas. As previously noted, however,

[12]In a 1987 GAO report, Highway Needs: An Evaluation of DOT's Process for Assessing the Nation's Highway Needs, GAO/RCED-87-136 (Washington, D.C.: 1987), the HPMS sampling plan and data collection procedures, along with federal and state editing and control procedures, were found to be reasonable approaches for developing nationwide information.

[13]This study, conducted between 1982 and 1986, assessed freeway and major operating conditions in 7 Texas cities and 22 other urban areas. Data on vehicle miles of travel and lane miles of roadway were collected from a variety of sources to estimate congestion levels. The values for each road system were combined into a congestion index used to rank these urban areas on a relative scale.

this study did not include all metropolitan areas with congestion problems; it excluded New York City, for example.

Another study, conducted by FHWA staff, relied on quantifying total urban freeway delay per vehicle miles of travel in order to estimate total delay nationwide and to rank 37 large metropolitan areas by the severity of their traffic congestion problems. Using the method for calculating delay discussed earlier in this chapter, FHWA found that traffic congestion increased significantly in large and small metropolitan areas across the country. In figure 3.4, FHWA showed that between 1983 and 1985, traffic delays in 37 metropolitan areas greater than 1 million in population increased more than 90 percent in rural sections, about 50 percent in outlying sections, and approximately 20 percent in central sections. In addition, FHWA found that over 90 percent of the nation's congested urban freeways were in these metropolitan areas. The results of this staff study and other agency-supported studies are being considered by FHWA in its formulation of surface transportation policy. Because of the potential policy implications of the urban freeway congestion study, we review in chapter 4 the model that was used to estimate current and future levels of traffic delay.

Review of FHWA's Urban Freeway Delay Model

We undertook a methodological review of the FHWA model because it is uniquely designed to estimate national trends for traffic congestion on urban freeways and because of the potential policy implications of its results. With the assistance of four transportation experts, we focused our review on the theory and computational procedures of the model as well as the data used to estimate trends. For example, we looked at the model's assumptions, the use of HPMS data to quantify traffic congestion, and methods for forecasting freeway delay. In addition, we asked FHWA to run its computer program with updated data and different assumptions so that we could test the sensitivity of the model.

The Computer Model

In order to study the national problem of urban freeway congestion for both existing and future traffic levels, FHWA developed a computer model to quantify traffic delay, determine its monetary consequences in terms of excess fuel consumption and wasted time, or user costs, and assess the effects of various mitigation options. The approach FHWA took involved developing a program to analyze key data input items for freeway and nonfreeway sections from several subsets of the overall HPMS data base.[1] For freeways, 1983, 1984, and 1985 data were used; for nonfreeways, only 1985 data were used. The freeway data were used for approximately 8,000 sections representing about 15,300 miles of urban freeways, and the nonfreeway data for 33,700 sections represented about 137,000 road miles.[2]

These data were used to represent the total urban freeway system of a state and its metropolitan areas through the use of appropriate "expansion factors" supplied by each state. According to an FHWA official, because the section sampling rate for freeways in the HPMS data base is approximately 50 percent, the expansion factor given by many states is generally close to 2. However, he told us that because the sampling rate for nonfreeway sections is only about 15 percent, the agency has less confidence in the estimates of nonfreeway delay.

[1] Data items used in this study included information on freeway section lengths, number of lanes, annual average daily traffic, K-factor (percentage of daily traffic flow occurring during peak hours), peak-hour directional factors, shoulder widths, lane widths, and the percentage of trucks in the traffic flow.

[2] According to FHWA, the HPMS data allow for separating analysis of sample sections in both urban (population greater than 50,000 persons) and small urban (fewer than 50,000 persons) areas. For this study, a further breakdown was made by urban areas with over 1 million persons, as defined by standard metropolitan statistical areas.

In developing its model, FHWA made certain assumptions about vehicle operating characteristics under both congested and uncongested conditions. One assumption was that traffic delays occur at speeds of 54 mph or less on freeway sections that have corresponding V/C ratios of 0.77 or greater. A second assumption was based on the appropriateness of the data used to develop a series of traffic profiles to calculate hourly V/C ratios. The data to produce these profiles came from 1983 and 1984 traffic volume counts on interstates 66 and 395 near Washington, D.C.

FHWA created 12 different 24-hour traffic profiles to represent a reasonable range of possible daily traffic flows—that is, different peaking characteristics—for a given sample section. For example, urban freeways with a low percentage of daily traffic flow during peak hours are common in metropolitan areas such as Los Angeles, California, where traffic flows are fairly constant. Urban freeways with a high percentage of the flow during these periods are typical in metropolitan areas with traditional morning and evening rush hours, such as Indianapolis, Indiana. According to an FHWA official, it was necessary to develop these profiles because the HPMS data base contains information on only the percentage of the average daily traffic that occurs during peak hours (K-factor), the percentage of traffic flowing in each direction during these hours (peak-hour directional factor), and average daily traffic volume.

Several basic steps are involved in calculating recurring and nonrecurring freeway delay.[3] To calculate daily recurring traffic delay per vehicle per section, the program first generated hourly V/C ratios by matching one of the "typical" traffic profiles to each section, based on its K-factor and directional factor. For each hour, the actual average travel speeds were then subtracted from the maximum speed of 55 mph to obtain total delay per vehicle per section. Total daily traffic delay per section for all vehicles was derived by multiplying vehicle delay by the percentage of daily traffic experiencing congested conditions and by the annual average daily traffic. Annual delay was then calculated by multiplying this figure by the number of weekdays during the year—that is, 260.

Determining delay from nonrecurring traffic congestion, stemming from incidents, was more complicated. Nonrecurring delay was based on a set of average incident frequencies for various types of incidents that could

[3]Only the steps involved in calculating freeway congestion parameters are discussed in this section; separate steps are also required for calculating nonfreeway congestion.

occur based on vehicle miles of travel. The more vehicle miles of travel, the more likely it is that incidents will occur. The actual amount of delay caused by an incident on a given road section depends on a number of factors, including the number of freeway lanes and the widths of the shoulders. For example, delay from an accident on a multilane freeway may be less than on a two-lane freeway because the former provides more room to maneuver around the accident than the latter. To obtain a figure for annual delay from nonrecurring congestion, the model expands data on the delay from single incidents to a full year of occurrences. To avoid counting recurring and nonrecurring delay twice, nonrecurring delay was reduced by the amount of recurring delay that would have occurred in the absence of an incident.

To obtain an estimate for total delay in 2005, FHWA used traffic volume projections supplied by the state. For each sample section, FHWA developed hourly V/C ratios using higher traffic volume counts but the same capacity. In effect, V/C ratios increased, thereby increasing the difference between the ideal speed and the actual speeds associated with these higher V/C ratios. The end result represented a significant increase in total freeway delay.

Finally, to quantify the monetary consequences of urban freeway delay, values for fuel and user costs were determined and then used in estimating dollar effects nationally. A value of $1.00 per gallon of gasoline was assumed for the cost of fuel, and an average value of travel time was calculated at $6.25 per vehicle hour. This latter figure was inflated from a 1977 base value of $2.40 per traveler hour for work trips, given an average vehicle occupancy of 1.25 persons.[4] The outputs of the model are discussed in the following section.

Study Results

The FHWA model was used in staff studies to develop estimates of freeway and nonfreeway traffic delay for metropolitan areas greater than 50,000 population, for small urban areas, and specifically for metropolitan areas over 1 million in population. National estimates are listed in table 4.1 for 1984 and 2005. Estimates for 2005 do not consider the effect of improvements to existing highway facilities or changes in the peaking characteristics of traffic. In addition, delay forecasts are based

[4]The $2.40 per traveler hour figure comes from a 1977 American Association of Highway and Transportation Officials' Red Book for trip delays of between 5 and 15 minutes. This 1977 value was inflated using values from the October 1985 consumer price index.

on state-supplied estimates of future traffic volumes that may or may not be tied to expected growth of road capacity.

Table 4.1: Urban Freeway Congestion Statistics[a]

Measure	1984	2005
Freeway miles	15,335	15,335
Vehicle miles of travel (billion)	276.645	410.987
Recurring congested vehicle miles of travel (billion)	31.486	98.280
Delay		
Recurring (billion vehicle hours)	0.485	2.049
Nonrecurring (billion vehicle hours)	0.767	4.858
Total delay (billion vehicle hours)	**1.252**	**6.906**
Excess fuel consumption (billion gallons)	1.378	7.317
User cost (billion)	$9	$51

[a]Numbers for recurring, nonrecurring, and total delay, excess fuel consumption, and user cost have been rounded off.

Source: Jeffrey Lindley, "Urban Freeway Congestion: Quantification of the Problem and Effectiveness of Potential Solutions," ITE Journal, 57:1 (January 1987), 29.

As noted in this table, significant increases can be expected in both recurring and nonrecurring urban freeway delay between 1984 and 2005. Total delay increased from 1.252 billion vehicle hours in 1984 to 6.906 billion vehicle hours in 2005, about a 452-percent increase.[5] The consequences of delay in terms of excess fuel consumption and user costs is also significant. Total excess fuel consumption increased from 1.378 billion gallons in 1984 to 7.317 billion gallons in 2005. In addition, total user costs, based on $6.25 per vehicle hour of delay, increased from $9.2 billion in 1984 to $50.5 billion dollars in 2005.

In table 4.2, the model was used to compare urban freeway congestion in 37 metropolitan areas with populations greater than 1 million persons. This table shows the ranking of these metropolitan areas in 1984 and 2005 based on a traffic congestion severity index developed by FHWA staff. Based on this study, it was estimated that approximately 91 percent of all urban freeway delay occurs in these areas and that all areas are expected to experience significant increases in freeway and non-freeway delays by 2005.

[5]The estimate of a 452-percent increase in traffic delay was based on data that were not as current as the data used to derive FHWA's 1987 estimate of a 436-percent increase in delay by the year 2005.

Table 4.2: Congestion Severity Index[a]

	Index		Rank	
Urban area	1984	2005	1984	2005
Houston, Texas	11,112	54,810	1	2
New Orleans, Louisiana	10,576	27,641	2	7
New York, New York	8,168	12,282	3	14
Detroit, Michigan	7,757	42,394	4	3
San Francisco, California	7,634	18,734	5	10
Seattle, Washington	7,406	27,523	6	8
Los Angeles, California	6,376	12,139	7	15
Boston, Massachusetts	5,538	21,237	8	9
Charlotte, North Carolina	5,263	76,393	9	1
Atlanta, Georgia	5,034	11,205	10	18
Minneapolis, Minnesota	4,704	9,529	11	21
Dallas, Texas	4,630	36,938	12	5
Norfolk, Virginia	4,505	9,258	13	23
Chicago, Illinois	4,501	10,700	14	19
Denver, Colorado	4,454	8,828	15	20
Washington, D.C.	4,188	15,160	16	11
Hartford, Connecticut	4,111	7,043	17	26
San Antonio, Texas	3,938	37,831	18	4
Pittsburgh, Pennsylvania	3,216	7,243	19	25
San Diego, California	2,823	5,958	20	28
Cincinnati, Ohio	2,590	6,223	21	27
Baltimore, Maryland	2,441	15,037	22	12
Philadelphia, Pennsylvania	2,421	11,376	23	17
Kansas City, Kansas	2,347	4,302	24	34
Salt Lake City, Utah	2,132	5,811	25	29
Columbus, Ohio	2,099	4,652	26	33
Cleveland, Ohio	2,061	4,099	27	35
Sacramento, California	1,803	8,037	28	24
Milwaukee, Wisconsin	1,724	5,653	29	30
Portland, Oregon	1,696	9,372	30	22
St. Louis, Missouri	1,612	4.938	31	32
Phoenix, Arizona	987	12,717	32	13
Providence, Rhode Island	660	2,617	33	37
Miami, Florida	609	28,549	34	6
Buffalo, New York	577	3,983	35	36
Tampa, Florida	575	11,870	36	16
Indianapolis, Indiana	89	5,148	37	31

[a]Congestion severity index equals total delay divided by million vehicle miles of travel.

Source: Jeffrey Lindley, "Urban Freeway Congestion: Quantification of the Problem and Effectiveness of Potential Solutions," ITE Journal, 57:1 (January 1987), 30. While these data are based on an FHWA freeway delay model, FHWA has never officially published these results.

From the results of the model, FHWA staff concluded that urban congestion is a serious and rapidly growing problem.[6] Both large and small metropolitan areas (under 1 million in population) are expected to experience increased congestion, but the rate of increase will be greater in the smaller ones. They also noted that the growth of congestion in the outlying areas appears to be a barometer of the overall growth of congestion between 1985 and 2005.

In addition to the analysis of freeway and nonfreeway delay, FHWA staff used the model to assess five strategies for reducing traffic congestion: highway reconstruction to improve traffic flow; increasing highway capacity with new construction; supply management using transportation systems management techniques; techniques to reduce demand, such as ridesharing; and advanced technologies to improve highway mobility. FHWA officials noted in their study that no single measure can effectively relieve all aspects of congestion and that the levels of reduction are affected by both unknown and uncontrollable world and national events. For example, the stronger the U.S. economy, the greater the expected increase in congestion, but the more likely it is that there will be support for developing technologies to alleviate the problem. They conclude that strategies to increase supply, such as lane widening, might reduce future congestion by 20 percent and that measures to reduce vehicle miles traveled might have a somewhat greater effect. Parenthetically, the likely effect of advanced technology was not considered, because its full potential is not expected to be realized until after 2020. In addition, FHWA did not consider the effect of new construction and major reconstruction because this is virtually impossible to accomplish using HPMS data.

Methodological Review

From our review, we determined that the urban freeway delay forecast for 2005 may be an overstatement for a number of reasons, including the way congested travel was defined and the assumptions the study used regarding future highway improvements and changes in drivers' behavior. Our methodological review identified five potential threats to the accuracy of the agency's forecast: (1) the use of a low V/C ratio and a correspondingly high average travel speed as a threshold for congestion, (2) the use of Washington, D.C., freeway data to develop representative traffic volume profiles, (3) the assumption of no change in highway capacity, (4) the assumption of no change in drivers' behavior, and (5)

[6]Federal Highway Administration, The Future National Highway Program 1991 and Beyond: Urban and Suburban Congestion, working paper no. 10 (Washington, D.C.: December 1937), p. 26.

limitations in the HPMS data used to estimate present and future urban freeway and nonfreeway delays across metropolitan areas.

Volume-to-Capacity Ratio

Although this FHWA model uses a 0.77 V/C ratio and a 54 mph average travel speed as interrelated threshold indicators of traffic congestion, the ratio is lower than that used by some metropolitan planning organizations and local governments, particularly the California Department of Transportation. These organizations consider a road to be congested when its V/C ratio is closer to 1.00, with an expected average travel speed near 35 mph. According to one of our expert reviewers, a V/C ratio of close to 1.00 is perfectly acceptable and represents a reasonable use of the freeway system during peak hours. Also, another reviewer noted that it is unrealistic to take a V/C ratio of 0.77 as the point at which congestion begins, based on the public's perception of the problem. On congested freeways around Los Angeles, for example, freeways with traffic flowing at or above 30 mph are generally not considered congested (30 mph corresponds approximately to a V/C ratio of 1.00).

FHWA officials support their selection of V/C ratio and average travel speed based on studies it has conducted on interstates across the country. In addition, one official told us that the model quantifies congestion in terms of the amount of delay drivers experience relative to an ideal travel speed of 55 mph. However, he noted that because congestion is a qualitative term, others may quantify it differently. For example, some transportation agencies from heavily congested metropolitan areas such as Los Angeles quantify congestion based on traffic flowing at speeds much lower than 55 mph. In other words, if traffic is flowing at 40 mph on a given stretch of urban freeway, the freeway is not considered congested.

Traffic Volume Profiles

We believe that the traffic volume profiles used in the model, based on Washington, D.C., freeway conditions, may not be "typical" profiles that could be developed with data from other metropolitan areas. As we mentioned earlier, FHWA used traffic counts from sections of interstates 66 and 395 in the metropolitan Washington, D.C., area to develop traffic volume profiles. As these two interstates are known to be heavily congested, their use in developing representative traffic volume profiles is questionable.

An FHWA official acknowledged that the way FHWA developed hourly V/C ratios for each section has caused some concern in the transportation community. However, this official supported the use of the Washington, D.C., profiles because, he claimed, they are similar in shape to the profiles developed with traffic volume data from interstates near other metropolitan traffic. In regard to the K-factors, this official told us that although some states may not update their section K-factors as regularly as they should, he did not believe that this would significantly change the estimates of delay.

Highway Capacity

The model's assumption of no change in road conditions over a 21-year period (1984 to 2005), and its resultant failure to incorporate probable additions to capacity, suggests that the estimates of future traffic delays may be overstated. Failure to consider future additions to capacity has the effect of squeezing projected traffic volumes onto existing freeways, creating the appearance that congestion will be much worse than anticipated. If capacity is increased through new construction and improvements, the level of congestion associated with growing amounts of traffic may be partially offset.

Officials at FHWA acknowledge that the omission of capacity improvements produces a worse-case scenario that overstates the problem. They told us that up to a 20-percent increase in highway capacity might be expected over the next 18 years. However, they also said that additional improvements are unlikely unless existing political and funding constraints on building new urban freeways, along with constraints on rights-of-way and the widening of existing urban freeways, are somehow eased.

Drivers' Behavior

The model's failure to consider drivers' responses to congested traffic conditions may also overstate the problem. The model assumes that as congestion levels increase, drivers will still continue to "pile on" and that conditions will steadily worsen. According to one reviewer, as freeway conditions change, drivers respond by adjusting their driving behavior, thereby altering traffic flow conditions. For example, as traffic congestion starts to move beyond a driver's personal tolerance, the driver may begin to seek alternative routes and modes of transportation. Although we can assume that there might be some changes in drivers' behavior, determining the effect of behavioral changes on freeway and nonfreeway delay is problematic.

HPMS Data Base Limitations

According to an FHWA official, although the HPMS data base is considered to be a statistically sound representative sample of the nation's freeways, some of the state-supplied data on K-factors, peak-hour directional factors, and section capacities may be miscoded or inaccurate.[7] In addition, we were informed that the validity of the state-supplied estimates of future traffic volume counts is questionable. According to this official, the estimates of future traffic volumes provided by the states for 2005 and 2010 are the most uncertain input item in the model. In regard to the other concerns, this official said that efforts were made to check the accuracy of the section capacity data and that any problems with the two other concerns would not significantly affect the results.

In addition, because the states have some latitude in the way they sample their urban freeway sections, actual freeway mileage for a particular metropolitan area may be inaccurate. According to one expert reviewer, some states are permitted to base the collection of their sample data on criteria developed for sampling road conditions in the entire state, not particular urban areas. While these criteria may be appropriate for developing state data on road conditions, they may not be appropriate for estimating traffic congestion levels in certain urban areas.

An FHWA official acknowledged that the way some states sample their urban freeways may pose a problem in comparing congestion between certain urban areas. For example, in its report, FHWA stated that the sampling approach California selected may have resulted in an overstatement of mileage in the San Francisco area and an understatement of mileage in the Los Angeles area. However, this official told us that state data, based on a high rate of sampling, were reliable for developing national estimates of urban freeway delay. This official could not make this statement for the HPMS data on nonfreeways, which is based on a small sample of these roads.

Alternative Analyses

Because of the results of our methodological review of the FHWA model, we requested that the agency conduct alternative analyses of urban freeway congestion using 1987 data and various combinations of alternative assumptions regarding the threshold of congestion and highway capacity. The analyses included a range of V/C ratios from 0.77 to 0.99,

[7] Confidence in the validity of the nonfreeway delay estimates is much lower than for freeways, because the sampling rate for nonfreeways is low and because detailed data on intersection configurations, cycle lengths of signalization, and flow rates are lacking in the HPMS data base.

along with their expected average travel speeds, and increasing highway capacity from the status quo by 20 percent, 25 percent, and 40 percent. Table 4.3 contains the results of these analyses and the commensurate reductions in the original estimate of delay these changes produced.

Table 4.3: FHWA's Model Results Using GAO Alternative Assumptions

Case	V/C ratio boundary	Congested mph boundary	Capacity assumption	Delay[a] Recurring	Delay[a] Nonrecurring	Percent change from base condition
0	0.77	55	100%	2.230	5.430	0
1	0.77	55	120	1.543	4.036	−27.2%
2	0.77	55	125	1.383	3.698	−33.7
3	0.77	55	140	1.034	2.889	−48.8
4	0.85	50	100	2.055	5.486	−1.6
5	0.85	50	120	1.413	4.080	−28.3
6	0.85	50	125	1.262	3.740	−34.7
7	0.99	35	100	1.435	5.702	−6.8
8	0.99	35	120	0.978	4.240	−31.9
9	0.99	35	125	0.869	3.887	−37.9

[a]In billions of vehicle hours of delay.

Source: Prepared by FHWA with alternative V/C and capacity assumptions provided by GAO. Figures are based on 1987 HPMS data for urban interstates with a system size of 9,890 miles and total vehicle miles of travel of 345.932 billion for each case.

A review of this table illustrates the model's relative insensitivity to changes in the V/C ratio compared to changes in capacity. Without changing facility capacity, increasing the V/C ratio to 0.85 and 0.99 reduces overall delay by about 1.6 percent and 6.8 percent, respectively. However, changing the assumptions regarding capacity changes in 2005 has a more predictable and dramatic effect on reducing traffic delay. Increasing capacity by 20 percent, 25 percent, and 40 percent, without changing the V/C ratio variable (cases 1 to 3), reduces the expected level of traffic delay in 2005 by approximately 27 percent, 34 percent, and 49 percent, respectively.

FHWA acknowledges that significant reductions in urban freeway delay could be achieved by reasonable increases in capacity and changes in drivers' behavior. In regard to the relative insensitivity of changes in the V/C ratio values used to define the threshold of congestion, FHWA offered two rationales. First, a large proportion of recurring delay and all the nonrecurring delay (by definition) occur when the V/C ratio is greater than 1.00—that is, when traffic flow is unstable at speeds of less than 20 mph. Second, as calculating nonrecurring delay is reduced by an amount equal to any recurring delay that would have occurred in the absence of the incident, in some cases during peak periods of congestion, a reduction in recurring delay is offset by an increase in nonrecurring delay. For example, given no increase in capacity, nonrecurring delay is greater at a V/C ratio of 0.99 (case 7) than at a V/C ratio of 0.77 (case 0), but recurring delay is less in the former than in the latter.

Case 8 represents a combination of assumptions that, when used in the model, provide a reasonable alternative forecast of traffic delay. In this case, a V/C ratio of 0.99, along with an expected average travel speed of 35 mph and a 20-percent increase in capacity, yielded about a 32-percent reduction in the original 2005 forecast of urban freeway delay, using the same traffic volume projections. A reduction of 32 percent would lower the forecast of a 436-percent increase in urban freeway delay to a still substantial 297 percent. However, this new estimate of urban freeway delay does not consider additional reductions that could be attributable to changes in drivers' behavior, the introduction of advanced technologies, and other strategies to improve metropolitan traffic flow. Similarly, it does not consider increases in delay from higher-than-anticipated traffic volumes in 2005.

The Effects of Traffic Congestion

Through various sources in the literature and in discussions with transportation officials, we identified three areas potentially affected by traffic congestion: the economy, the environment, and human stress. Our review uncovered limited empirical investigation of the measurable effects of traffic congestion on these areas. Although we found some evidence that congestion increases business costs, diminishes air quality, and raises stress levels, we did not critique the studies supporting these claims. Moreover, the lack of broad empirical evidence pertaining to these effects may be attributable to the problem of separating traffic congestion effects from other factors that may have stronger influences.

Besides the FHWA staff study of urban freeway congestion that quantified the monetary effect of congestion in terms of user costs and wasted fuel, we were not able to identify other studies that attempted to aggregate these effects or others to the national level.[1] The information available does, however, provide a framework for understanding the nature of these effects and their potential consequences.

Effects on the Economy

Delay in traffic can result in some level of economic cost to both the individual and society. Studies have attempted to place monetary values on the time and fuel wasted while vehicles are moving slowly or idling in congested traffic. While individuals are affected in terms of their own wasted time and the added costs of operating their vehicles, societal costs are associated with the hampering of mobility and the resultant losses in economic productivity. For example, delays in traffic can have a direct effect on many industries that transport raw commodities and finished goods through congested metropolitan areas or that distribute goods within these areas.

Economic Costs to the Individual

Traffic congestion imposes direct costs upon the individual by increasing personal travel time and vehicle operating costs in terms of fuel and motor oil consumption. For example, the California Chamber of Commerce estimated that traffic delays and rough roads cost motorists $135 a year in lost time and another $97 in fuel and maintenance costs.[2] The Texas Transportation Institute, however, estimated the 1986 per capita

[1] In a 1988 study of declining mobility in Texas and 22 other urban areas in the United States, the Texas Transportation Institute analyzed the economic cost of time, fuel use, and higher insurance premiums related to traffic congestion, but it did not cover several large metropolitan areas such as New York City.

[2] Transportation 2020 Program, Beyond Gridlock: The Future of Mobility as the Public Sees It (Washington, D.C.: 1988), p. 65.

cost of congestion (user cost and additional fuel cost) at $330, without the added cost of higher insurance premiums associated with more congestion-related accidents, and $400 per capita including the insurance adjustments.[3] Indirect costs, stemming from higher accident rates associated with driving in congested traffic, added vehicle wear and tear, degradation in the quality of travel, and higher insurance premiums, are more difficult to quantify. In addition, both direct and indirect costs are sensitive to the value of time and other variables such as insurance rates and vehicle repair costs.

Cumulatively, these costs can be significant. For example, various organizations in Southern California have estimated that traffic delays amount to 300,000 to 485,000 hours per day for motorists in the greater Los Angeles area. According to a transportation official for Los Angeles County, the cost of these hours of delay is valued at over $507 million per year.[4] The Southern California Association of Governments estimated the daily cost of recurring congestion in the Los Angeles region at over $7 million, using 1984 data and 1987 prices.[5] Further, FHWA estimated that traffic delays burn up about 1.4 billion gallons of fuel annually and cause over $9 billion in user costs in terms of wasted time and fuel. These figures are predicted to grow to 7.3 billion gallons of wasted fuel and over $50 billion in user costs by 2005.[6]

Economic Costs to Society

Traffic congestion not only results in economic costs to the individual but can also be associated with societal effects. We identified potential effects on the national economy, business costs, and the trucking industry.

Transportation experts have emphasized the important role that transportation plays in advancing our national economic welfare. From a more global perspective, one of the keys to being competitive in the

[3] Timothy Lomax, Diane Bullard, and James Hanks, "The Impact of Declining Mobility in Major Texas and Other U.S. Cities," draft research report 431-1f, The Texas A&M University System, Texas Transportation Institute, College Station, Texas, August 1988, p. 56.

[4] Rich Richmond, executive director, Los Angeles County Transportation Commission, National Council on Public Works Hearing, Los Angeles, July 29, 1987, as described in Institute of Transportation Engineers, Traffic Congestion: P's & Q's (Washington, D.C.: August 16, 1988), p. 8.

[5] Southern California Association of Governments, Congestion in the Los Angeles Region: Costs Under Future Mobility Strategies, Economic Planning and Development Program (Los Angeles, Calif.: 1988), p. 4.

[6] Jeffrey Lindley, "Urban Freeway Congestion: Quantification of the Problem and Effectiveness of Potential Solutions," ITE Journal, 57:1 (January 1987), 29.

world marketplace lies in our ability to provide safe, efficient, and low-cost transportation for goods and services. New manufacturing and production techniques that depend on the mobility of freight services are affected by traffic congestion. According to an OTA report, delays in traffic reduce mobility and can limit the growth of dynamic production networks based on the "just in time" integration of large and small producers in different parts of the country or different parts of a metropolitan area.[7] For example, the Commission on California State Government Organization and Economy has stated that urban areas in California are facing such serious traffic congestion that the state's economic vitality is in jeopardy.

Traffic congestion can have direct and indirect costs on business activities. The direct costs of congestion that affect production costs include additional labor costs associated with longer trips made by employees during business hours; higher vehicle operating costs; and suboptimal vehicle use. Indirect costs of traffic congestion include increases in accidents and insurance premiums; the degradation or loss of employee productivity; and increases in delivery costs, employee turnover, and recruiting problems. For example, a recent survey of business leaders in 13 metropolitan areas found that about half indicated that traffic conditions affected their businesses in terms of reduced productivity and poor employee punctuality and morale, as well as increased employee stress.[8] In addition, about one third of those responding to this survey indicated that traffic conditions had an influence on plans to develop or expand their operations.

The trucking industry is both a contributor to and a victim of traffic congestion. According to FHWA officials, the total annual cost for trucks being delayed on freeways is between $4.2 and $7.6 billion, based on estimated vehicle operating costs combined with driver time charges of between $30 and $55 hour.[9] According to these officials, although no U.S. study has been conducted on the overall cost of trucking time losses within metropolitan areas, translating the results of foreign studies to these data would suggest that losses on urban streets, docking areas,

[7]Office of Technology Assessment, Technology and the American Economic Transition: Choices for the Future, OTA-TET-283 (Washington, D.C.: U.S. Government Printing Office, May 1988), p. 229.

[8]Lomax, Bullard, and Hanks, "The Impacts of Declining Mobility in Major Texas and Other U.S. Cities," p. 53. This survey was conducted of business leaders primarily from large service, manufacturing, and construction industries. Approximately 933 of 3,554 leaders responded to the survey.

[9]Frank Cechini and Bruce Cannon, "Traffic Congestion," paper given at the California League of Cities meeting, Federal Highway Administration, Sacramento, California, October 16, 1988, pp. 2-3.

and so on would range between $19.4 and $22.9 billion. Further, it was noted that these estimates do not include many indirect and direct costs to industry, such as lost sales opportunities in not having products available on time.

Effects on the Environment

Although there are many sources of urban air pollution, motor vehicles account for a large share of nearly all the major pollutants found in the atmosphere, particularly carbon monoxide and ozone-producing compounds. Carbon monoxide is a toxic gas by-product of the incomplete combustion of hydrocarbons. It has been estimated that 80 percent of ambient carbon monoxide is generated by automobile exhaust.[10] Ozone is produced in the atmosphere from complex reactions of volatile organic compounds, such as reactive hydrocarbons, and nitrogen oxides in the presence of sunlight. It has been estimated that mobile sources account for 40 to 60 percent of the ozone problem.[11]

Traffic congestion, which reduces travel speeds, increases the frequency of accelerations, and periodically increases the number of vehicles occupying the road, tends to increase the level of mobile source emissions for certain air pollutants. Carbon monoxide and hydrocarbon emissions are higher at slower speeds, particularly below 40 mph, which are typical speeds on metropolitan streets and congested freeways. They are also higher when the vehicle is accelerating or decelerating or idling. In addition, emission levels are higher from engines that are warming up or are poorly maintained. Frequent cold engine starts are a common result of the pattern of short-distance trips that are made on metropolitan streets. Although it is recognized that these factors increase vehicle emission rates, various levels of controversy surround the models and data used to measure pollution levels, particularly at congested intersections.[12]

[10]Ximena de la Barra MacDonald, "Health Costs of Traffic Congestion," draft paper submitted to Metropolitan Transportation Authority Planning Department, New York, New York, September 30, 1987, p. 7.

[11]Statement of an official at the Environmental Protection Agency Motor Vehicle Emissions Laboratory, Ann Arbor, Michigan, September 30, 1988.

[12]Even generally reliable emissions data generated by EPA's Motor Vehicle Emissions Laboratory have been criticized as not reflecting actual urban driving conditions, such as cold engine starts, low speeds, rapid accelerations, idling, and heavy loads.

Experts indicate that motor vehicles are and will continue to be the major source of many atmospheric pollutants, barring any new technological breakthroughs or significant shifts in transportation modes. Today's catalytic converters, which significantly reduce emission levels, have furthered a trend in reduced emissions for all major air pollutants.[13] However, in a June 16, 1988, Federal Register, the Environmental Protection Agency identified 59 metropolitan areas in the United States that did not meet the carbon monoxide standard and 68 that violated the ozone standard.[14] And, because of an anticipated decline in the turnover of vehicles to new models, continued growth in the number of vehicles, increased traffic congestion, and the generally low effect of transportation control measures, the downward trends in pollutant levels are expected to reverse by the mid-1990's.[15]

Adverse Environmental Effects

Motor vehicle emissions, accentuated under congested traffic conditions, produce gases that contribute to the greenhouse effect, the creation and destruction of ozone molecules, and acid rain. Vehicle emissions are adding somewhat to the atmospheric buildup of carbon dioxide and several other greenhouse gases, such as nitrogen oxides, methane, and ozone.[16] Some experts claim that a warming trend in the earth's atmosphere, caused by the accumulation of these gases, will eventually affect the decisions that American farmers make about what crops to grow. Vehicle exhaust also emits ozone-producing compounds that are believed to have caused up to a 20-percent reduction of crop yields in some rural areas and damage to forests. In addition, the protective ozone layer in the upper atmosphere is deteriorating because the breakup of chlorofluorocarbon molecules, used as coolants in cars and for other purposes, releases chlorine that destroys ozone molecules. Finally, studies have shown that highly acidic precipitation, formed when nitrogen oxides and unburned hydrocarbons from motor vehicle exhaust react

[13]Today's catalytic converters typically reduce hydrocarbon emissions by 87 percent, carbon monoxide emissions by 85 percent, and nitrogen oxide emissions by 62 percent.

[14]As administrator of the Clean Air Act of 1970, the agency has promulgated air quality standards for the air pollutants that endanger public health. Carbon monoxide and ozone are two of six criteria pollutants for which air quality control regions must attain specified standards.

[15]David Gushee and Sandra Sieg-Ross, The Role of Transportation Controls in Urban Air Quality, 88-101-S (Washington, D.C.: Congressional Research Service, January 28, 1988), and Gary Hawthorn, The Role for Transportation Control Measures in the Post '87 Era (Washington, D.C.: Environmental Protection Agency, 1988).

[16]About half the greenhouse effect is thought to be from the accumulation of carbon dioxide, which is generated by the burning of fossil fuels such as gasoline in cars.

with sulfur dioxide from industrial plants, is destroying freshwater aquatic life and forests throughout central Europe and North America.[17]

Adverse Health Effects

In general, the adverse health effects of motor vehicle emissions are proportional to the concentration, duration, and level of exposure to toxic substances, such as carbon monoxide and ozone gases. Carbon monoxide, emitted from automobile exhaust along highways, streets, and in garages, is inhaled by vehicle occupants and others in close proximity to the exhaust. Typically, the highest concentrations occur along heavily traveled urban highways, during periods of peak traffic density, and in places where traffic moves slowly.[18] Carbon monoxide is harmful because in restricting the flow of oxygen to the brain, it can impair driving performance, among other things.

Ozone is not emitted but is produced in the atmosphere and slowly dispersed to various parts of a region. Exposure to ozone can cause chest tightness, cough, headache, and nausea, although these effects are often subtle and difficult to isolate. Exposure to ozone also has potentially more disturbing effects—the possibility that substances in these emissions are causing pulmonary disease, ischemic heart disease, or cancer.

Various studies have established links between air pollutants and health effects; however, laboratory experimentation is of little help in quantifying the general health effects of traffic-related emissions.[19] In general, data on the health effects of motor vehicle emissions are flawed by the relative or absolute failure of the analysis to take into account the effects of confounding variables. For example, it is difficult to differentiate the effects of exposure to carbon monoxide and ozone from other factors that have more powerful health effects, such as smoking, various occupations, and genetic health factors.

[17]This issue has recently been reviewed by the National Academy of Sciences, the Environmental Protection Agency, and environmental groups such as the Environmental Defense Fund and World Watch.

[18]Because concentrations of carbon monoxide drop by a factor of 10 only a few meters from major highways, studies show that variations over short distances within a city can be as great as those between cities.

[19]Lester Lave and Eugene Seskin, Air Pollution and Human Health, A Resources for the Future Book (Baltimore, Md.: Johns Hopkins University Press, 1977), conducted an extensive review and analysis of this subject. Their work was followed by other reviews, including Theodore Joyce, Michael Grossman, and Fred Goldman, "An Assessment of the Benefits of Air Pollution Control: The Case of Infant Health," Journal of Urban Economics, 25 (1989), 32-51.

Effects on Stress

The effect of traffic congestion on motorists who can adapt to traffic delays by altering their behavior is probably lower than for individuals who do not have this flexibility or who place higher value on the time wasted in terms of money, frustration, and anger. To adapt, many commuters have changed their work hours to avoid peak conditions, have made better use of their time while commuting, and have made their commute more relaxing. Some drivers equip their cars with cellular phones and dictaphones to conduct business, and some upgrade their car stereo equipment to make the commute more enjoyable.

The lack of longitudinal studies, however, impedes an assessment of the actions drivers take to cope with and, in some instances, alter their exposure to unpleasant transportation situations. In addition, adding vehicle amenities to better cope with traffic congestion does not appear to alter tolerance limits for commuting time. According to OTA, commuters put a comparatively low value on commuting time for the first 20 minutes but approach psychological limits after 45 minutes.[20]

Aggressive behavior and physiological reactions have been linked to exposure to congested traffic conditions. Although the causes of stress and aggression have been studied, most studies have neglected to analyze potentially important transportation-related outcomes, such as the cumulative emotional, behavioral, and health consequences of travel conditions upon the individual.

Aggressive Behavior

Recent articles on topics related to traffic congestion in the news media have made references to freeway shooting incidents as evidence of the stress that is caused by exposure to congested traffic conditions. However, Dr. Raymond W. Novaco, a recognized expert on the relationship between automobile driving and aggressive behavior, believes that connecting freeway shootings with traffic-induced stress is a narrow and misguided explanation for these incidents.[21] Investigations of these incidents have revealed that the shootings followed no distinct patterns during the week or during the time of day; shooting was also clearly not done by rush-hour commuters stuck in traffic jams, for it is precisely the anonymity and escape potential of freeways that allows this behavior to

[20] OTA, Technology and the American Economic Transition: Choices for the Future, OTA-TET-283 (Washington, D.C.: U.S. Government Printing Office, May 1988), p. 118. OTA noted that in 1980, only 10 percent of all workers commuted more than 44 minutes.

[21] Raymond Novaco, Automobile Driving and Aggressive Behavior: Effects of Multiple Disinhibitory Influences (Irvine, Calif.: University of California, Program in Social Ecology, April 1988).

occur. Although being delayed in traffic is stressful for some people, Novaco believes that it is this stress alone or with other factors such as preexisting habits, alcohol consumption, and the availability of weapons that can provoke incidents at other times.

Physiological Reactions

Some studies of automobile drivers have shown a significant relationship between exposure to traffic congestion and a variety of adverse physiological reactions. For example, researchers have reported a significant and positive correlation between high traffic volumes and increased heart rates, blood pressure, and electrocardiogram irregularities.[22] Studies have also shown that chronic exposure to traffic congestion, especially over long distances, long waits, and frequent trips, increases negative mood states, lowers tolerance for frustration, and can even lead to more impatient driving habits.[23] Experts in the field point out, however, that most physiological research tends to focus on the short-term reactions of drivers to acute environmental demands rather than on the cumulative behavioral and health consequences of chronic exposure to traffic conditions.[24]

[22]Daniel Stokols and Raymond Novaco, "Transportation and Well-Being: An Ecological Perspective," p. 89, in Irwin Altman et al., Transportation and Behavior (New York: Plenum Press, 1981).

[23]Novaco, Automobile Driving and Aggressive Behavior, pp. 8 and 9.

[24]Acute environmental demands that cause physiological reactions might be excessive temperature, air pollution, and crowding conditions.

Conclusions and Recommendation

The purpose of this review has been to provide the Congress with an overview of the traffic congestion problem. The report provides an assessment of (1) the major trends that have shaped traffic congestion, (2) the various ways traffic congestion is measured and the credibility of the estimates of present and future urban freeway delay developed by FHWA staff, and (3) some of the potential effects of traffic congestion. This assessment is supported by an extensive literature review, interviews with more than 40 transportation officials in 12 congested metropolitan areas, and the consultation of 4 transportation experts. Through this review, we provide the Congress with a resource document that can be used when considering traffic-related issues.

Conclusions

We identified six forces that have shaped the nature and severity of the traffic congestion problem. Trends in suburban development, the economy, the labor force, automobile use, truck traffic, and the highway infrastructure have had significant effects on the magnitude of this problem. We found that these forces are not mutually exclusive but interact in various ways to expand the location and occurrence of traffic congestion. Recurring and particularly nonrecurring traffic congestion have increased in metropolitan areas, especially on roads between suburban activity centers, at major interchanges, and between nonmetropolitan and metropolitan counties. We conclude that these forces have combined to make traffic congestion a metropolitanwide phenomenon and an interjurisdictional problem.

We identified six interrelated measures that characterize the traffic flow for six levels of service on an ordinal scale ranging from A to F. Level-of-service A represents the best operating conditions of free-flowing traffic, level-of-service F the worst condition of a breakdown in traffic flow. The six measures were (1) traffic density, (2) average travel speed, (3) maximum service flow rate, (4) V/C ratio, (5) average daily traffic volume, and (6) daily vehicle miles of travel. Because traffic density values best represent the maneuverability of vehicles in a traffic stream, the Transportation Research Board's 1985 Highway Capacity Manual recommends that it be used to establish the level-of-service rating given to a lane or road section. However, we found that many practitioners still rely on the V/C measure to determine levels of service.

Transportation agencies use a variety of methods to measure traffic congestion, and no standard approach seems to be universally accepted. We found that the level of service at which traffic flows are considered to be congested varied among transportation agencies as did their preference for methods of measurement. Urban freeways operating at the boundary of levels-of-service C and D through level-of-service F have been associated with congested conditions during peak hours of traffic. Two major national studies as well as studies conducted by metropolitan planning organizations using various measures have concluded that the traffic congestion problem is escalating.

We conducted a methodological review of an FHWA model for estimating national trends for a portion of traffic congestion on urban freeways because of its uniqueness and the potential policy implications of its results. From our review, we believe that the FHWA model represents a positive step toward quantifying the extent of urban freeway delay nationwide. This model has broken new ground with respect to estimating current and future levels of urban freeway delay, ranking metropolitan areas by the severity of their freeway congestion problems, and quantifying national economic effects in terms of wasted fuel and time.

Our review uncovered several reasons why the estimates of freeway delay for 2005 that were made by FHWA staff may represent an upper boundary of the magnitude of the congestion problem. Based on our review with the assistance of four transportation experts, we identified five potential threats to the accuracy of these forecasts: (1) the use of a low V/C ratio and correspondingly high average travel speed as a threshold for congestion; (2) the use of Washington, D.C., freeway data to develop representative traffic volume profiles; (3) the assumption of no change in highway capacity; (4) the assumption of no change in drivers' behavior; and (5) limitations in the HPMS data used to estimate present and future freeway and nonfreeway delays across metropolitan areas.

By using 1987 data and various combinations of alternative assumptions regarding the threshold of congestion and freeway capacity, we found that the 2005 forecast for urban freeway delay could be reduced by about 32 percent. Our analysis showed that this reduction was primarily dependent on increasing capacity as opposed to changing the threshold of congestion. We conclude that a reduction of this magnitude would lower the 2005 forecast of a 436-percent increase in delay to a still substantial 297-percent increase over 1985 levels.

Although we did not assess possible changes in drivers' behavior, the application of advanced technologies to improve metropolitan traffic flow, or alternative traffic volume projections, these factors may also alter the 2005 urban freeway delay forecast. In addition, we suggest caution in using the FHWA model and HPMS data either to quantify the extent of the urban freeway and nonfreeway traffic congestion problem in given metropolitan areas or to compare metropolitan areas by the severity of their freeway delay problems.

Finally, we found limited empirical investigation of the effects of traffic congestion, although some relationships between congestion and higher business costs, health and environmental effects, and behavioral changes are generally thought to hold. A few studies were identified that quantified the substantial economic costs of traffic delays by applying dollar values to wasted time and fuel. We also found that the health and environmental effects of motor vehicle emissions have received considerable study and that emission levels of some pollutants are recognized to be higher from vehicles in congested traffic. It is commonly accepted that urban living can be stressful, but the effects of traffic congestion on human stress levels are difficult to separate from other contributing factors and, therefore, may never be fully quantifiable. We conclude, however, that the information available on potential economic, environmental, and human stress effects does provide a framework for understanding the nature of these effects, if not their magnitude.

Recommendation

Our review has documented important efforts by FHWA to provide information on traffic congestion through the use and analysis of the Highway Performance Monitoring System data. Estimates of traffic congestion help inform federal and state transportation agencies as well as the Congress on the present and potential severity of this problem. Our methodological review of FHWA's model for estimating urban freeway delay suggests that while the agency is taking aggressive steps to assess the present and future magnitude of traffic congestion, additional attention to this area is warranted. Therefore, we recommend that the secretary of Transportation direct the administrator of FHWA to review and, where appropriate, modify the collection, use, and analysis of traffic congestion data to ensure that accurate statistics on congestion are available for policy decisions regarding freeway mobility.

In a forthcoming report on federal efforts to improve freeway mobility, we have noted the need for information on the effectiveness of federal strategies to alleviate traffic congestion. The HPMS data base and related analyses are important data sources that can be used to understand and assess the effect of federal as well state and local actions on the traffic congestion problem. Consequently, careful review and refinement of these data sources could lead to valuable improvements in the quality of information available to transportation policymakers as they seek effective approaches for improving freeway mobility.

Agency Comments

In the Department of Transportation's response to a draft of this report, it generally agreed with our recommendation but cautioned that studies by its staff may not represent or have a potential effect on department or FHWA policy. The studies cited in our report are, however, considered by the department to be important resource documents that both quantify congestion and assess the relative effectiveness of various ways to reduce the problem. We made changes in the final report where appropriate, based on technical points identified by the department.

In addition to this general statement, the Department commented on the importance of other efforts it has made to quantify congestion, besides the model GAO reviewed; the confidence it has in the HPMS data base, as representative of freeway and nonfreeway conditions in urbanized areas of each state; and finally, GAO's lack of attention to the critical effect that land use development patterns have on congestion. In addition, the department specifically mentioned an omitted FHWA report that quantified conditions of highway supply and use, including measures of congestion.

Having conducted a careful review of the department's comments to consider the need to revise our report, we remain convinced that our focus on the urban congestion study mentioned above is supportable, but we recognize that our discussion in chapter 3 of other department efforts to quantify road and traffic congestions was limited. In regard to the value of the HPMS data base, we did recognize its usefulness in chapter 3 and in discussing the agency's congestion model in chapter 4. However, we still question the adequacy of this national data base, as does the department, for monitoring and forecasting congestion across urban areas. Finally, we concur that a specific discussion of the effect of land-use planning and development on traffic congestion was omitted from our report, but such effects could be considered a result of the suburban and economic trends that have shaped the traffic congestion problem, as discussed in chapter 2.

In response to our failure to review the FHWA report, Highway Planning Technical Report: Issue 2 - Supply and Use of the Nation's Urban Highways (September 1989), we point out that our data-gathering efforts were completed prior to the issuance of this report and its earlier drafts. When we did review this report, however, we found that the analyses of 1982 to 1985 HPMS data suggested congestion trends that were in line with what we found through other sources. For example, the report highlighted the gap between the supply and demand for highways, particular congestion problems in the suburbs of the largest metropolitan areas, and variances in the congestion levels by facility and urban population. In addition, we note that this report used daily vehicle miles of travel per lane per mile and a V/C ratio (0.85) to measure traffic congestion.

Expert Review Questionnaire

Our methodological review of the FHWA urban freeway congestion model relied on responses to structured review questions that we received from four transportation experts and our own research. The four experts were selected with the assistance of the Institute of Transportation Engineers, an international scientific and educational association of more than 9,000 transportation professionals from more than 70 countries. The institute recommended two experts from its technical committee: Richard Beaubien, Director of Transportation, Troy, Michigan, and Marshall Elizer, Director of Transportation, Arlington, Texas. We identified the two other experts during the course of our investigation: David Hartgen, Director of Information Resource Management, New York Department of Transportation, Albany, New York; and Timothy Lomax, Texas Transportation Institute, College Station, Texas.

The experts were asked to respond to review criteria that we developed to assess the strengths and limitations of the FHWA urban freeway congestion model. We synthesized their written responses, along with additional comments they had. The following review criteria were grouped by potential theoretical, data, and operational issues associated with this model.

Theoretical Issues

1. In your opinion, what key theories (statistical, modeling, economic, and so on) are applied in the FHWA model?

2. Please comment on the assumptions (stated and unstated) used in fitting these theories to the problem.

Data Issues

3. In your judgment, is the subset of the HPMS data base used in this study representative of national road conditions? If not, is there a better data source that could be used to quantify national urban traffic congestion?

4. The following list contains some key input data items from HPMS that are used in the FHWA model:

- physical characteristics data: selection length and expansion factor, number of lanes, lane width, shoulder type and width, median type and width, widening feasibility, and speed limit;
- traffic data: annual average daily traffic (AADT), percentage trucks, K-factor, directional factor, capacity, and future AADT.

In your opinion, how reliable are these data and how appropriate are the data aggregation procedures used in the model?

Operational Issues

5. The model operates on the assumption that peaking characteristics of traffic can be grouped into 12 representative 24-hour traffic volume profiles. In your opinion, how appropriate is this assumption, and how might the model outputs be affected, given this assumption?

6. Please comment on any other significant (stated and unstated) assumptions used by the model and the extent that "real world" conditions might diverge from these assumptions.

7. In your judgment, have the key elements and element relationships of urban traffic congestion been identified in this model as a forecasting tool? If not, what elements and relationships should be added to improve its predictive ability?

8. The model relies on a methodology used by HPMS to expand its sample of road sections to represent an entire road system. In your judgment, does this approach pose any unique problems for estimating national urban traffic congestion?

9. Please comment on the appropriateness of the methodology used in this model for determining road capacity.

10. In your opinion, how appropriate are the methodologies used to derive the following congestion statistics:

- vehicle miles traveled,
- recurring congestion per vehicle miles traveled,
- recurring delay per million vehicle hours,
- excess fuel consumption from recurring delay,
- nonrecurring delay from incidents per million vehicle hours, and
- excess fuel consumption from incidents.

11. To the extent that congestion statistics resulting from the use of these methodologies diverge from "real world" conditions, how in your judgment might the results of the study be affected and, if they do diverge, how might these methodologies be improved?

12. We are interested in your opinion regarding the policy relevance of FHWA's congestion severity index. For example, is this index an appropriate measure of traffic congestion and are the relative metropolitan rankings for 1984 and 2005 consistent with your expectations?

Comments From the Department of Transportation

U.S. Department of Transportation

Assistant Secretary for Administration

400 Seventh St., S.W.
Washington, D.C. 20590

SEP 27

Ms. Eleanor Chelimsky
Assistant Comptroller General
Program Evaluation and
Methodology Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Ms. Chelimsky:

Enclosed are two copies of the Department of Transportation's comments concerning the U.S. General Accounting Office report entitled "Traffic Congestion: Driving Forces, Measures, and Impacts."

Thank you for the opportunity to review this report. If you have any questions concerning our reply, please call Bill Wood on 366-5145.

Sincerely,

Jon H. Seymour

Jon H. Seymour

Enclosures

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Enclosure

Department of Transportation

Reply to GAO Report of August 18, 1989, on Traffic Congestion: Driving Forces, Measures, and Impacts

Summary of GAO Findings and Recommendations

The GAO identified six forces that have shaped the nature and severity of the traffic congestion problem: (1) trends in suburban development, (2) the economy, (3) the labor force, (4) automobile usage, (5) truck traffic, and (6) the highway infrastructure. These forces were found not to be mutually exclusive, but interact in various ways to expand the location and occurrence of traffic congestion. Traffic congestion has increased, and these forces have combined to impact on its severity, and to make traffic congestion a metropolitan-wide phenomenon. The GAO found that transportation agencies use a variety of methods to measure traffic congestion with no standard approach being universally accepted. Upon a methodological review of a Federal Highway Administration (FHWA) model for estimating national trends for traffic congestion, the GAO concluded the model represents a positive step toward quantifying the extent of urban freeway delay nationwide. However, in its analysis, the GAO also concluded that forecasts for urban freeway delay for the year 2005 could be reduced by about 32 percent.

The GAO recommends that the Secretary of Transportation direct the Federal Highway Administrator to review and where appropriate, modify the collection, use, and analysis of traffic congestion data to ensure that accurate congestion statistics are available for policy decisions regarding the freeway mobility issue.

Summary of Department of Transportation Position

We are in general agreement with the recommendations; but we think the overall findings tend to place too much emphasis on "staff studies" as representative of, or having "potential impact" on, transportation or FHWA "policy." While the fact-finding portion of the effort was very detailed and contained a great deal of important background information involving technical issues, the report sometimes used the data in the technical resources out of context in order to draw conclusions regarding FHWA policy matters. The FHWA staff efforts, which were utilized as important resources in the report, were developed because of known gaps in congestion data, analysis, and/or evaluation. These studies serve FHWA and the transportation community as further indicators of the extent of the problem of urban/suburban congestion and provide some analysis of potential improvements for mitigation. The studies should not be considered as having importance beyond their original purpose: to document efforts to quantify congestion and to assess the relative effectiveness of various ways to reduce the problem.

- 2 -

The GAO review of methodology for assessing urban congestion was limited to the methodology advanced by Jeffrey Lindley in A Methodology for Quantifying Urban Freeway Congestion. While this approach has received much visibility over the past 18 months, it is a research tool to help quantify urban freeway congestion. The FHWA recognizes it as such and realizes that it includes generalizations and assumptions that will require further improvements if its use is to be extended beyond its current application. The FHWA has been assessing congestion for years using the Highway Performance Monitoring System (HPMS) analytical process. With the output of this tool, FHWA can assess urban freeways in terms of the volume-to-capacity ratio (V/C), average annual daily traffic (AADT), vehicle miles traveled (VMT), average overall travel speed, user costs, and many other factors both now and in the future. In contrast to Mr. Lindley's approach, these procedures do take future capacity improvements to the existing system into consideration and use daily congestion relationships that reflect relative AADTs being carried by freeways and the capacity of the freeways. These relationships were developed using data reported by all States. Congestion information from the Analytical Process is being reported in the biennial reports to the Congress. We recommend that GAO broaden its effort to recognize all other FHWA efforts addressing congestion. As example of the broad based effort to quantify and analyze traffic congestion, we have attached a copy of a recent Highway Planning Technical Report. This report quantifies current conditions of highway supply and use, including measures of congestion.

Deleted.

There are several statements in the GAO report concerning the quality, accuracy, and limitations of the HPMS data and the way it is obtained that are incorrect or poorly stated. For example, in contrast to the statements of the FHWA official quoted, we have high confidence in the fact that the HPMS data base contains very good representative data on the extent, condition, and performance of both freeways and non-freeways in urbanized areas of each State. With this information, we can determine the level of congestion and an estimate of delay on each functional class on a Statewide basis. While States have been given the latitude to sample either individual urbanized areas or sample all urbanized areas as a group, this does not reduce the quality of the data, as suggested, but only limits our ability to address individual urbanized area congestion in specific States. Even in these cases, congestion can be estimated on a less statistically sound basis.

The FHWA recognizes that the existing HPMS data base needs to be enhanced to improve our capability to monitor and forecast congestion in the Nation's urbanized areas. During the next fiscal year, FHWA will be developing recommendations to improve our capabilities in this area.

- 3 -

In addition, land use is a factor impacting on congestion that is not mentioned. The FHWA's efforts to develop and improve transportation planning procedures include research on methods to maximize transportation system performance and its positive impact on economic development. This includes methods to more effectively coordinate transportation and land use planning and development.

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