Bureau of Transportation Statistics

United States Department of Transportation

Transportation Statistics Annual Report 1996

transportation and the environment

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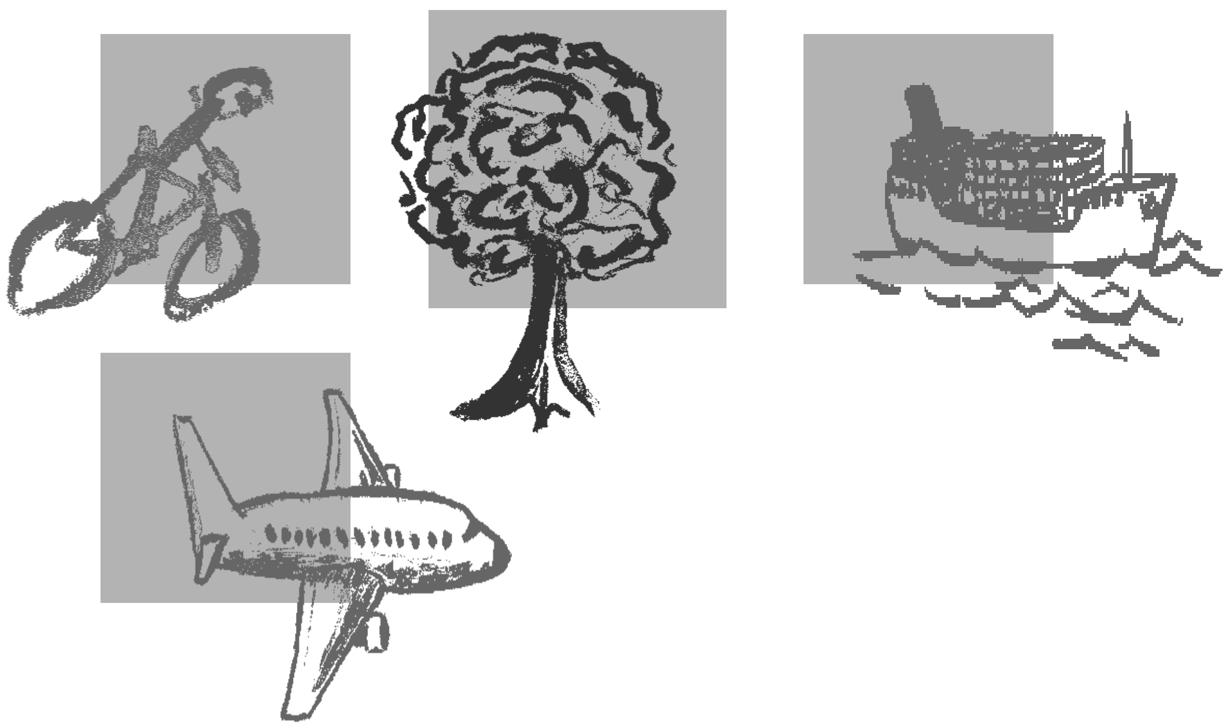

transportation and the environment

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STATEMENT OF THE DIRECTOR

AS DIRECTED BY THE INTERMODAL SURFACE TRANSPORTATION EFFICIENCY ACT (ISTEA), THE BUREAU OF TRANSPORTATION STATISTICS (BTS) PREPARES AN ANNUAL COMPREHENSIVE ASSESSMENT OF THE NATION'S TRANSPORTATION SYSTEM AND THE STATE OF TRANSPORTATION STATISTICS. THIS DOCUMENT IS THE THIRD SUCH ANNUAL REPORT TO THE PRESIDENT AND CONGRESS.

Transportation, by moving goods to where they are required and people to where they wish to go, is a vital component of all products and services produced in an economy. By expanding the markets for goods and labor, transportation promotes regional specialization, large-scale production, interregional and international trade, personal mobility, and social interactions. Consequently, in a large and affluent industrialized country such as the United States, transportation is a vast enterprise.

The U.S. transportation system comprises an extensive physical network of highways, railroads, transit systems, pipelines, waterways, ports, and airports, in addition to the industries that produce and maintain the vehicles (e.g., motor vehicles, ships, planes, bicycles) that use the physical network; the providers and arrangers of for-hire transportation services; and the agencies that administer transportation programs. Transportation is thus a broad and important economic sector, accounting for about 11 percent of the gross domestic product (GDP) in 1994, roughly comparable to health (14 percent), food (12 percent), and education (7 percent).

Part I of this report surveys the *state of the transportation system* in the United States. It opens with an assessment of the nature, patterns, and trends in the use of the transport system for passenger and freight movements, as well as the condition and performance of the U.S. transportation system, which currently offers U.S. residents the world's highest level of personal mobility. It proceeds to a discussion of transportation's importance to the economy and society as indicated by a variety of economic indicators. Next, Part I describes the unintended consequences—accidents, fatalities, and oil import dependency—associated with transportation. Finally, it explores the state of transportation statistics.

This year's theme section, "Transportation and the Environment" (Part II of the report), surveys the collateral damage to the environment arising from transportation. It focuses on the scale and dimensions of the damage, and the effect of actions to ameliorate the damage. Part II surveys transportation-related environmental trends for three geographical scales—national-level trends and impacts, air quality at the metropolitan level, and a comparison of U.S. transport-related air pollution with that in several industrialized and developing countries. As noted in Part II, vehicle emissions have decreased impressively in the United States, but some pollutants have increased recently, suggesting the need for continued monitoring of pollution trends.

▶The State of the Transportation System

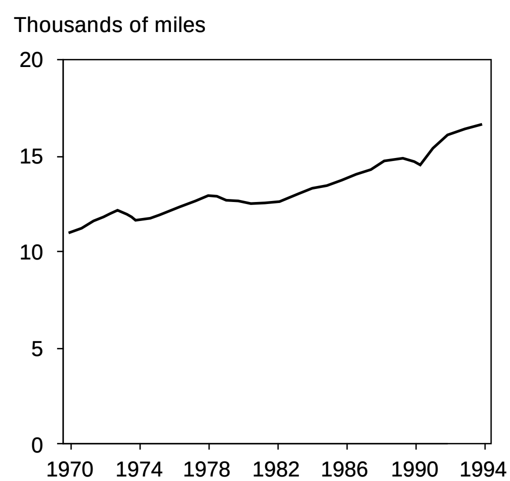
Travel, the Movement of Freight, and the Transportation System

Americans travel more and move more goods than ever before. Passenger travel grew in the United States on average 2.7 percent a year between 1970 and 1994. Passenger-miles traveled per person increased from 11,400 miles in 1970 to 16,800 miles in 1994. In the same period, ton-miles of freight increased by 2.2 percent annually. By 1994, 12,600 ton-miles of freight were moved per person.

On the passenger side, while the growth in automobile use in terms of absolute miles traveled overshadows that in all other modes, air travel tripled and travel in light-duty trucks (including pickups, mini-vans, and sport-utility vehicles) quadrupled between 1970 and 1994. Among the many factors that contributed to this rapid growth in personal transportation are growth in population and jobs (including greater labor force participation of women), increased household formation, income, vehicle ownership and licensed driver population, and metropolitan growth, coupled with residential and job dispersion. These and other factors will likely continue to push up passenger travel in the future, though at a more moderate pace.

Freight transportation grew substantially in all modes. Information from the 1993 Commodity Flow Survey (CFS), conducted by BTS and the Bureau of Census, allows us for the first time in nearly two decades to look at the complex world of freight movement in a technologically evolving and globalizing economy—how much and what moves over which modes within

PASSENGER-MILES PER CAPITA



SOURCE: See chapter 1, figure 1-3.

the United States. The CFS shows that in 1993 the nation's freight transportation system carried 12.4 billion tons of goods worth more than $6.3 trillion over a total distance of 3.7 trillion ton-miles. Nearly three-quarters of the *value* of items transported moved by truck, followed by, in order of magnitude, intermodal, rail, water, and pipeline transport. Over half the *weight* of all freight was moved by truck, with rail and water accounting for most of the remaining tonnage. In terms of *ton-miles*, the split between truck, rail, water, and pipeline is more even, given the greater distances moved by large shipments in the nonhighway modes. Air cargo shipments registered the sharpest increase, although in absolute terms this mode's share remains small.

The performance and condition of the nation's transportation system are mixed. The condition of highways has generally improved, but greater demand has increased congestion in many metropolitan areas. Transit, on the other hand, has generally experienced somewhat improved performance with little change in condition. The condition of airport runways has improved slightly, and airline performance is somewhat better, even though the average age of the industry's fleet increased slightly. The condition and performance of freight rail transportation have both improved, but the condition and performance of passenger service have generally worsened. Despite the fact that little new construction has been initiated over the past decade, the performance and condition of pipelines has improved slightly.

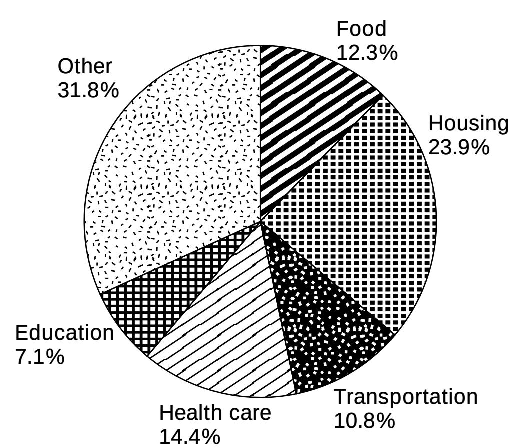
Three key transportation events were noteworthy in 1995. The first two events were specific to the United States: the designation of the National Highway System and changes in the industrial concentration of the railroads, with the number of Class I carriers reduced from 14 to 12 through consolidation during 1995. The third, the Kobe, Japan, earthquake, which occurred a year to the day after the Northridge, California, earthquake has many lessons for transportation systems in earthquake-vulnerable locations in the United States.

Transportation and the Economy

Transportation reaches into every facet of our economic life. A variety of economic indicators is needed to capture the rich interplay between transportation and the larger economy and measure transportation's importance to the economy.

One measure of transportation's contribution to the economy is provided by its share of the gross domestic product. This can be computed either as transportation's share of final demand in GDP, or as a share of value-added created by transportation in GDP. Transportation-related final demand is defined as the value of all transportation-related goods and services, regardless of industry origin, delivered to final demand (which includes consumer and government expenditures, investments, and net exports). In 1994, transportation-related final demand amounted to $725 billion, or 10.8 percent of the GDP. As noted earlier, the economic signifi-

U.S. GROSS DOMESTIC PRODUCT BY MAJOR SOCIAL FUNCTION, 1994



SOURCE: See chapter 2, figure 2-1.

cance of transportation is comparable to that of health, food, and education.

While GDP attributed to transportation-related demand provides a measure of transportation's importance to the economy, it does not fully reflect the *transport content* of the variety of goods and services delivered to final demand. Value-added by transport industries should provide that information, except that the Standard Industrial Classification used in the National Accounts recognizes only for-hire transportation services. The for-hire industry does not include the significant role of so-called own-use transport activities carried out by nontransportation industries in support of their primary production. Thus, transportation's contribution to the economy is significantly undercounted. Indeed, in 1993 (the last year of available data), value-added originating in the for-hire transportation services industry was $208 billion.

This offers BTS an important challenge to find a comprehensive and systematic way to measure transportation's contribution to the economy more fully. In turn, such a measure will allow a better assessment of the need for transportation infrastructure and transportation's impacts on the production of other industries and the environment. To this end, BTS and the Bureau of Economic Analysis (BEA) are jointly developing a Transportation Satellite Account (TSA). The aim of the TSA is, first, to develop a consistent, comprehensive, and reliable means of assessing transportation activities (both for-hire and own-use) in relation to other industries and activities of the economy; and, second, to create a framework that organizes different types of transportation data (e.g., employment, output, cost, energy use, infrastructure) in order to facilitate consistent analysis of relationships between the various aspects of transportation.

The importance of transportation services as inputs to production varies by industry. In general, material-intensive industries tend to be transportation intensive. Measured in producer prices, transportation costs range from 10 cents per dollar of output in the glass, stone, and clay product industry to 2 cents per dollar of output in the finance, insurance, and real estate industries.

Consumer and government expenditures also are important indicators of the value of transportation to society. In the United States, transportation's share in total household expenditures was 19 percent in 1994. Only housing subsumed a larger percentage of total household expenditures. Not surprisingly, transportation expenditures in rural and urban areas differ. For example, in 1994, rural households spent almost 24 percent of their incomes on transportation compared with about 18 percent for urban households. Also, rural households spent more (both absolutely and proportionately) on vehicle purchases and fuel, but less on insurance and repairs than urban households.

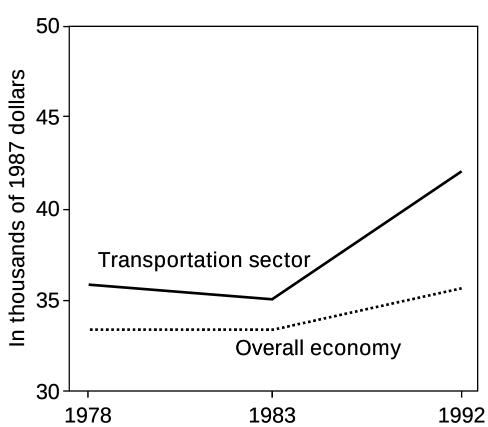
Federal spending on transportation increased in real terms by 6.5 percent between 1982 and 1992, while spending by state and local governments (excluding federal grants) increased by 46 percent over the same period. In relative terms, the federal role in financing transportation diminished from 39 percent to 32 percent between 1982 and 1992. Taking federal, state, and local together, most government funds were spent on highways (about 60 percent), followed by transit, air, and water transportation. Between 1982 and 1992, the proportion of federal spending on transit, rail, and water transport decreased, while air transport and highway funding shares increased.

Between 1977 and 1994, federal transportation-related budget receipts including revenue from transportation-related federal trust funds (taxes and user fees dedicated to a specific mode) increased from $16.0 billion to $19.7 billion (in constant 1987 dollars). The two largest federal revenue generators are the Highway Trust Fund—which has a highway account and, since 1983, a transit account—and the Airport and Airway Trust Fund. Of these, aviation trust fund revenues increased the most; transit account revenues also grew, but more slowly. Highway account revenues remained unchanged. Taken together, the trust fund balances (unspent money in these accounts at the end of the year) grew substantially from the mid-1980s to the early 1990s, but have since declined from the 1992 high point.

The transportation sector's labor productivity (measured by value-added per worker) has been well above that of the economy as a whole since 1978. For example, transportation's productivity was 9 percent higher than the national economy in 1978 and 19 percent higher in 1992. Deregulation and technological change in the for-hire transportation industries were partially responsible for their higher than average levels and growth rates. In particular, the air transport industry has experienced a rapid rise in labor productivity, arising in part from the use of larger and faster aircraft, the computerization of passenger reservations, the hub-and-spoke flight network, and changes in flight personnel requirements.

The railroad, trucking, and airline industries are of vital importance to the U.S. economy. Railroad's share of intercity ton-miles has been fairly steady since the 1970s, following decades of decline. In addition to moving bulk commodities, railroads also move time-sensitive cargo, such as mail, and international containers. After years of financial difficulty, the rail industry is recovering. The airline industry has been very responsive to changes in demand for innovative services, such as just-in-time delivery and intermodal cargo shipments. Its financial performance has been mixed, but remains fairly strong. Appendix A of this report provides an economic overview of the commercial aviation industry, with special emphasis given to the post-deregulation era.

VALUE-ADDED PER EMPLOYEE



SOURCE: See chapter 2, figure 2-2.

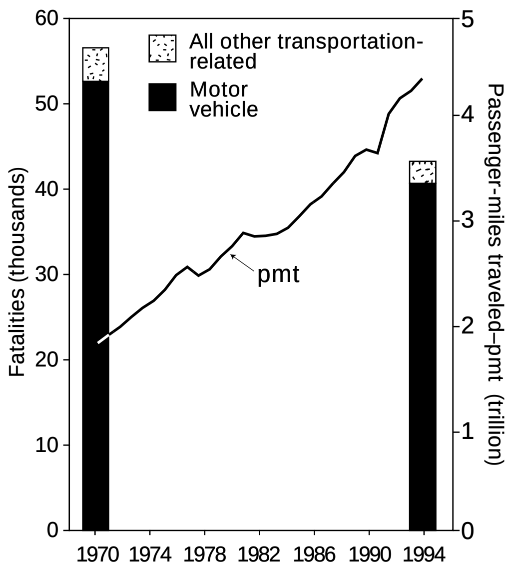
Transportation and Safety

The number of motor vehicle traffic fatalities has declined significantly from its historically highest level in 1972, when 54,589 people lost their lives in crashes. The decline occurred despite a doubling in vehicle-miles traveled (vmt) in the last two decades. The rate of motor vehicle fatalities per mile of travel reached its lowest point ever in 1994—1.7 fatalities per 100 million vmt—and stayed at this level in 1995. (In the 1960s, there were more than 5 fatalities per 100 million vmt.)

Other statistics allow little room for complacency. While *rates* of fatalities and injuries have slowly dropped, 1995 is the third year in a row in which there were *absolute increases* in motor vehicle fatalities—an estimated 41,700 fatalities or about 115 per day. Moreover, motor vehicle crashes are the leading cause of death for Americans ages 15 to 24.

The total costs of transportation accidents extend well beyond the pain and suffering experienced by the crash victims, including economic and social costs such as direct costs sustained by the injured individuals and their insurers, lost productivity and a lower standard of living for the injured, losses of public revenue, and increases in publicly funded health care costs and public assistance expenses. Such economic costs to

TRANSPORTATION-RELATED FATALITIES



SOURCE: See chapter 1, figure 1-3 and chapter 3, table 3-4.

U.S. society over the lifetime of persons injured and killed in transportation-related incidents in 1990 are estimated at $135 billion.

Much work remains to be done to improve understanding about the causes of crashes and how to prevent them. Analysis of data from police reports suggests that about 85 percent of the factors contributing to motor vehicle crashes were associated with the driver, 10 percent involved the road environment, and 5 percent involved the vehicle. We need to know more about the relationship between human factors and crashes, including substance abuse, fatigue, and the many complex elements that affect the way vehicle operators interact with the surrounding environment. As information about human factors improves, research priorities can be directed to projects where remedies would have the greatest potential to avoid crashes.

While airline travel is among the safest means of passenger transportation, there has long been a difference between the safety records of major air carriers and commuter airlines, which in recent years have grown rapidly in revenue passenger-miles. Commuter airlines in the past were not required to adhere to the same safety requirements as major carriers. New commuter airline safety standards, promulgated in December 1995 by the Federal Aviation Administration (FAA), will be phased in over the next few years to bring commuter airlines under the same standards, except where common sense dictates different requirements.

Energy and Transportation

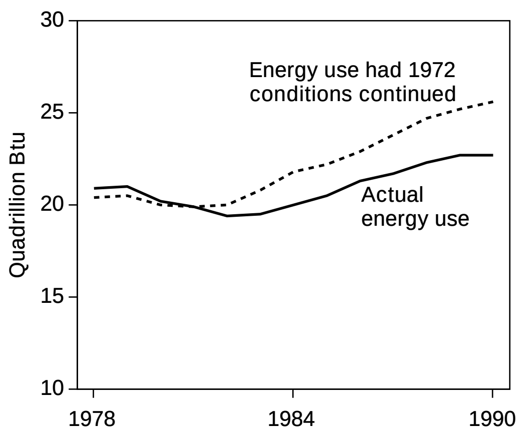
U.S. dependence on imported oil has grown over the last decade. Imported oil as a share of total U.S. consumption increased from a low of 27 percent in 1985 to 45 percent in 1994—just slightly shy of the historic high reached in 1977. Because transportation energy use is increasing and domestic oil production continues to decline, U.S. reliance on imports is likely to continue in the future. The Energy Information Agency projects that imported oil will supply about 60 percent of U.S. oil demand by the year 2005.

While other sectors shifted away from oil over the past two decades, the transportation sector remains almost entirely dependent on petroleum. In 1994, transportation used 22.7 quadrillion Btu (quads) of petroleum products to satisfy 97 percent of its energy requirements. Transportation accounts for about two-thirds of total U.S. oil consumption.

Highway vehicles account for the largest share of transportation energy use, followed distantly by air transport. For example, passenger cars use 42 percent of total transportation energy; light trucks, 20 percent; and heavier trucks, 16 percent.

Transportation energy use in the last two decades increased only half as much as would be expected, based on the growth in passenger travel, because of improvements in energy efficiency and changes in the modal structure. Most of

TRANSPORTATION ENERGY USE



SOURCE: See chapter 4, figure 4-9.

the efficiency gains derive from improvements in energy use per vehicle-mile for passenger cars, light trucks, and aircraft, with a cumulative reduction over 20 years of 4.8 quads.

Changes in modal composition affect energy use, depending on the energy intensities and load factors of the modes. In highway travel, declining vehicle occupancy rates have worked against efficiency gains, although these have been partially offset by smaller and more fuel-efficient vehicles. Improved load factors have been key to enormous efficiency gains of rail freight and commercial air passenger traffic. The net effect of modal structure changes has been to increase energy use, cumulatively over the past two decades, by a little less than 1 quad. In the case of passenger air travel, without the efficiency gains due to technological improvements, larger aircraft, and improving load factors, energy use would have been more than two times higher than it was in 1993 (4.7 quads instead of 2.3 quads), almost as much as all freight modes combined.

In recent years, highway vehicle energy efficiency improvements (based on energy use per passenger- and ton-mile) have tapered off. Gains from the corporate average fuel economy standards and initiatives have nearly reached their full effects. Also, the collapse of oil prices in 1986 negatively affected efficiency improvements: lower prices and stable supplies greatly weakened the market incentives for energy efficiency. Government energy efficiency regulations, technological change, and transportation capital stock turnover drove efficiency for several years after the fall in oil prices until the early 1990s when energy efficiency improvements slowed.

Concerns about the transportation sector's dependence on oil imports and the environmental impacts of fossil fuel combustion spurred interest in alternative fuels and vehicles. The Alternative Motor Fuels Act of 1989, the Clean Air Act Amendments of 1990, and the Energy Policy Act of 1992 established programs and incentives to encourage the use of alternative fuels and vehicles. If successfully implemented, these programs could result in a significant increase in the number of alternative vehicles on the road and supplies and availability of alternative fuels. Whether these programs will be sufficient to initiate a self-sustaining market for these fuels and vehicles is not known.

The State of Transportation Statistics

A great deal is known about the physical components of the transportation system and their location. Much less is known about the condition and performance of the system, how the system is used, and how use of the system affects the economy and society. In some cases, data gaps impede understanding. In other cases, basic measurement concepts need to be more fully developed. Examples include how to fully measure the economic importance of transportation, and how to measure the full social costs and benefits of transportation.

To further the state of knowledge, BTS's research program is building on its base of expertise and working with other agencies to collect and compile statistical information and conduct analyses and studies. Results from the Commodity Flow Survey, conducted in partnership with the Bureau of the Census of the U.S. Department of Commerce, provide the most comprehensive picture since 1977 about where and how goods are shipped.

BTS and the Census Bureau are also jointly conducting the American Travel Survey (ATS), which aims to provide a comprehensive picture of long-distance (more than 75 miles), domestic, and international travel by people who live in the United States. It provides insights about how, where, when, and for what purpose people travel.

Even with this added information, however, important data gaps about the extent and use of the system remain. For example, little validated data are available about the flow within the United States of goods that are internationally traded. Similarly, the ATS may need to be supplemented to identify the domestic travel of foreign visitors to the United States, particularly given the termination of the traditional source of such data—the U.S. Travel and Tourism Administration. Uncertainties also exist about the number of highway vehicles and the miles these vehicles travel on average.

Remarkably little is understood about transportation as a consumer of economic resources, and many transportation activities (such as in-house shipping of goods by companies) are not accounted for by BEA's National Income and Products Account. As noted earlier, BTS and BEA are working together to establish a Transportation Satellite Account associated with the NIPA, which should reveal previously hidden dimensions of transportation's importance in the economy.

As new information is collected and analyzed, it will need to be disseminated to a wide range of transportation decisionmakers in the private sector and at all levels of government. BTS is pursuing the application of new technologies to accomplish this task in a timely, comprehensive, and efficient manner. Information technology also allows data to be presented in more effective ways. The Bureau is developing innovative ways to overlay data from the CFS and the upcoming ATS with geographic, demographic, and economic information, using geographic information system technologies.

Transportation and the Environment

Although the vast enterprise of American transportation, constituting one-ninth of the economy, confers the highly prized benefits of mobility and access across an enormous range of goods and services, it also imposes undesired consequences on the environment. Part II of *Transportation Statistics Annual Report 1996* focuses on these environmental consequences: how adverse environmental effects accompany growth in transportation, and how public and private actions are mitigating the effects. The emphasis is on identifying which environmental problems associated with transportation are being tackled successfully, and which problems are getting worse or are proving resistant to current policies and approaches to solve them.

This discussion is organized in four parts:

- **Introduction.** Delineation of the multiple dimensions of environmental damage associated with transportation, a demonstration of the inability of markets to price environmental consequences into the cost of transportation (and hence a rationale for government intervention through environmental policies and standards), and the evolution of U.S. environmental policy as a mix of market incentives, regulations, and information programs.
- **National trends.** What is the progress of transportation-related national environmental indicators? Which criteria pollutant emissions are declining in a period of increasing travel and thus qualify as success stories? In which cases have transportation-related emissions increas-

ed? In what complex areas of environmental damage is our information and knowledge inadequate to form a reliable opinion?

- **Metropolitan air quality.** What progress is being made in improving metropolitan air quality where 90 million of the 200 million residents were estimated to be exposed to unhealthy levels of air pollution during some period in 1994? As we go beyond technology-based solutions to reduce emissions, what is the promise of the various short- and long-term transportation control measures (TCMs)?
- **International comparisons.** How does transportation-related air quality in the United States compare with that in other industrialized countries and in the newly industrializing developing countries? As developing countries are on the threshold of a rapid motorization phase, how will air quality and greenhouse gas emissions be affected and what are the climate change implications?

Environmental Impacts of Transportation

Transportation-related activities can degrade environmental quality and adversely impact human health and productivity. Motor vehicle emissions are a significant source of urban air quality problems. Carbon dioxide emissions from the combustion of fossil fuels by vehicles are increasing the concentration of greenhouse gases, which have the potential to alter the earth's climate. Crude oil and gasoline leaks and spills from tankers, motor vehicles, and above- and below-ground fuel storage tanks pollute surface and groundwater. Old vehicles, tires, and paving materials that are not recycled can cause problems for landfills, contaminate water systems, and contribute to air pollution emissions. Transportation infrastructure affects land use, flora and fauna habitats, and may cause changes in local water tables and drainage patterns.

The extent of these environmental impacts depends on the complex interactions of transportation-related pollution with local geographic and meteorological conditions, technology, markets, and public policy. Although governments play important roles in supplying components of transportation infrastructure and in carrying out environmental policies pertaining to transportation, the vast majority of transportation decisions are made in the marketplace by businesses and individuals.

Markets are efficient at producing and allocating private goods and services, but they tend to ignore the environmental harm that can occur from the byproducts of transportation activities. Pricing mechanisms seldom reflect environmental damage in the cost of transportation, and this has been a rationale for government intervention through environmental policies and standards. Emissions standards for newly manufactured highway vehicles first imposed by the federal government in the late 1960s and early 1970s are examples. Today, more than 20 laws have provisions that address many environmental impacts from transportation. The effectiveness of these laws is somewhat dependent on the accuracy and comprehensiveness of data on environmental impacts. Over the past 25 years, a good deal of progress in data collection has been made, particularly for motor vehicle emissions. Unfortunately, other aspects of environmental quality are less well documented. More needs to be known about transportation impacts on surface and groundwater resources and the interaction between transportation and land use, particularly in terms of the costs of urban sprawl.

Much of the data about the environmental impacts of transportation was developed to monitor progress in meeting the goals of national policies. Hence, there are many limitations to the data. For the most part, the environmental management system now in place treats each kind of pollution separately, even though there are complex interactions among environmental media. Most analyses of transportation's environmental impacts focus on individual modes—highway vehicles, aviation, railroads—rather than comparative environmental performance among modes. Moreover, a complete analysis of the environmental impacts of transportation would need to take into account upstream activities (e.g., oil field development, petroleum refining, vehicle production) that make transportation possible.

In order to distribute resources efficiently, the unintended costs of transportation must be balanced against the benefits. Some have argued that full-cost accounting is needed to measure the social costs and to fully identify the benefits of transportation. Of course, full-cost accounting places even greater emphasis on data collection for a wide range of transportation activities. Appendix B of this report reviews the BTS conference on measuring the full social costs and benefits of transportation.

Environmental Trends and the U.S. Transportation System

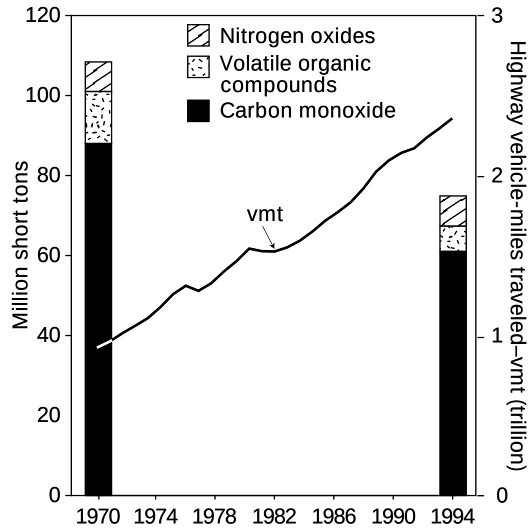
The U.S. transportation system—capable of moving 3 trillion ton-miles of freight to their destination, and accommodating 4 trillion passenger-miles of travel—inevitably has unintended adverse environmental impacts from the more than 200 million vehicles. Many, but by no means all, of these impacts stem from reliance of the transportation system on fossil fuels, especially petroleum. Highway vehicle travel is the primary source of environmental impacts from the transportation sector.

Air pollution—the most conspicuous and well-studied environmental impact of transportation—has been the subject of extensive remedial action and related monitoring and data collection. Since 1970, much progress has been made in curbing so-called criteria air pollution from highway vehicles. Criteria air pollutants are carbon monoxide (CO), ozone, nitrogen dioxide, airborne particulate matter of less than 10 microns, lead, and sulfur dioxide. Airborne lead emissions from highway vehicles have all but been eliminated, and the sulfur content of fuel has been lowered appreciably. Even though vehicle-miles traveled doubled between 1970 and 1994, total emissions of CO and volatile organic compounds (VOC) from transportation sources have been cut significantly, and oxides of nitrogen (NO_x) emissions have remained almost level.

According to BTS's analysis, *if emissions rates had not been reduced, emissions of VOC from transportation would be 4.5 times current levels, CO emissions would be 3.2 times as great, and NO_x emissions about twice as great.* Moreover, because transportation accounts for such a large share of all emissions of these pollutants, national emissions from all sources in 1994 would have been 2.4 times as great for CO, twice as great for VOC, and 40 percent greater for NO_x had emissions rates not been reduced. Nearly all of this progress is attributable to lower emissions rates resulting from federal new vehicle emissions standards and fuel-content requirements.

While the effort to control air pollution from highway vehicles has been an environmental success story, increases in some air pollutants from transportation occurred in 1992, 1993, and 1994 (the last years for which data are available). Moreover, the United States continues to be the world's largest producer of greenhouse gas emissions—both absolutely and on a per capita basis.

Surface and groundwater pollution from transportation, and from the transportation and storage of fuels and other substances used for transportation, are extensive. Oil and fuel spills from oil tankers, filling stations, and storage tanks are major problems. Coast Guard data on oil discharged into U.S. waters suggests that both the volume and overall amounts of reported spills has trended downward over the last 20 years, although analysis is complicated by the



SOURCE: See chapter 7, figure 7-1; and U.S. Department of Transportation, Federal Highway Administration.

unpredictable timing of major tanker spills. Water pollution also arises when oil, fuel, and other chemicals leak from vehicles and run off highways into bodies of water. Improper disposal by vehicle owners who change their oil at home is a pervasive, but unreported problem.

Millions of people who live or work near major highways, airports, and railyards are exposed to annoying levels of transportation noise. Transportation noise rarely leads to hearing impairment, but can lead to sleep loss and related health problems. Policy measures are primarily aimed at reducing noise at the source and shielding or removing the receptor from the source. The localized nature of noise makes it hard to characterize its impacts at a national level.

Transportation vehicles and infrastructure are major sources of solid waste. Recycling and reuse of highway pavement is extensive, and over 90 percent of retired cars are partly recycled. Over the past two decades, cars have become much lighter as manufacturers increasingly replace steel and other metals that are more cost-effective to recycle with plastic and composite materials that are less so. These materials are often shredded and delivered to landfills. As the materials used in cars continue to change, new challenges are created for recycling and reuse. Recovery for obsolete components or parts of cars vary. Well over 90 percent of obsolete car batteries are recycled; for tires, however, the proportion was probably in the range of 20 percent in 1990, although data are limited.

The direct and indirect effects of transportation on biodiversity and wildlife habitat are poorly understood at the aggregate national level. This is an area for research that will become more important as land for wildlife habitats becomes more scarce. The interrelationships between transportation and land use, and their implications for the geography of development, are also important. Transportation improvements often lead to urban sprawl, which increases the amount of developed land and also the demand for transportation.

Transportation and Air Quality: A Metropolitan Perspective

Most travel, particularly by automobile, is completed within metropolitan areas. Despite the improvement in national air quality trends, the Environmental Protection Agency (EPA) currently lists 182 metropolitan areas as nonattainment for at least one of the six criteria air pollutants.

While urban highway travel has doubled in less than 20 years, advances in automotive technology have reduced pollutant emissions in metropolitan areas and improved air quality. BTS analysis of data collected by EPA for 13 major metropolitan statistical areas shows decreases between 1985 and 1994 in all criteria pollutant emissions, with the exception of two areas showing NO_X increases. For instance, Los

Angeles recorded 208 unhealthful days in 1985 but only 136 in 1994. Similarly, over the same period the number of unhealthful days in New York dropped from 65 to 8, in Pittsburgh from 9 to 2, and in Phoenix from 88 to 7. (Unhealthful days are those in which EPA's pollution standards index exceeded 100.)

This progress notwithstanding, the most recent evidence shows that emissions reductions are slowing and, barring any major changes, will soon be overwhelmed by travel growth. Some have suggested, therefore, that policies are needed to reduce travel (such as employee trip reduction) or to shift people from automobiles to other modes (by improving transit or bicycle/ pedestrian facilities). An examination of these policies, collectively known as transportation control measures, shows that they tend to have a small positive impact on reducing emissions, but are often expensive in comparison with technology-based solutions. The most effective TCMs include parking fees and congestion pricing.

Longer term measures—highway construction and land-use planning—are also considered TCMs. Highway construction, or the decision not to build, affects the volume and distribution of traffic, and therefore affects emissions. Elements of land-use planning may also affect travel patterns and emissions, because overall development may affect trip lengths, mode split, and congestion. And at a more localized level, transit-oriented development may be a means to reduce the dominance of single-occupant vehicles. The impact of these longer term TCMs on emissions and air quality, however, is uncertain. Few places have attempted to implement land-use planning as a TCM, thereby limiting direct empirical analyses. Moreover, analytical modeling of the long-term impacts—of highway construction, for instance—is generally inconclusive because it can only address the direct, short-term impacts on vehicle-miles traveled, and even then imperfectly.

While the evidence suggests that individual TCMs have relatively modest impacts, complementary TCMs, taken together, may have higher impacts than current research indicates. Hence, TCMs could play an important role in the long-term strategy for emissions reduction. Also, it should not be assumed that the current preferences of Americans, such as the preference of many for large suburban lots and single-occupancy vehicle transportation, will continue indefinitely. Demographic changes and changes in tastes and attitudes may increase the popularity of options like transit-oriented development at some future date.

International Comparison of Transportation and Air Pollution

The transportation community faces the major challenge of curbing air pollution and greenhouse gas emissions, especially carbon dioxide (CO_2) stemming from worldwide growth in motor vehicle use. The world's motor vehicle fleet has more than doubled since 1970, exceeding 615 million vehicles in 1993. Over three-quarters of these vehicles are owned by citizens of the most affluent countries of the Organization for Economic Cooperation and Development (OECD).

The United States and several other countries, mostly in the OECD, have reduced vehicular emissions rates with catalytic converters and cleaner fuels. As a result, OECD's share of several kinds of air pollution from transportation is less than its share of all vehicle-miles traveled (more than 70 percent). In 1990, OECD countries accounted for 48 percent of CO, 59 percent of VOCs, and 64 percent of NO_x emitted by the global motor vehicle fleet. There is growing uncertainty, however, about whether technological solutions to pollution, by themselves, will be sufficient to keep up with future growth in transportation demand in OECD countries.

The share of the world's motor vehicle fleet held by non-OECD countries increased from 14 to 24 percent between 1970 and 1993. Growth in motorized transport is overwhelming transportation capacity in many large cities in developing countries, where air pollution from motor vehicles is adding to significant pollution from industries and residences. Often, cars and trucks are not equipped with properly functioning emissions controls, and cleaner burning fuels are unavailable. Lead and suspended particulates from vehicles can pose an immediate health risk to exposed urban populations. Although countries as diverse as the United States, Japan, Brazil, Canada, and South Korea now require use of unleaded gasoline, leaded gasoline is still in wide use in many developing and in some OECD countries.

Transportation accounts for about 20 percent of the world's greenhouse gas emissions. Motor vehicles are responsible for nearly all of transportation's contribution. CO_2, the major greenhouse gas of concern, is an unavoidable byproduct of fossil fuel combustion and is not reduced by emissions control technologies now used to curb other pollutants in exhaust gas from cars. Short of using certain alternative fuels or limiting vehicle use, the only practical way to reduce CO_2 emissions rates is by improving fuel efficiency. Worldwide emissions of CO_2 closely parallel global vehicle use. OECD countries were responsible for 65 percent of mobile-source CO_2 emissions in 1993, a smaller share than in the 1970s and 1980s. Between 1971 and 1993, OECD countries' emissions grew 45 percent. U.S. emissions grew more slowly, about 38 percent, as car ownership and annual highway travel in other OECD countries continue to climb toward U.S. levels, and as U.S. passenger cars made larger gains in fuel efficiency. U.S. energy efficiency improvements have, however, tapered off.

Transportation-related CO_2 emissions in non-OECD countries will grow as highway vehicle use increases. CO_2 emissions from former East Bloc countries fell in the 1980s because of severe economic decline. Among other non-OECD countries, transportation-related CO_2 emissions grew 67 percent between 1980 and 1993. Although per capita rates are still low compared with the United States and many other OECD countries, 10 non-OECD countries (including Russia, China, Brazil, and India) are among the 20 countries that account for the most CO_2 generated by transportation.

♦ ♦ ♦

BTS has issued a companion volume to this report, *National Transportation Statistics 1996 (NTS)*. The 1996 *NTS*, the 24th edition of this report, contains 134 statistical tables and 42 figures, many of which cover the time period 1960 through 1994. It provides modal profiles, statistics on the state of transportation, the economic importance of transportation, safety trends, and energy and environmental aspects of transportation. The 1996 edition also provides preliminary results from the 1993 Commodity Flow Survey.

We encourage readers to comment on the *Transportation Statistics Annual Report 1996*, the *NTS*, and other BTS products so that we can make future products as responsive as possible to the needs of decisionmakers and the transportation community. Part of BTS's mission is to make information about the nation's transportation resources widely available. Hence, most of the *NTS* tables can be found on the BTS Internet homepage. BTS has prepared several CD-ROMs that provide more detailed information on many aspects of transportation. Information about contacting BTS can be found on the back cover of this report.

T.R. Lakshmanan
Director

Part I

The State of the Transportation System

CHAPTER ONE

TRAVEL, THE MOVEMENT OF FREIGHT, AND THE TRANSPORTATION SYSTEM

AN ENORMOUS AND DIVERSIFIED TRANSPORTATION SYSTEM SERVES 260 MILLION PEOPLE, 6 MILLION BUSINESS ESTABLISHMENTS, AND 87,000 GOVERNMENTAL UNITS SCATTERED OVER THE 3.7 MILLION SQUARE MILES OF THE UNITED STATES. IN 1994, THE SYSTEM CARRIED MORE THAN 4.2 TRILLION PASSENGER-MILES OF TRAVEL AND 3.7 TRILLION TON-MILES OF FREIGHT. (USDOT BTS 1995)

Geography partly explains the scale of the U.S. transportation system. For example, the two largest metropolitan regions—New York and Los Angeles—are 2,800 miles apart by the most direct Interstate highway route. Our nation's capital is 4,800 air-miles away from the most distant state capital in Honolulu, Hawaii. One National Park Service ranger travels more than 4,400 miles by road each spring and fall between seasonal assignments in Denali National Park, Alaska, and Everglades National Park, Florida.

The quantity of passenger travel and goods movement continues to increase faster than the U.S. population

To bridge such distances, the United States developed an extensive interconnected network of public roads, railroads, pipelines, public transit systems, commercially navigable waterways and ports, and the airports and other facilities that make up the aviation system (see table 1-1). This network is supported by a multifaceted transportation industry. When broadly defined, it

Table 1-1: Major Elements of the Transportation System, 1994

Mode	Major defining elements	Components
Highways[a]	Public roads and streets; automobiles, vans, trucks, motorcycles, and buses (except local transit buses) operated by transportation companies, other businesses, governments, and households; garages, truck terminals, and other facilities for motor vehicles	*Roads* 45,826 miles of Interstate highway 110,673 miles of other proposed National Highway System roads 3,764,422 miles of other roads *Vehicles and use* 134 million cars driven 1.6 trillion miles 57 million light trucks driven 0.6 trillion miles 6.3 million freight trucks driven 0.2 trillion miles, carrying 877 billion ton-miles of freight 670,000 buses driven 6.4 billion miles
Air	Airways and airports; airplanes, helicopters, and other flying craft for carrying passengers and cargo	*Public use airports* 5,474 airports *Airports serving large certificated carriers*[b] 28 large hubs (71 airports), 372 million enplaned passengers 33 medium hubs (57 airports), 89 million enplaned passengers 61 small hubs (75 airports), 34 million enplaned passengers 530 nonhubs (562 airports), 13 million enplaned passengers *Aircraft* 5,221 certificated air carrier aircraft, 4.4 billion miles flown *Passenger and freight companies* 82 carriers with 489 million revenue passenger-enplanements and 11.7 billion ton-miles of freight
Rail[c]	Freight railroads and Amtrak	*Railroads* 122,492 miles of major (Class I) 19,842 miles of regional 25,599 miles of local *Equipment (Class I)* 1.2 million freight cars 18,505 locomotives *Freight railroad firms* Class I: 12 companies, 189,962 employees, 1.2 trillion ton-miles of freight carried Regional: 32 companies, 10,701 employees Local: 487 companies, 13,070 employees *Passenger (Amtrak)* 24,991 employees, 1,874 passenger cars, 338 locomotives, 21.2 million passengers carried
Transit[d]	Commuter trains, heavy-rail (rapid-rail) and light-rail (streetcar) transit systems, and local transit buses	*Number of systems* 508 local public transit operators, 291,749 employees *Vehicles* 44,041 buses, 17.4 billion passenger-miles 8,960 rapid and light railcars, 10.9 billion passenger-miles 4,214 commuter railcars, 6.9 billion passenger-miles 92 ferryboats, 241 million passenger-miles 11,262 demand response vehicles, 389 million passenger-miles

TABLE 1-1 (CONT'D): MAJOR ELEMENTS OF THE TRANSPORTATION SYSTEM, 1994

Mode	Major defining elements	Components
Water[e]	Navigable rivers, canals, the Great Lakes, St. Lawrence Seaway, Intercoastal Waterway, ocean shipping channels; ports; commercial ships and barges, fishing vessels, and recreational boats	*U.S.-flag domestic fleet* Great Lakes: 694 vessels, 109.8 million short tons Inland: 31,340 vessels, 681.7 million short tons Ocean: 7,074 vessels, 276.7 million short tons *Ports* Great Lakes: 507 berths Inland: 1,789 terminals Ocean: 2,666 berths
Pipeline[f]	Crude oil, petroleum product, and gas trunk lines	*Oil* Crude lines: 112,990 miles of pipe, 344.5 billion ton-miles Product lines: 86,033 miles of pipe, 248 billion ton-miles, 145 companies with 18,400 employees *Gas* Transmission: 272,000 miles of pipe, 19.3 trillion cubic feet, 135 companies with 195,700 employees

[a] U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1994* (Washington, DC: 1995).
[b] U.S. Department of Transportation, Bureau of Transportation Statistics and Federal Aviation Administration, *Airport Activity Statistics of Certificated Route Air Carriers, 1994* (Washington, DC: 1996).
[c] All numbers from American Association of Railroads, *Railroad Facts* (Washington, DC: March 1995), except Amtrak figures from National Railroad Passenger Corp., *1994 Annual Report* (Washington, DC: 1995).
[d] All numbers are for 1993. U.S. Department of Transportation, Federal Transit Administration, *National Transit Summaries and Trends for the 1993 National Transit Database Section 15 Report Year* (Washington, DC: 1995).
[e] Data for 1993 from U.S. Department of Transportation, Federal Highway Administration, Federal Transit Administration, and Maritime Administration, *1995 Status of the Nation's Surface Transportation System: Condition and Performance* (Washington, DC: October 1995), pp. 213, 219–220, 236.
[f] Data for 1993. Miles of gas distribution pipeline not included.
SOURCE: Unless otherwise noted, U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 1996* (Washington, DC: November 1995).

includes for-hire transportation services (such as taxicab companies and worldwide parcel express carriers), and in-house transportation providers (such as the trucking fleet of a grocery chain); it also encompasses construction and maintenance companies, vehicle manufacturers, transportation facility operators, gas stations, travel agents and freight forwarders, transportation equipment sales and leasing firms, and agencies that administer transportation programs.

This chapter describes the passenger and freight movements that vie for space on the nation's transportation system, and summarizes the physical condition and performance of the system as it stretches to meet the demand. Chapter 2 discusses the economic performance of transportation followed in later chapters by an examination of the unintended consequences of transportation such as safety problems, oil import dependence, and environmental impacts.

Passenger Travel

People in the United States travel more now than ever before. Annual passenger-miles per person, including commercial travel, rose from about 11,400 in 1970 to 16,800 in 1994. Passenger-miles traveled increased 89 percent between 1970 and 1994 for an average annual growth rate of 2.7 percent. (USDOT BTS 1995) According to the Nationwide Personal Transportation Survey (NPTS), the annual number of trips per person increased from 736 in 1969 to 1,042 in 1990. (USDOT FHWA 1993a, table 4-1; USDOT BTS 1995) Over this period, trip lengths declined by 4 percent, but in more recent years (1983 to 1990) the average trip length increased from 8.68 miles to 9.45 miles. (USDOT FHWA 1993a)

Despite the recent increase in trip length and growth in domestic and international air travel, local travel (defined as trips under 75 miles) still accounted for 69 percent of passenger-miles. Most trips were made for family and personal business reasons (41.5 percent), followed by pleasure (24.8 percent), and work-related travel (21.6 percent). The rest were predominantly for civic, educational, and religious reasons. (USDOT FHWA 1993a, table 4.10) The pattern of local and nonlocal travel varies by mode of transportation. About 98 percent of passenger-miles by rail or subway are for trips under 75 miles in length. Three-quarters of passenger-miles made by car are local.

Excluding commercial driving (e.g., miles driven by cab drivers, truck drivers, and delivery people), long-distance travel accounted for 890 billion passenger-miles of travel in 1990 (USDOT FHWA 1993a, table 2.3), most of which (660 billion miles) were for pleasure, particularly for visiting friends and vacationing. About 15 percent (129 billion miles) were for family and personal business, including shopping and doctor or dentist visits. Only 9 percent (81 billion miles) were for long-distance commuting or business trips. More detailed and up-to-date information on long-distance travel will soon be available from the American Travel Survey (ATS), which was conducted by the Bureau of the Census for the Bureau of Transportation Statistics (BTS). The Census Bureau surveyed 80,000 households for the ATS and will report on trips of more than 75 miles in length.

Globalization of the economy has resulted in a marked increase in passenger travel to and from the United States for both business and pleasure. Foreign vacations have become more affordable; international trade and investment have also encouraged international travel. The number of air passenger arrivals in the United States from foreign countries (regardless of the nationality of the passenger) increased from about 12.6 million in 1975 to 44 million in 1994. The top countries of embarkation are Canada, the United Kingdom, Japan, Mexico, Germany, and France. (USDOT FHWA 1993a)

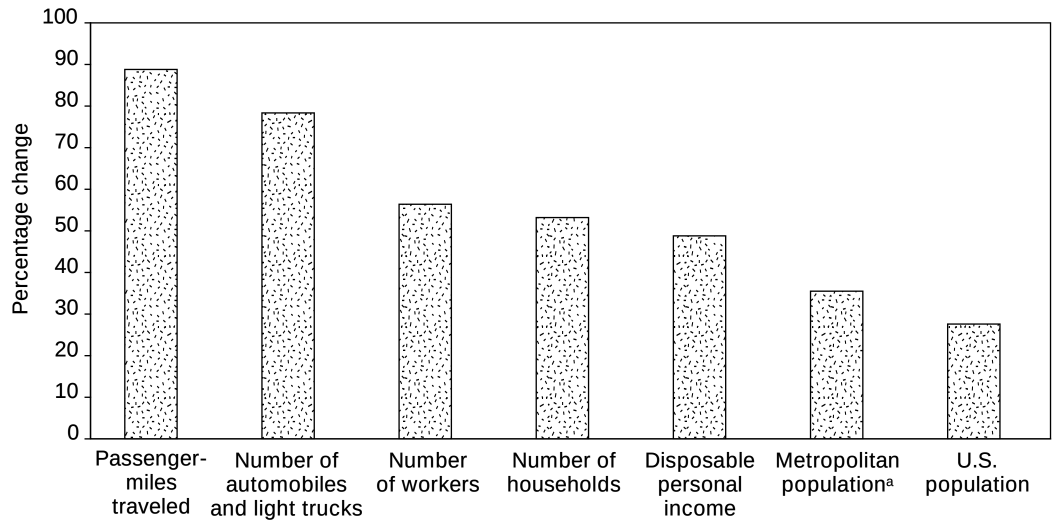
Many people also enter the United States by land. In 1994, nearly 12 million Canadian residents—80 percent of all arrivals from Canada—visited the United States for one or more nights by non-air modes of transportation, predominantly by automobile. (Statistics Canada 1995) In the same year, Mexicans visiting the United States for more than one night numbered 11 million. (Secretaria de Turism 1995) The transportation mode used by Mexican visitors cannot be estimated with the available data.

► Sources of Travel Growth

Several factors have contributed to the growth in passenger-miles traveled, including population, job, and income growth, access to motor vehicles, and residential and job location changes (see figure 1-1). The U.S. population grew by 56 million people between 1970 and 1994 reaching 260 million people in 1994. Natural increase (the difference between births and deaths) accounted for 70 percent of the growth; immigrants, who numbered nearly 17 million over the period, accounted for 30 percent of the increase in population. Immigration has a greater near-term impact on transportation because most immigrants are adults who use the transportation systems more than children.

Employment is another factor that impacts passenger travel. Between 1970 and 1994, the civilian labor force increased more than twice as fast as the population, growing from 83 million to 131 million. The two main reasons for the worker boom are that the baby boom generation reached labor force age, and women joined the labor force in great numbers. The number of women in the civilian labor force nearly doubled, rising from 32 million in 1970 to 60 million in

FIGURE 1-1: CHANGE IN PASSENGER-MILES TRAVELED AND FACTORS AFFECTING TRAVEL DEMAND, 1970–94



[a]1970–1990. Figures for 1990 are calculated using 1980 metropolitan area definitions and therefore differ from figures based on current U.S. census definitions.

SOURCES: Adapted from U.S. Department of Transportation, Federal Highway Administration, Federal Transit Administration, and Maritime Administration, *1995 Status of the Nation's Surface Transportation System: Condition and Performance* (Washington, DC: Oct. 27, 1995); U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: U.S. Government Printing Office, 1995); and various sources as compiled and cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 1996* (Washington, DC: November 1995).

1994. Women now constitute 46 percent of the U.S. workforce, up from 38 percent in 1970.

Growth in passenger travel is also related to recreation and other household activities. Such travel is more closely related to the number of households than to population size. The number of households grew more rapidly than the population because households became smaller. While the population grew 28 percent between 1970 and 1994, the number of households grew 53 percent. In 1994, the average household comprised 2.67 people, down from 3.14 in 1970.

Another factor contributing to the growth in passenger-miles is the increase in motor vehicles and licensed drivers. The number of automobiles and light trucks grew from 107 million in 1970 to 191 million in 1994, and the number of vehicles owned or available to households on a regular basis (including cars, trucks and vans, recreational vehicles, motorcycles and mopeds) rose from 1.2 vehicles in 1969 to 1.8 in 1990.[1] Between 1969 and 1990, the number of licensed drivers increased by almost 60 percent. (USDOT FHWA FTA MARAD 1995, 12)

Increases in the number of vehicles are partly related to income growth. When people have more money to spend, they spend more on transportation, including personal vehicles. Rising income also generates demand for long-distance travel, especially international travel.

Disposable personal income per capita rose from $9,875 in 1970 to $14,696 in 1994 (in constant 1987 dollars). (USDOC Bureau of the

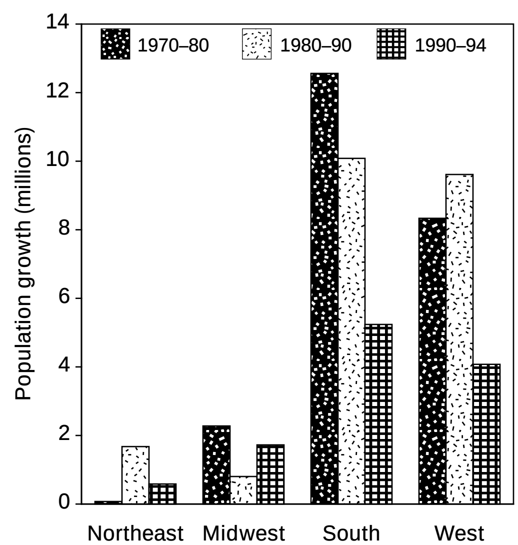
[1] The 1969 NPTS did not include pickup and other light trucks as household vehicles, and thus the number of household vehicles are underestimated somewhat compared with the 1990 survey. Chapter 5 discusses problems with the data on the number of vehicles. (USDOT FHWA 1993a, 3-37)

Census 1995, 456) Median household income, however, remained almost constant, partly because of the decrease in household size and partly because of the changing income distribution among income groups. (In constant 1993 dollars, median household income was $30,558 in 1970 and $31,242 in 1993.) A comparison of income and car prices shows that it now takes longer for a household to earn the money needed to purchase an average-priced new car: about 26 weeks in 1993 as opposed to 19 weeks in 1969 (see chapter 2, figure 2 in box 2-1). Despite the fact that cars are now more expensive in real terms than they were 25 years ago, the number of cars per capita and the number of cars per household has grown.

Growth in travel has not been evenly distributed across the country. Population in the South and West grew much faster than the Northeast and Midwest, resulting in major regional differences in transportation demand (see figure 1-2). Between 1970 and 1994, the South grew by 28 million people and the West by 22 million. By contrast, the Midwest grew by only 5 million and the Northeast by only 2 million.

Moreover, a much larger percentage of the U.S. population now lives in metropolitan areas than in 1970. Metropolitan populations are, however, dispersed over wider areas than before, contributing to travel growth. (USDOT FHWA FTA MARAD 1995, 43) According to decennial census data, metropolitan areas grew from 140 million in 1970 to 189 million in 1990.[2] Between 1970 and 1990, central city areas grew from about 64 million to 72 million people, and suburbs grew from 76 million to 117 million people. Between 1980 and 1990, however, the population of central cities declined by about 500,000 while suburbs grew by 17.5 million. The suburban share of the metropolitan population was 62 percent in 1990, up from 54 percent in 1970. The share of jobs in the suburbs also increased: 42 percent of jobs in 1990 were in the suburbs, up from 37 percent in 1980.

FIGURE 1-2: POPULATION GROWTH BY REGION, 1970–94



SOURCE: U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: 1995), table 27.

While these factors will most likely contribute to continued growth in passenger travel in the future, the rate of growth may taper off (see summary in table 1-2). Demographic changes could affect trends in local and intercity travel. For example, the age cohort with the highest propensity to travel (ages 40 to 49) is now entirely composed of baby boomers. (USDOT FHWA 1993a, 4-11) They are likely to travel more and travel longer distances, particularly abroad (foreign travel increases with income). Long-distance travel is also likely to be affected by such things as the number of family members attending out-of-town colleges. The number of 18- to 24-year-olds, which declined from the early 1980s to the mid-1990s, is expected to rise from the recent low of 24 million

[2] Figures for 1990 are calculated using 1980 metropolitan area definitions and therefore differ from figures based on current U.S. census definitions.

Table 1-2: Possible Contributions to Future Transportation Demand

Factor	Comments
Forces of stability	
Population growth	Slow overall growth (approximately 1 percent annually), but higher than most western European countries.
Household formation	Leveling off.
Migration patterns	Slowing of internal migration to growth areas of South and West.
Employment	Slower growth in the labor force.
Women's labor force participation	Slower growth as it approaches that of men's participation.
Vehicle availability	Reaching saturation levels.
Forces of change	
Immigration	Possibly large, with immediate impact on transportation systems.
Aging	Baby boomers coming into prime traveling age: large impact on long-distance domestic and international travel.
Residential and job dispersal	Continued dispersal will lead to more travel, particularly single-occupancy vehicles.
Income	Slow increases in income, but large increases in travel by the low-income population.
Women's travel	Increasing travel by women, not related to having a driver's license or labor force participation.
Work-at-home/telecommuting	Uncertain.

people to 30 million people by 2010.[3] (USDOC Bureau of the Census 1995, table 24)

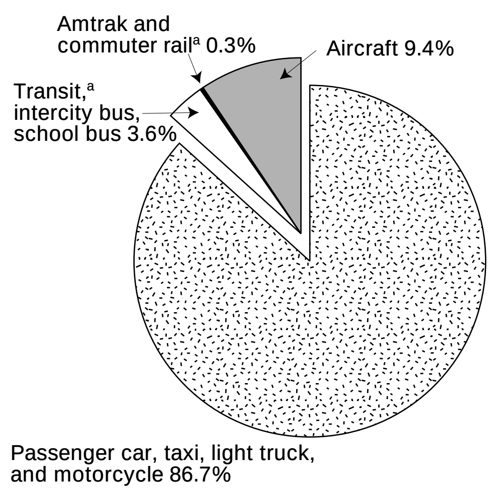
► Patterns of Travel

In 1994, 87 percent of the passenger-miles traveled in the United States were in automobiles and light trucks, including pickups, sport utility vehicles, and minivans (see figure 1-3). Much of the rest, 9 percent, was by air. (USDOT BTS 1995) In 1993, passenger travel on transit, was less than 1 percent of the total, or 36 billion passenger-miles. (USDOT FTA 1995)

Highway Vehicle Travel

Although passenger-miles in automobiles and light trucks increased by 80 percent over the past quarter century, the share of passenger-miles made by cars and light trucks decreased from 90 percent in 1970 to 87 percent in 1994. The cause is the great increase in air travel—from 5 percent of all passenger-miles in 1970 to 9 percent in 1994. In the category of highway travel, trav-

Figure 1-3: Passenger-Miles by Mode, 1994



[a]Data are for 1993.

NOTE: Excludes heavy trucks.

SOURCE: Eno Transportation Foundation and other sources cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 1996* (Washington, DC: November 1995).

[3] Projections are middle series.

el in light trucks (pickups, minivans, and sport-utility vehicles) increased most rapidly over this period (by 361 percent). Light trucks accounted for 8.5 percent of all passenger-miles in 1970, but 21 percent in 1994. (USDOT BTS 1995)

Highway vehicles-miles traveled (vmt) by all vehicles was 2.4 trillion miles in 1994, up from 1.1 trillion in 1970.[4] Automobiles and light trucks traveled 92 percent of the vmt in 1994, with most of the rest traveled by trucks, which is almost unchanged from 1970. Figure 1-4 shows the variation in vmt by state.

Air Travel

Aviation is key to intercity and international travel (see appendix A). Over the past 25 years, total air passenger-miles more than tripled—from 108 billion in 1970 to 388 billion in 1994 (measured by domestic revenue passenger-miles). By 1994, annual domestic per capita travel by air reached 1,492 miles, up from 532 miles in 1970. (USDOT BTS 1995)

Enplanements take place primarily at the 28 large airport hubs, which are geographic areas boarding more than 1 percent of the total air passengers in a year. A hub can include more than one airport. (For example, the Washington, DC, hub includes Dulles and National Airports.) Large hubs enplaned 73 percent of passengers in 1994. As can be seen in figure 1-5, the largest hubs are Chicago, Dallas-Fort Worth, Atlanta, Los Angeles, and New York. The most growth (in percent) occurred in Las Vegas, rising from 5 million to 12 million enplanements, Orlando (5 million to 9 million), Salt Lake (4 million to 8 million), Phoenix (7 million to 12 million), and Charlotte (5 million to 9 million).

General aviation passenger-miles (including corporate, air taxi, sightseeing, and instructional aircraft) grew by only 7 percent between 1970 and 1994, now accounting for approximately 9.7 billion miles. (USDOT BTS 1995)

Travel by Transit, Trains, and Intercity Buses

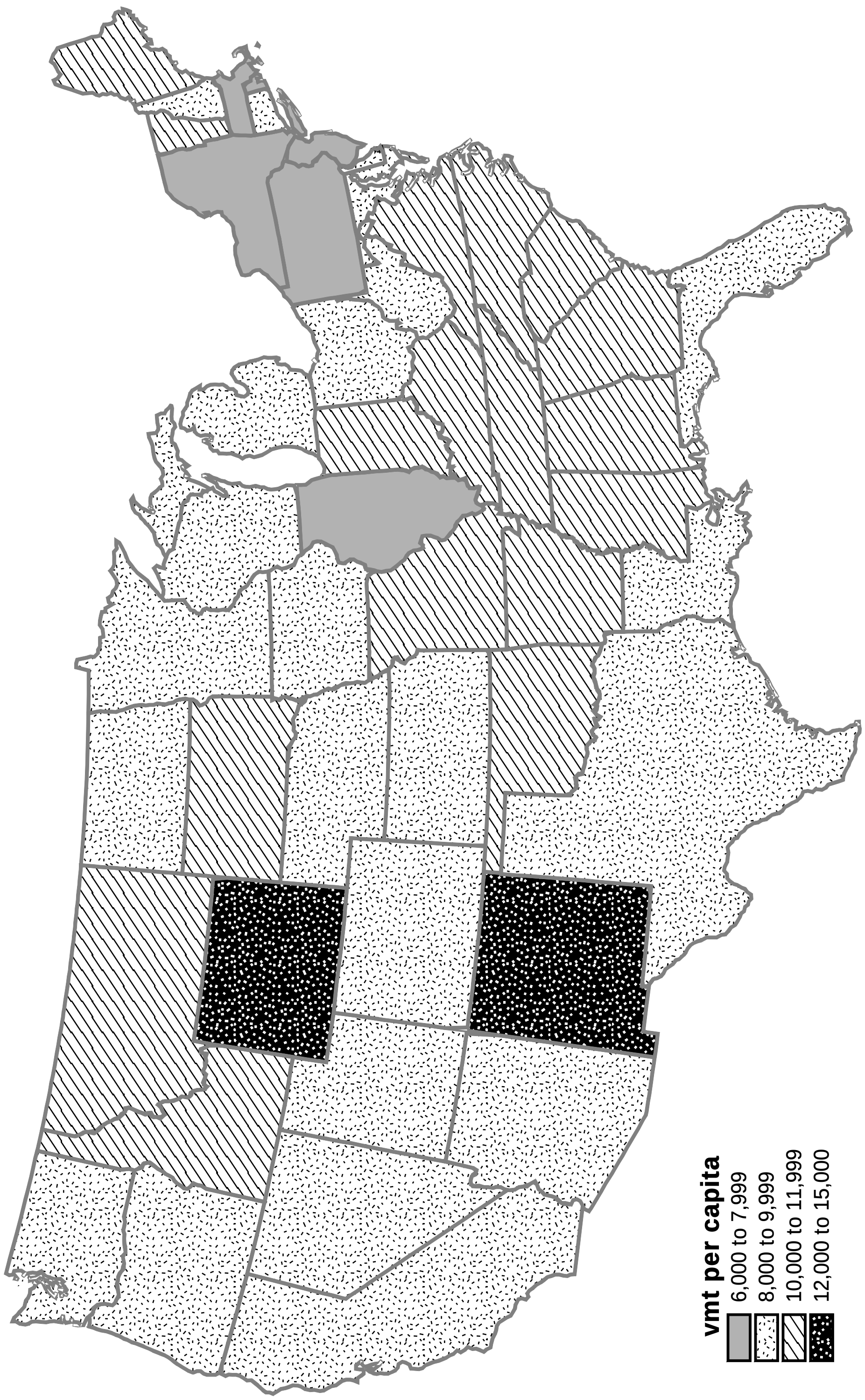
Transit (including buses, heavy rail, commuter rail, light rail, and demand response transit), accounted for 36 billion passenger-miles in 1993. Transit use is split almost equally between rail and nonrail systems with 17.8 billion passenger-miles on rail systems in 1993 and 18.4 billion on nonrail (mostly bus) systems. (USDOT FTA 1995, 71) Passenger travel on transit increased in the 1970s from approximately 6.5 billion unlinked trips at the nadir in 1972 to 8.2 billion unlinked trips in 1980, and remained at that level during the 1980s. Recently, unlinked passenger trips and passenger-miles on transit decreased. Passenger-miles fell from 38.5 billion on 8.1 billion unlinked trips in 1989 to 36.2 billion passenger-miles on 7.4 billion trips in 1993. As a result of growth in other modes, the fraction of passenger-miles on transit declined from approximately 1.4 percent in 1970 to 0.9 percent in 1994. Most transit passenger-miles are made in large metropolitan areas that have large transit agencies. Indeed, 79 percent of passenger-miles are made in the transit systems of the 30 largest agencies. Figure 1-6 shows rail and bus system passenger-miles traveled for the nation's urban areas in 1993.

Passenger-miles on Amtrak have increased from about 3 billion in 1972, Amtrak's first full year of operation, to about 6 billion in 1994. (AAR 1980 and 1995b) Thus, intercity train travel on Amtrak accounted for one-tenth of 1 percent of total passenger travel in 1994. Amtrak carried 21.8 million passengers in 1994 compared with 22.1 in 1993. (Amtrak 1995, 20)

In both 1970 and 1994, intercity buses accounted for 25.3 billion passenger-miles. In the intervening years, passenger-miles increased to 27.7 billion and dropped to 22.6 billion in the

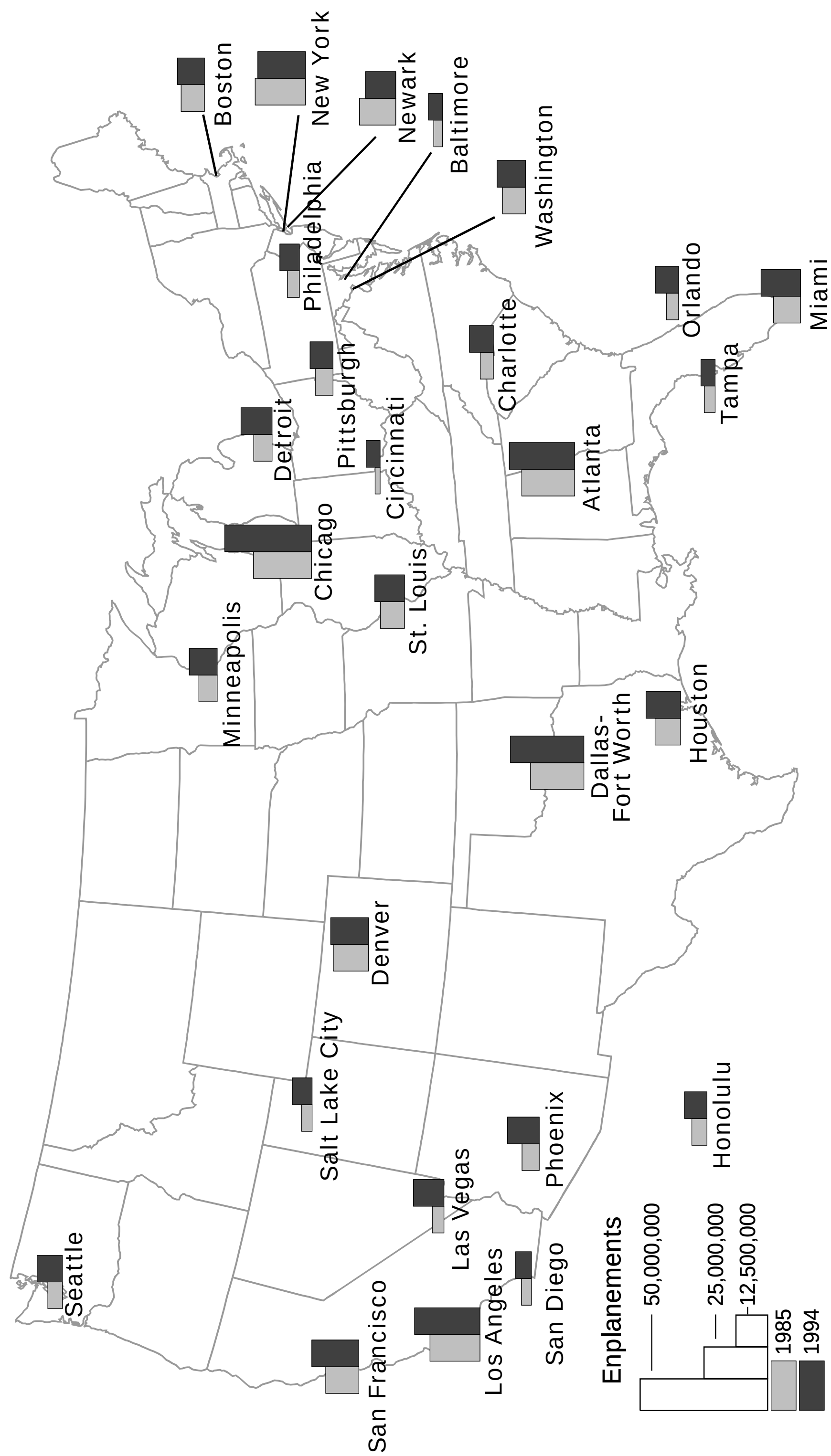
[4] Chapter 5 discusses problems with vmt data.

FIGURE 1-4: VEHICLE-MILES TRAVELED PER CAPITA, 1994



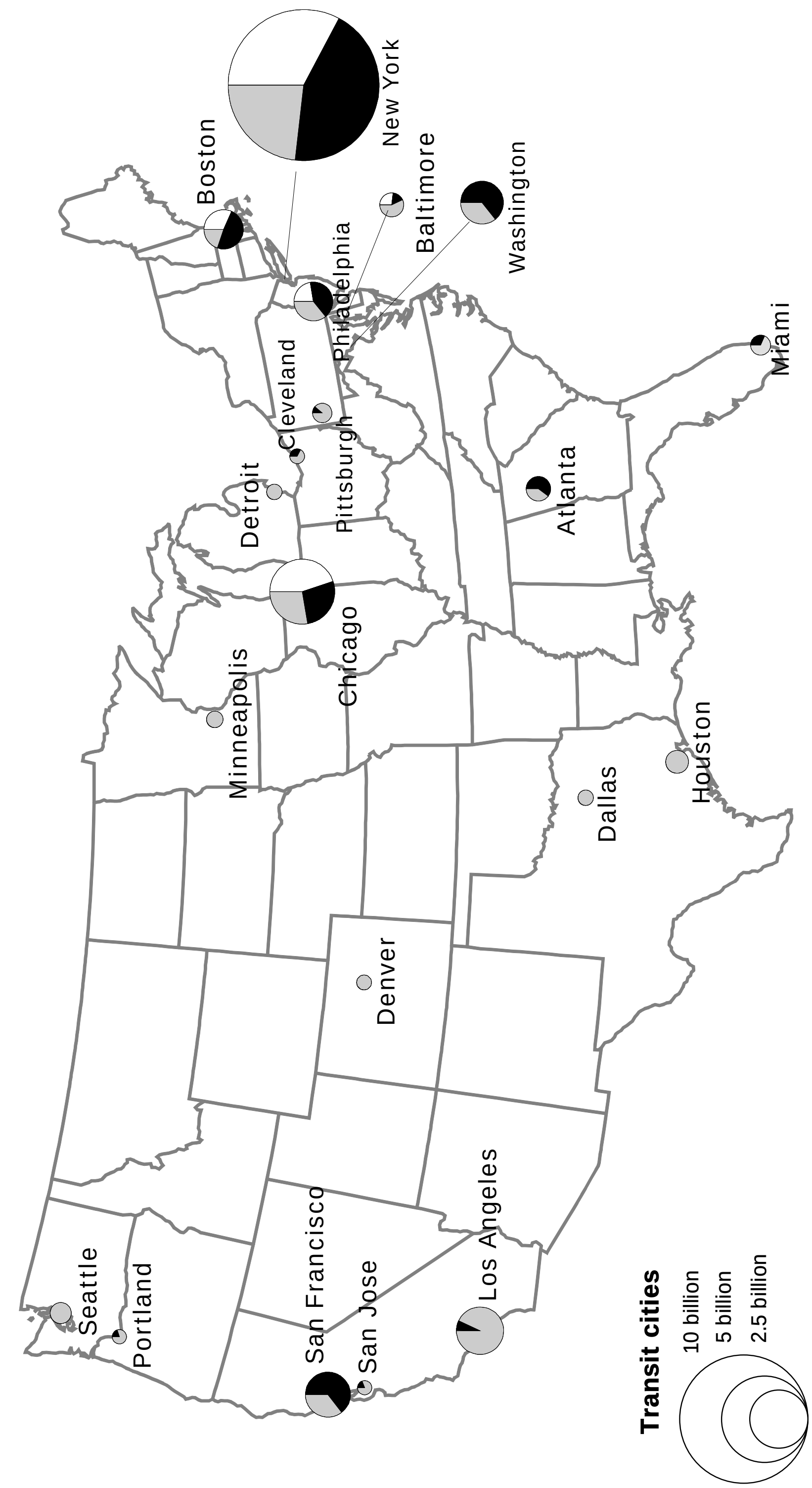
SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1994* (Washington, DC: 1995), p. V-116.

Figure 1-5: Enplanements at Major Hubs, 1985 and 1994



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

FIGURE 1-6: TRANSIT PASSENGER-MILES BY CITY, 1993



SOURCE: U.S. Department of Transportation, Federal Transit Administration, *Transit Profiles: The Thirty Largest Agencies* (Washington, DC: December 1994).

early 1990s. (Eno Transportation Foundation 1995, 47)

Since 1980, the earliest date for which data are available, passenger-miles on school buses doubled from 41 billion to 85 billion in 1994. (National Safety Council various years)

Water Transportation

Passenger transportation by water is principally for general use, including commuting and recreation. Transit ferryboat operations are the most important component of general use water transportation. The 14 ferryboat agencies included in the National Transit Database provided 240 million passenger-miles of service in 1993, down from over 300 million passenger-miles in 1980. In 1993, more than 80 percent of ferry passenger-miles were provided in Seattle and New York. (USDOT FTA 1995, 32)

Recreational water transportation comprises cruises and recreational boating, both of which have grown rapidly since 1980. According to the Cruise Lines Industry Association, between 1980 and 1993, the North American cruise market's annual growth averaged 9.2 percent. In 1994, 4.8 million passengers, 85 percent of them U.S. citizens, sailed overnight from U.S. and Canadian ports. (Krapf 1994) The top two ports-of-call for cruise ships in 1993 were Miami and San Juan, Puerto Rico, accounting for 41 percent of all cruise ship port calls. (USDOT FHWA FTA MARAD 1995, 243) The increase in boat ownership shows the growth of recreational boating, which went from 8.6 million in 1980 to 11.4 million in 1994.

Nonmotorized Transportation

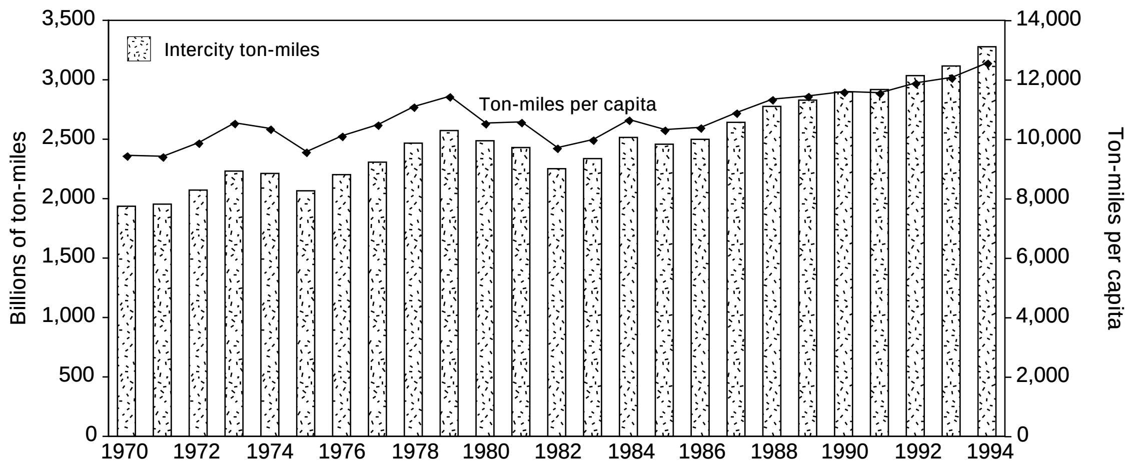
Nearly 8 percent of all personal trips in 1990 were by nonmotorized forms of transportation, 7.2 percent on foot and 0.7 percent by bicycle. (USDOT FHWA 1993a, 4-41) Because pedestrian and bicycle trips are short (averaging 0.6 miles and 2 miles, respectively), they accounted for only about 0.5 percent of all passenger-miles in 1990. In its study of commuting behavior, the Census Bureau found that 4.5 million people (4 percent of the employed civilian labor force) commuted to work by walking, a decline from 5.6 percent in 1980. In addition, 0.5 million people bicycled to work in 1990. (USDOT FHWA 1993b) Bicycle production and importation increased rapidly over the past two decades. Domestic shipments of bicycles increased from 5.6 million in 1975 to 8 million in 1993, and bicycle imports grew from 1.7 million in 1970 to 5 million in 1993. (USDOC Bureau of the Census 1995, 259; USDOT FHWA 1994)

Movement of Freight

Intercity (nonlocal) freight transportation increased substantially between 1970 and 1994 for all modes. The most rapid growth was in air cargo ton-miles, which increased by 434 percent. (USCAB 1973; USDOT BTS 1995) A direct estimate of the growth in ton-miles of freight carried by truck is not available, but the increase in vmt of combination trucks, assuming average load did not change, yields an estimate of 210 percent. (USDOT FHWA 1986 and 1995) The ton-miles carried by major railroads (Class I[5]) increased by 57 percent (AAR 1995a, 27), while ton-miles carried by oil pipelines rose 41 percent. (Eno Foundation for Transportation 1995, 44) Freight moved by water grew the slowest over this period, increasing by 37 percent. (U.S. Army Corps of Engineers 1994) As figure 1-7 shows, intercity ton-miles summed across all modes increased steadily since the early 1980s, the last time an economic recession caused a major reduction in freight transportation. (Eno Foundation for Transportation 1995)

[5]Defined as railroads with operating revenue above $255.8 million in 1994.

FIGURE 1-7: **INTERCITY FREIGHT TRANSPORTATION, 1970–94**



SOURCE: Eno Transportation Foundation, *Transportation in America* (Lansdowne, VA: 1995).

BTS is now able to report on how much freight was moved in a year by all modes in the United States, including trucking and intermodal combinations, and for intercity and local freight transportation. This information is provided for 1993 by the Commodity Flow Survey (CFS), conducted by BTS and the Bureau of the Census. The CFS differs from other published data in several ways. First, it provides survey data of freight movement. Second, it includes both intercity and local freight movement. Third, the CFS identifies parcel, post, and courier as a separate category, giving lower estimates of air freight cargo. Fourth, the CFS includes coastwise movement of goods often ignored elsewhere. Fifth, there are some definitional differences in the CFS, such as rail, which produce different estimates of modal share. Finally, the CFS estimates for the first time freight carried by intermodal combinations.

Preliminary results from the CFS show that the nation's freight transportation systems carried goods worth more than $6.3 trillion weighing 12.4 billion tons, yielding a total of 3.7 trillion ton-miles in 1993. As shown in figure 1-8, over half the weight of all freight was moved by truck, with rail, water, and pipeline transport accounting for most of the remaining tonnage. In terms of ton-miles, the split between truck, rail, water, and pipeline transportation is more even, given the greater distances moved by large shipments in the nonhighway modes. In terms of value, however, nearly three-quarters of all shipments moved by truck, followed by postal, parcel, and courier service, rail, water, and pipeline.

The CFS shows the importance of local transportation to the nation's commerce (see figure 1-9). Nearly 30 percent of the value and over 56 percent of the tons of all shipments measured by the CFS are shipped between places less than 50 miles apart. Of course, significant quantities of goods are also shipped long distances. For example, for shipments originating in California, the major destinations by value include Texas, Arizona, New York, Illinois, and Florida. California is among the major destinations of shipments from Maine.

► Domestic Freight Transportation

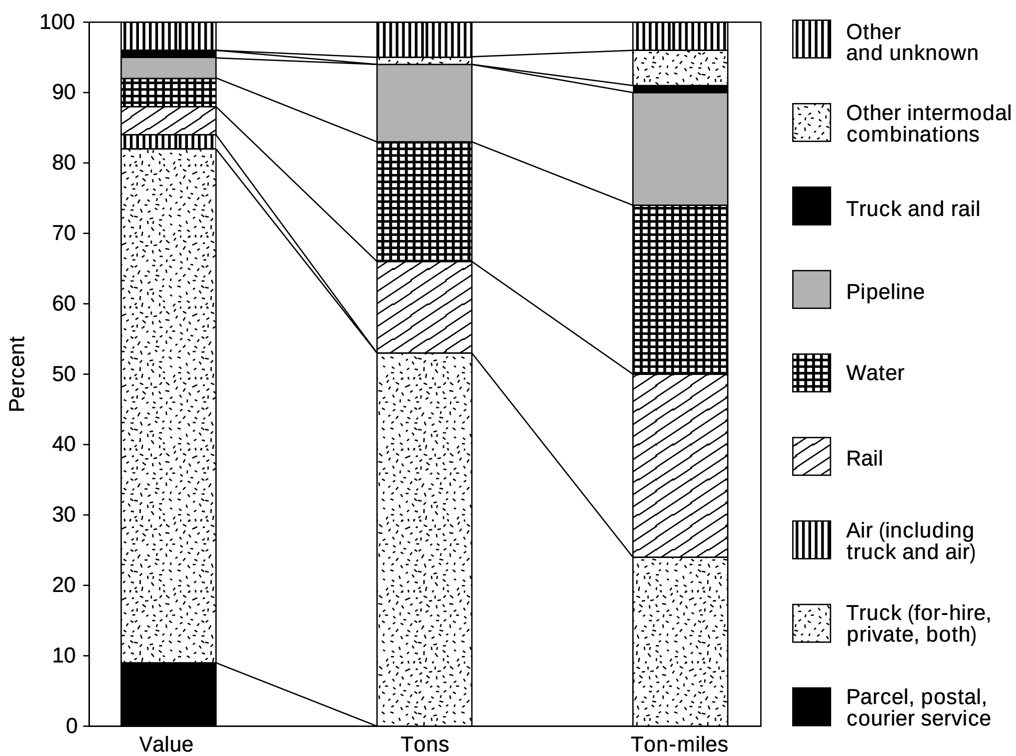
Trucks and Trains

The growth of trucking has been dramatic. According to the Census Bureau's Truck Inventory and Use Survey, the number of trucks increased 76 percent between 1982 and 1992, and the distance they traveled more than doubled (see table 1-3). While much of the growth was in personal use vehicles, trucks used in for-hire transportation increased by nearly 25 percent in number and over 50 percent in miles traveled during that period.

Two-axle trucks are the most common commercial trucks, but travel fewer miles per vehicle than the combination trucks with one or more trailers that are so visible on major highways (see table 1-4). Combination trucks with more than one trailer traveled the farthest per vehicle in 1992, but generated far less total travel than single combination trucks (most typically a three-axle tractor with a two-axle semi-trailer).

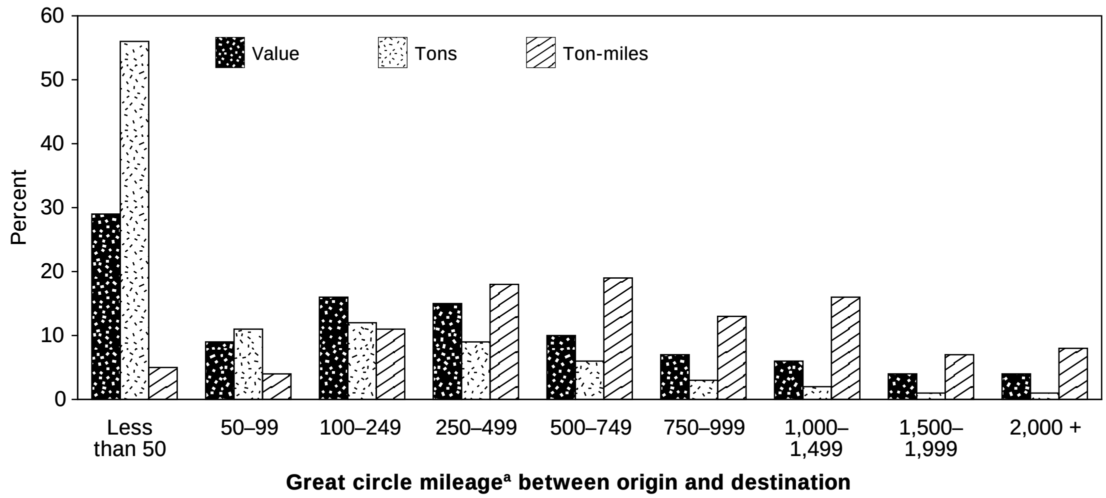
The truck fleet appears to be getting heavier as well as traveling farther (see table 1-5). Between 1982 and 1992, trucks with operating weights

FIGURE 1-8: VALUE, TONS, AND TON-MILES OF FREIGHT SHIPMENTS BY MODE, 1993



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, "1993 Commodity Flow Survey: Preliminary Observations," August 1995.

FIGURE 1-9: VALUE, TONS, AND TON-MILES OF FREIGHT SHIPMENTS BY DISTANCE, 1993



[a]Great circle mileage is the shortest distance between two points on the surface of a sphere, lying in a plane that intersects the sphere's center.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, "1993 Commodity Flow Survey: Preliminary Observations," August 1995.

above 80,000 lbs. increased in number by 181 percent and in miles traveled by 193 percent. Trucks below 33,000 lbs. increased 78 percent in number and 120 percent in miles traveled. Trucks of intermediate weight increased substantially less in numbers and miles traveled.

In 1994, railroads carried the most originating tons in a decade. (AAR 1995b, 28) Of the 1.5 billion tons of freight originating on Class I carriers, coal accounted for 39 percent, chemicals and allied products for 10 percent, and farm products for 9 percent. (AAR 1995b, 29) Moreover, the average length of haul increased from 224 miles in 1944 to 817 miles in 1994. (AAR 1995b, 36)

Rail freight flows are shown in figure 1-10. Particularly prominent are traditional east-west oriented routes, especially in the West. Coal shipments explain the large east-west volumes through Wyoming and Nebraska and through Virginia and West Virginia. The map also shows the prominence of North American Free Trade Agreement (NAFTA)-supporting routes such as the routes between the Midwest and Texas.

Water and Pipelines

Domestic waterborne freight transportation includes coastwise, internal, and lakewise movements. Coastwise movement is defined as domestic traffic with carriage over the ocean or the Gulf of Mexico. In 1994, 56 percent of ton-miles of domestic waterborne freight moved coastwise. Internal freight transportation is defined as traffic taking place solely on inland waterways, and accounted for 37 percent of ton-miles. Lakewise movement, 7 percent of freight-miles, is defined as domestic traffic between ports on the Great Lakes. Between 1970 and 1994, internal transport nearly doubled, while coastwise movement increased by 27 percent. Lakewise freight transport decreased 27 percent over this period. (US Army Corps of Engineers various years)

The principal commodities moved by pipeline are oil and gas. Intercity ton-miles of oil moved

Table 1-3: Number of Trucks, Miles Traveled, and Miles Per Truck by Truck Use, 1982 and 1992

Use	1982	1992	Change (percent)[a]
Number of trucks (thousands)			
For-hire transportation	718	888	24
Other business use	13,611	15,704	15
Mixed and daily rental	168	1,524	807
Personal Use	19,214	41,076	114
Total (including unknown)	33,722	59,191	76
Vehicle-miles traveled (billions)			
For-hire transportation	33.1	51.8	57
Other business use	173.4	244.5	41
Mixed and daily rental	3.4	25.6	661
Personal Use	166.4	464.2	179
Total (including unknown)	376.2	786.1	109
Miles per truck (thousands)			
For-hire transportation	46.1	58.3	27
Other business use	12.7	15.6	22
Mixed and daily rental	20.0	16.8	–16
Personal Use	8.7	11.3	31
Total (including unknown)	11.2	13.3	19

[a]Percentages may not add due to rounding.

NOTES: For-hire transportation = motor carrier + owner/operator + mixed private common.
Other business use = business use.
Mixed and daily rental = mixed + daily rental.
Personal use = personal.
Total (including unknown) = all.

SOURCE: Oak Ridge National Laboratory tabulations from the Truck Inventory and Use Survey public use microdata files.

by pipeline increased from 431 billion in 1970 to 608 billion in 1994. (Eno Foundation 1995) Gas moved by pipeline, measured in cubic feet, has remained almost unchanged from 1970 to 1994 at about 20 trillion cubic feet. (USDOE 1995)

Intermodal

The CFS provides the first comprehensive picture of intermodal transportation (see box 1-1). About 38 million tons, worth $83 billion, moved by the classic intermodal combination of truck and rail. Assuming 50,000 pounds of payload per truck, this intermodal combination means that 1.5 million large trucks were diverted from the highways for a major part of their trips. Fast, flexible forms of intermodal transportation have emerged in recent years. For example, parcel, postal, and courier services now account for about 9 percent of the value of

Table 1-4: Number of Trucks, Miles Traveled, and Miles per Truck by Truck Type, 1982 and 1992

Type	1982	1992	Change (percent)[a]
Number of trucks (thousands)			
Multiple combination	30	59	98
Single combination	1,303	1,670	28
2 axles, 6 tires	6,956	3,363	–52
2 axles, 4 tires	25,433	54,099	113
Total	33,722	59,191	76
Vehicle-miles traveled (billions)			
Multiple combination	1.9	4.7	152
Single combination	53.1	74.7	41
2 axles, 6 tires	74.9	37.8	–50
2 axles, 4 tires	246.4	668.8	171
Total	376.2	786.1	109
Miles per truck (thousands)			
Multiple combination	62.2	79.2	27
Single combination	40.8	44.7	10
2 axles, 6 tires	10.8	11.3	5
2 axles, 4 tires	9.7	12.4	29
Total	11.2	13.3	19

[a]Percentages may not add due to rounding.

SOURCE: Oak Ridge National Laboratory tabulations from the Truck Inventory and Use Survey public use microdata files.

Table 1-5: Number of Trucks, Miles Traveled, and Miles per Truck by Truck Weight, 1982 and 1992

Weight (thousand lbs[a])	1982	1992	Change (percent)[b]
Number of trucks (thousands)			
<33	32,436	57,562	78
33-60	674	798	18
60-80	594	781	32
>80	18	50	181
Total	33,722	59,191	76
Vehicle-miles traveled (billions)			
<33	322	709	120
33-60	18	24	29
60-80	35	51	46
>80	0.9	2.5	193
Total	376	786	109
Miles per truck (thousands)			
<33	9.9	12.3	24
33-60	27.2	29.6	9
60-80	59.1	65.3	11
>80	47.4	49.5	4.4
Total	11.2	13.3	19

[a]Thousands of pounds of typical operating weight.
[b]Percentages may not add due to rounding.

SOURCE: Oak Ridge National Laboratory tabulations from the Truck Inventory and Use Survey public use microdata files.

all shipments. When shipments reported as being sent by more than one mode are added to those sent by parcel and courier services, intermodal transportation exceeds 200 million tons valued at $660 billion.

Intermodal shipments tend to be high in value. Shipments by parcel, postal, and courier services average $15.08 per pound; truck-rail intermodal shipments are worth $1.09 per pound. Although short of the $26.77 value per pound of air and air-truck shipments, these intermodal shipments are higher in value than the 35 cents per pound for truck-only shipments and the less than 10 cents per pound for railroads, water transport, and pipeline shipments.

International Freight Transportation

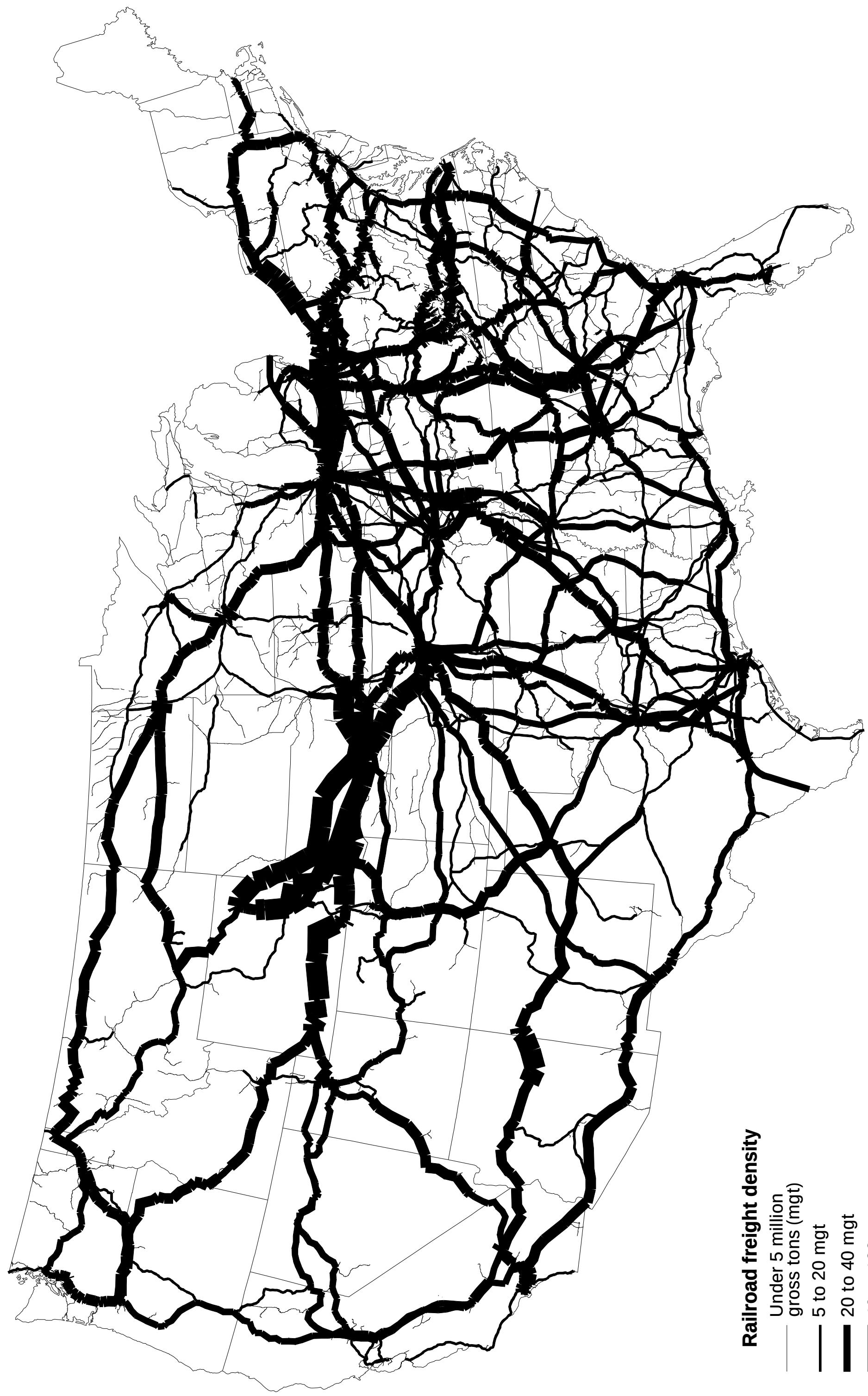
International trade is a source of growth in transportation, placing demands on the domestic transportation system for access between ports of entry or exit and the interior. The value of commodities exported and imported in 1993 was about one-sixth the value of commodities counted in the CFS. (USDOC Bureau of the Census 1995, table 1081; USDOT BTS 1995, table 131) NAFTA increased the importance of north-south movements relative to the traditional east-west movement of goods in international trade. Based on information collected for BTS by the Census Bureau:

- $259.3 billion in goods moved by land between Canada and the United States between April 1994 and March 1995, an increase of more than 15 percent over the preceding 12 months. In terms of value, 76 percent moved by truck, 20 percent by rail, and 4 percent by pipeline.
- More than $90 billion in goods moved by land between Mexico and the United States between April 1994 and March 1995, an increase of over 15 percent over the preceding 12 months. In terms of value, 87 percent moved by truck and 14 percent by rail.

During the 12 months ending in March 1995:

- The top three border crossings in value of shipments for surface freight to and from Canada were Detroit (32 percent of northbound traffic and 29 percent of southbound), Buffalo (18 percent of northbound traffic and 20 percent of southbound), and Port Huron, Michigan (9 percent of northbound traffic and 10 percent of southbound).
- The top three border crossings in value of shipments for southbound surface freight to Mexico were in Texas: Laredo (40 percent), El Paso (16 percent), and Brownsville (8 percent).
- The top three border crossings in value of shipments for northbound surface freight from Mexico were El Paso (24 percent),

FIGURE 1-10: RAILROAD NETWORK SHOWING VOLUME OF FREIGHT, 1994



SOURCE: U.S. Department of Transportation, Federal Railroad Administration, *Carload Waybill Statistics: Territorial Distribution, Traffic and Revenue by Commodity Class* (Springfield, VA: National Technical Information Service, 1995).

Box 1-1: Intermodalism

In a departure from the transportation community's historic focus on individual modes, the Intermodal Surface Transportation Efficiency Act recognized the growing importance of intermodalism. The term intermodalism is used in three ways.

Most narrowly, it refers to containerization, piggyback service, and other technologies that provide the seamless movement of goods and people by more than one mode of transport.

More broadly, intermodalism refers to providing connections among different modes, such as adequate highways to ports or bus feeder services to rail transit. In its broadest interpretation, intermodalism refers to a view of transportation in which individual modes work together or within their own niches to provide the user with the best choices of service, and in which the consequences on all modes of policies for a single mode are considered. In the past, this view was called balanced, integrated, or comprehensive transportation.

Finally, Congress and others frequently use the term intermodalism as a synonym for multimodal transportation, without necessarily requiring an integrated approach.

The Bureau of Transportation Statistics (BTS) accepts the broadest interpretation of intermodalism in its philosophy, but prefers the middle ground in its use of the term. BTS collects and reports information on multimodal transportation systems, including both individual modes and intermodal combinations.

Laredo (24 percent), and San Ysidro, California (11 percent).

These patterns may change if the areas in which motor carriers can operate across the border are expanded (see figure 1-11). Until NAFTA, foreign trucks on both sides of the Mexico-U.S. border could operate only in a narrow commercial zone. A provision of NAFTA allows foreign trucks to operate in border states, although the implementation of this policy has been delayed.

While transborder land crossings are important, most international trade moves in and out of the United States through ports. Seaports handled international cargo valued at $517 billion in 1994, an increase of 81 percent from 1980.

Figure 1-12 illustrates the geographic pattern of port activity. The concentrations of tonnage in Texas, Louisiana, Alaska, and the Delaware River arise in large part from petroleum products. Louisiana also handles a significant amount of grain. The large ports with the most general cargo are in the New York metropolitan area and California.

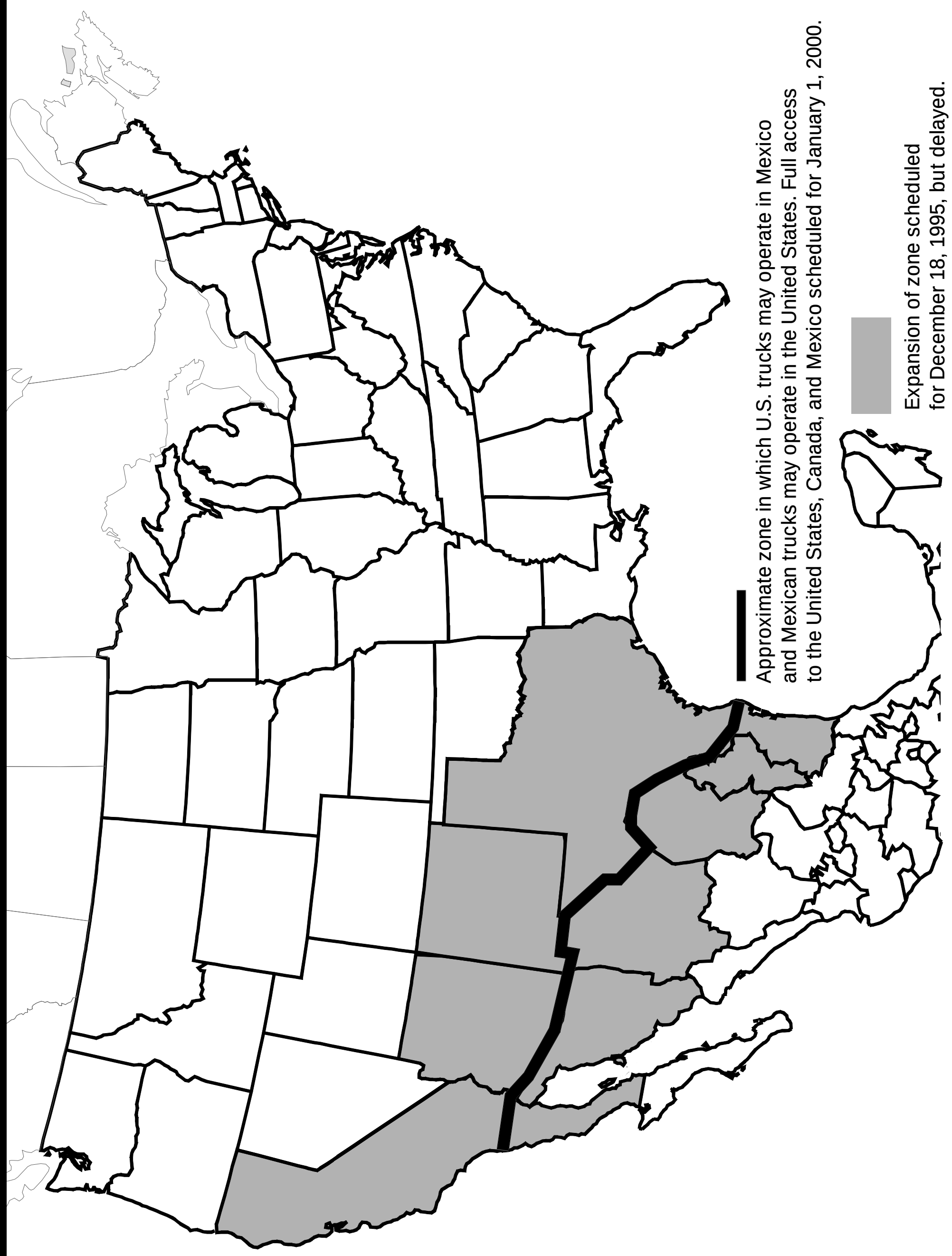
The pattern of demand is shifting significantly among regions, as illustrated by the growth of intermodal container traffic through east coast and west coast ports. Since 1980, growing Pacific Rim trade has benefited west coast ports (see figure 1-13). In 1980, west coast ports accounted for about 24 percent of the value of U.S. oceanborne foreign trade, and east coast ports 41 percent. By 1993, west coast ports almost doubled their share to 45 percent, while the share handled by east coast ports declined to 38 percent.

Where Passengers and Freight Meet

Most highways, railways, airports, and seaports carry both passengers and freight, a source of efficiency and inefficiency. Joint use of the system allows for fuller utilization of the infrastructure. The overlap between passengers and freight on the transportation network, however, means competition for network space, scheduling conflicts, and possible safety, noise, congestion, and environmental problems.

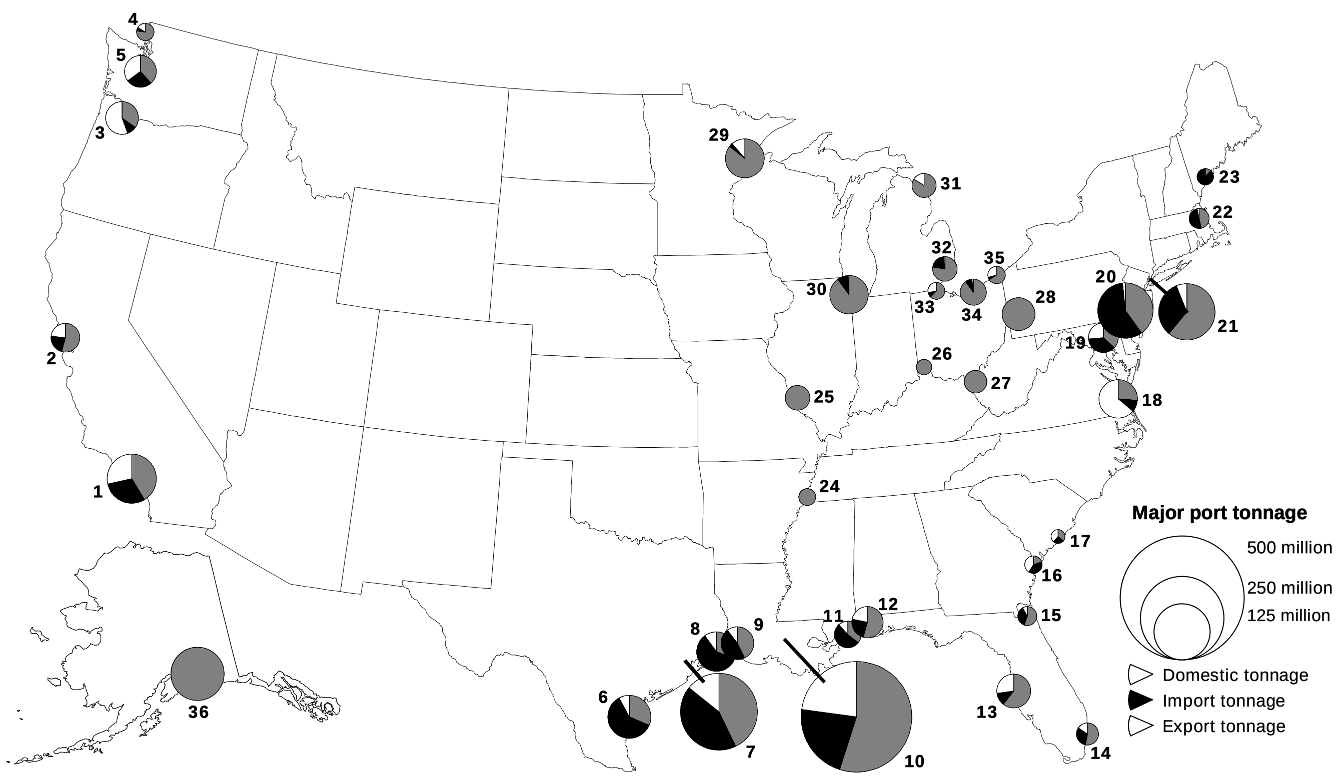
Trucks and cars share virtually all major roads. The exceptions, roads limited to passenger vehicles, include parkways, bus and high-occupancy-vehicle lanes, and some major

FIGURE 1-11: TRANSBORDER TRUCK ACCESS



SOURCE: U.S. General Accounting Office, *Commercial Trucking Safety and Infrastructure Issues Under the North American Free Trade Agreement*, GAO/RCEO-96-61 (Washington, DC: U.S. Government Printing Office, February 1996).

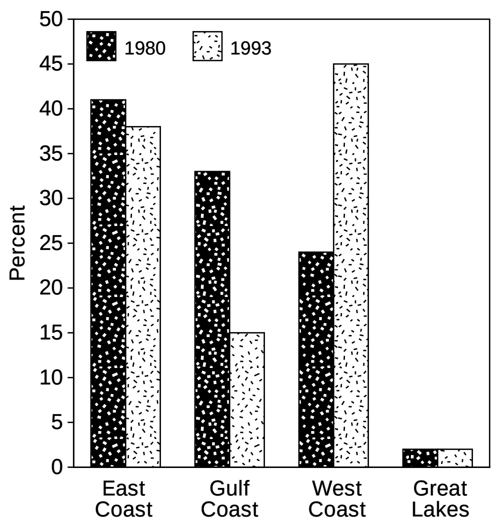
FIGURE 1-12: TONNAGE HANDLED BY MAJOR U.S. PORTS, 1994



1. **Los Angeles-Long Beach**
Los Angeles, CA
Long Beach, CA
2. **San Francisco Bay**
San Francisco, CA
Oakland, CA
Richmond, CA
3. **Columbia River**
Portland, OR
Vancouver, WA
Longview, WA
Kalama, WA
4. **Northern Puget Sound**
Port Angeles, WA
Port Townsend, WA
Anacortes, WA
Bellingham, WA
5. **Southern Puget Sound**
Seattle, WA
Tacoma, WA
Everett, WA
Olympia, WA
6. **Corpus Christi**
Corpus Christi, TX
7. **Houston-Galveston**
Houston, TX
Galveston, TX
Freeport, TX
Texas City, TX
8. **Beaumont-Port Arthur**
Beaumont, TX
Port Arthur, TX
Orange, TX
9. **Lake Charles**
Lake Charles, LA
10. **South Louisiana**
Port of South Louisiana
New Orleans
Baton Rouge
Port of Plaquemine
11. **Biloxi - Gulfport**
Biloxi, MS
Gulfport, MS
Pascagoula, MS
12. **Mobile**
Mobile, AL
13. **Tampa**
Tampa Bay, FL
14. **Miami**
Port Everglades, FL
Miami, FL
15. **Jacksonville**
Jacksonville, FL
16. **Savannah**
Savannah, GA
17. **Charleston**
Charleston, SC
18. **Norfolk-Newport News**
Norfolk Harbor, VA
Newport News, VA
Richmond, VA
Hopewell, VA
Cape Charles, VA
19. **Baltimore**
Baltimore, MD
20. **Delaware River**
New Castle, DE
Wilmington, DE
Marcus Hook, DE
Paulsboro, PA
Chester, PA
Philadelphia, PA
Camden-Gloucester, NJ
21. **New York**
New York, NY
22. **Boston**
Boston, MA
Salem, MA
23. **Portland**
Portland, ME
24. **Memphis**
Memphis, TN
25. **St. Louis**
St. Louis, MO
26. **Cincinnati**
Cincinnati, OH
27. **Huntington**
Huntington, WV
28. **Pittsburgh**
Pittsburgh, PA
29. **Duluth-Superior**
Duluth-Superior, MN
Two Harbors, MN
Silver Bay, MN
Ashland, WI
Taconite, MN
30. **Chicago-Gary**
Chicago, IL
Indiana Harbor, IN
Gary, IN
Buffington, IL
Burns Waterway Harbor, IN
31. **Alpena**
Alpena, MI
Calcite, MI
Stoneport, MI
Presque Isle, MI
32. **Detroit**
Detroit, MI
Marine City, MI
St. Clair, MI
Port Huron, MI
33. **Toledo**
Toledo, OH
Monroe, MI
34. **Cleveland-Lorain**
Cleveland, OH
Lorain, OH
Fairport Harbor, OH
35. **Ashtabula**
Ashtabula, OH
Conneaut, OH
36. **Valdez**
Valdez, AK

SOURCE: U.S. Army Corps of Engineers, *Waterborne Commerce of the United States: Calendar Year 1994* (New Orleans, LA: 1995).

FIGURE 1-13: REGIONAL SHARE OF TOTAL ANNUAL VALUE OF OCEANBORNE FOREIGN TRADE, 1980 AND 1993



SOURCE: U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: U.S. Government Printing Office, 1995), p. 664.

highways like the automobile lanes of the New Jersey Turnpike. Local roads may restrict the largest trucks, but allow smaller trucks in addition to automobiles.

In the case of railroads, passenger service usually occurs over rail lines that primarily carry freight. For example, freight companies and other entities own most of the more than 25,000 miles of railroad track used by Amtrak. (The notable exception is the Northeast Corridor, which is largely owned by Amtrak). The overlap of passenger and freight has raised capacity and safety issues.

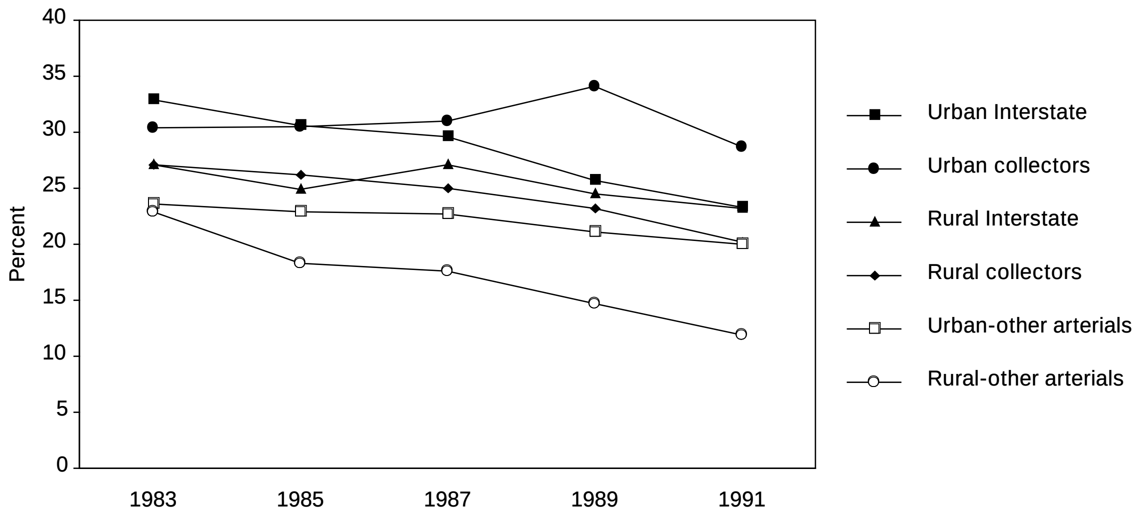
In water transportation, the growth in popularity of recreational boating means more conflicts with waterborne freight movement are possible, particularly in redeveloped older harbor areas. Moreover, landside access to U.S. ports can create conflicts between passenger and freight transportation. A recent report by DOT's Maritime Administration found that the efficiency of more than half of U.S. ports is threatened by increasing passenger car congestion on truck routes. Congestion is made worse at many ports by rail lines that intersect local streets. (USDOT MARAD 1993) Also, some container ports are not served by tunnels or bridges able to carry double-stack trains. Moreover, ports in many metropolitan areas cannot expand or be reconfigured because of competition with other land uses.

In the aviation industry, the overlap between passengers and air cargo (freight, mail, and air express) has increased efficiency. Wide-body aircraft, in use since the late 1960s, allow almost all passenger carriers to carry both cargo and passengers. Much of the all-freight business occurs in overnight parcel delivery, allowing passenger services to operate unimpeded during the day. Some conflict arises at airports, where most air cargo arrives and leaves on trucks traveling over highways through metropolitan areas.

Physical Condition and Performance

The U.S. Department of Transportation monitors the condition and performance of the transportation system. This section discusses indicators to assess the condition of the system and examines performance measures from the perspective of the user. Ideally, performance would be judged on a systemwide basis regardless of how many modes it involved. The current data, however, only allow performance evaluations of each mode separately. Other measures of system condition and performance, such as economic condition, safety, and environmental performance, are discussed elsewhere in this report.

FIGURE 1-14: HIGHWAY MILEAGE IN POOR AND MEDIOCRE CONDITION BY FUNCTIONAL SYSTEM, 1983–91



SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics* (Washington, DC: various years).

► Highways

According to the *1995 Status of the Nation's Surface Transportation System: Condition and Performance*:

- Between 1983 and 1991, highway pavement conditions improved as measured by the Present Serviceability Rating (see figure 1-14). For example, the percentage of urban Interstates in poor or mediocre condition dropped from 32.9 percent in 1983 to 23.2 percent in 1991. The corresponding drop for rural Interstates is 27.1 to 23.2 percent. Because of a change to a new measure, the International Roughness Index (IRI), it is difficult to say anything about more recent trends in pavement condition. (USDOT FHWA FTA MARAD 1995, 121–131) Table 1-6 shows the condition of roads in 1994.
- Bridge conditions have improved over the past few years (see table 1-7). The number of deficient bridges on Interstates, arterials, and collectors have all decreased between 1990 and 1994. Approximately one-quarter of these bridges are still deficient. (USDOT FHWA FTA MARAD 1995, 132–135)

Congestion, one measure of performance, can be expressed in total vehicle-hours of delay. One estimate of urban roadway congestion suggests that vehicle-hours of delay in 50 cities increased from 8.7 million per day in 1986 to 11 million per day in 1992. (Texas Transportation Institute 1995) Congestion estimates are supported by calculating highway vmt per lane-mile. In every category, vmt per lane-mile increased between 1985 and 1994; the greatest increase was on urban arterials (see table 1-8).

► Transit

The condition of urban transit equipment has not changed greatly from 1985 to 1993 (see table 1-9). Although the fleet of large and mid-size buses has become older, many smaller

Table 1-6: Pavement Condition, 1994

	Poor	Mediocre	Fair	Good	Very good	Unpaved	Total
Interstate (miles)[a]	3,607	11, 954	10,561	13,742	4,682	0	44,546
Percent of system	8	27	24	31	11	0	100
Other arterials (miles)	43,788	95,226	99,016	87,274	46,025	306	371,635
Percent of system	12	26	27	23	12	0	100
Collectors (miles)	36,304	62,750	178,786	84,200	108,331	46,838	517,209
Percent of system	7	12	35	16	21	9	100
Total (miles)	83,699	169,930	288,363	185,216	159,038	47,144	933,390
Percent of system	9	18	31	20	17	5	100

[a]Interstates are held to a higher standard than other roads because of higher volumes and higher speed.

KEY: Poor = needs immediate improvement.
Mediocre = needs improvement in the near future to preserve usability.
Fair = will likely need improvement in the near future, but depends on traffic use.
Good = in decent condition; will not require improvement in near future.
Very good = new or almost new pavement, will not require improvement for some time.

NOTE: Because of the switch to the International Roughness Index (IRI) from the Present Serviceability Rating (PSR) some states are reporting the PSR for some facilities and the IRI for others. As a result, this table portrays a mixture of the two rating schemes. Several years of measurement using the IRI procedures are needed to define an accurate trend in pavement condition.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1994* (Washington, DC: 1995).

Table 1-7: Bridge Conditions, 1990 and 1994

	1990	1994
Interstate bridges	53,183	54,726
Number deficient	15,208 (28.6%)	13,262 (24.2%)
Other arterial bridges	124,615	129,465
Number deficient	39,492 (31.7%)	36,199 (28%)
Collector bridges	164,300	162,314
Number deficient	56,622 (34.5%)	45,330 (27.9%)

NOTE: Deficient bridges include a) structurally deficient bridges—those that need significant maintenance, attention, rehabilitation, and sometimes replacement; and b) functionally deficient bridges—those that do not have the lane widths, shoulder widths, or vertical clearances to serve traffic demand.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, Federal Transit Administration, and Maritime Administration, *1995 Status of the Nation's Surface Transportation System: Condition and Performance* (Washington, DC: Oct. 27, 1995), pp. 132–134.

Table 1-8: Annual Highway Vehicle-Miles Traveled per Lane-Mile by Functional Class, 1985 and 1994

	1985 vmt/lm	1994 vmt/lm	Change (percent)
Rural Interstate	1,170,452	1,644,613	41
Rural arterial	554,290	674,765	22
Rural collector	140,943	161,204	14
Urban Interstate	3,770,649	4,674,863	24
Urban arterial	1,082,705	1,804,094	67
Urban collector	552,098	654,972	19

KEY: vmt = vehicle-miles traveled; lm = lane-miles.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1994* (Washington, DC: 1995).

buses and vans were added for paratransit services over the past few years. These new vehicles have resulted in no change in the average age of all urban transit buses nor has the percentage of overage full-size buses changed significantly over this period. For rail transit, significant improvement occurred in the condition of power systems, stations, structures (e.g., bridges and tunnels), and maintenance between 1984 and 1992. (USDOT FHWA FTA MARAD

Table 1-9: Urban Transit Bus Condition, 1985 and 1993

	1985	1993
Articulated buses		
Total fleet	1,423	1,807
Number of overage vehicles	0	295
Average age (years)	3.4	9.5
Full-size buses		
Total fleet	46,138	46,824
Number of overage vehicles	9,277	9,362
Average age (years)	8.1	8.5
Mid-size buses		
Total fleet	2,569	3,598
Number of overage vehicles	237	865
Average age (years)	5.6	6.4
Small buses		
Total fleet	1,685	4,064
Number of overage vehicles	280	513
Average age (years)	4.8	4.0
Vans		
Total fleet	1,733	8,353
Number of overage vehicles	790	1,804
Average age (years)	3.8	3.1
Total		
Total fleet	51,863	60,582
Number of overage vehicles	10,584	12,839
Average age (years)	7.9	7.9

SOURCE: U.S. Department of Transportation, Federal Highway Administration, Federal Transit Administration, and Maritime Administration, *1995 Status of the Nation's Surface Transportation System: Condition and Performance* (Washington, DC: Oct. 27, 1995), p. 137.

1995, 143) The average age of rail transit vehicles, however, has not changed between 1985 and 1993. But the condition of powered commuter-railcars worsened significantly because of age: these cars averaged 12.3 years in age in 1985 and 18.2 years in age in 1993. (USDOT FHWA FTA MARAD 1995, 144)

One performance measure for transit is speed of service. No data are available on the average speed of passenger trips, but there is information on the average speed of transit service. Weighting this information by passenger-miles produces a useful indicator. Rail speed increased from 24.8 to 26.3 miles per hour from 1984 to 1993 and bus speed increased from 12.9 to 13.7 miles per hour. (USDOT FHWA FTA MARAD 1995, 116)

► Air Transportation

Data for a complete condition and performance measurement system in air transportation do not exist. The Federal Aviation Administration (FAA), however, does compile data on the condition of airports and aircraft. For the air traveler, an important element of the performance of commercial air service is delays and on-time performance. FAA, therefore, also compiles performance data on airport and air traffic delay. The Office of Airline Information, part of BTS, collects data on air carrier on-time performance.

Runway Condition

In 1993, 79 percent of commercial service airports had runways with pavement condition rated good, 18 percent fair, and 3 percent poor. This is an improvement over 1986 when 78 percent were rated good, 15 percent fair, and 7 percent poor. (USDOT FAA 1995, 19)

Aircraft Condition

While the age of aircraft (one measure of condition) appears to have a strong relationship to the financial condition of air carriers, regulations being considered by FAA would require special maintenance and the retirement of older planes. The average age of aircraft owned by major U.S. companies was 11.4 years in 1992; in 1983 the average age was 10.5. The average age of aircraft in the U.S. airline industry as a whole increased from 10 years in 1983 to 11.5 in 1992. (USDOT Office of Airline Information)

On-Time Performance

A flight is considered on-time if it arrives at the gate less than 15 minutes after the scheduled arrival time. Canceled and diverted flights are considered late. In 1994, the proportion of on-time flights for major air carriers was 81.5 percent. Overall on-time performance improved from 1989 when the percent on time was 76.3. (USDOT BTS 1995, 75) Another measure is the number of passengers with confirmed seats that are either denied boarding or asked to let others occupy their seats. With a total of 841,000 denied boarding, 1994 was the worst year since 1987 when the number was 874,000; this is, however, a very small fraction of enplanements. (USDOT BTS 1995, 84)

Airport and Aircraft Delay

Most U.S. airports are uncongested, but seven airports had average airliner delays exceeding nine minutes in 1992 (the last year for which data were available), and are termed severely congested. Those were Boston Logan, Dallas-Fort Worth, Denver Stapleton, Newark, John F. Kennedy, La Guardia, and Chicago O'Hare. (USDOT FAA 1995, 10-11) Another indicator of congestion is the number of airports where delays to aircraft exceed 20,000 hours per year. There were 23 airports with such delay in 1992. One other indicator of congestion is average delay per aircraft operation (delay per departure and arrival over 15 minutes). Average delay per operation, 7.1 minutes in 1992, down from 7.4 minutes in 1990, is projected to increase to 7.7 minutes in 2002 if all the runways proposed in the National Plan of Integrated Airport Systems are built. (USDOT FAA 1995) Improvements in air traffic control, however, could prevent increased airspace delay. (USDOT FAA 1995, 12) FAA finds that the number of long delays (of 15 minutes or more) has been falling the past several years from 298,000 in 1991 to 237,000 in 1994. (USDOT FAA 1996)

► Rail

The condition of track, rolling stock (locomotives and cars), stations, and maintenance facilities is one aspect to consider in appraising rail transportation. In some situations these can be reported separately for passenger and freight service. Performance can also be measured by speed for both passenger and freight, and on-time performance for passenger services.

The condition of rail transportation systems is a tale of two industries. On the whole, the condition of the freight side is improving while passenger service (Amtrak) is deteriorating. On the freight side, 1.2 million railcars operated in 1994—virtually the same number as in the previous half-dozen years. In 1994, however, 51,000 new and rebuilt railcars were brought into the fleet—the greatest number in at least a decade—and these cars embody improved technology. (Welty 1995) Additionally, 1,216 new and rebuilt locomotives were added to the rail fleet in 1994, again the most in over a decade. (AAR 1995b, 54) Capital expenditures for equipment in 1994 were $1.7 billion, compared with $1.4 billion in 1993 and $874 million in 1992. Total capital expenditures, including roadway and structures, were $4.9 billion, a figure—although not corrected for inflation—never before attained by the rail industry. (AAR 1995b, 43)

By contrast Amtrak's equipment is old: the average age of its passenger cars was about 22 years and locomotives averaged over 13 years old in 1994. Despite some new equipment, the trend of the past decade has been for the average age of equipment to become even older. Amtrak's active locomotive fleet in 1994 was 338, but locomotive availability, which improved slightly the past two years, averages only about 85 percent during a typical day. (Amtrak 1995, 11) Some 66 percent of the locomotive fleet is at or beyond the locomotive's typical useful life; most passenger cars are half-way or more through their life-cycles. (Amtrak 1995, 13) Amtrak's contractors, the freight railroads, had only 77 serviceable passenger locomotives on January 1, 1995, having retired 21 locomotives during 1994. They replaced none in 1994 and had no new units on order. (AAR 1995a, 5)

On-time performance for Amtrak's trains was virtually the same in 1994 as in 1993, about 79 percent for short-distance trains, 50 percent for long-distance ones and about 72 percent overall.[6] On-time performance in 1994, however, was much worse than in 1984 when about 80 percent of all trains were on-time. Freight railroads over whose tracks Amtrak operates were responsible for 41.2 percent of delays in 1994 versus 38.8 percent in 1993. Amtrak-caused delays were 24.6 percent in 1994 and 25.7 percent in 1993. (Amtrak 1995, 10)

► Water Transportation

The report *1995 Status of the Nation's Surface Transportation System: Condition and Performance* provides some information on the waterborne transportation system, mostly on vessels. Of the 25,000 oceangoing vessels over 1,000 gross tons in 1995, approximately 543 sail under the U.S. flag. The U.S. fleet ranks 10th by deadweight capacity. The largest number of those, 187, are tankers. The U.S. fleet also contains 88 containerships, 50 roll-on/roll-off ships, 18 dry bulk carriers, and 8 cruise and passenger ships. The remaining 192 include breakbulk ships, partial containerships, refrigerated cargo ships, barge carriers, and specialized cargo ships. The U.S. domestic fleet, including those sailing on the Great Lakes, inland waterways, and along the coasts, consists of nearly 40,000 vessels. Approximately three-quarters of these are dry cargo barges and most of the rest are tankbarges and tug/towboats. The U.S. domestic fleet also includes 150 ferries. (USDOT FHWA FTA MARAD 1995, 202–203, 213)

Ports in the United States include deep-draft seaports, Great Lakes port facilities, and inland waterway ports. In 1993, there were 1,917 major U.S. seaport and Great Lakes terminals with 3,173 berths. Of these, 507 berths were in the Great Lakes system. In the same year, there were 1,789 river terminals, with nearly 97 percent in the Mississippi River System and the rest in the Columbia-Snake River System. Data on the condition of ports is limited to investment data on public shoreside port facilities. The data show that investment remained fairly constant from 1990 to 1993 at around $650 million per year. (USDOT FHWA FTA MARAD 1995, 218–222)

► Pipelines

With little new construction, pipeline throughput has remained relatively constant. The pipeline system is aging, prompting concerns about corrosion and the ability of pipelines to withstand stress. Frequent monitoring, corrosion control programs, and selective rehabilitation or replacement, however, can offset the effects of aging. (TRB 1988, 16–17) Performance then can be measured by output and by the number of pipeline failures, a key indicator of pipeline condition.

[6] This figure is a slight improvement from the 1993 figure of 47 percent, which was influenced by the extensive floods of that year.

In 1994, there were 222 gas pipeline incidents with 21 fatalities and 112 injuries, and 244 for liquid pipelines, with 1 fatality and an astounding 1,858 injuries caused largely from flooding in Texas. The number of incidents in 1990 was 199 for gas and 180 for oil. Pipeline incidents during the 1990s were far lower than in past decades, such as the 1,524 gas pipeline incidents in 1980 (15 fatalities) and the 246 oil pipeline incidents the same year (with 4 fatalities). (USDOT BTS 1995, 55–59)

Transportation Events in 1995

Trends in transportation can be powerfully shaped or temporarily interrupted by special events. For 1995 we identify three key transportation events. The first two events were specific to the United States: the designation of the National Highway System and changes in the industrial structure of the railroad industry. The third, the Kobe, Japan, earthquake, has no direct bearing on transportation in the United States but can be compared with the Northridge, California, earthquake of 1994, discussed in *Transportation Statistics Annual Report 1995*.

The Interstate Commerce Commission (ICC) was terminated at the end of 1995. Its railroad data programs were transferred to the Surface Transportation Board, a new Department of Transportation entity; motor carrier registration and insurance oversight were transferred to the Federal Highway Administration. Quarterly and annual reporting of financial and operating data by motor carrier was transferred to BTS.

BTS also notes the loss of 11 employees of the Oklahoma City office of the Federal Highway Administration, who were among the 168 killed in the bombing of the Alfred P. Murrah Federal Building on April 19, 1995.

► The National Highway System Designation

In 1995, Congress passed the National Highway System Designation Act (Public Law 104-59), formally establishing the National Highway System (NHS), which was first called for in the Intermodal Surface Transportation and Efficiency Act of 1991. The NHS, approximately 157,000 miles, is only 4 percent of all public roads and is composed of five parts: the Interstate highways (46,000 miles), 21 congressionally designated high-priority corridors (5,000 miles), key primary and urban arterials (89,000 miles), the non-Interstate part of the Strategic Highway Corridor Network (15,000 miles), and key Strategic Highway Corridor Network connectors (2,000 miles).

The main purpose of the NHS is to focus federal resources on the most heavily used highways and on those that link the highway system and other key elements of the transportation system, such as ports, international border crossing points, major airports, and public transportation facilities. System changes, as demanded by passenger and freight transportation needs, can be made by the Secretary of Transportation based on requests submitted by states.

► Changes in the Railroad Industry

The number of Class I railroads in the United States has been declining for decades. In 1980, there were 32 Class I railroad systems; only 10 remained at the end of 1995. Fifteen carriers were merged or consolidated with other systems. The other seven were reclassified for regulatory reporting purposes.

The Interstate Commerce Commission approved the merger of the Burlington Northern Railroad Company (Burlington Northern) and the Atchison, Topeka and Santa Fe Railway Company (Santa Fe) in August 1995. Burlington

Northern was ranked first among U.S. rail carriers in 1994, measured by miles of road and number of employees, and second in operating revenue. Santa Fe was seventh in all three categories. (AAR 1995a, 64–65) Burlington Northern operated 25,000 miles of track in the United States and Canada, and Santa Fe operated 10,400 miles in the United States. Together they are the most extensive rail property in the country.

The second consolidation approved by the Interstate Commerce Commission in 1995 was the acquisition of the Chicago and North Western Transportation Company by the Union Pacific Corporation. Union Pacific is ranked third in road miles (17,500) and employees (29,000). CNW ranked eighth in both categories. Union Pacific and CNW ranked first and eighth, respectively, in operating revenue.

► The Kobe, Japan, Earthquake and Transportation

One year to the day after the Northridge, California earthquake (on January 17, 1995) a Richter magnitude (M) 6.8 earthquake hit the port city of Kobe—located toward the southern end of Honshu, Japan's main island—killing more than 6,000 people and causing property damage of $94 billion. (Doi 1996) Officials estimated that nearly 180,000 buildings were badly damaged or destroyed and more than 300,000 of the city's 1.4 million people were made homeless by the 20 seconds of severe ground shaking. Centered just 12 miles southwest of downtown, much of the earthquake's energy passed through the most built-up part of Kobe, a three-mile-wide corridor of land between Osaka Bay to the south and the Rokko Mountains to the north.

The city's highways and railroads were very badly damaged, breaking the land connection between the southwestern part of Honshu island and the central and northeastern areas, including Tokyo. The two main limited-access highways—the Hanshin and Wangan expressways—that served the Kobe-Osaka transportation corridor were severed by the earthquake. Rail lines, including the bullet train, were also severed. The subway and local roads were damaged. Port facilities were almost completely destroyed. (EQE International 1995) Before the earthquake, Kobe was the largest container port in Japan, handling approximately 30 percent (2.7 million containers a year) of Japan's container shipping. Eight thousand containers a day had to be redirected to other ports. The long-term effects on the port are unknown. Some worry that traffic diverted may never return and that other ports such as Pusan in South Korea, Taiwan's Kaohsiung, Hong Kong, and Singapore might gain in the long run (Box 1995). About the only unscathed parts of the transportation system were the two major airports—Kansai and Itami. Repair costs for transportation facilities alone have been estimated at $60 billion.

By comparison, the 1994 Northridge earthquake on the same day in 1994, an M6.4, resulted in 57 deaths and $20 billion to $25 billion of damage. Another $6.5 billion in losses was due to business interruption, of which $1.5 billion can be ascribed to transportation-related effects. (Gordon et al 1996) The much greater devastation in Kobe resulted not from differences in engineering technology, but rather from the timing and location of the earthquakes, Kobe's generally older built environment, and Kobe's coastal location of soft alluvial soil and reclaimed land. A contributing factor to the immense damage to the transportation system was the elevation of many primary routes because of the lack of developable land. Seismologists and engineers note that the Kobe event has many implications for the United States, particularly San Francisco (another high-density port founded on alluvial soils, with relatively old building stock, and many elevated transportation routes). It has been calculated that the Hayward fault, which runs under a part of the San Francisco Bay area, including Oakland and Berkeley, could possibly generate energy of M8+. (EQE International 1995) The San Francisco earthquake of 1906 registered M8.3. Other areas, such as the Pacific Northwest, should not be complacent about the chances of a major earthquake either, even though the probability of a major earthquake there is lower than one in California. Most people expected that Tokyo would be the site of a major earthquake rather than Kobe. Possibly more frightening is that—as devastating as it was—the Kobe earthquake is considered a moderate event. Neither Kobe nor Northridge was the "big one."

In general, older structures and those not retrofitted to new building codes implemented in 1981 performed very poorly in Kobe. This includes the Hanshin Expressway built in the 1960s and old elevated railway lines. Post-1981 structures performed much better. The major exceptions to this were buildings, bridges, and other structures built on the softest soil and reclaimed land, including portions of the Wangan Expressway and the entire port. Finding ways of mitigating the effects of liquefaction, lateral spreading, and settlement in such places seems to be a high priority. (EQE International 1995) As was found after the Northridge earthquake, newer design standards can work well in moderate to large earthquakes, and retrofitting older structures is important. Kobe also points to a concern for U.S. ports on or near faults. Many ports on the west coast including the ports of Los Angeles, Long Beach, Oakland, Seattle, and Vancouver are prone to earthquake damage. Lessons from Kobe's railways also need to be studied for application to commuter rail systems and subways such as those in San Francisco and Los Angeles.

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CHAPTER TWO

Transportation and the Economy

Transportation is a major sector of the U.S. economy. It uses considerable private and public capital, employs millions of workers, and consumes resources and services produced by other sectors in order to move people and goods to their destinations. In 1994, transportation-related final demand accounted for 11 percent of the total value of U.S. gross domestic product (GDP).

To capture the rich interplay between the transportation system and the larger economy that it serves, many types of measurements are needed. Physical measures, depicting the output and capacity of the U.S. transportation system—for example, tons of goods moved and number of people carried—are detailed in chapter 1. Physical measurement alone, however, cannot illustrate the value society places on transportation. Measures of the various economic dimensions of transportation are better gauges of transportation's contribution to the overall economy.

As a proportion of GDP, transportation-related final demand has remained stable since 1989, suggesting the importance of technological change and productivity growth in the transportation sector.

This chapter opens with a discussion of the measures of transportation's importance to the economy and society as indicated by 1) transportation's share of gross domestic product and 2) its share of consumer and government expenditures. The chapter also discusses employment and productivity trends and cost structures in the transportation sector. Finally, it describes changes in revenue and expenditure patterns in the trucking and railroad industries. The commercial aviation industry is discussed in detail in appendix A of this report.

To help explain transportation's contribution to the U.S. economy, the Bureau of Transportation Statistics (BTS) is developing several new approaches. First, it is combining existing statistics in ways that better illustrate the family of industries that make up the transportation sector. Second, in cooperation with the U.S. Department of Commerce, Bureau of Economic Analysis (BEA), BTS is seeking to improve and expand existing statistics and build a new accounting structure for transportation consistent with the system of National Income and Products Accounts (NIPA).[1] The new accounting structure, called a "satellite account," will provide more comprehensive information on U.S. transportation. The scope of the Transportation Satellite Account (TSA) is described in this chapter.

The Economic Importance of Transportation as a Component of GDP

The importance of transportation in the economy can be shown in two ways: 1) as the share of transportation-related final demand in GDP,[2] and 2) as the share of value-added generated by transportation activities in GDP. Each measure presents a different perspective on transportation's economic importance. The use of both measures provides a more accurate and complete picture of transportation's contribution to the U.S. economy.

[1]The NIPA is a summary of the nation's economic income and output and the interaction of its major components. BEA collects NIPA data.

[2]GDP is defined as the net output of goods and services produced by labor and property located in the United States, valued at market prices. As long as the labor and property are located in the United States, the suppliers (workers and owners) may be either U.S. residents or residents of foreign countries.

This section will first discuss the share of transportation-related final demand in the GDP. The section then examines the contribution of the transportation industry to the GDP, focusing on the "for hire" component of the industry, which had a value-added contribution of $207.9 billion to GDP in 1993. Focusing on the for-hire segment, though, undercounts transportation's contribution, as explained below. Thus, the section discusses the TSA, the aim of which is to provide better measures of the contribution of transportation to the economy. Finally, transportation services as an intermediate input to production are examined, focusing again on the for-hire component of the transportation industry, but also analyzing the direct and indirect intermediate inputs of transportation to a variety of industries.

▶ Share of Transportation-Related Final Demand in GDP

Transportation-related final demand is defined as the value of all transportation-related goods and services, regardless of industry origin, delivered to final demand. Components of final demand include consumer and government expenditures (discussed in more detail later in the chapter), investments, and net exports.

Transportation-related final demand is a measure of the overall economic importance of transportation as a social function—a far broader measure than the contribution of the transportation industry[3] to GDP alone.

[3]The transportation industry can be thought of narrowly as comprising for-hire transportation services, or broadly as consisting of all business activities that are needed to carry out the social function of transportation. Under the broad definition, the transportation industry includes those establishments or parts of establishments that: 1) build transportation facilities and equipment; 2) operate transportation facilities; 3) provide for-hire transportation services for individuals, households, businesses, or government agencies; 4) provide supporting in-house transportation for a business or government agency; 5) arrange for the provision of transportation services; or 6) administer transportation programs. The broad definition includes a diverse cross-section of the economy, such as railroads, travel agents, school district bus operators, port authorities, gas stations, and the trucking fleets of major grocery chains.

TABLE 2-1: U.S. GROSS DOMESTIC PRODUCT ATTRIBUTED TO TRANSPORTATION-RELATED DEMAND, 1989–94 (BILLIONS OF CURRENT DOLLARS)

	1989	1990	1991	1992	1993	1994
Personal consumption of transportation	**$439.1**	**$453.7**	**$434.6**	**$466.3**	**$504.2**	**$538.0**
1. Motor vehicles and parts	205.6	202.4	185.5	204.1	228.0	251.2
2. Gasoline and oil	95.5	108.5	102.9	105.5	105.6	107.2
3. Transport services	138.0	142.8	146.2	156.7	170.6	179.6
Gross private domestic investment	**79.6**	**88.3**	**88.1**	**95.2**	**108.8**	**124.6**
4. Transportation structures	3.0	3.0	3.2	3.7	4.6	5.3
5. Transportation equipment	76.6	85.3	84.9	91.5	104.2	119.3
Net exports of goods and services	**–33.3**	**–26.9**	**–15.9**	**–14.0**	**–24.8**	**–38.3**
Exports (+)	**92.6**	**106.0**	**114.8**	**124.8**	**124.8**	**132.8**
6. Civilian aircraft, engines, and parts	26.6	32.2	36.6	37.7	32.7	31.6
7. Automotive vehicles, engines, and parts	34.9	36.5	40.0	47.0	52.4	57.6
8. Passenger fares	10.6	15.3	15.9	17.4	16.6	17.5
9. Other transportation	20.5	22.0	22.3	22.7	23.1	26.1
Imports (–)	**125.9**	**132.9**	**130.7**	**138.8**	**149.6**	**171.1**
10. Civilian aircraft, engines, and parts	9.6	10.5	11.7	12.6	11.3	11.3
11. Automotive vehicles, engines, and parts	87.4	88.5	85.7	91.8	102.4	118.7
12. Passenger fares	8.2	10.5	10.0	10.9	11.4	12.7
13. Other transportation	20.7	23.4	23.3	23.5	24.5	28.4
Government transport-related purchases	**81.4**	**87.7**	**98.7**	**94.7**	**98.1**	**100.7**
14. Federal purchases	9.6	10.4	11.8	12.6	13.1	12.9
15. State and local purchases	63.8	68.4	70.9	72.5	76.0	79.6
16. Defense-related purchases	8.0	8.9	16.0	9.6	9.0	8.2
Total final uses for transportation	**566.8**	**602.8**	**605.5**	**642.2**	**686.3**	**725.0**
Gross domestic product	$5,250.8	$5,546.1	$5,724.8	$6,020.2	$6,343.3	$6,738.4
Total transport in gross domestic product	10.8%	10.9%	10.6%	10.7%	10.8%	10.8%

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, based on U.S. Department of Commerce, Bureau of Economic Analysis, "Survey of Current Business," 1994, National Income and Products Account data.

Tables 2-1 and 2-2 present transportation-related final demand and its share in GDP using current and 1987 dollars, respectively. In current dollars, GDP amounted to $6.7 trillion in 1994, an increase of 6.2 percent from the previous year. Transportation-related final demand was $725 billion in 1994, an increase of 5.6 percent from 1993. (USDOC BEA 1994)

Personal consumption is a significant component of transportation-related final demand. Its share was 74 percent in 1994, as shown in table 2-1. International trade in transportation-related goods and services consistently ran a deficit over the six-year period from 1989 to 1994, primarily as a result of lackluster automobile and parts trading. In contrast, trade of civilian air-

Table 2-2: U.S. Gross Domestic Product Attributed to Transportation-Related Demand, 1989–94
(billions of 1987 dollars)

	1989	1990	1991	1992	1993	1994
Personal consumption of transportation	**$407.5**	**$403.3**	**$373.6**	**$390.3**	**$410.5**	**$428.1**
1. Motor vehicles and parts	190.8	192.2	170.5	181.8	196.1	208.2
2. Gasoline and oil	88.6	86.4	83.1	85.6	86.5	87.2
3. Transport services	128.1	124.7	120.0	122.9	127.9	132.7
Gross private domestic investment	**75.4**	**81.3**	**77.5**	**81.6**	**91.6**	**102.5**
4. Transportation structures	2.8	2.8	2.8	3.3	3.8	4.2
5. Transportation equipment	72.6	78.5	74.7	78.3	87.8	98.3
Net exports of goods and services	**–29.3**	**–25.1**	**–14.1**	**–12.4**	**–21.0**	**–30.5**
Exports (+)	**87.4**	**96.1**	**99.8**	**105.5**	**104.7**	**114.7**
6. Civilian aircraft, engines, and parts	25.0	28.6	31.1	30.7	25.9	24.4
7. Automotive vehicles, engines, and parts	33.4	34.1	36.3	41.9	46.3	50.4
8. Passenger fares	9.7	13.4	12.7	13.2	12.6	16.0
9. Other transportation	19.3	20.0	19.7	19.7	19.9	23.9
Imports (–)	**116.7**	**121.2**	**113.9**	**117.9**	**125.7**	**145.2**
10. Civilian aircraft, engines, and parts	9.0	9.3	10.0	10.2	8.9	8.7
11. Automotive vehicles, engines, and parts	80.7	81.4	75.8	79.7	87.4	97.9
12. Passenger fares	7.8	9.2	7.8	8.1	8.8	11.9
13. Other transportation	19.2	21.3	20.3	19.9	20.6	26.7
Government transport-related purchases	**75.8**	**78.7**	**86.6**	**80.4**	**81.0**	**80.8**
14. Federal purchases	8.9	9.3	10.1	10.5	10.5	9.9
15. State and local purchases	58.8	60.4	60.6	60.4	61.8	63.1
16. Defense-related purchases	8.1	9.0	15.9	9.6	8.7	7.8
Total final uses for transportation	**529.4**	**538.2**	**523.6**	**539.9**	**562.0**	**580.9**
Gross domestic product	$4,838.0	$4,897.3	$4,867.6	$4,979.3	$5,134.5	$5,344.0
Total transport in gross domestic product	10.9%	11.0%	10.8%	10.8%	10.9%	10.9%

SOURCE: Based on U.S. Department of Commerce, Bureau of Economic Analysis, "Survey of Current Business," 1994, National Income and Products Account data.

craft and parts ran a surplus, with exports consistently about three times imports. Without the aviation surplus, the transportation-related trade deficit would have been even larger.

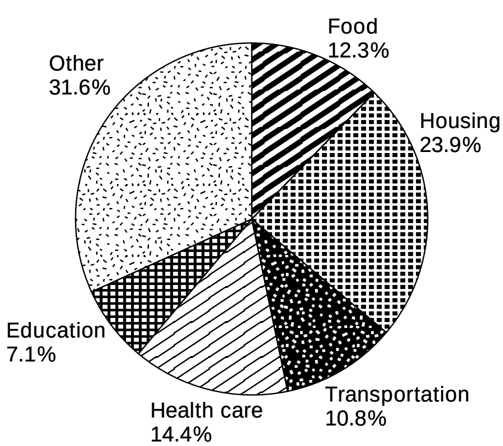
The categories of personal consumption of transportation presented in tables 2-1 and 2-2 show the kinds and quantities of products that were necessary to meet personal transportation demand, including motor vehicles and parts, gasoline and oil, and transport services. These categories differ from those reported in the *Transportation Statistics Annual Report 1995.* The categories highlighted in last year's report—user-operated transportation, purchased local transportation, and purchased intercity transportation—were intended to show what kinds of transportation services consumers bought, not which of the economy's goods and services comprised consumers' expenditures on transportation.

Transportation is one of many social functions or purposes supported by an economy's GDP. Other major social purposes include food, housing, health care, and education.

Figure 2-1 presents a breakdown of GDP by major social function. Among these social functions, transportation's share in GDP ranks behind housing, health care, and food, but ahead of education. The share of health care in GDP increased from 12.4 percent in 1989 to 14.4 percent in 1994, while the share of food in GDP decreased from 13.1 percent in 1989 to 12.3 percent in 1994. The share of transportation remained almost unchanged (see table 2-3). This reflects the different characteristics of the goods and services required to support these functions. In general, the demand for food and food-related services have low income elasticity; that is, after demand reaches a certain level, an increase in income will cause a smaller percentage increase in demand. In contrast, the demand for health care-related goods and services have high income elasticity; that is, at higher levels of income, proportionally more money will be spent on health care.

Between 1989 and 1994, personal mobility, freight traffic, and the globalization of the American economy increased substantially. Transportation output measured in passenger-miles and ton-miles grew faster than transportation output measured in dollars. In this context, the fact that transportation-related final demand remained stable as a proportion of GDP suggests the importance of technological change and productivity growth in the transportation sector. Productivity in the transportation sector is shown in figure 2-2, which charts the higher rate of growth of value-added per employee in transportation, compared to the overall economy.

FIGURE 2-1: U.S. GROSS DOMESTIC PRODUCT BY MAJOR SOCIAL FUNCTION, 1994



SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business,* April 1995, tables 2.4, 4.1, 4.3, 5.6, 5.8, 5.10 and September 1992, tables 3.16 and 3.17.

► Share of Transportation in GDP Based on Value-Added Origination

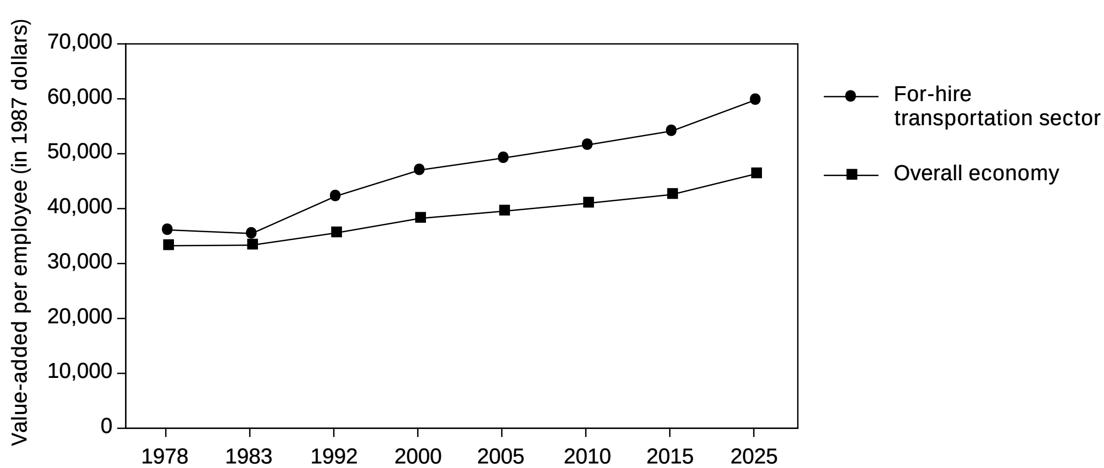
The share of transportation-related final demand in GDP is a good measure of the importance of transportation as an end demand (or function) in people's lives, national defense, and international trade. As already mentioned, however, it is not an accurate measure of the contribution of the transportation industry to GDP, because many other industries' products are also used to satisfy consumers' demand for transportation. For example, consumers purchase automobiles for transportation purposes. Thus, the value of automobiles is counted as a measure of how much GDP is produced for transportation-related final demand, or the importance of transportation in GDP. It is inappropriate, though, to count the value of automobiles as a contribution of the transportation industry to GDP, because cars are products of the automobile industry. Even at more aggregated levels of industrial classification, automobiles would be

TABLE 2-3: GROSS DOMESTIC PRODUCT BY MAJOR SOCIAL FUNCTION, 1989–94

	1989	1990	1991	1992	1993	1994
	Billions of current dollars					
Food	685.3	721.7	740.5	755.9	786.8	825.5
Housing	1,271.6	1,298.8	1,313.1	1,401.8	1,501.8	1,610.6
Transportation	566.8	602.8	605.5	642.2	686.3	725.0
Health care	653.2	719.3	766.7	833.1	901.8	970.3
Education	370.1	397.8	419.7	437.3	454.4	477.4
Other	1,703.8	1,805.4	1,879.4	1,949.9	2,012.4	2,129.5
Gross domestic product	5,250.8	5,546.1	5,724.8	6,020.2	6,343.5	6,738.3
	Percentage of Gross Domestic Product					
Food	13.1	13.0	12.9	12.6	12.4	12.3
Housing	24.2	23.4	22.9	23.3	23.7	23.9
Transportation	10.8	10.9	10.6	10.7	10.8	10.8
Health care	12.4	13.0	13.4	13.8	14.2	14.4
Education	7.0	7.2	7.3	7.3	7.2	7.1
Other	32.4	32.6	32.8	32.4	31.7	31.6
Gross domestic product	100.0	100.0	100.0	100.0	100.0	100.0

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, "Survey of Current Business," 1994.

FIGURE 2-2: TREND OF LABOR PRODUCTIVITY



SOURCE: Calculated from gross domestic product and employment data in U.S. Department of Commerce, Bureau of Economic Analysis, *BEA Regional Projections to 2045, Vol. 1, States* (Washington, DC: U.S. Government Printing Office, July 1995), p. 10.

counted as products of the manufacturing industry, rather than the transportation industry.

There is another reason why calculating transportation-related final demand as a component of GDP does not accurately reflect the industry's contribution to the economy. This is because products of other industries delivered to final demand for other social functions, such as housing, also contain values generated by the transportation industry. For example, when a consumer buys a new house, he or she pays not only for the land, materials, and labor, but also for the transportation required to deliver goods and services used in the construction of the house.

A proper measure of the contribution of the transportation industry to GDP is the value-added generated by transportation in the production of its total output, that is, transportation services used by all industries in their production, plus transportation services delivered to final demand.

Measuring the contribution of the transportation industry to GDP based on value-added origination, however, leads to undercounting it, given the current system of industrial classification used in the NIPA. Table 2-4 presents the value-added contribution to GDP of several industries, including the for-hire component of the transportation industry. This component of the transportation industry includes only establishments that offer transportation services to the public for a fee—the so-called for-hire transportation industries. The share of value-added in GDP originating from for-hire transportation decreased in current dollars from 3.8 percent in 1980 to 3.3 percent in 1993 (the latest year for which data are available). This reflects increases in the prices charged for other industries' products rather than a decrease in the for-hire transportation's contribution to GDP. If constant dollars are used, the for-hire transportation's value-added contribution to GDP actually increased, reflecting the smaller inflation in the prices of transportation services as well as their relatively higher productivities.

Transportation-related GDP is undercounted from the industrial side because the value of private transportation is not included. Private transportation can be defined as transportation

TABLE 2-4: CONTRIBUTIONS TO GROSS DOMESTIC PRODUCT (GDP): SELECTED INDUSTRIES

	1980	1990	1991	1992	1993	1980	1990	1991	1992	1993
	Billions of current dollars					Billions of 1987 dollars				
GDP	2,708.0	5,546.1	5,724.8	6,020.2	6,343.3	3,776.3	4,897.3	4,867.6	4,979.3	5,134.5
For-hire transportation	102.9	176.8	183.7	193.8	207.9	120.2	168.9	175.0	183.7	193.5
Communications	68.9	146.7	154.2	162.1	169.8	94.4	140.8	148.2	153.8	158.9
Health care	111.5	304.4	335.2	364.4	389.4	196.1	241.4	248.0	252.0	255.3
Education	16.4	38.1	43.4	45.6	47.8	26.3	32.1	34.8	35.1	35.5
	Percentage of GDP					Percentage of GDP				
For-hire transportation	3.8	3.2	3.2	3.2	3.3	3.2	3.4	3.6	3.7	3.8
Communications	2.5	2.6	2.7	2.7	2.7	2.5	2.9	3.0	3.1	3.1
Health care	4.1	5.5	5.9	6.1	6.1	5.2	4.9	5.1	5.1	5.0
Education	0.6	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, "Survey of Current Business," May 1993, tables 9 and 12; October 1994, table 2; April 1995, table 1.

activities conducted by industries whose primary business is not transportation. Under the current industrial classification system of national accounts, the value of private transportation is counted as the output of an industry's primary activity, rather than as a transportation output.

► Transportation Satellite Account

The undercounting of transportation-related GDP based on value-added origination, noted above, results from including only the for-hire transportation industry and excluding the private transportation of nontransportation industries. The Standard Industrial Classification (SIC), which is used in the NIPA, recognizes two types of establishments—operating and support. Operating establishments offer goods and services for a fee, and support establishments provide functions such as research, central administrative services, and warehousing for other establishments of the same company. The operating establishments' SIC depends on the primary activity of the establishment; support establishments, on the other hand, are given the same SIC as the operating establishments they serve. Consequently, an operating establishment providing trucking services for a fee is classified as part of the transport industry, while a support establishment providing trucking services within a grocery firm or a manufacturing firm is considered part of the retail or manufacturing industry. Thus, value-added originating from private transportation is counted as part of the industries served.

To address this artificial distinction, BTS is engaged, jointly with BEA, in developing the Transportation Satellite Account. The TSA, developed around the U.S. Input-Output Account, will provide credible and consistent measures of transportation's contribution to the national economy and its interactive relationship with other productive sectors of the economy. It distinguishes between for-hire and private transportation and presents information on the industry-by-industry distribution of transport activities of both types. The TSA also will facilitate analyses of interdependencies between transportation and the economy. For example, the TSA will estimate the total transportation costs embodied in each commodity delivered to final demand and assess the impact of structural changes in the economy on transportation demand.

► Transportation Services as an Intermediate Input to Industrial Production

As noted earlier, transportation services are components of both final demand and production. A larger share of transportation activities, particularly freight, however, is identified as an intermediate input[4] in the production of goods. Table 2-5 shows intermediate and final uses of for-hire transportation services in 1987, the last year for which data are available. Nearly 59 percent of for-hire transportation was destined for intermediate consumption in 1987. Intermediate usage accounted for a high percentage of the total output of pipelines and motor freight. Fifty-six percent of railroad output was consumed as intermediate input. Water and air transport were oriented more toward final demand, with only 33 percent and 46 percent, respectively, consumed as intermediate input.

Transportation's importance as an input to production varies by industry. Table 2-6 presents the direct and indirect for-hire transportation inputs[5] required to produce and deliver a dollar's

[4]An intermediate input is defined as goods, materials, and services used as inputs in the production of other goods or services. Intermediate inputs can be categorized as either direct or indirect (see footnote 5).

[5]Direct inputs are defined as goods, materials, and services that are used directly in the production of a product or service; e.g., steel is a direct input to the production of automobiles. Indirect inputs are defined as goods, materials, and services that are used in the production of inputs to the production of a product or service; e.g., steel is an indirect input to transportation services because it is used in the production of transportation equipment.

TABLE 2-5: INTERMEDIATE AND FINAL USES OF FOR-HIRE TRANSPORTATION OUTPUT BY MODE, 1987 (MILLIONS OF 1987 DOLLARS)

	Intermediate use	Final use	Transport output	Intermediate use share (percent)
Railroads and services	$27,231	$21,164	$48,394	56.3%
Motor freight and warehousing	80,137	35,056	115,194	69.6
Water transport	8,029	16,169	24,198	33.2
Air transport	36,314	42,745	79,060	45.9
Pipeline and other services	18,525	4,776	23,301	79.5
Total	$170,236	$119,910	$290,147	58.7%

NOTE: The latest year for which data are available is 1987.

SOURCE: U.S. Department of Commerce, Economics and Statistics Administration, Bureau of Economic Analysis, *Benchmark Input-Output Accounts of the United States,1987* (Washington, DC: U.S. Government Printing Office, November 1994).

worth of industrial output to final demand. Private transportation services are not included in this table.

Among the 22 industries presented in table 2-6, the transportation industry had the highest direct requirement for its own output. This reflects the fact that each transportation mode uses the services of other modes as input in providing its own services. For example, in order to provide door-to-door transportation service, a railroad may hire a trucking company to move goods from a train station to their final destinations. Moreover, all transportation modes use a significant amount of pipeline services.

Other industries also have high direct requirements for transportation. The petroleum refinery industry transports crude oil through pipelines and thus has high direct requirements for transportation services. Because of the high weight-to-value ratio of the inputs of the stone, glass, and clay products industry, transportation is a large portion of that industry's total input cost.

The mining industry's low direct requirement for transportation services is surprising. Two factors may contribute to this situation. First, natural resources, under the current NIPA, are not valued before they are brought into the production system. Hence, minerals are valued in the NIPA only after they are extracted from the ground and have become the output of the mining industry. Therefore, a larger portion of output is counted as value-added. This, in turn, makes intermediate inputs, including transportation services, a small portion of the value of the mining industry's output. Second, inputs and outputs are valued at producer's prices in the U.S. Benchmark Input-Output Accounts. In other words, the NIPA assigns the costs of transporting inputs to the producer and assigns the costs of transporting outputs to the purchaser. Thus, the costs of transporting the mining industry's output to other industries are not counted as production costs of the mining industry. An industry's direct coefficient for transportation services is derived by dividing its transportation input by its output. Hence, high value-added industries, in general, have low direct requirements for transportation services. Processing industries that have low value-added components have high direct transportation requirements.

The table further reveals that for most of the industries examined indirect transportation requirements are larger than direct requirements. This finding underscores the importance of

TABLE 2-6: DIRECT AND INDIRECT TRANSPORTATION COSTS PER DOLLAR FINAL DEMAND

	Transportation cost per dollar of industry output (direct requirement)	Indirect transport service required per dollar of final demand	Total transport service required per dollar of final demand
Agriculture	$0.026	$0.036	$0.063
Mining	0.013	0.014	0.027
Construction	0.018	0.029	0.047
Food and tobacco	0.023	0.040	0.064
Textiles	0.010	0.028	0.038
Wood products	0.027	0.032	0.059
Chemistry	0.030	0.031	0.061
Petro-refinery	0.045	0.033	0.078
Glass and stone production	0.065	0.036	0.100
Steel and metal production	0.029	0.033	0.062
General machinery	0.013	0.025	0.038
Electric machinery and equipment	0.015	0.025	0.040
Transport equipment	0.021	0.036	0.057
Precision equipment	0.010	0.021	0.031
Miscellaneous manufacturing	0.015	0.023	0.039
Transportation	0.146	1.037[a]	1.183[a]
Communications and utility	0.015	0.022	0.037
Wholesale and retail	0.011	0.012	0.023
Finance, insurance, real estate	0.009	0.011	0.021
Personal services	0.011	0.021	0.032
Business services	0.015	0.019	0.034
Government enterprise	$0.039	$0.026	$0.065

[a] Includes a dollar's worth of transport service delivered to final demand. The number is larger than one because the transportation industry uses its own output as input to produce transportation services.

NOTE: Data are in 1987 dollars and at producer's prices.

SOURCE: U.S. Department of Commerce, Economics and Statistics Administration, Bureau of Economic Analysis, *Benchmark Input-Output Accounts of the United States, 1987* (Washington, DC: U.S. Government Printing Office, November 1994).

including indirect impacts in analyses of the role of transportation in the economy and society.

Finally, the coefficients listed in table 2-6 may understate the requirements of industries for transportation services, because they do not include private transportation services provided by nontransportation industries.

Measures of Transportation's Importance to Society: Consumer Expenditures

Consumer expenditures on transportation are important indicators of the value of transportation to society. Consumer expenditures, however, tend to understate the full social value of transportation because they do not include certain costs of transportation, such as a driver's time or compensated expenditures, such as a company-owned car.

In the United States, households spent an average of $31,750 in 1994, an increase of 3.4 percent from 1993 (see table 2-7). Of that total, $6,044 was spent on transportation-related services,[6] an increase of 10.8 percent from 1993. Household expenditures on vehicle purchases and to a lesser extent on other vehicle expenses and purchased transportation strongly affected the increase.

As a result of increased spending, transportation's share in household total expenditures rose from 17.8 percent in 1993 to 19.0 percent in 1994. In contrast, the shares of other major categories of household expenditures, such as food, clothing, health care, and insurance and pensions, decreased. Households still spent the most on housing, followed by transportation (see figure 2-3). Vehicle purchase accounted for the largest share of household transportation expenditures. On average, household expenditures on vehicles increased 18 percent between 1993 and 1994, reflecting demand for bigger, more powerful, better equipped, and more comfortable vehicles. (USDOL BLS 1993 and 1994a) See figure 2-4 and box 2-1 for information on vehicle ownership and operating costs.

In 1994, an average household spent $381 on purchased transportation, an increase of 21 percent from 1993 (see table 2-7). In recent years, expenditures on airline tickets accounted for more than 64 percent of household spending on purchased personal transportation. (USDOL BLS 1994a) The combination of increased expenditures on air travel and relatively stable expenditures on automobile operations indicates a shift to air travel for personal intercity travel.

[6]Household expenditures do not include business travel paid for by others.

TABLE 2-7: TRANSPORTATION EXPENDITURES BY AVERAGE CONSUMER UNIT, 1993 AND 1994 (IN CURRENT DOLLARS)

Spending category	1993	1994	Change (percent)
All spending	$30,692	$31,750	3.4%
All transportation spending	5,453	6,044	10.8
Vehicle purchases	2,319	2,725	17.5
Gas and oil	977	986	0.9
Other vehicle expenditures	1,843	1,953	5.9
Purchased transportation services	314	381	21.4%

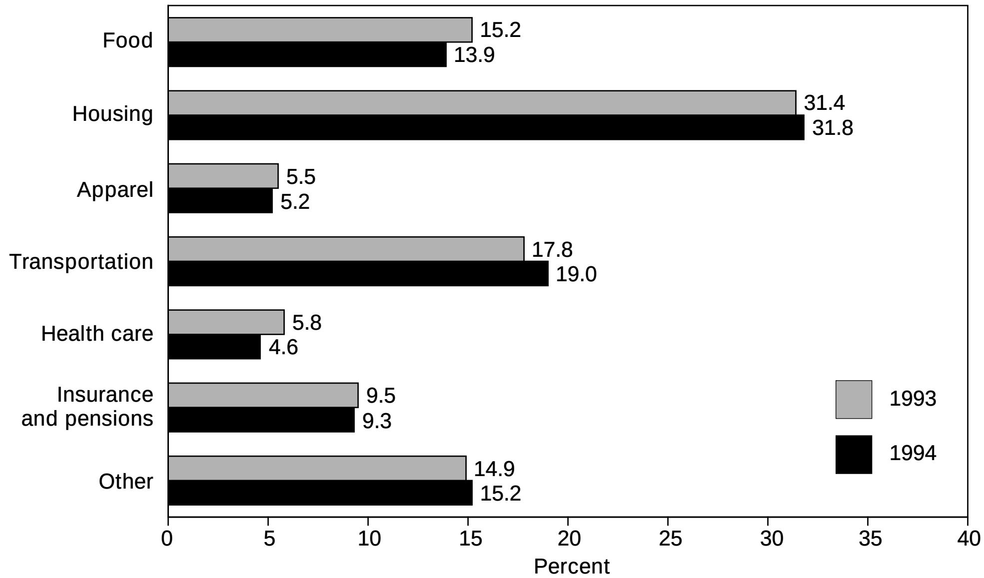
NOTE: A consumer unit comprises either one individual or members of a household who are related by blood, marriage, adoption, or other legal arrangement; a financially independent person living alone or sharing a household with others, living as a "roomer" in a private home or lodging house, or in temporary living quarters, such as a hotel or motel; two or more persons living together who use their income to make joint expenditure decisions.

SOURCES: U.S. Department of Labor, Bureau of Labor Statistics, "Consumer Expenditure Survey," 1993; and unpublished data from "Consumer Expenditure Survey," 1994.

► Spending by Region

Figure 2-5 shows the regional variations in the major categories of consumer spending on transportation. The Northeast region differs significantly from other regions. Northeastern consumers spent the least on transportation, both in absolute and relative terms, arising in large part from the region's low spending on vehicle purchases. Furthermore, the Northeast region had only 1.5 vehicles per household compared with 2.1 for the Midwest, 1.8 for the South, and 2.2 for the West. The West had the highest spending on gasoline and oil and other

FIGURE 2-3: TOTAL CONSUMER EXPENDITURES BY MAJOR CATEGORY, 1993 AND 1994



SOURCES: U.S. Department of Labor, Bureau of Labor Statistics, "Consumer Expenditures Survey," 1993; and unpublished data from the "Consumer Expenditures Survey," 1994.

vehicle expenditures. Expenditures on public transport accounted for a much larger share of Northeastern consumers' total transportation spending than that in other regions. (USDOL BLS 1994a)

► Spending by Rural/Urban Location

Rural households spend on average 11 percent less than do urban households. Rural residents, however, spend more on transportation in both absolute and relative terms (see table 2-8)—about 24 percent compared with about 18 percent for urban residents.

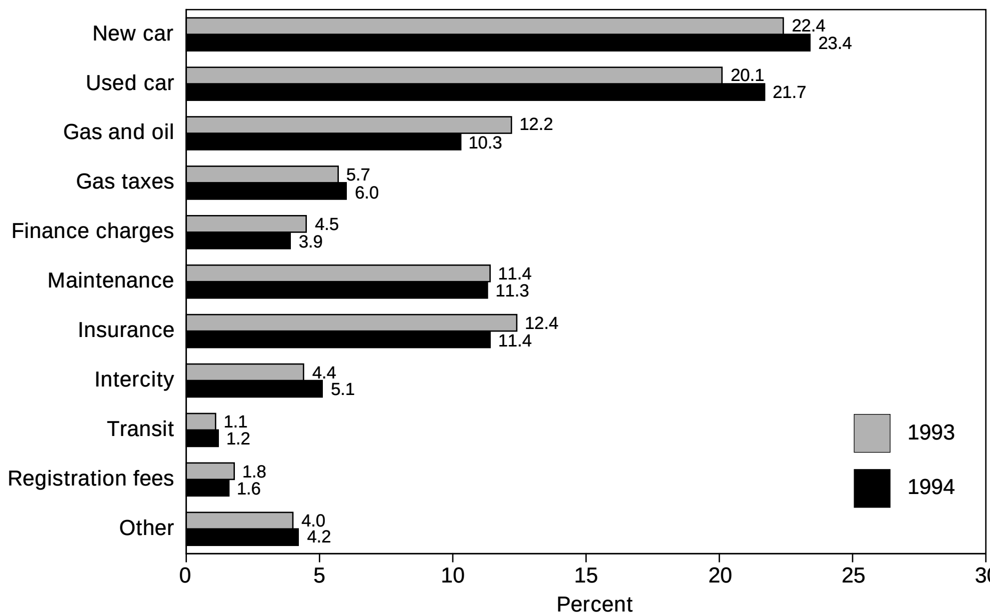
Rural residents spend a great deal more to purchase vehicles and fuel, but less for other vehicle-related costs such as insurance and repairs. Urban dwellers spend more for vehicle leasing, which is included under "Other vehicle expenditures" in table 2-8. The greatest disparity between urban and rural areas is in purchased transportation services, such as taxis. Urban dwellers spend twice as much as rural residents for this service.

► Spending by Race

The Consumer Expenditure Survey (CES)[7] delineates black consumer spending from other population groups, but cannot provide detailed racial and ethnic spending information because of sample size limitations. Table 2-9 shows 1994 spending patterns of black and white or other consumers. Black consumers spend less overall on transportation. The greatest differences

[7] The Consumer Expenditure Survey is a major source of information on U.S. consumer buying habits. This information, which is collected by the Bureau of Census for the Bureau of Labor Statistics, is an important component of the Consumer Price Index. About 95 percent of consumer expenditures are covered by the Survey. It excludes nonprescription drugs, household supplies, and personal care items. Also excluded from the Survey are all business-related expenses for which a family is reimbursed.

FIGURE 2-4: DETAILED CONSUMER EXPENDITURES ON TRANSPORTATION, 1993 AND 1994



SOURCES: U.S. Department of Labor, Bureau of Labor Statistics, "Consumer Expenditures Survey," 1993; and unpublished data from the "Consumer Expenditures Survey," 1994.

between the two groups are found in the vehicle purchases and other vehicles expenditures categories. Black consumers spend a greater share on vehicle purchases while white consumers spend more for other vehicle expenses. These differences are, in part, a product of substituting vehicle leasing for vehicle purchases among white households.

The area of significant variation in spending is in the category of purchased transportation services. Black and white consumers spend about 1 percent of total expenditures on purchased transportation. Black consumers, however, spend twice as much on taxis as do white consumers. Also, black consumer spending on public transit is more than three times that of white consumers. White consumers spend substantially more than blacks for all categories of intercity travel—about three times more for air and rail travel.

► Spending Away from Home

Consumer expenditures on travel while away from home are difficult to ascertain. The CES sheds valuable light on that segment of travel, but several expenses are not included, such as any travel paid for or reimbursed by employers and institutions. Certain expenditures, such as taxicabs, can be easily identified as to whether the service was bought at home or on travel. Other spending, however, such as vehicle purchases or repairs, are more difficult to assign. An allocation based on miles traveled or another method would have to be developed in order to determine the split between expenses incurred at home and those incurred while traveling.

Identifiable expenditures reported by the CES are shown in table 2-10. According to the table, out-of-town consumer spending added up to an average of about $450 per household in

Box 2-1: Vehicle Ownership and Operating Costs

Vehicle purchases account for a large percentage of household transportation budgets. According to the Consumer Price Index, new car costs have risen less rapidly than general costs since 1970, and far less rapidly than used car costs. This may seem counterintuitive, but the reason is that the average new car of the 1990s is very different from the average new car of the 1970s, as explained below.

New Car Costs

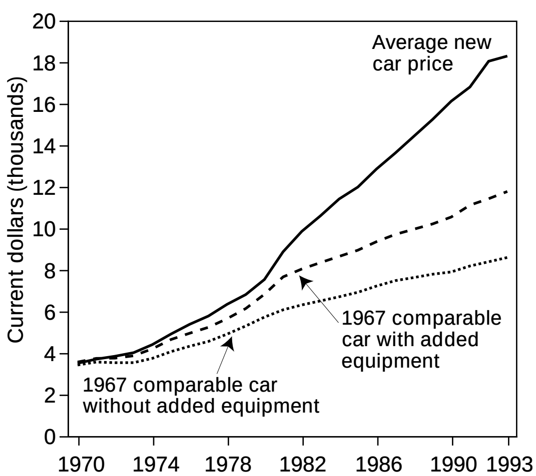
The average price of a new car, in current dollars, rose from about $3,500 in 1970 to almost $20,000 in 1994.[1] In 1990 dollars, correcting for inflation, new car prices hovered around $12,000 throughout the 1970s, then rose to about $16,900 by 1995.

[1] American Automobile Manufacturers Association, *Motor Vehicle Facts & Figures* (Washington, DC: 1995), p. 60.

Figure 1 breaks down the trend in vehicle prices into three components of vehicle costs. The bottom curve tracks the price of a basic vehicle, comparable in design and equipment to a 1967 model vehicle. The middle curve shows the impact on price of added equipment and modifications required by federal and state mandated safety and emissions regulations. These requirements increased vehicle price to about $11,800. The top curve adds the price increase attributable to improvements and amenities demanded by consumers, including air conditioning, power assists, and stereo equipment. Today, these options are standard on most new vehicles.

In 1993, a family earning the median national income needed about 26 weeks of salary to purchase a new car compared with less than 20 weeks in the 1970s (see figure 2). *(continued)*

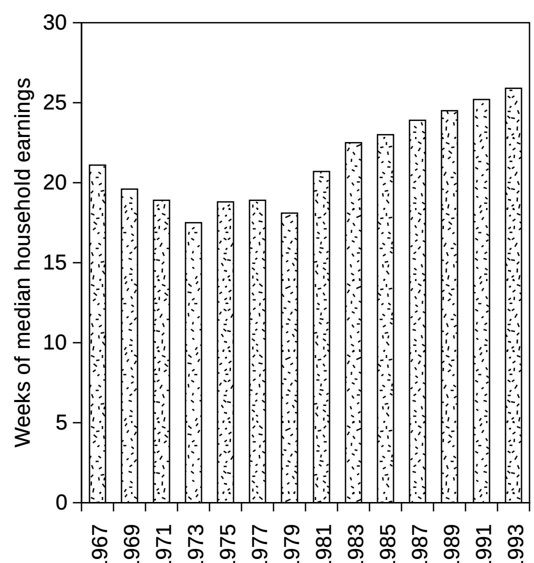
Figure 1: Trends in the Cost of Automobiles, 1970–93



NOTES: 1967 comparable = basic car as of 1967.
1967 with added equipment = basic 1967 car with costs for mandated federal safety and emissions equipment.
Average new car price = basic car with mandated equipment, plus amenities and improvements added.

SOURCE: American Automobile Manufacturers Association, *Motor Vehicle Facts & Figures* (Washington, DC: 1989 and 1994).

Figure 2: Weeks of Household Earnings Required to Purchase an Average-Priced New Car



SOURCE: American Automobile Manufacturers Association, *Motor Vehicle Facts & Figures 94* (Washington, DC: 1994).

Box 2-1 (cont'd): Vehicle Ownership and Operating Costs

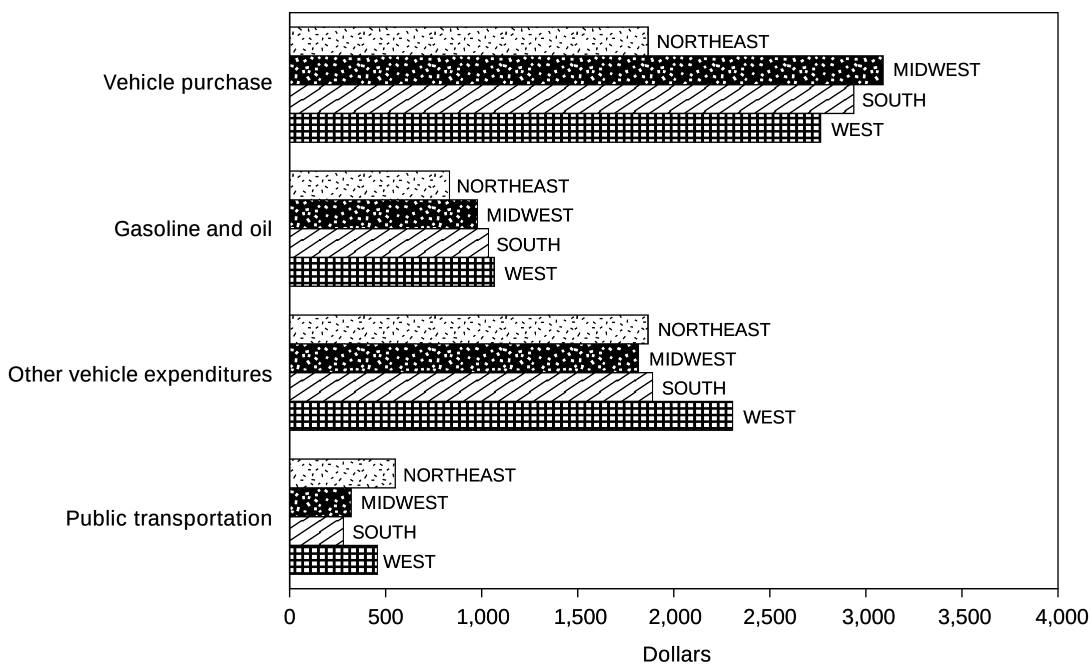
Vehicle Operating Costs

Vehicle operating costs vary per mile of travel and the price of fuel. Since the early 1980s, the price of unleaded regular fuel has declined substantially, both in current and constant dollars. Fuel efficiency improvements also have an impact on vehicle operating costs by reducing fuel costs per mile of travel. Of course, fuel costs vary by region.

Generally, the more miles a vehicle travels in a year, the more the cost per mile decreases. It is estimated that the annual cost of operating a vehicle in 1995 ranged from 50.6 cents per mile, if 10,000 miles were traveled, to 37.0 cents, if 20,000 miles were traveled.[2]

[2] Based on American Automobile Association data.

Figure 2-5: Average Consumer Unit Transportation Expenditures by Region, 1994



SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, "Consumer Expenditure Survey," 1994.

1994 or about 7 percent of total transportation expenditures. This figure does not include other costs of travel away from home, such as lodging and food. Also, it is important to remember that these expenditures are averages for all households and that only a few households incur these out-of town travel expenses in any given year.

Foreign visitors also expend substantial funds in the United States, a large part of which is for transportation. Foreign visitors arriving by air in the United States spent, on average per person, $3,222 in 1994: $1,654 was spent on international air travel and $1,568 on all expenses incurred in the United States. About $200 per

TABLE 2-8: HOUSEHOLD TRANSPORTATION EXPENDITURES IN URBAN AND RURAL AREAS, 1994

Expenditure category	Urban	Rural	Urban (percent)	Rural (percent)	Rural/Urban (ratio)
All expenditures	$32,247	$28,724	100.0%	100.0%	0.89
All transportation expenditures	5,919	6,807	18.4	23.7	1.15
Vehicle purchases	2,581	3,601	8.0	12.5	1.40
Gas and oil	946	1,232	2.9	4.3	1.30
Other vehicle expenditures	1,982	1,771	6.2	6.2	0.89
Purchased transportation services	410	202	1.3	0.7	0.49

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, "Consumer Expenditure Survey," 1994.

TABLE 2-9: COMPARISON OF HOUSEHOLD TRANSPORTATION SPENDING BY RACE, 1994

	White and other	Black	White and other (share in percent)	Black (share in percent)	Black/white (ratio)
All expenditures	$32,935	$22,418	100.0%	100.0%	0.68
All transportation expenditures	6,268	4,271	19.0	19.0	0.68
Vehicle purchases	2,814	2,014	8.5	9.0	0.72
Gas and oil	1,020	713	3.1	3.2	0.70
Other vehicle expenditures	2,037	1,283	6.2	5.7	0.63
Purchased transportation services	396	261	1.2	1.2	0.66

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, "Consumer Expenditure Survey," 1994.

traveler was spent on transportation within the United States, including car rentals, air, bus and rail fares, taxis, and mass transit. In 1994, foreign visitors arriving by air accounted for almost $4 billion of the revenues of U.S. transportation firms. (USDOC USTTA 1995) Expenditures of visitors who arrived by land and sea are not included in these totals. The use of transportation modes by foreign visitors who arrive by air is shown in figure 2-6.

Transportation Expenditures and Revenues: The Public Sector

Federal, state, and local governments are important providers and purchasers of transportation infrastructure, equipment, and services. Governments finance these activities through general tax revenues, special user taxes, and user fees. State and local governments also rely on grants from the federal government. This section describes trends in government expenditures and revenues.

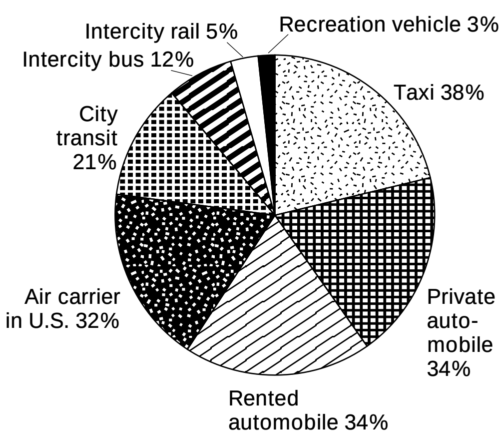
TABLE 2-10: OUT-OF-TOWN HOUSEHOLD EXPENDITURES, 1994

Expenditure category	Average expenditure	As a portion of all household purchases in category
Gasoline	$86.21	Roughly 10%
Motor oil	0.87	Roughly 8%
Auto rental	24.44	Roughly 4 times local auto rental
Truck rental	4.32	Roughly 3 times local truck rental
Aircraft rental	1.01	
Parking	3.10	Roughly 14% of nonresidential parking
Tolls	4.63	Roughly the same amount as local tolls
Airline fares	249.48	
Intercity bus fares	11.34	
Public transit	10.35	Roughly 18%
Taxi fares	6.08	Roughly 45%
Intercity train fares	16.24	
Ship fares	31.13	Mostly cruise ships
Total	$449.20	

NOTE: Reimbursed travel is not included.

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, "Consumer Expenditure Survey," 1994.

FIGURE 2-6: USE OF TRANSPORT MODES BY FOREIGN VISITORS TO THE UNITED STATES, 1994



NOTE: Multiple responses are included. Respondents limited to those departing by air.

SOURCE: U.S. Department of Commerce, U.S. Travel and Tourism Administration, "In-Flight Survey of International Air Travelers," 1995.

► Government Expenditures

Federal, state, and local governments spent $113.3 billion on transportation in fiscal year 1992, or 4.6 percent of total government expenditures (see table 2-11). Transportation expenditures by all levels of government increased by 31 percent in real terms between 1982 and 1992. The federal government spent $34.8 billion, transferring $21.4 billion or just over 60 percent to state and local governments. In addition to the $21.4 billion in federal grants, state and local governments spent $78.5 billion of their own funds on transportation. It is important to note that federal and state and local government transportation expenditures shown in table 2-11 do not correspond to transportation-related government purchases reflected in table 2-1. There are two main reasons. First, government transportation expenditures shown in table 2-11 include subsidies paid to operators of private systems. These subsidies are not counted as transportation-related govern-

TABLE 2-11: GOVERNMENT TRANSPORTATION EXPENDITURES
(MILLIONS OF DOLLARS)

	Current dollars		Change (percent)	Constant 1982 dollars		Change (percent)
	1982	1992		1982	1992	
Federal: excluding grants to state and local government	$9,786	$13,388	36.8%	$9,786	$9,693	–1.0%
Federal grants to state and local government	13,844	21,365	54.3	13,844	15,469	11.7
State and local spending excluding federal grants	36,766	78,544	113.6	36,766	53,744	46.2
Total government expenditures	$60,396	$113,297	87.6	$60,396	$78,906	30.7

NOTE: Different deflators for different levels of government are used: 1982 = 100; all government, 1992 = 142.5; state and local government, 1992 = 146.1; federal government, 1992 = 138.1. As a result, totals in tables 2-11, 2-12, and 2-13 will not agree.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, *Federal, State and Local Transportation Financial Statistics—Fiscal Years 1982–1992*, DOT-VNTSC-BTS-95-2 (Washington, DC: 1995), table 3, p. 17.

ment purchases in GDP calculations. Second, and to a lesser extent, GDP calculations for highway expenditures by state and local government are derived from the *Census of Governments* and the *Annual Survey of State and Local Government Finances*, which are both publications of the Bureau of the Census. The highway expenditures reported by the Bureau of the Census are generally slightly lower than those reported in table 2-11, which provide a more complete accounting of highway-related expenditures. For example, the data include highway law enforcement and highway safety costs as well as interest on debt and debt retirement. These costs are not included in the *Census of Government's* highway expenditures but are included under Civilian Safety and Interest Paid categories.

In relative terms, the federal role in financing transportation diminished in recent years, but in absolute terms, the federal transportation budget increased (see box 2-2). Although federal spending, including grants to state and local governments increased by 6.5 percent (in constant dollars) between 1982 and 1992, spending by state and local governments, excluding federal grants, increased by 46 percent. As a result, the federal portion of government transportation spending declined from 39 percent in 1982 to 32 percent in 1992. (USDOT BTS 1995a)

Transportation is a more important part of state and local government budgets than of the budget of the federal government. In 1992, before intergovernmental transfers, transportation was 2.3 percent of total federal government expenditures, but 8.1 percent of state and local spending. (USDOT BTS 1995a, 12, 17)

Most government transportation funds were spent on highways (59.5 percent) in 1992, approximately the same proportion spent in 1982 (see table 2-12). A large proportion of the rest goes to transit, air transportation, and water transportation. Very small shares go to rail and pipelines. Starting from a small base, spending on pipelines grew the most, 167 percent from 1982 to 1992 in real terms. Spending on air transportation also increased substantially over this period. Spending on transit and highways also grew, but less rapidly, while spending on rail and water transportation decreased.

As shown in table 2-13, state and local governments spend proportionately more of their money on highways and transit than the federal government. By contrast, the federal government spends proportionately more on air and water transportation.

Table 2-13 also shows how government spending priorities shifted within transportation between 1982 and 1992. The proportion of

Box 2-2: U.S. Department of Transportation 1994 Budget

The U.S. Department of Transportation (DOT) outlays increased by 13 percent in real terms between 1984 and 1994, to a total of $34.8 billion in current dollars. The Federal Highway Administration accounts for the largest share of DOT outlays, spending 55 percent of the budget in 1994 compared with 48 percent in 1984. The other large administrations are the Federal Aviation Administration (FAA), which received 25 percent of outlays, and the Federal Transit Administration (FTA), at 11 percent. FAA outlays increased by 67 percent, and U.S. Coast Guard outlays increased by 23 percent in real terms between 1984 and 1994. The outlays of FTA, the Maritime Administration, and the National Highway Traffic Safety Administration, however, decreased in real terms over this period. Federal Railroad Administration outlays fell the most—76 percent in real terms between 1984 and 1994 (see table).

SOURCE: Volpe National Transportation Systems Center data.

Department of Transportation Outlays, 1984 and 1994
(in millions of constant 1987 dollars)

Modal Administration	1984	1984 (percent)	1994	1994 (percent)	Percentage change
Federal Highway Administration	$11,255	47.7%	$14,712	55.2%	30.7%
Federal Aviation Administration	4,067	17.2	6,783	25.4	66.8
Federal Transit Administration	4,024	17.0	2,926	11.0	–27.3
Federal Railroad Administration	2,665	11.3	643	2.4	–75.9
U.S. Coast Guard	749	3.2	920	3.5	22.8
Maritime Administration	540	2.3	393	1.5	–27.2
National Highway Traffic Safety Administration	211	0.9	201	0.8	–4.7
All other DOT organizations	109	0.5	81	0.3	–25.7
Total	$23,620	100.0%	$26,659	100.0%	12.9%

SOURCES: 1984—U.S. Department of Transportation, Office of Economics, Assistant Secretary for Policy and International Affairs, *Federal Transportation Financial Statistics* (Washington, DC: various years). 1994—U.S. Department of Transportation, Bureau of Transportation Statistics, *Federal Transportation Financial Statistics*, prepared by Volpe National Transportation Systems Center (Washington, DC: in press).

federal funds spent on transit, rail, and water transportation decreased while air transportation's proportion of federal funding increased over this period. Highway spending increased slightly.

State and local government spending priorities changed less and in a different way. Most notably state and local governments spent a slightly smaller proportion of funds on highways in 1992 than in 1982 and a slightly greater proportion on transit.

► Government Revenues

Revenues collected by government for transportation purposes fall into three categories:

- general tax receipts including income, property, and sales taxes;
- special user taxes, such as the airport tax and gas tax, placed in trust funds separate from general tax receipts; and
- user fees, such as road and bridge tolls.

Table 2-12: Transportation Expenditures by All Levels of Government, 1982 and 1992 (millions of constant 1982 dollars)

Mode	1982		1992		Change (percent)
Highway	$35,731	59.2%	$47,310	59.5%	32.4%
Transit	11,401	18.9	15,684	19.7	37.6
Air	6,043	10.0	11,055	13.9	82.9
Water	4,412	7.3	3,967	5.0	–10.1
Rail	2,250	3.7	635	0.8	–71.8
Parking	395	0.7	630	0.8	59.5
Unallocated	155	0.3	203	0.3	31.0
Pipeline	9	0.01	24	0.03	166.7
Total	$60,396	100.0%	$79,508	100.0%	31.6%

NOTE: Different deflators for different levels of government are used: 1982 = 100; all government, 1992 = 142.5; state and local government, 1992 = 146.1; federal government, 1992 = 138.1. As a result, totals in tables 2-11, 2-12, and 2-13 will not agree.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, *Federal, State and Local Financial Statistics—Fiscal Years 1982–1992*, DOT-VNTSC-BTS-94-2 (Washington, DC: 1995).

Transportation-generated revenues totaled $80.2 billion in 1992 (in current dollars), a 55 percent increase in real terms since 1982. Revenues grew more rapidly than expenditures; hence, coverage (the proportion of expenditures covered by user taxes and fees) grew from 60 percent in 1982 to 71 percent in 1992. (USDOT BTS 1995a, 17)

State governments collected the largest amount of revenue—48 percent of the total in 1992. The federal government collected about 33 percent and local governments, almost 19 percent. The proportion of transportation-related revenues collected by the federal government increased from about 28 percent in 1982. This is due, in part, to high federal revenue growth rates over this period. Both state and local revenues grew as well, but their proportion of total revenue decreased. (USDOT BTS 1995a, 17)

Several taxes and user fees collected by the federal government are placed in trust funds dedicated to a specific mode. There are four federal transportation-related trust funds: the Highway Trust Fund, the Airport and Airway Trust Fund, the Inland Waterway Trust Fund, and the Harbor Maintenance Trust Fund. Revenue is also generated by the Panama Canal, the Pipeline Safety Fund, the Oil Spill Liability Trust Fund, and the Emergency Preparedness Fund. The two main federal transportation trust funds are the Highway Trust Fund—which has a highway account and, since 1983, a transit account—and the Airport and Airway Trust Fund.

Table 2-13: Transportation Expenditures by Level of Government Before Transfers (millions of constant 1982 dollars)

Mode	1982		1992	
Federal				
Highway	$10,740	45.5%	$12,144	48.3%
Air	3,564	15.1	6,743	26.8
Transit	3,954	16.7	2,661	10.6
Water	2,991	12.7	2,745	10.9
Rail	2,225	9.4	652	2.6
Pipeline	2	0.01	9	0.04
Unallocated	155	0.7	209	0.8
Total	$23,630	100.0%	$25,162	100.0%
State and local				
Highway	$24,991	68.0%	$34,654	64.5%
Air	2,479	6.7	4,407	8.2
Transit	7,447	20.3	12,778	23.8
Water	1,422	3.9	1,273	2.4
Rail	25	0.07	3	0.01
Parking	395	1.1	615	1.14
Pipeline	7	0.02	13	0.02
Total	$36,766	100.0%	$53,744	100.0%

NOTE: Different deflators for different levels of government are used: 1982 = 100; all government, 1992 = 142.5; state and local government, 1992 = 146.1; federal government, 1992 = 138.1. As a result, totals in tables 2-11, 2-12, and 2-13 will not agree.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, *Federal, State and Local Financial Statistics—Fiscal Years 1982–1992*, DOT-VNTSC-BTS-95-2 (Washington, DC: 1995).

The total collections from all these revenue-generating mechanisms rose from $10.0 billion in 1982 to $18.7 billion in 1992 (in 1982 dollars). In 1992, the bulk of federal transportation revenues (71.3 percent) came from the federal Highway Trust Fund, which is generated mostly by a tax on highway vehicle fuels (see table 2-14) but also includes taxes on tires and truck, bus, and trailer sales. Highway trust revenue increased by 70 percent in real terms since 1982. The Airport and Airway Trust Fund and federal water receipts both increased more rapidly. The pipeline safety fund, instituted in 1987, now represents 0.05 percent, or $10 million of federal revenue (in 1982 dollars).

Federal Trust Fund Revenue and Balances

From the standpoint of changes in federal receipts, particularly the large federal trust funds, the period from 1982 to 1992 does not provide a very accurate picture because of a large dip in revenues in the early 1980s. Thus, a longer view of trust fund revenue balances is necessary. From 1977 to 1994, the tax revenue collected for the Highway Trust Fund and the Airport and Airway Trust Fund increased from $14.1 billion to $16.9 billion (in constant 1987 dollars), a 20 percent increase. Revenue fell sharply in the early 1980s to a low of $7.8 billion in 1981, but recovered by 1984. The trust fund dedicated to aviation increased the most in absolute terms over this period, almost doubling from $2.1 billion in 1977 to $4 billion in 1994, in constant 1987 dollars. The transit account of the Highway Trust Fund, started in 1983, collected $1.6 billion in 1994. The largest trust fund in terms of revenue, the highway account of the Highway Trust Fund, however, declined slightly from $11.9 to $11.3 billion in constant 1987 dollars. In current dollars, trust fund revenues increased from $7.9 billion in 1977 to $21.9 billion in 1994 (see figures 2-7 and 2-8).

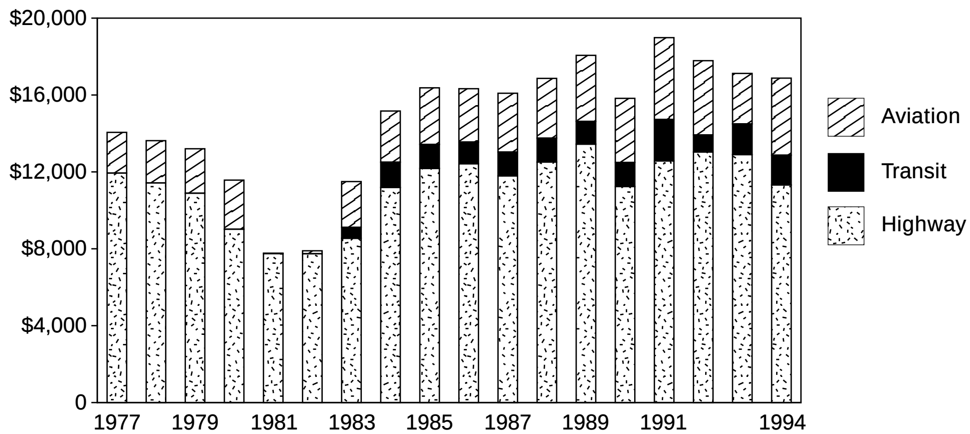
The trust fund balances—the unspent money in these accounts at the end of the year—declined in the late 1970s, grew substantially from the mid-1980s to the early 1990s, but have since declined to approximately the same level (in real terms) in 1994 as in 1977. In constant 1987 dollars, from 1977 to 1994 the total cash balance in the Highway Trust Fund and the Airport and Airway Trust Fund declined by 5 percent from $24.6 billion in 1977 to $23.4 billion in 1994. The balances in the various funds fluctuated in different ways. The balance in the Airport and Airway Trust Funds grew by 65 percent from $5.8 billion in 1977 to $9.6 billion in 1994 (in constant 1987 dollars). By contrast, the balance in the highway account of the Highway Trust

TABLE 2-14: FEDERAL REVENUE
(IN MILLIONS OF CONSTANT 1982 DOLLARS)

Mode	1982		1992		Percentage Change
Federal Highway Trust Fund, Highway Account	$7,822	78.2%	$11,999	64.3%	53.4%
Federal Highway Trust Fund, Transit Account	n/a	n/a	$ 1,315	7.0%	n/a
Federal Airport and Airway Trust Fund	$1,711	17.1%	$ 4,285	22.9%	150%
Total federal water receipts	$474	4.7%	$ 1,067	5.7%	125%
Pipeline Safety Fund	n/a	n/a	$ 10	0.05%	n/a
Total	$10,008	100.0%	$18,676	100.0%	86.6%

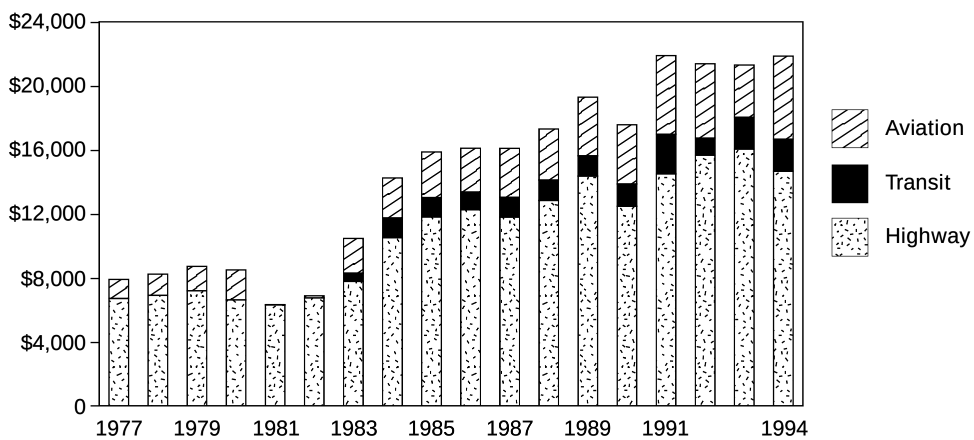
SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, *Federal, State and Local Financial Statistics—Fiscal Years 1982–1992*, DOT-VNTSC-BTS-95-2 (Washington, DC: 1995).

FIGURE 2-7: **TRANSPORTATION TRUST FUND REVENUES, 1977–94**
(MILLIONS OF CONSTANT 1987 DOLLARS)



SOURCE: Based on data from the Volpe National Transportation Systems Center.

FIGURE 2-8: **TRANSPORTATION TRUST FUND REVENUES, 1977–94**
(MILLIONS OF CURRENT DOLLARS)



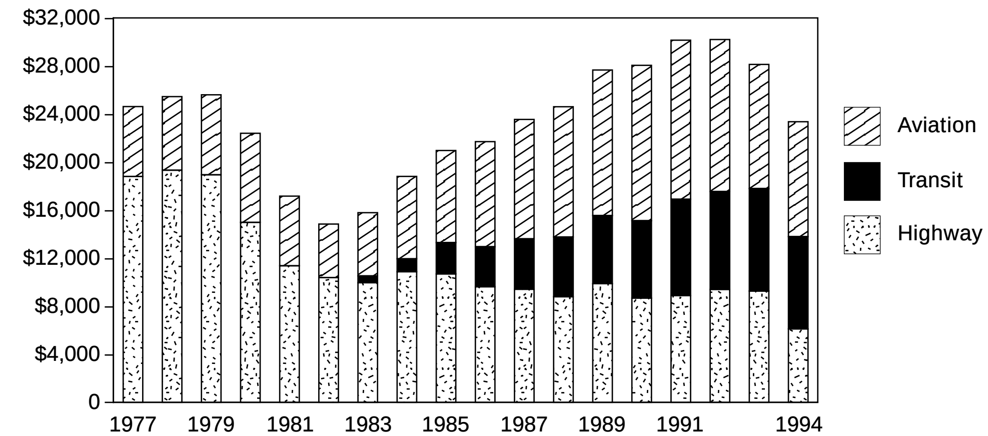
SOURCE: Based on data from the Volpe National Transportation Systems Center.

Fund declined by 68 percent from $18.9 billion to $6.1 billion over this period. The transit account balance stood at $7.7 billion in 1994 (in 1987 dollars) (see figure 2-9). In current dollars the total balance in the two trust funds rose from $13.4 billion in 1977 to $30.4 billion in 1994 (see figure 2-10).

Employment

Transportation employment can be analyzed from either an industry or occupation perspective. For example, transportation occupations include vehicle operators in any industry. From an industry perspective, vehicle operators are

FIGURE 2-9: TRANSPORTATION TRUST FUNDS—END OF YEAR CASH BALANCES, 1977–94
(MILLIONS OF CONSTANT 1987 DOLLARS)

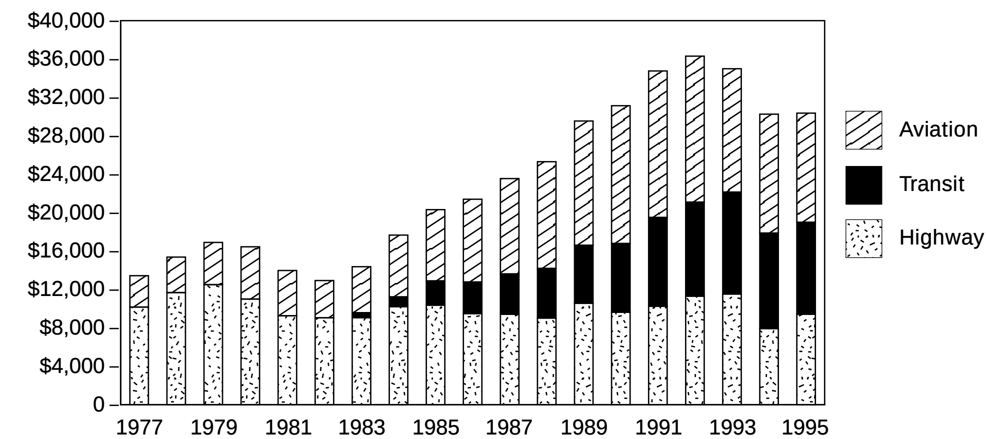


SOURCE: Based on data from the Volpe National Transportation Systems Center.

classified under the industry in which they work. Similarly, an accountant in a trucking firm is an accountant by occupation but is a transportation employee from an industrial viewpoint. Few statistical sources provide data that permit detailed delineation of transportation employment within nontransportation establishments. (USDOT FHWA 1995)

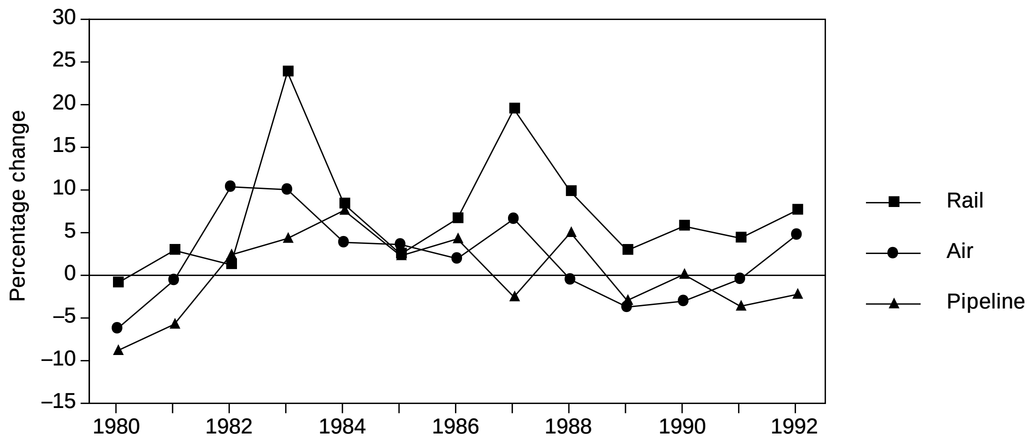
In 1993, more than 3.2 million people were employed in for-hire transportation industries, an increase of 4.4 percent from 1992. The figure of 3.2 million people excludes 2 million employees

FIGURE 2-10: TRANSPORTATION TRUST FUNDS—END OF YEAR CASH BALANCES, 1977–95
(MILLIONS OF CURRENT DOLLARS)



SOURCE: Based on data from the Volpe National Transportation Systems Center.

FIGURE 2-11: **ANNUAL GROWTH OF TRANSPORTATION PRODUCTIVITY, 1980–92**



SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, *Productivity Measures for Selected Industries and Government Services* (Washington, DC: In press).

of 200,000 retail establishments, such as car dealerships and gas stations, and 900,000 people employed by 175,000 service businesses, such as car washes, body shops, and repair facilities. Also excluded are all government and manufacturing employees with transportation jobs. (USDOC Bureau of the Census 1993) The *National Transportation Statistics 1996* report provides detailed information on transportation employment for 1994 and earlier. According to the report, when all related activities are included, more than 9 million people were employed in transportation activities in 1994. (USDOT BTS 1995b)

Establishments with one to four employees constitute 55 percent of total transportation businesses. Conversely, 21 percent of total transport employees work in establishments with more than 1,000 workers. These large businesses constitute less than one-tenth of 1 percent of establishments.

Establishment size varies by mode as well. The airline industry, for example, consists of a few large establishments with more than 1,000 employees. These few large businesses account for half of all airline employees.

▶ Costs and Productivity Trends

Table 2-15 shows growth in labor costs in the transportation industry relative to all workers and to similar labor groups such as communications and utilities workers. Transportation labor costs have risen less than for these groups.

Transportation Statistics Annual Report 1995 extensively discussed productivity patterns in the transportation sector. Figure 2-11 presents the most current productivity data.

TABLE 2-15: **EMPLOYMENT COST INDEX**

Worker category	Index (June 1993)
All civilian workers	118.3
Private industry	118.0
All services	117.3
Transportation	114.1
Communications	117.5
Utilities	119.4

NOTE: June 1989 = 100.

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, *Monthly Labor Review,* September 1994, table 21.

The airline industry is using fewer employees to provide service to a growing number of passengers. The striking increase in productivity arises, in part, from larger and faster aircraft, the computerization of passenger reservations, the hub and spoke flight network, and changes in flight personnel requirements. Various new management techniques adopted by airlines after deregulation may also have increased productivity. Over the same period, operating revenues per employee significantly increased.

Expenditures and Revenues of the Trucking and Railroad Industries

This section discusses the financial performance of for-hire transportation service providers and presents revenue and expenditure trends for the trucking and railroad industries. (See appendix A for an indepth review of the U.S. commercial aviation industry.)

▶ Trucking Industry

As noted earlier, no single source provides comprehensive economic and financial data for all transportation service providers. However, there are specialized data sources that provide information on specific industries. A major source of disaggregated data on trucking operating revenues and expenditures is the Annual Survey of Motor Freight Transportation and Public Warehousing, also known as the Warehousing and Trucking Survey (WATS). Since 1988, the Bureau of the Census has compiled WATS data. Although this survey is one of the more comprehensive data sources for the trucking industry, it has several limitations. First, the survey covers only for-hire trucking firms. Activities of private trucking auxiliaries of nontransportation establishments, or shipper-owned trucking operations, are estimated to be at about the same level as for-hire trucking. (As noted earlier, the Transportation Satellite Account will more accurately reflect the transportation activities of nontransportation establishments.) Second, only revenues and expenditures of for-hire establishments with payrolls are provided. This excludes the thousands of truck owners-operators, sole proprietorships, and partnerships that technically have no employees, but account for a substantial proportion of industry activity (about 50 percent). Currently, BTS and the Bureau of Economic Analysis are investigating alternative methods to address these limitations.

The trucking industry cost structure is a combination of relatively high variable expenses and low fixed costs. Public investment in the extensive U.S. highways system is a major factor that contributes to the industry's low fixed costs. Other factors are fixed depreciation and interest expenses and low management overhead. A high proportion of trucking industry expenditures is related to variable operating expenses—wages and benefits, fuel, and maintenance and repairs. Purchased transportation is another high-cost item for the industry.

Table 2-16 shows detailed expenses of the trucking industry between 1988 and 1993. Both labor and fuel costs have increased their shares of total expenditures. Wages and benefits accounted for 41.2 percent of total expenditures in 1993, a slight increase from 39.5 percent in 1988 (see figure 2-12). Over the same period, trucking industry spending on purchased fuel increased by 60 percent, from $6.7 billion to $10.8 billion, and fuel costs as a proportion of total costs rose from 6.6 percent to 8.4 percent.

Although spending on purchased transportation also increased (by 17 percent), its share of total costs declined from 20.2 percent in 1988 to 18.7 percent in 1993. This decline suggests

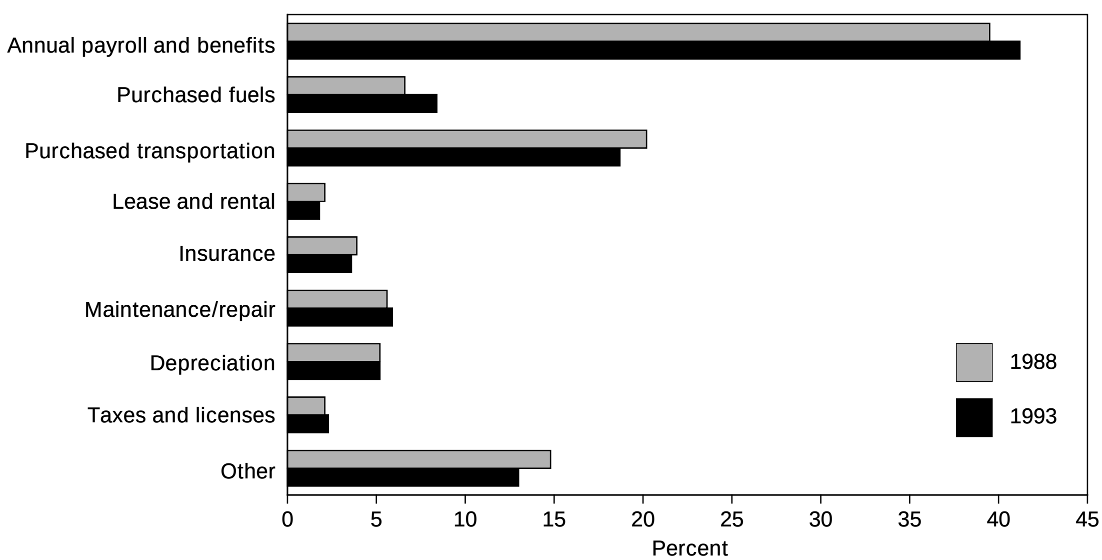
Table 2-16: Expenditures of For-Hire Trucking and Public Warehousing, 1988–93 (millions of current dollars)

Cost items/year	1988	1989	1990	1991	1992	1993	Percentage change 1988–93
Annual payroll/benefits	$40,097	$43,598	$46,257	$47,303	$49,876	$52,747	32%
Purchased fuels[a]	6,739	7,753	9,011	9,080	10,078	10,754	60
Purchased transportation	20,446	19,896	20,505	20,191	22,187	23,880	17
Lease and rental[b]	2,098	2,102	2,238	2,231	2,246	2,264	8
Insurance	3,914	3,996	4,040	4,141	4,283	4,547	16
Maintenance of vehicles	5,669	6,055	6,358	6,357	7,091	7,586	34
Depreciation	5,289	5,622	5,829	5,856	6,199	6,594	25
Taxes and licenses	2,178	2,347	2,416	2,534	2,865	2,988	37
Other	15,011	15,093	15,951	15,044	16,068	16,586	10
Total	$101,441	$106,462	$112,605	$112,737	$120,890	$127,946	26%

[a] Includes vehicle fuels and heating fuels for buildings.
[b] Nonvehicular leases and rentals.

SOURCE: U.S. Department of Commerce, Bureau of the Census, *Motor Freight Transportation and Warehousing Survey: 1993* (Washington, DC: 1995).

Figure 2-12: For-Hire Trucking Industry Operating Expenditures by Cost Items, 1988 and 1993



SOURCE: U.S. Department of Commerce, Bureau of the Census, Economics and Statistics Administration, *Motor Freight Transportation and Warehousing Survey: 1993* (Washington, DC: 1995).

that businesses that once depended on outsourced trucking services shifted to private inhouse sources.

Purchased transportation by trucking establishments is normally categorized into three groups: vehicle leasing without drivers; vehicle leasing with drivers; and directly purchased transportation from air, rail, water, or other motor carriers (see table 2-17). Of these categories, leasing without drivers grew the most rapidly, increasing more than 41 percent from 1988 to 1993, compared with an overall increase of 17 percent for purchased transportation. The category of vehicle leasing with drivers provides an insight into the scale of owner-operator (nonpayroll) activities. This category accounted for almost 67 percent ($16 billion) of purchased transportation by truckers in 1993. Data on the third category—directly purchased transport—suggests an increasing level of intermodal activity in the trucking industry. Although this category remains below $3.5 billion per year in expenditures, it grew 34 percent between 1988 and 1993. Almost 85 percent of purchased transportation from other transport modes is bought by general carriers (carriers not classified as specialized to transport goods such as household items, farm and forest products, electronics, and hazardous and toxic materials). Unfortunately, data are not provided for rail, water, or other motor carrier transport.

► Railroad Industry

The railroad industry plays a vital role in the U.S. economy. Although railroads' relative position in the national transportation system declined from 1929 to 1970, its share of intercity (nonlocal) ton-miles remained fairly constant since the 1970s. In addition to moving bulk commodities, railroads move time-sensitive freight, such as motor vehicles and parts, mail, and international containers. Since partial economic deregulation in 1980, the railroads have increased their investment in plant and equipment and improved their service, while competition has led to decreased rates for shippers.

Most railroads in the United States are privately owned carriers; Amtrak is an exception, as are some small railroads owned by states and municipalities. The 12 major railroads, categorized as Class I, handle over 90 percent of total rail freight ton-miles, and account for over 90 percent of freight revenues.

Table 2-18 shows railroad industry expenditures in a form comparable to that of the WATS data on the trucking industry. In 1993, total expenditures of Class I railroads were $26.3 billion. This was only slightly larger than the purchased transportation segment of trucking. Unfortunately, railroad data do not identify purchased transportation as a separate expenditure category.

TABLE 2-17: EXPENDITURES FOR PURCHASED TRANSPORTATION BY TRUCKING COMPANIES, 1988–93
(MILLIONS OF CURRENT DOLLARS)

Type of company	1988	1989	1990	1991	1992	1993	Percentage change 1988–93
Vehicle leased with drivers	$14,734	$13,893	$14,016	$13,623	$14,675	$15,995	9%
Vehicle leased without drivers	3,159	3,459	3,742	3,907	4,289	4,469	41
Air, rail, water, and other motor carriers	2,553	2,544	2,747	2,661	3,223	3,416	34
All purchased transportation	$20,446	$19,896	$20,505	$20,191	$22,187	$23,880	17%

SOURCE: U.S. Department of Commerce, Bureau of the Census, *Motor Freight Transportation and Warehousing Survey: 1993* (Washington, DC: 1995).

TABLE 2-18: EXPENDITURES FOR THE CLASS I RAILROAD INDUSTRY, 1988–93 (MILLIONS OF CURRENT DOLLARS)

Cost items	1988	1989	1990	1991	1992	1993	Percentage change 1988–93
Annual payroll and benefits	$11,541	$11,814	$11,316	$10,806	$10,726	$10,642	–7.8%
Purchased fuels	1,564	1,796	2,170	1,968	1,913	1,962	25.4
Lease of equipment and rental	2,518	2,512	2,538	2,749	2,786	2,945	17.0
Insurance	1,256	1,403	1,246	1,734	1,195	1,248	–0.6
Depreciation	2,208	2,225	2,295	2,506	2,320	2,386	8.1
Taxes and licenses	1,048	981	1,162	1,173	1,124	1,339	27.8
Other	5,818	5,331	4,993	8,229	6,330	5,785	–0.6
Total	$25,953	$26,062	$25,720	$29,165	$26,394	$26,307	1.4%

SOURCE: American Association of Railroads, *AAR Factbook* (Washington, DC: 1994).

Between 1988 and 1993, railroad labor costs declined by 7.8 percent from $11.5 billion to $10.6 billion. Despite this decline, labor costs continue to be the main expenditure item for the railroad industry. Labor accounted for 40.5 percent of total expenditures in 1993, down from 44.5 percent in 1988 (see figure 2-13). During this same period, railroad expenditures on purchased fuel rose by 25 percent from $1.6 billion to about $2.0 billion. Not surprising, fuel cost as a proportion of total costs increased from 6.0 percent to 7.5 percent. As discussed in chapter 4, the energy efficiency of railroad freight operations improved significantly. Improvements in load factors accounted for 75 percent of the overall reduction in rail freight energy use.

Operating Performance and Revenues

Recent trends in revenues and expenditures suggest that the industry's operating performance improved substantially between 1984 and 1993. The railroad industry's operating ratio (expenditures over revenues) declined from 87.6 percent in 1984 to 85.1 percent in 1993. Since 1984, net railway operating revenue increased by 18 percent, from $3.6 billion in 1984 to $4.3 billion in 1993 (see figure 2-14). The net loss of $216 million experienced in 1991 was due to two factors: a steep rise in general and administrative expenses and a moderate increase in several costs, including maintenance, rights-of-way, structures, and equipment. Equipment is a major expenditure for the railroad industry. Despite the weak financial performance in 1991, the railroad industry appears to be recovering.

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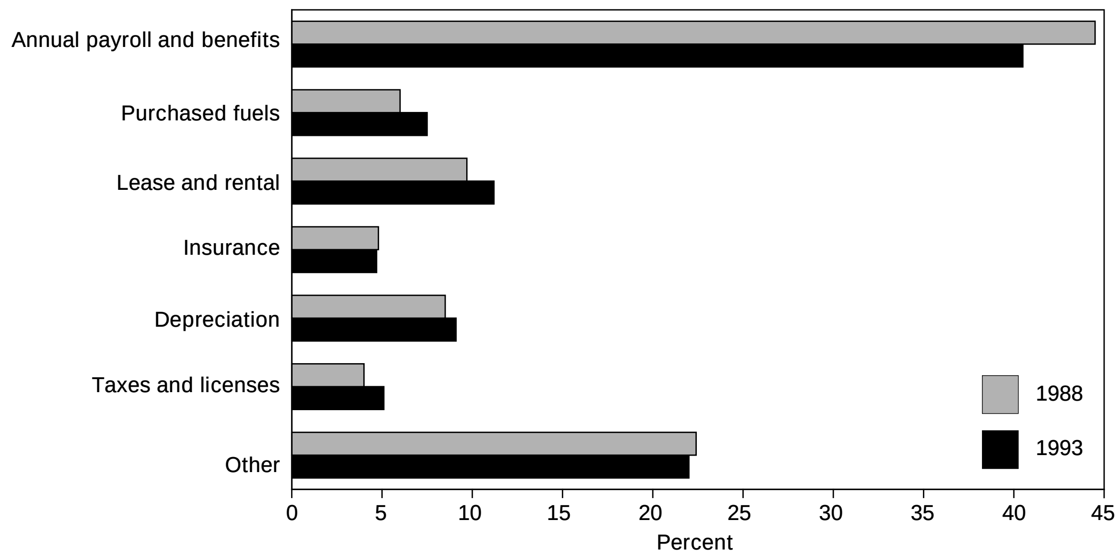
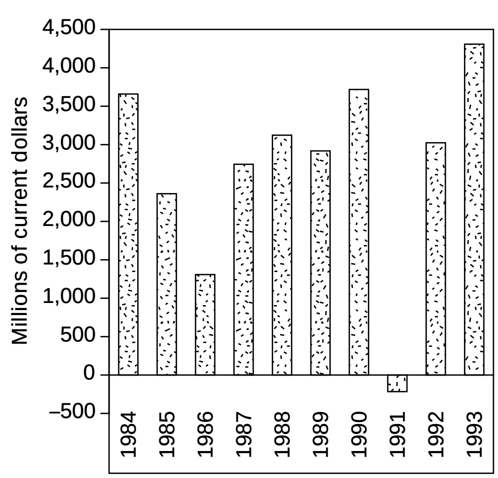
FIGURE 2-13: CLASS I RAILROAD INDUSTRY
TOTAL EXPENDITURES BY COST ITEMS, 1988 AND 1993



SOURCE: American Association of Railroads, Economics, Policy and Statistics Department, *Railroad Facts* (Washington, DC: September 1995).

FIGURE 2-14: CLASS I RAILROADS
NET OPERATING REVENUE, 1984–93



SOURCE: American Association of Railroads, Economics, Policy and Statistics Department, *Railroad Facts* (Washington, DC: September 1995).

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CHAPTER THREE

TRANSPORTATION AND SAFETY

TRANSPORTATION-RELATED INJURIES AND DEATHS ARE A MAJOR PUBLIC HEALTH PROBLEM IN THE UNITED STATES. OVER THE PAST DECADE, TRANSPORTATION CRASHES HAVE BEEN RESPONSIBLE FOR APPROXIMATELY HALF OF ALL ACCIDENTAL DEATHS IN THIS COUNTRY (SEE TABLE 3-1). HIGHWAY VEHICLE CRASHES ARE THE LEADING CAUSE OF DEATH OF AMERICANS BETWEEN THE AGES OF 15 AND 24, and accounted for 93 percent of all transportation-related deaths in 1994. They are also responsible for as many pre-retirement years of life lost as cancer and heart disease, about 1.2 million years annually (see figure 3-1). This reflects the relative youth of crash victims. Nonfatal injuries from highway crashes are a major problem as well. These injuries are the second largest category of both hospitalized and nonhospitalized injuries.

Inadequate data and inconsistent measures of accident risk across modes complicate efforts to formulate strategies to reduce transportation risks.

Despite the progress made in the past two decades in transportation safety, millions of people are still injured and tens of thousands of people are killed in transportation crashes each year. Thus, much work remains to be done to develop a better understanding of the causes of crashes and to prevent them. In particular, we need to better understand the human factors that cause or facilitate crashes. Examples include operator impairment because of substance abuse, medical conditions, or human fatigue, and the operator's interaction with new technologies used both inside and outside the vehicle. Understanding the role of human

TABLE 3-1: ACCIDENTAL DEATHS, 1981–94

Year	All causes	Transportation related	Transportation related (percent)
1981	100,704	51,335	51.0%
1985	93,457	46,400	49.6
1990	91,983	47,269	51.4
1994	92,200P	43,322	47.0

NOTE: Deaths reported in the "All causes" column generally occurred within one year of an accident or crash; deaths reported in the "transportation related" column generally occurred within 30 days of an accident or crash. Hence, the percentage column may understate the proportion of transportation-related deaths.

KEY: P = preliminary.

SOURCES: All causes—National Safety Council, *Accident Facts,* 1995 Ed. (Itasca, IL: 1995). Transportation related—various sources, as compiled and cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 1996* (Washington, DC: November 1995).

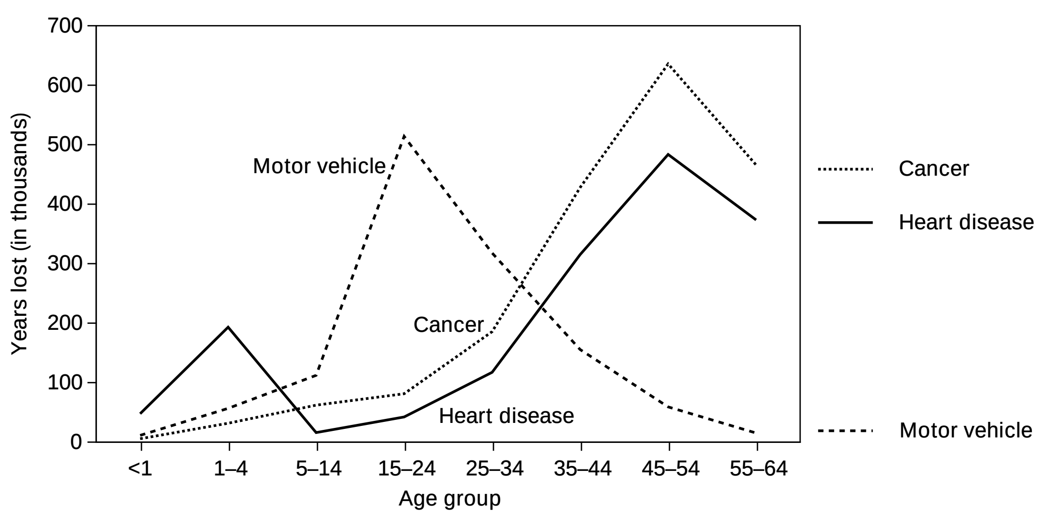
factors is one of the most pressing tasks facing the transportation safety community today.

This chapter summarizes recent transportation safety trends, including the number and nature of transportation accidents, injuries, and fatalities. It also examines human factors affecting accidents and addresses two areas of particular concern, commuter airline safety and accidents at highway-rail crossings. The chapter also discusses technological concepts now under development that have the potential to improve transportation safety. Finally, data needs in transportation safety research are examined.

Trends in Transportation Safety

There are many ways to analyze accident, injury, fatality, and cost trend data. One often used approach is to examine annual totals. Annual totals, however, do not take into account the evolving nature of the transportation system and, in particular, changes in *exposure to risk.* Therefore, to increase the comparability and usefulness of accident statistics over time and across modes, measures that account for variations in risk exposure must be used.

FIGURE 3-1: PRE-RETIREMENT YEARS OF LIFE LOST BY AGE, 1992



SOURCE: Calculated based on a method and data in U.S. Department of Health and Human Services, *Health, United States, 1994,* DHHS Pub. No. (PHS) 95-1232 (Hyattsville, MD: 1995).

Risk exposure means that the more an individual uses the transportation system, the more that person is at risk of involvement in a transportation-related crash. Risk exposure can be expressed in many ways, and the "best" measure may vary according to the mode under examination and the kind of analysis performed.

Indeed, as our transportation system grows, more people will be exposed to risk, and more accidents can be expected to occur, barring changes in behavior or advances in safety technology. Therefore, it is instructive to examine the number of crashes in a way that acknowledges changes in risk exposure. Accident rates are a measure of incidents per unit of risk exposure, and can take several forms: injury costs per number of vehicle-miles traveled, fatalities or injuries per number of hours of operation, fatalities per unit distance of travel, injuries and/or accidents per number of registered vehicles, and fatalities per number of person-miles traveled.

► Fatalities, Injuries, and Accidents

More than 6.5 million transportation accidents or incidents occurred in 1994, a 6.4 percent increase from 1993, and an 8.3 percent increase from 1992 (see table 3-2). These accidents were responsible for more than 3 million injuries and over 43,000 fatalities (see tables 3-3 and 3-4.)

By all measures, accident statistics are dominated by motor vehicle accidents. During the past two decades, motor vehicle accidents accounted for 90 to 93 percent of all transportation fatalities and an even larger percentage of

TABLE 3-2: ACCIDENTS/INCIDENTS[a] BY TRANSPORTATION MODE, 1985–94

Year	Air carrier[b]	Commuter air[c] and air taxi[d]	General aviation[e]	Motor vehicle[f]	Railroad[g]	Rail-highway grade crossings[h]	Rail rapid transit[i]	Waterborne transport	Recreational boating	Gas and liquid pipelines
1985	22	173	2,738	—	3,275	6,919 **R**	—	3,439	6,237	514
1990	24	123	2,216 **R**	6,471,000[j]	2,879	5,713	12,178 **R**	3,613	6,411	379
1991	26	110	2,177 **R**	6,117,000	2,658 **R**	5,386	14,102	2,222	6,573	450 **R**
1992	18	99	2,075 **R**	6,000,000	2,359 **R**	4,910	15,512	3,297	6,048 **R**	388 **R**
1993	23	87	2,042 **R**	6,105,000	2,611 **R**	4,892	15,082 **R**	2,654 **R**	6,335	447 **R**
1994 **P**	22	94	1,989	6,492,000	2,504	4,979	15,258	2,833	6,906	466

[a] Rail rapid transit incidents are collisions, derailments, personal casualties, fires, and property damage in excess of $1,000 associated with transit agency revenue vehicles; all other facilities on the transit property; and service vehicles, maintenance areas, and rights-of-way. Hazardous materials incidents are reported separately in chapter 7, table 7-9.
[b] Large carriers operating under 14 CFR 121, all scheduled and nonscheduled service.
[c] All scheduled service operating under 14 CFR 135 (commuter air carriers).
[d] Nonscheduled service operating under 14 CFR 135 (on-demand air taxis).
[e] All operations other than those operating under 14 CFR 121 and 14 CFR 135.
[f] Includes only police-reported crashes.
[g] Train accidents only.
[h] Motor vehicle accidents at grade crossings are also counted in the motor vehicle column.
[i] Reporting criteria and source of data changed between 1989 and 1990; beginning in 1990, accidents/incidents include those occurring throughout the transit station (e.g., stairways), including injuries to nonpatrons. Reporting level for property damage was lowered, and property damage only accidents were reported for the first time.
[j] National Safety Council procedures for estimating the number of accidents were changed in 1989. Thus, the data shown are not comparable to earlier years.

KEY: **R** = revised; **P** = preliminary.

SOURCES: Various sources, as compiled and cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 1996* (Washington, DC: November 1995).

TABLE 3-3: INJURIES BY TRANSPORTATION MODE, 1985–94

Year	Air carrier[a]	Commuter air[b] and air taxi[c]	General aviation[d]	Motor vehicle[e]	Railroad	Rail-highway grade crossings[f]	Rail rapid transit[g]	Waterborne transport	Recreational boating	Gas and liquid pipelines
1985	30	59	517	—	31,617	2,687	—	172	2,757	126 **R**
1990	39	47	391	3,231,000	22,736	2,407	10,036	175	3,822	76 **R**
1991	26	57	420	3,097,000	21,374	2,094	9,285	110	3,967	98 **R**
1992	13	24	418	3,070,000	19,408	1,975	10,446	172	3,683	118 **R**
1993	16 **R**	26	386 **R**	3,125,000	17,284	1,837	10,532 **R**	133 **R**	3,559	112 **R**
1994 **P**	35	38	452	3,215,000	14,850	1,961	11,170	146	4,084	1,970[h]

[a] Large carriers operating under 14 CFR 121, all scheduled and nonscheduled service.
[b] All scheduled service operating under 14 CFR 135 (commuter air carriers).
[c] Nonscheduled service operating under 14 CFR 135 (on-demand air taxis).
[d] All operations other than those operating under 14 CFR 121 and 14 CFR 135.
[e] Injuries from police-reported crashes only. Procedures for estimating injuries were changed in 1989. Thus, data shown are not comparable to prior years.
[f] Motor vehicle injuries at grade crossings are also counted in the motor vehicle column.
[g] Reporting criteria and source of data changed between 1989 and 1990. Beginning in 1990, injury data includes those occurring throughout the transit station (e.g., stairways), and including injuries to nonpatrons.
[h] Includes 1,851 injuries from two flood-related incidents involving two oil pipelines. The large number of reported injuries reflects the widespread distribution of the oil by the flood waters.

KEY: **R** = revised; **P** = preliminary.

SOURCES: Various sources, as compiled and cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 1996* (Washington, DC: November 1995).

transportation accidents and injuries (see tables 3-2, 3-3, and 3-4). According to 1992 data, motor vehicle accidents are the leading cause of accidental death for people under the age of 75. (National Safety Council 1995)

The number of motor vehicle fatalities has declined significantly from the historic high of 54,589 fatalities in 1972. In 1992, the number of highway fatalities was 39,250 (table 3-4), the lowest number of fatalities since the early 1960s. The number of fatalities, however, grew in 1993 and 1994. Preliminary data indicate there were 41,700 fatalities involving highway vehicles in 1995. (USDOT NHTSA 1996) In spite of the recent increases in the number of deaths, the fatality rate per 100 million vehicle-miles traveled reached its lowest recorded level in 1994 (see figure 3-2 and table 3-5), where it remained in 1995.

Serious injuries, especially those resulting from highway accidents, are a major problem. Severe injuries (those in which the victim is incapacitated) outnumber traffic deaths by 10 to 1. After declining in the 1985 through 1992 period, the total number of injuries increased in 1993 and 1994 (see table 3-3). Injury statistics are underreported. Many highway crashes resulting in a minor injury are not reported to the police. Furthermore, of the crashes reported to the police, only slightly more than 80 percent of the injuries are identified. Police often find it difficult to determine injury severity. Considering the underreporting of both crashes and injuries, police accident reports capture only 82 percent of hospitalized crash victims and 55 percent of injured people not requiring hospital care. (Miller 1995)

Both the number of fatalities and injuries, and their rate of occurrence, will merit close monitoring in the years ahead. The increase in the number of motor vehicle deaths and injuries, while troubling, occurred at the same time that the fatality rate reached its lowest level ever in terms of vehicle-miles traveled. Whether the

TABLE 3-4: **FATALITIES BY TRANSPORTATION MODE, 1960–94**

Year	Air carrier[a]	Commuter air[b] and air taxi[c]	General aviation[d]	Motor vehicle	Railroad[e]	Rail-highway grade crossings[f]	Rail rapid transit[g]	Waterborne transport[h]	Recreational boating	Gas and liquid pipelines
1960	499	—	787	36,399	924	—	—	—	819	—
1965	261	—	1,029	47,089	923	—	—	—	1,360	—
1970	146	100	1,310	52,627	785	—	—	178	1,418	26
1975	122	97	1,252	44,525	575	917**R**	—	243	1,466	21
1980	1	142	1,239	51,091	584	833	83	206	1,360	19**R**
1985	526	113	955	43,825	454	582	17	131	1,116	31
1990	39	56	766	44,599	599	698	117	85	865	9**R**
1991	50	150	785**R**	41,508	586	608	103	30	924	14
1992	33	91	860**R**	39,250	591	579	91	105	816	15**R**
1993	1	66	737**R**	40,150	653	626	83**R**	95**R**	800	17**R**
1994**P**	239	89	706	40,676	611	615	76	52	784	22

[a] Large carriers operating under 14 CFR 121, all scheduled and nonscheduled service.
[b] All scheduled service operating under 14 CFR 135 (commuter air carriers).
[c] Nonscheduled service operating under 14 CFR 135 (on-demand air taxis).
[d] All operations other than those operating under 14 CFR 121 and 14 CFR 135.
[e] Includes fatalities resulting from train and nontrain accidents.
[f] Includes pedestrian fatalities not otherwise counted. Motor vehicle fatalities at grade crossings are also counted in the motor vehicle column.
[g] Reporting criteria and source of data changed between 1989 and 1990. Starting in 1990, fatality figures include those occurring throughout the transit station, including nonpatrons.
[h] Vessel casualties only.

KEY: **R** = revised; **P** = preliminary.

SOURCES: Motor vehicles—historical data provided by U.S. Department of Transportation, National Highway Traffic Safety Administration. All other modes—various sources, as compiled and cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 1996* (Washington, DC: November 1995).

fatality rate will continue to decline will depend on many factors, as discussed below. Highway travel will inevitably increase in the future, however, thereby increasing accident risk, all else being equal.

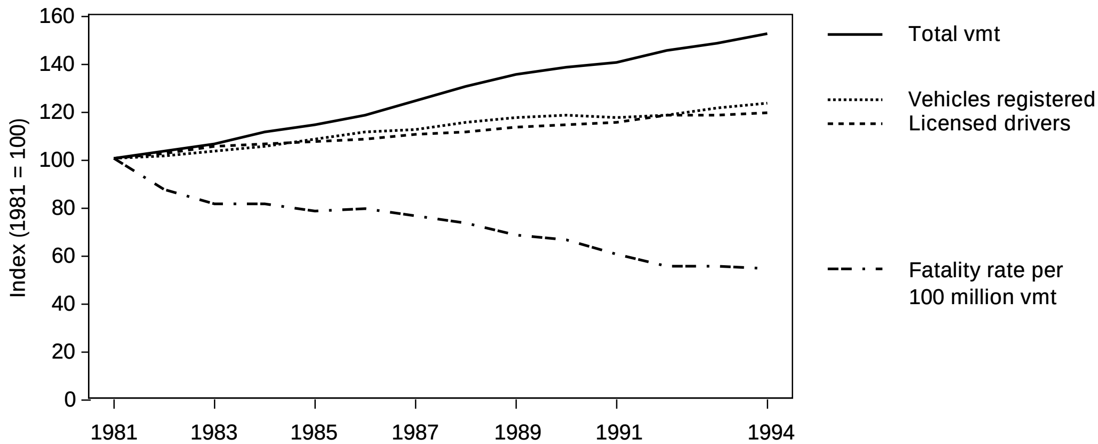
A complicating factor for future analysis will be the greater variation among the states in speed limit and other policies relevant to safety. Congress, in the 1995 National Highway System Designation Act, authorized states to set their own policies about speed limits and about whether to require motorcyclists to wear helmets. How the states respond will be an important highway safety issue in the coming years.

▶ Costs of Transportation Crashes

The personal, social, and economic costs of transportation accidents include pain and suffering, direct costs sustained by injured people and their insurers, and, for many crash victims, a lower standard of living or quality of life. The taxpayer and society may be burdened by health care costs not paid by individuals or insurers, lost productivity and associated loss of tax revenues, and public assistance for injured people.

The total economic costs to U.S. society over the lifetime of people killed or injured in 1990 transportation crashes is estimated at over $135 billion. (USDOT NHTSA 1993) This includes

FIGURE 3-2: INDICATORS OF MOTOR VEHICLE USE AND FATALITY RATE, 1981–94



KEY: vmt = vehicle-miles traveled.

SOURCES: Fatality rate—U.S. Department of Transportation, *National Transportation Statistics 1996* (Washington, DC: November 1995). Total vmt, vehicles registered, licensed drivers—U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1994,* FHWA-PL-95-042 (Washington, DC: October 1995).

TABLE 3-5: FATALITY RATES BY TRANSPORTATION MODE, 1960–94

Year	U.S. air carrier (per 100 million miles flown)	General aviation (per 100,000 hours flown)	Motor vehicle (per 100 million vehicle-miles)	Railroad (per million train-miles) [a]	Recreational boating (per 100,000 numbered boats) [b]
1960	0.864	6.49	5.06	—	32.8
1965	0.329	6.54	5.30	—	21.3
1970	0.002	5.04	4.74	0.94	19.2
1975	0.069	4.35	3.36	0.76	20.1
1980	0.000	3.40	3.35	0.81	15.8
1985	0.073	3.37	2.47	0.80	11.6
1990	0.009	2.69**R**	2.08	0.98	7.8
1991	0.011 [c]	2.88**R**	1.91	1.02	8.3
1992	0.007	3.61**R**	1.75	1.00	7.3
1993	0.000 [d]	3.28	1.75	1.06	7.1
1994	0.046	3.36**P**	1.73	0.93	6.9

[a] Calculated as total railroad fatalities (from train accidents, train incidents, and nontrain incidents) per million train-miles.
[b] The Coast Guard changed its methodology for calculating the number of boats in 1994. The numbers have been updated from 1975 to 1994. The figures cited here represent numbered boats.
[c] Does not include 12 persons killed on a commuter aircraft that collided with an airliner.
[d] Figure does not reflect one fatality.

KEY: **R** = revised; **P** = preliminary.

SOURCES: Motor vehicles—U.S. Department of Transportation, National Highway Traffic Safety Administration. All other modes—various sources, as compiled and cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 1996* (Washington, DC: November 1995).

more than $14 billion in health care expenditures, $35.6 billion in property damage costs, and nearly $40 billion in market productivity losses. Taxpayers will pay $11.4 billion of the total cost of crashes to cover publicly funded health care expenses, reductions in income tax revenues, and increases in public assistance expenses. (USDOT NHTSA 1993) The above estimate does not include the value of *lost quality of life*. If this valuation is included, the cost measure is called the *comprehensive injury cost.* There is considerable uncertainty about how to express such broader costs in monetary terms. According to a preliminary estimate by one research group, the comprehensive injury costs for motor vehicle crashes in 1988 were more than twice the lifetime monetary cost of motor vehicle injuries, fatalities, and property damage. (Miller 1995) The omission of the cost of lost quality of life can result in underestimating the benefits of investments to make travel safer.

► Modal Comparison

Assessing the relative safety of transportation modes is necessary for informed research, development, and investment decisions. Modes, however, differ in their functions, risk exposures, and other characteristics; thus, modal comparisons should be made with caution.

Fatality rate is one method for comparing transportation safety among modes (see table 3-5.) Although a lack of common measures impedes analysis, in general, fatality rate trends show that commercial air and rail continue to be the two safest modes. The rates for highway vehicles (which include vehicles as different in their safety profiles as buses and motorcycles), general aviation, and recreational boating are much higher, but these modes have become much safer over the past two decades. The risk associated with motorcycles is striking: on a per-vehicle-mile basis motorcycle riders are over 15 times more likely to be involved in fatal crashes than occupants of either passenger cars or trucks (see table 3-6).

Despite the continued increases in the number of vehicles, the number of drivers, and the amount of driving, the 1994 fatality rate for all highway vehicles was 1.73 per 100 million miles driven, the lowest ever recorded (see table 3-5 and figure 3-2). The improvement in highway safety can be attributed to several factors, including better designed, safer highways, increased use of seat belts, increased market penetration of air bags and other safety equipment, aggressive anti-drunk-driving programs, and lower vehicle occupancy rates.

Similarly, the boating fatality rate decreased despite an increase in registered boats. Nearly all deaths in boating accidents were drownings, and 75 percent of these deaths could have been prevented if boaters had worn life jackets or other floatation devices. (USDOT Coast Guard 1995)

► International Comparison of Transportation Fatalities

Transportation safety is a major public health concern, not just in the United States, but in other highly motorized Organization for Economic Cooperation and Development (OECD) countries. Among the seven major OECD countries (the G-7 countries), the United States, with its large and highly mobile population, has the greatest number of transportation fatalities. However, its fatality rate is one of the lowest when vehicle-miles driven is considered. (USDOT BTS 1994) Furthermore, statistics indicate that motor vehicle accidents in the United States tend to be less severe than those in the other G-7 countries: the fatality rate in the United States is 13 deaths per 1,000 casualties (see table 3-7). Accidents are most severe in France, which has a fatality rate almost four times as high as that of the United States. Thus,

Table 3-6: U.S. Motor Vehicle Fatalities, 1975–94

Year	Passenger car occupants: Fatalities	Passenger car occupants: Fatality rate [a]	Light-truck occupants: Fatalities	Light-truck occupants: Fatality rate [a]	Large-truck occupants: Fatalities	Large-truck occupants: Fatality rate [a]	Motorcyclists: Fatalities	Motorcyclists: Fatality rate [a]	Pedestrian fatalities	Total nonoccupant [b] fatalities
1975	25,928	2.5	4,856	2.4	961	1.2	3,189	56.7	7,516	8,600
1980	27,449	2.5	7,486	2.5	1,262	1.2	5,144	50.4	8,070	9,164
1985	23,212	1.9	6,889	1.7	977	0.8	4,564	50.2	6,808	7,782
1990	24,092	1.7	8,601	1.6	705	0.5	3,244	33.9	6,482	7,465
1991	22,385	1.6	8,391	1.4	661	0.4	2,806	30.6	5,801	6,768
1992	21,387	1.5	8,096	1.3	585	0.4	2,395	25.1	5,549	6,370
1993 **R**	21,566	1.5 [c]	8,511	1.3	605	0.4	2,449	24.8	5,649	6,576
1994 **R**	21,997	1.5	8,904	1.3	670	0.4	2,320	22.6	5,489	6,398

[a] Calculated as fatalities per 100 million vehicle-miles traveled.
[b] Includes pedestrian, pedalcyclist, and other nonoccupant fatalities.
[c] Some minivans and sport-utility vehicles that were previously classified as passenger cars are classified as trucks.

KEY: **R** = revised.

NOTE: Excludes buses. Passenger car and light-truck occupant fatality rates reflect National Highway Traffic Safety Administration revisions. In some instances, data may differ from previously published figures.

SOURCE: U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA), *Traffic Safety Facts 1994,* DOT HS 808 292 (Washington, DC: August 1995). Revised data for 1994 provided by NHTSA.

Table 3-7: Accident Severity by Road-User Category, 1992
(Number of fatalities per 1,000 casualties)

Country	Drivers	In-vehicle passengers	Pedestrians	On bicycles	On mopeds	On motorcycles	Other[a]	Total
United States[b]	10	10	62	12	—	42	14	13
Canada[b]	13	12	34	9	—	26	38	15
Japan	13	13	48	12	12	29	47	17
France	55	43	52	51	25	51	50	48
Germany[b]	22	20	40	13	15	25	20	22
Italy[b]	28	25	51	55	22	31	48	31
Great Britain	11	10	26	8	5	19	11	14

[a] Other includes in commercial vehicles, buses and coaches, and on horse.
[b] 1991 data are used.

SOURCE: European Conference on Ministers of Transport, *Statistical Report on Road Accidents in 1992* (Paris, France: 1994), table 6, p. 47.

in terms of fatalities per distance driven and fatalities per number of injuries, the United States has one of the safest transportation systems in the world. Comparing safety statistics among various countries is, however, complicated by inconsistencies in definitions and reporting criteria, particularly for motor vehicle injuries.

Human Factors

Lapses in operator performance contribute to a significant number of fatalities and injuries in all modes of transportation. Such lapses are responsible for one-third of all railroad accidents and are the number one cause cited in aviation accidents. Operator error is also probably the single-most important factor in truck and bus accidents.

Analysis of police reports suggests that approximately 85 percent of the factors contributing to motor vehicle crashes were associated with the driver, 10 percent involved the highway, and 5 percent involved the vehicle. (Evans 1991) Two other studies have obtained similar results. A U.S. study found that road users are identified as the sole factor in 57 percent of crashes, the road environment in 3 percent, and the vehicle in 2 percent. (Evans 1991) The interaction between the road environment and road users contributes to 27 percent of crashes, and the interaction between road users and vehicles contributes to 6 percent. Results from a United Kingdom study are remarkably consistent. (Evans 1991) The importance of human factors in causing transportation accidents is unquestioned.

The study of human factors in transportation safety is extremely complex and must take many factors into account. These include the operator's risk-taking propensity and risk perception, and the operator's interaction with technology (including the vehicle) and the surrounding environment. Operator impairment (poor driving performance because of alcohol, drugs, medical conditions, aging, fatigue, or any combination of these factors) also must be taken into account.

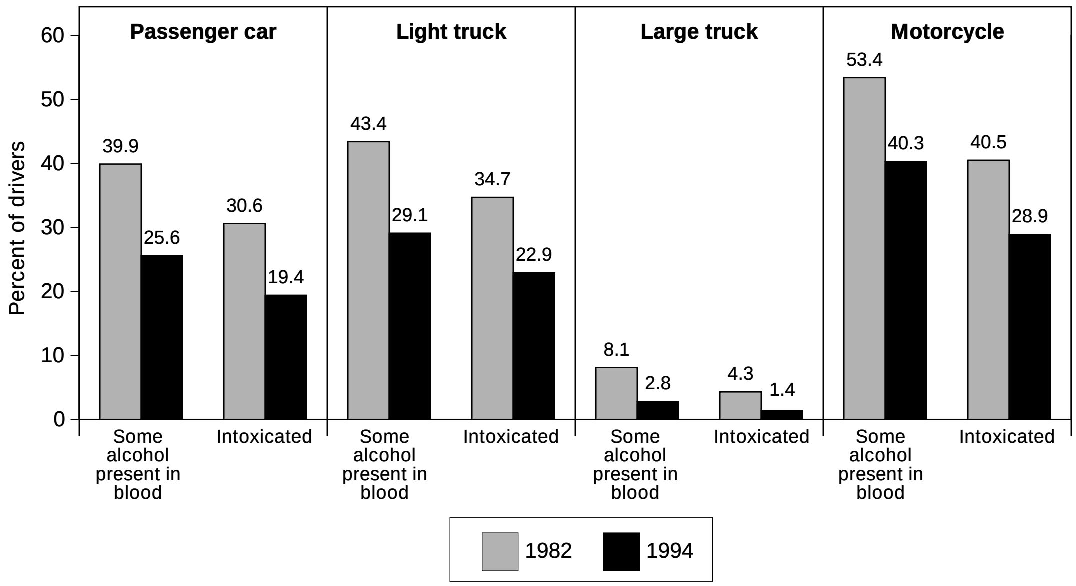
► Alcohol and Drugs

In 1994, 16,589 people were killed in alcohol-related highway accidents. (USDOT BTS 1996, 125) These accidents accounted for 41 percent of the people killed in highway accidents and 18 percent of people killed in accidents of all kinds. Alcohol was also involved in crashes resulting in 297,000 injuries. (USDOT NHTSA 1995c) Over the past five years, many states have reported that from one-quarter to one-third of drivers arrested each year for driving while intoxicated are repeat offenders. For drivers involved in fatal crashes, rates of alcohol involvement are highest for people aged 21 to 24, followed by people aged 25 to 34.

Progress has been made in curtailing drunk driving. From 1982 to 1994, the percentage of alcohol-related fatalities declined from 57 percent to 41 percent of crash fatalities. Moreover, a lower percentage of drivers involved in fatal crashes were intoxicated or had been drinking (see figure 3-3). For example, the intoxication rate for drivers of large trucks involved in fatal crashes fell from 4.3 percent to 1.4 percent in this period. Alcohol use for motorcyclists continues to be stubbornly high; some alcohol was present in the blood of 40.3 percent of the motorcycle operators involved in fatal crashes in 1994, and 28.9 percent were intoxicated. (USDOT NHTSA 1995c) Despite progress, drunk driving and its tragic consequences remain at unacceptable levels.

Several factors have reduced alcohol-related fatalities: deterrence strategies, raising the legal drinking age to 21, changes in societal patterns of alcohol consumption, and increased public

FIGURE 3-3: DRIVERS IN FATAL CRASHES BY LEVEL OF BLOOD ALCOHOL CONCENTRATION AND VEHICLE TYPE, 1982 AND 1994



NOTE: The National Highway Traffic Safety Administration considers police-reported fatal traffic crashes as alcohol-related if either a driver or a nonmotorist had a blood alcohol concentration (BAC) of at least 0.01 grams per deciliter. Persons with a BAC of 0.10 grams per deciliter are considered intoxicated in most states.

SOURCE: U.S. Department of Transportation, National Highway Traffic Safety Administration, *Traffic Safety Facts 1994,* DOT-HS-808-292 (Washington, DC: August 1995), table 17, p. 35.

awareness. Sobriety checkpoints and administrative license revocation (i.e., immediate loss of license following arrest) are two proven deterrents. Research shows that communities using sobriety checkpoints experience significant decreases in alcohol-related traffic crashes. (Ross 1992) The effectiveness of sobriety checkpoints, however, has been demonstrated only in the short run, because most programs were either new when they were evaluated or were designed as short-term programs. Administrative license revocation has been found to reduce fatal crashes by 7 to 9 percent. (Stewart and Voas 1994) Currently, 33 states and the District of Columbia have administrative license revocation laws.

Another way to deter drunk driving is to lower the legal blood alcohol concentration (BAC) limit. By 1994, 11 states had reduced the BAC limit from 0.10 grams per deciliter (g/dl), which is standard in most states, to 0.08 g/dl; and most states also had set an even lower BAC legal limit for drivers under 21 years of age. In California, administrative license revocation combined with a BAC limit of 0.08 has contributed to a 12 percent reduction in alcohol-related fatalities. (Stewart and Voas 1994)

As of 1994, all 50 states and the District of Columbia had set 21 as the legal drinking age, a step that has reduced alcohol-related traffic fatalities among young people. Nearly 14,000 lives have been saved since 1975 because of the increase in the legal drinking age. (USDOT NHTSA 1995a) In 1982, 31 percent of drivers ages 16 to 20 who were involved in fatal crashes had a BAC of 0.10 g/dl or higher. By 1994, that figure had dropped to 14 percent. A comparison among states found that those with lower BAC limits experienced a 42 percent decrease in teenage fatalities, while those without the lower limit had a 29 percent decrease over the same period. (Hingson 1992)

Many pedestrians who are killed in accidents with motor vehicles are intoxicated. In 1994, alcohol was present in the blood of over 40 percent of the pedestrians killed, ages 14 and older, and about one-third had BAC levels of 0.10 g/dl or more. By comparison, about 19 percent of motor vehicle drivers in crashes involving a pedestrian fatality had some alcohol in their blood. (USDOT NHTSA 1995c) Although the vast majority of alcohol- and other drug-related accident fatalities occur on highways, other transportation modes are not immune. Still, there has been progress in reducing the number of alcohol-related crashes for these modes.

The reduction in alcohol- and other drug-related crashes in the transportation workplace is largely attributable to drug- and alcohol-testing programs. Early estimates of the rate of alcohol and drug abuse ranged from 10 to 20 percent of the transportation workforce. Since the testing programs began in December 1989, the percentage of operators testing positive in the aviation and railroad industries has dropped to 3 percent. (Smith 1993)

► Human Fatigue

Human fatigue has long been recognized as a contributing factor in transportation accidents. The three-watch system was mandated in the maritime sector some 80 years ago, and hours-of-service (HOS) requirements in commercial trucking date back to 1939. Only recently, however, has human fatigue been recognized as a major problem in personal transportation.

Historically, fatigue was thought to be directly related to the amount of time behind the wheel. The HOS regulations established in the motor vehicle industry in 1939 were written from this viewpoint. Recent scientific evidence clearly shows, however, that two major physiological phenomena create fatigue: sleep loss and disruption in circadian rhythm, the body's internal 24-hour clock.

In transportation safety, human fatigue refers to the mental or cognitive fatigue of operators in any part of the transportation system. Unlike alcohol and drugs, which can be detected by tests, cognitive fatigue leaves no clear chemical or physiological evidence.

In general, fatigue increases the variability in operator performance, making it less reliable. It also increases cognitive errors, false responses, recall errors, the time to do a task, and reaction times.

Four main factors are usually assessed in accident investigations to determine whether fatigue played a role: 1) acute sleep loss or cumulative sleep debt, 2) length of time awake prior to the accident, 3) time of day of the accident (related to the body's circadian rhythm), and 4) existence of a sleep disorder such as chronic insomnia or sleep apnea. (NTSB and NASA Ames Research Center 1995)

Modal Comparisons of Human Fatigue

Each mode of transportation has examples of accidents attributed to human fatigue. One example was the grounding of the Exxon *Valdez* in Prince William Sound in 1989. Fatigue also was seen as the probable cause of the crash of American International Airways Flight 808 at the U.S. Naval Air Station at Guantanamo Bay, Cuba, in 1993. In the 24 hours prior to the accident, the flight's captain had only one-half hour of sleep. (NTSB 1994a)

The fatigue problem in transportation safety is difficult to assess, and therefore the size of the problem may be underestimated. This is particularly true of highway accidents for a number of reasons. First, the reporting practice for citing driver fatigue/drowsiness varies from state to state. Second, there are no tests that can provide firm evidence on which to base a police finding. Third, both police officers and drivers may not be aware of the role drowsiness or fatigue played in the crash, because it may be subtle and difficult to detect.

Based on National Highway Traffic Safety Administration (NHTSA) analysis, driver fatigue or drowsiness is cited on the police report for between 79,000 to 103,000 highway crashes each year (about 1.2 to 1.6 percent of the total highway crashes). (Knipling and Wang 1995) These crashes account for about 3.6 percent of all fatal highway crashes. Other studies place the incidence rate of drowsy-driver crashes between 1 and 4 percent. (Knipling and Wang 1994)

NHTSA's analysis also showed that gender and age are important in drowsiness/fatigue-related crashes. Male drivers are twice as likely to be involved in drowsiness/fatigue-related crashes than female drivers, on a per vehicle-mile basis. Drivers younger than 30 years of age are four times more likely to be involved in drowsiness/fatigue-related crashes than those older than 30. (Knipling and Wang 1994) Time of day is also important. Drowsiness/fatigue-related crashes are most frequent in the early morning and early afternoon.

Drivers of passenger vehicles (cars and light trucks) accounted for 96 percent of drowsy-driver crashes according to NHTSA crash data for 1989 to 1993. Drivers of combination trucks (tractor trailers) accounted for 3.3 percent. Although passenger vehicles comprise the vast majority of drowsy-driver crashes, fatigue/drowsiness is a problem for many combination truck drivers. (Knipling and Wang 1994) Although police reports indicate that combination trucks have a lower rate of involvement in fatigue-related crashes on a vmt basis than passenger vehicles, they are driven, on average, over five times as many miles per year. Hence, their exposure level is high. Drowsy-driver crashes involving combination trucks generally result in more severe injuries and property damage. Moreover, crashes involving combination trucks cause more severe injuries to people outside the truck, such as pedestrians or occupants of other vehicles, than crashes involving only passenger vehicles. Thirty-seven percent of the fatalities and 20 percent of the injuries associated with drowsy-truck-driver crashes occurred to people outside the truck. Comparable percentages for passenger vehicles were 12 percent of the fatalities and 13 percent of the injuries. For all combination truck crashes, 87 percent of the fatalities and 75 percent of the injuries occurred to people outside the truck. (Knipling and Wang 1994)

The National Transportation Safety Board (NTSB) recently evaluated the role of fatigue in 107 single-vehicle heavy-truck accidents in which the driver survived. The study's purpose was to examine fatigue characteristics, not to determine the statistical incidence of fatigue; NTSB examined both fatigue- and nonfatigue-related accidents. Through interviews with drivers and review of log books, NTSB sought to reconstruct the duty/sleep patterns of the drivers in both groups for the 96 hours preceding the accidents. The review concluded that, among the cases, the most critical factors distinguishing the fatigue-related accidents were the duration of the most recent sleep period, the amount of sleep in the past 24 hours, and whether the driver had split the required eight hours of sleep into segments. (NTSB 1995) The NTSB study reported that drivers in these fatigue-related accidents not only had 25 percent less sleep in the 24-hour period prior to the accident than drivers in non-fatigue-related accidents, but had 30 percent less sleep during the last sleep period. A higher proportion of the drivers in these fatigue-related crashes also had schedule irregularities or inverted duty/sleep periods before their accidents. Furthermore, driving at night with a sleep deficit is far more dangerous than simply driving at night. (NTSB 1995)

Technological innovation and economic competition have reduced the size of ship crews in the maritime industry. Because the safety of modern ships is more dependent on the ships' crews than on any other factor, merchant vessel casualties are often the result of human error. Because of a lack of reliable data and the difficulty in identifying the role of fatigue in marine incidents, the impact of reduced manning on marine safety has yet to be quantified. Still, some recent research suggests that the current three-watch system, in conjunction with reductions in manpower, might intensify the fatigue problem aboard merchant vessels. (Williams and Helmick 1995)

Measures To Combat Fatigue

Fatigue as a cause of transportation accidents can be addressed through: 1) education and training, 2) HOS limits, 3) scheduling, and 4) countermeasures and technology. Education and training can play a critical role in efforts to combat the effects of human fatigue in transportation. It has been widely recognized that the amount of sleep needed varies from person to person, that operators may not be aware of, or recognize, fatigue symptoms, and that regulations and laws alone cannot guarantee that drivers and other operators get enough sleep. Transportation Secretary Federico Peña underscored the importance of education and training: "If it's human behavior we must change, then we need to educate and not just regulate." (Peña 1995)

In commercial transportation, HOS and scheduling are key to understanding the fatigue problem. Current HOS rules require truck drivers to be off duty for at least eight consecutive hours after either 10 hours of driving and/or spending 15 hours on duty. The eight-hour off-duty requirement has been criticized by NTSB as not providing enough time for drivers to get adequate rest while also taking time for travel, eating, personal hygiene, and recreation. The Federal Highway Administration is conducting research to provide a technically sound basis for evaluating HOS regulations.

Current aviation regulations require a rest period of at least 10 hours for a pilot scheduled to fly an eight- to nine-hour flight. To provide scheduling flexibility under unexpected circumstances, however, the regulations allow flight crews to operate with a shorter rest period as long as they subsequently get compensatory rest. According to NTSB, some airlines not only apply these provisions in unexpected circumstances, as originally intended, but also routinely use them when scheduling flight crews. (NTSB 1995) Thus, NTSB recommended that airlines be made aware of, and comply with, the *original intent* of the rest regulations.

Finally, research suggests that other countermeasures may be effective in combating fatigue. Examples include bright lights, strategic napping, in-vehicle fitness-to-drive devices, and rumble strips on the shoulders of highways. Vehicle-based driver drowsiness detection and warning systems are also the subject of research. The cost-effectiveness of some of these countermeasures has yet to be proven.

The U.S. Department of Transportation (DOT) has assumed leadership in the effort to prevent fatigue-related transportation accidents. (USDOT 1995) Because the quantity and quality of sleep are critical to avoiding fatigue, DOT conducts some research on sleep. Much of DOT's activity, however, concentrates on vehicles and environments: control centers, airplane cockpits, truck cabs, locomotive cabs, ship bridges, and driver compartments of cars and buses.

Occupant Protection Devices

Accidents and injuries can be reduced through various devices that protect the occupant. Seat belts, when properly worn, greatly reduce the number and severity of injuries in highway accidents. According to NHTSA, lap/shoulder belts reduce the fatality risk for front-seat passengers by 45 percent and are slightly more effective in preventing moderate to critical injuries. In 1994, seat belts saved an estimated 9,175 lives of all occupants. (USDOT NHTSA n.d.a) As of 1994, all but three states had a mandatory seat belt use law, and observational survey data showed that 67 percent of all passenger car occupants wore their seat belts. (USDOT NHTSA n.d.a) It is, however, becoming harder to increase the rate of seat belt use.

In 1994, airbags saved the lives of an estimated 374 people. The most effective protection is provided when lap/shoulder belts are used in vehicles equipped with airbags. (USDOT NHTSA n.d.a) Child safety seats placed in the correct position can reduce the risk of fatal injury by 69 percent for infants and by 47 percent for toddlers. (USDOT NHTSA n.d.a) Motorcycle helmets saved an estimated 527 lives in 1994, and an additional 294 lives might have been saved if all motorcyclists had worn helmets. (USDOT NHTSA n.d.b)

Despite significant progress in vehicle safety standards and occupant protection devices, there is still much work to be done. For example, the aging of the U.S. population presents challenges. The design of traffic control devices is often based on performance measures of younger drivers. Likewise, vehicle designers often overlook the needs of older drivers, and driver licensing programs often do not adequately address problems faced by older drivers.

Mode-Specific Safety Issues

► Commuter Airline Safety

The commuter airline industry has grown dramatically and changed significantly over the past 15 years. From 1980 to 1993, the number of passengers flying in aircraft operated by regional airlines (which account for most commuter service) increased from 15 million to over 52 million; the number of their aircraft grew from 1,339 to 2,208. (NTSB 1994b) Because of growing demand, regional airlines have added larger, more sophisticated airplanes to their fleets. As a result, the average seating capacity increased from just under 14 seats per airplane in 1980 to 23 seats in 1993. Today, nearly 70 percent of U.S. communities with scheduled air service depend on regional or commuter airlines.

As commuter airlines moved into markets once served by major airlines or began to serve new markets, they often entered into *codesharing* arrangements with a major airline. Typically, the commuter airline uses a similar designator code in the airline reservation systems. It also paints its aircraft with a color scheme and does business under a company name that closely resembles that of the major airline. In 1993, 36 of the 50 largest commuter airlines had a codesharing arrangement with at least one major airline.

Although such associations have made many travelers less aware of the distinction between a major airline and its codesharing partner, there have been significant regulatory and operational differences between the major and commuter carriers. For example, the codesharing arrangement does not always mean that the major airline directly oversees its codesharing partner's flight operations, maintenance, or safety.

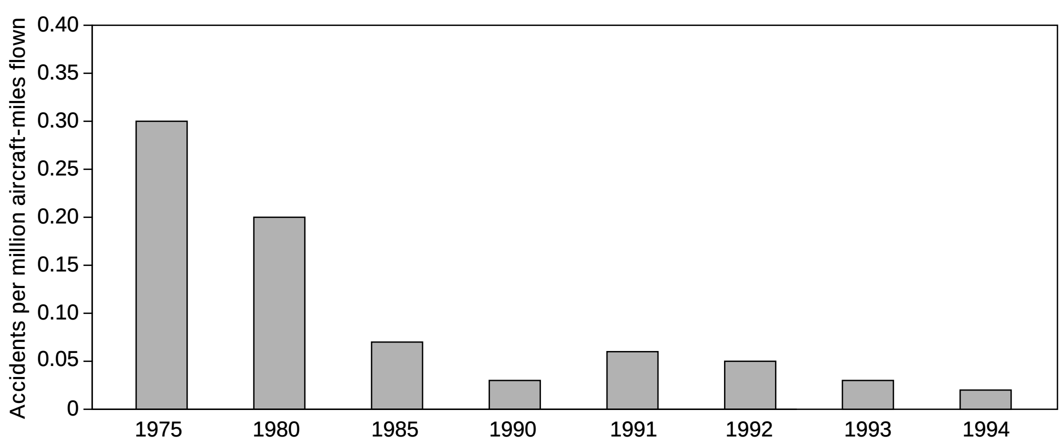
In the past, the regulations applied to commuter aircraft with 30 or fewer seats (Title 14 *Code of Federal Regulations*, Part 135) were less stringent than those applied to aircraft with more seats (Title 14 *Code of Federal Regulations,* Part 121). Different requirements existed for flight operations, pilot training, flight-time limits, operational control, and maintenance personnel. With the rapid growth in passenger traffic and changes in the operational characteristics of commuter airlines, the regulations had not kept pace with many of the changes in the industry. (NTSB 1994b)

Even so, the joint efforts of government and industry during the past 15 years have brought about significant safety improvements in the commuter airline industry. The accident rate per million aircraft-miles of service conducted under Part 135 has declined significantly since 1980 (see figure 3-4). Yet, accident rates for these aircraft continue to be higher than for larger commercial aircraft.

In its recent study of commuter airline safety, NTSB found that many commuter airlines had taken advantage of regulatory provisions allowing them to establish flight crew schedules, under unexpected circumstances, with reduced rest periods. Many pilots in the survey admitted flying while fatigued and attributed their fatigue to such factors as length of duty day and reduced rest periods. About one-third of the pilots interviewed in NTSB's study said that more formal crew resource management training and operating experience would be beneficial. Overall, the study found commuter airline regulations inadequate to make passengers as safe as those flying on major airlines. (NTSB 1994b)

On December 14, 1995, Transportation Secretary Federico Peña and Federal Aviation Administrator David R. Hinson announced issuance of tougher safety rules for commuter airlines. Under the new rules, all scheduled passenger service using airplanes with 10 or more seats will be operated under the same safety standards as larger planes, with a few "common sense" exceptions. (*FAA News* 1995)

FIGURE 3-4: ACCIDENT RATES FOR U.S. COMMUTER AIRLINES, 1975–94



NOTE: Commuter airlines refer to all scheduled service conducted under 14 CFR 135.

SOURCE: National Transportation Safety Board, *Aviation Accident Statistics,* annual issues, as compiled and cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 1996* (Washington, DC: November 1995), table 36.

► Accidents at Highway-Railroad Crossings

Although rail is one of the safest modes of transportation, accidents at highway-railroad crossings remain a significant problem. About half of all rail-related fatalities are the result of collisions between trains and vehicles at railroad crossings. In 1994, about 5,000 such collisions occurred, killing 615 people and injuring 1,961. (USDOT BTS 1996)

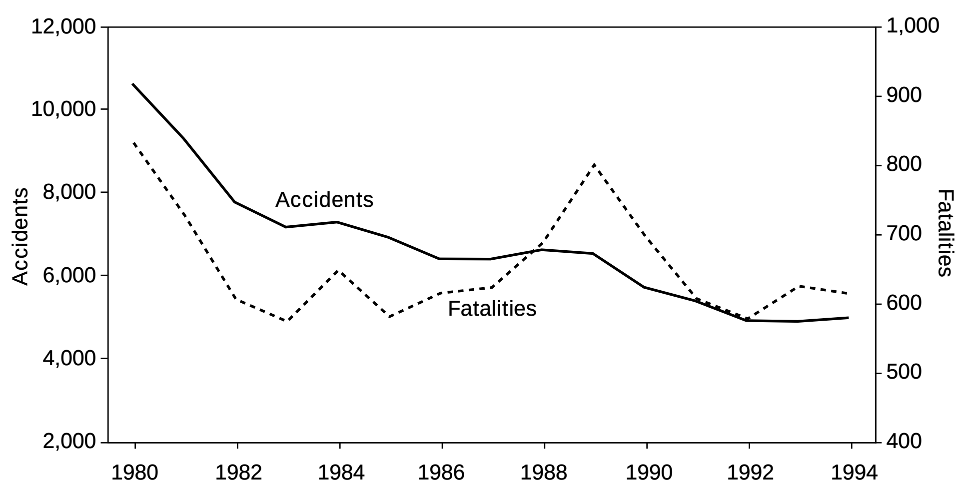
Government and the railroad industry have cooperated to improve railroad crossing safety through the Rail-Highway Crossing Program begun in 1974. Since 1980, the number of accidents at public railroad crossings has been more than cut in half. Fatalities, however, have risen in some years and declined in others (see figure 3-5).

The Federal Railroad Administration (FRA) has developed a surrogate accident exposure index based on train-miles traveled and vehicle-miles traveled. Based on this index, FRA estimated that accident exposure at railroad crossings rose by 39 percent between 1985 and 1993, adversely affecting safety at railroad crossings. (USGAO 1995)

From 1975 to 1994, the number of public crossings decreased by 24 percent. The level of warning provided at the 166,000 public crossings that remained in 1994 varies widely, from no visible warning devices to several kinds of active devices. Active devices (e.g., automatic flashing lights and lights with gates) are more effective than passive devices (e.g., crossbucks and stop signs). Even so, crossings pose a major safety challenge because of growing rail traffic and higher speed passenger and freight rail operations.

When it is not practical to close a crossing, states can use alternatives such as new technologies, public education, and law enforcement. Traditional technologies such as lights and gates are not foolproof. New technologies, such as those that prevent vehicles from entering the crossing when trains approach, may be effective, but they are more costly. Thus, they are reserved for more dangerous crossings.

FIGURE 3-5: **ACCIDENTS AND FATALITIES AT RAIL-HIGHWAY GRADE CROSSINGS, 1980–94**



SOURCES: Various sources, as compiled and cited in U.S. Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics Annual Report, Historical Compendium, 1960–1992* (Washington, DC: September 1993); and *National Transportation Statistics 1996* (Washington, DC: November 1995).

Drivers who ignore warning signs are a major cause of railroad crossing accidents and fatalities. Law enforcement and educational programs have modified motorist behavior in many states. For example, Ohio, which has comprehensive law enforcement and educational programs, experienced a reduction in accidents at crossings with active warning devices—from 377 in 1978 to 93 in 1993. (USDOT BTS 1996)

Under its Rail-Highway Crossing Safety Action Plan, DOT aims to reduce railroad crossing accidents and fatalities by 50 percent from 1994 to 2004. A combination of strategies will be needed to effect this large reduction. Thus, DOT plans to provide states with financial and technical assistance to remove unnecessary crossings and to mount public education campaigns. Joined by the industry, Operation Lifesaver, and the Brotherhood of Locomotive Engineers, DOT is promoting *Always Expect a Train*, a national multimedia campaign to educate people about the dangers of ignoring warning signs at railroad crossings. In addition, DOT seeks to eliminate half of the 4,500 highway-rail crossings on the National Highway System and to continue to sponsor research on innovative technologies.

Safety Technologies

Development of crash avoidance systems (CASs) is an area of intelligent transportation systems (ITS) research. An essential step in the development of these systems is to understand both the magnitude and causes of crashes. DOT is using data on different kinds of crashes to identify opportunities for the application of advanced technologies to crash avoidance. (USDOT FHWA 1994, USDOT NHTSA 1995b)

Three kinds of crashes (the rear-end collision, intersection crashes, and single vehicles going off roads) accounted for three-quarters of crashes in 1993. (USDOT NHTSA 1995b) (see table 3-8). Three other major crash types (those involving lane changes or merges, backing, and opposite-direction collisions) total only about 10 percent of crashes, but still each account for between 169,000 and 237,000 crashes per year. Drivers were a contributing factor in 89 percent of these crashes. Driver recognition and decision errors predominated, followed by erratic actions and physiological impairment.

Several collision avoidance methods are under development. *Advisory systems*, which range in sophistication from in-vehicle warning indicators to traffic control systems and road signs, caution a driver about potential hazards.

TABLE 3-8: NUMBER OF CRASHES BY MAIN CRASH TYPES

Accident type	Number of crashes
Rear-end	1,537,000
Rear-end, lead vehicle stationary	979,000
Rear-end, lead vehicle moving	558,000
Backing	177,000
Encroachment backing	82,000
Crossing path backing	95,000
Lane change/merge	237,000
Angle/sideswipe lane change/merge	226,000
Rear-end lane change/merge	11,000
Single-vehicle roadway departure	1,241,000
Intersection crossing path (ICP)	1,805,000
Signalized intersection straight crossing path	204,000
Unsignalized intersection straight crossing path	359,000
Left turn across path	405,000
Other ICP	837,000
Opposite direction	169,000
Other types of crashes	927,000
All crashes	6,093,000

SOURCE: U.S. Department of Transportation, National Highway Traffic Safety Administration, *Synthesis Report: Examination of Target Vehicular Crashes and Potential ITS Countermeasures,* prepared by Volpe National Transportation Systems Center, DOT-VNTSC-NHTSA-95-4 (Washington, DC: June 1995), table 2-1.

Driver warning systems alert the driver to a situation that requires immediate action to avoid a crash. *Control intervention systems* are triggered by an imminent collision in which driver action alone may be inadequate to avoid a crash.

There are challenges with each of these approaches that need to be addressed. Both advisory and warning systems must give the driver crucial information at critical times without becoming a nuisance or distraction. The tradeoffs between nuisance alarms and effective crash avoidance are not yet well understood. For example, repeated nuisance alarms in situations that do not pose a true crash threat could cause drivers to ignore warnings that should be taken seriously. Control intervention systems need to be designed so that adverse secondary safety consequences are minimized or eliminated. The systems need to be extremely reliable and readily acceptable to drivers.

Some research focuses on remedying *driving task errors* associated with particular kinds of crashes. Examples include headway detection systems, situation displays, in-vehicle signing, and lane position monitors. The effectiveness of these concepts is as yet unknown.

Many other ITS countermeasures are at various stages of research or development. Examples include driving vigilance monitors to alert drivers of drowsiness, intoxication, or other functional impairment, devices to monitor pavement conditions or status of vehicle components, and vision enhancement systems.

Although the potential of crash avoidance systems is promising, their effectiveness can only be evaluated through driving situations encountered in the real world. Understanding how drivers will respond to CAS countermeasures is central to evaluating their effectiveness. For example, it is possible that some drivers will erroneously believe that CAS protects them from all crashes, and will pay less attention to driving and take more risks. It is also important to understand how avoiding one crash might lead to another. For example, automatic emergency braking might avoid rear-ending a vehicle ahead, however, the maneuver might cause the braking vehicle to be rear-ended itself. (Tijerina 1995)

In sum, both positive and possible negative effects need to be taken into account in CAS design, implementation, and evaluation. Moreover, cost-effectiveness, hardware reliability, maintainability, and interoperability for cooperative systems needs to be considered in assessments of CASs. One of the greatest challenges facing the transportation system is to understand how technology—broadly defined, as well as specific technologies—can make transportation safer.

Data Needs

Inadequate data and inconsistent measures of accident risk across modes complicate efforts to formulate strategies to reduce transportation risks. Transportation safety data needs fall within four areas: 1) more uniform reporting of accidents throughout the nation, 2) more comprehensive data on environmental conditions and other contributing factors, 3) comprehensive and consistent measures of risk exposure, and 4) more thorough reporting of injuries.

Accident statistics across different data systems are difficult to compare because of inconsistent definitions and reporting criteria. For example, different states use different criteria to determine when police are required to report accidents involving only property damage. Most states use vehicle damage costs as the primary criterion. Damage thresholds vary significantly, however, ranging from $50 in Arkansas and the District of Columbia to $1,000 in Colorado. (O'Day 1993)

More comprehensive information on environmental conditions (e.g., weather, lighting, road conditions) and on other contributing factors is needed to better understand their roles in crashes.

The lack of accurate, comprehensive, and consistent measures of risk exposure hinder progress in understanding the relative importance of the various factors contributing to transportation crashes. Many different types of exposure measures (e.g., number of licensed drivers, vehicle-miles traveled, person-miles traveled, number of hours flown) are used to analyze accident statistics. There is disagreement, however, about which best measures crash risk. Furthermore, the available measures of risk exposure may differ from one mode to the next, making it difficult to compare risks among modes. For example, if vehicle-miles-traveled is the measure of risk exposure for highway crashes and the number of hours flown is the measure used for general aviation accidents, how will we compare safety trends between the two modes? Moreover, when data on risk exposure by vehicle type are broken down to take account of other considerations such as time of day and highway type, the data are not accurate enough for rigorous statistical analyses.

The underreporting of transportation injuries, along with inconsistencies in injury reporting, further complicates assessment of transportation safety. Using the Functional Capacity Index to quantify the reduction of a person's capacity to function following an injury, an estimated 1.3 million years of life are lost annually because of motor vehicle injuries, compared with 1.6 million years lost due to motor vehicle fatalities. (Evans 1991) This measure suggests the devastating consequences of injuries to society. The reporting of injuries, however, is less comprehensive and consistent than the reporting of fatalities. Reporting inconsistencies are reflected in a comparison of police-reported injuries from 23 states. For example, although all these states reported that they collect and automate data for *all* crashes with *any* injury, California reports that only 5 percent of its transportation injuries are incapacitating, while Illinois reports 24 percent. (Evans 1991) It would be useful to develop new training materials to promote consistent reporting of injuries across the nation.

Improvement in the data in these and other areas could contribute to a better understanding of transportation safety problems. Such understanding, in turn, could help in the development of strategies and countermeasures to reduce the frequency and severity of crashes. It also could help in establishing priorities in an era of limited resources.

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CHAPTER FOUR

ENERGY AND TRANSPORTATION

THE U.S. TRANSPORTATION SECTOR REMAINS ALMOST ENTIRELY DEPENDENT ON PETROLEUM. TRANSPORTATION'S OIL DEPENDENCE THROUGHOUT THE DEVELOPED ECONOMIES OF THE WORLD AND GROWING OIL DEMAND IN DEVELOPING COUNTRIES ARE PUSHING THE WORLD TOWARD GREATER RELIANCE ON ORGANIZATION OF PETROLEUM EXPORTING COUNTRIES (OPEC) OIL. ALTHOUGH THERE IS CONSIDERable uncertainty about the future consequences of oil dependence, the United States is clearly becoming more dependent on imported oil. In 1994, U.S. net oil imports came within two percentage points of the historic high of 47 percent of total U.S. consumption in 1977. (USDOE 1995b, 136)

Transportation energy efficiency (based on energy use per ton- or passenger-mile) in the United States remains stagnant. (Although these are the most commonly used measures of energy efficiency, they overlook changes in the quality of transportation services, such as speed or reliability.) The evidence is now very strong that past programs and initiatives, such as the corporate average fuel economy standards, have had very nearly their full effect and that in the future, transportation's energy demand is likely to grow in step with the growth of ton-miles and passenger-miles. There are some notable exceptions, however, such as rail freight transport, which continues to make impressive efficiency gains.

Over the next two decades, transportation is expected to be the principal reason for growing world oil demand.

At the same time that transportation's dependence on imported oil is growing and efficiency improvements have leveled off, new initiatives have been undertaken to foster markets for alternative fuels[1] and vehicles that reduce vehicular air pollution. In response to requirements of the 1990 Clean Air Act Amendments (CAAA), automobile manufacturers and the petroleum industry teamed up to develop cleaner gasoline and diesel fuels. The efforts to develop reformulated gasoline (RFG) and cleaner diesel fuel were novel in viewing vehicle and fuel as a single system and attempting to improve their performance jointly. Despite some initial start-up problems, the RFG program was successfully implemented. By the end of 1995, RFG accounted for about one-quarter of U.S. gasoline demand. RFG followed on the heels of cleaner diesel fuel, introduced nationwide in 1994.

The 1992 Energy Policy Act (EPACT) and the 1990 CAAA call for more widespread use of alternatives to petroleum fuels (a thrust also supported by the Intermodal Surface Transportation Efficiency Act (ISTEA). With the exception of reformulated gasoline, alternative fuels are still a very minor component of transportation fuels. Yet continued technological advances combined with the experience manufacturers and consumers are gaining with these technologies are making alternative fuels increasingly viable substitutes for gasoline. Alternative Fuel Vehicle Fleet programs prompted by the CAAA and ISTEA as well as EPACT also gained momentum in 1995.

It is important to note that many of the environmental impacts of transportation arise from its use of energy. Burning fossil fuels for transportation produces most of the harmful air pollution from transportation and nearly all of the emissions of greenhouse gases. Production of transportation fuels also can create upstream environmental impacts from, for example, oil spills and leaking storage tanks, and land-use conflicts related to exploration and development of oil fields. These and other environmental impacts associated with transportation energy use are discussed in detail in Part II.

This chapter reviews energy use in the transportation sector. Attention is given to the sector's continued dependence on imported oil and the slowing of energy efficiency gains in recent years. The growth in alternative fuels and vehicles use, prompted by environmental concerns, is also discussed. Finally, historical trends in transportation energy use is examined using Divisia Analysis.

Energy Use

Transportation, including equipment, travel, and freight shipments, is the fastest growing sector of the world economy. It has also been virtually the only growth sector for oil demand over the past 20 years. (World Energy Council 1995) Despite two price upheavals in the world oil market, transportation energy demand grew at an average annual rate of 1.8 percent per year in industrialized (Organization for Economic Cooperation and Development—OECD) economies and at 2.0 percent per year in the former communist economies. But in the developing world, where the greatest potential for growth lies, transportation energy use increased at 4.5 percent per year, despite the effects of oil price increases. Automobile ownership rates in most developing countries are only a small fraction of those in the advanced industrial economies (see chapter 9). Not surprisingly, ownership rates are growing most rapidly in the economies with the fewest vehicles. China and the former Soviet Union, with huge land areas and vast populations, have enormous potential for expansion of highway transportation. Worldwide, freight transport has grown 3 percent annually and air passenger transport 7 percent per year. Over the

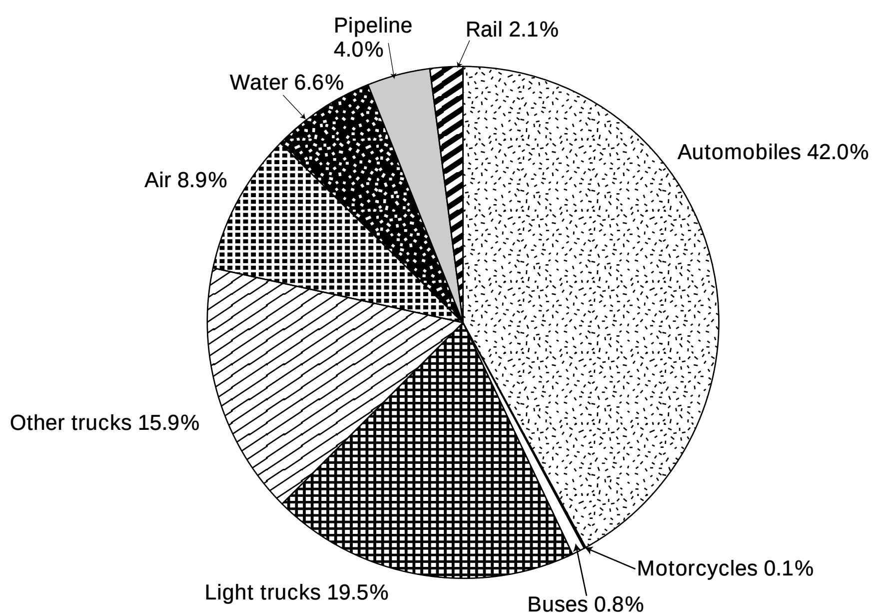
[1] Alternative fuels include methanol, ethanol, natural gas (in either compressed or liquid form), electricity (to power electric vehicles), hydrogen, and reformulated gasoline.

next two decades, transportation is expected to be the principal reason for growing world oil demand.

Highway vehicles continue to dominate transportation energy use and petroleum continues to be the dominant energy source. In the United States, passenger cars use 42 percent of total transportation energy, light trucks 20 percent, and heavier trucks 16 percent. Highway vehicles of all types account for 78 percent of the transportation sector's energy demand (see figure 4-1). Air transport is the biggest energy user among nonhighway modes and the fastest growing mode of all. Pipelines, which amount to 4 percent of total transportation energy use, are the only major mode that does not depend on petroleum as a fuel. Natural gas, used exclusively by natural gas pipelines, fuels 76 percent of pipelines' energy demand. All other types of pipelines (crude oil, oil products, coal slurry, and water) use electric pumps.

In the United States, transportation is the only major energy-using sector that consumes more petroleum today than it did in 1973. This in part arises from the continued growth of transportation, and in part from transportation's continued reliance on oil (see figure 4-2). The oil price shocks of 1973–74 and 1979–80 depressed energy demand but did nothing to shake transportation's dependence on oil.

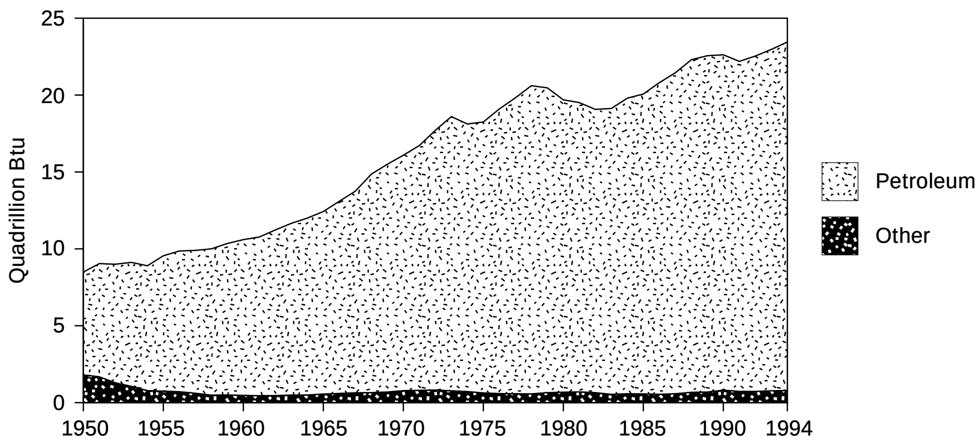
FIGURE 4-1: TRANSPORTATION ENERGY USE IN THE UNITED STATES BY MODE, 1993



NOTE: Does not include off-road motor vehicle use.

SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.10.

FIGURE 4-2: **U.S. TRANSPORTATION ENERGY USE, 1950–94**



SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1994,* DOE/EIA-0384(94) (Washington, DC: July 1995), table 2.1.

Oil Dependence

Around the world, oil consumption has been increasing in the transportation sectors of developed countries and in all sectors in developing countries (see figure 4-3). The growing demand for oil is increasingly met by the member states of OPEC. OPEC's share of the world crude oil market increased from a low of 30 percent in 1985 to 43 percent in 1994 and the first half of 1995. (USDOE 1995g) By 2000, the Energy Information Administration (EIA) projects that petroleum consumption could rise from its present level of 67 million barrels per day (MMBD) to 77 MMBD, and that OPEC's share could rise to 46 percent.[2] (USDOE 1995f) By 2010, world consumption is likely to grow to about 90 MMBD, of which OPEC is expected to supply more than 50 percent. (USDOE 1995e) This would give OPEC members a share of the world market equal to that which they held in 1973.

OPEC countries hold the majority of the world's oil reserves—66 to 77 percent of the world's proven reserves of crude oil (the range being due to uncertainty about the reserves of the former Soviet Union. (USDOE 1995d) Proven reserves are those recoverable at current prices using current technology. Considering as yet undiscovered reserves, the U.S. Geological Survey estimates that OPEC countries probably have 55 percent of the world's remaining 1.6 trillion barrels of "ultimate resources" of petroleum.[3] (Masters et al 1994; OPEC Secretariat 1995) Today, OPEC nations are producing at a rate of about 1 percent of their ultimate resources per year. The rest of the world is drawing down reserves at twice that rate. Unless these relationships are changed in a fundamental way, it seems inevitable that OPEC's market share and market power will expand.

[2] EIA defines total petroleum supply to include natural gas liquids, other liquids, and refinery gain, as well as crude oil. In 1993, e.g., crude oil production was 60.1 MMBD, natural gas liquids production came to 5.2 MMBD, and total world petroleum supply was estimated to be about 1.8 MMBD greater than the sum of the two.

[3] OPEC's own estimates put world undiscovered and discovered reserves at 1.5 trillion barrels, of which they believe they hold 64 percent.

While other sectors of the economy shifted away from oil over the past two decades, the U.S. transportation sector remains almost totally dependent on petroleum. Oil use in residential and commercial buildings declined from just under 18 percent in 1973 to 7 percent in 1994. Over the same period, utility oil use dropped 15 percent, while industrial oil consumption remained about the same, fluctuating between one-quarter to one-third of total energy use (see figure 4-4). The industrial sector's oil consumption remained relatively stable primarily because of the importance of petroleum as a feedstock for the petrochemicals industry.

In 1973, transportation used 17.8 quadrillion Btu (quads) of petroleum products to satisfy 96 percent of its total energy requirements. In 1994, transportation consumed 22.7 quads of petroleum, or 97 percent of its total energy use.

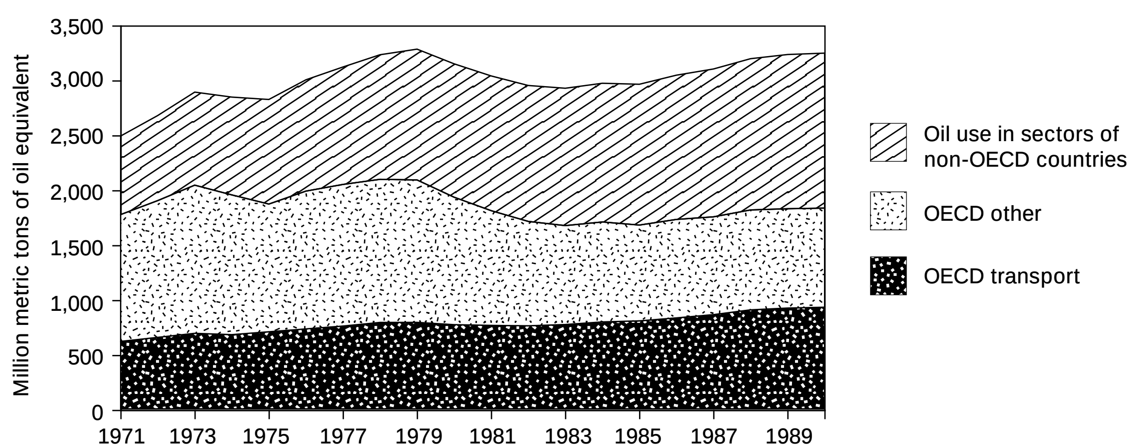
Transportation accounted for 51 percent of U.S. consumption of petroleum products in 1973. Today, transportation accounts for two-thirds of total U.S. oil consumption and more than 80 percent of the light products that drive the petroleum market. (USDOE 1995g)

Growing transportation energy use and continued dependence on petroleum, combined with declining U.S. oil production are increasing U.S. reliance on imported petroleum. In 1973, net imports of petroleum supplied 35 percent of total U.S. consumption. (USDOE 1995g) Dependence on imported oil reached a peak of 47 percent in 1977, then decreased to 27 percent by 1985 as a result of higher oil prices and energy conservation measures. Since the oil price collapse of 1986, U.S. oil import dependence has increased to 45 percent, and EIA projects imported oil will supply about 60 percent of U.S. petroleum demand by 2005.

State of Energy Efficiency Improvements

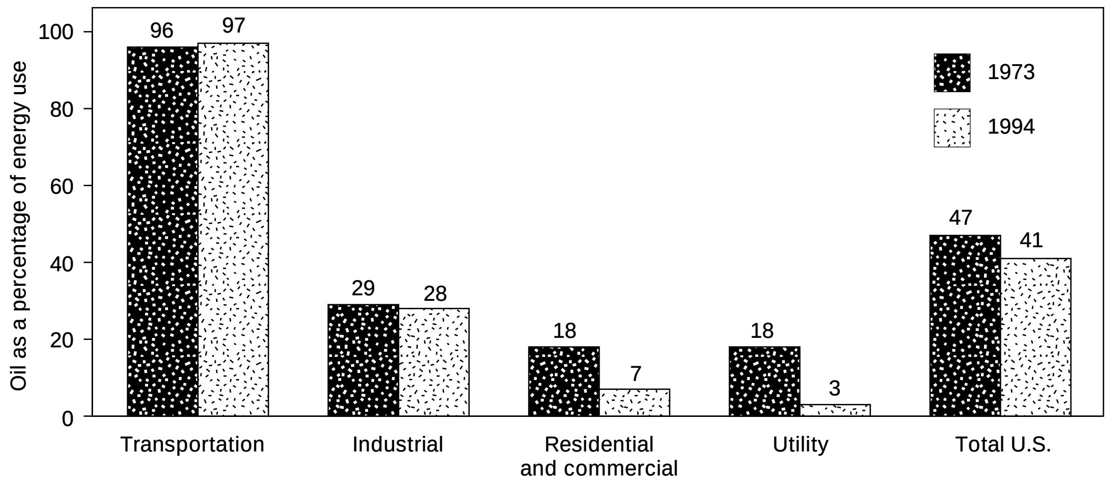
Although it continues to rely on petroleum, the U.S. transportation sector has made significant improvements in energy efficiency over the past 20 years. Since 1990, however, efficiency

FIGURE 4-3: **PETROLEUM DEMAND IN THE TRANSPORTATION SECTOR IN OECD COUNTRIES RELATIVE TO OIL USE IN ALL SECTORS OF NON-OECD COUNTRIES**



SOURCE: International Energy Agency, 1992.

FIGURE 4-4: PETROLEUM DEPENDENCY OF U.S. ECONOMIC SECTORS, 1973 AND 1994



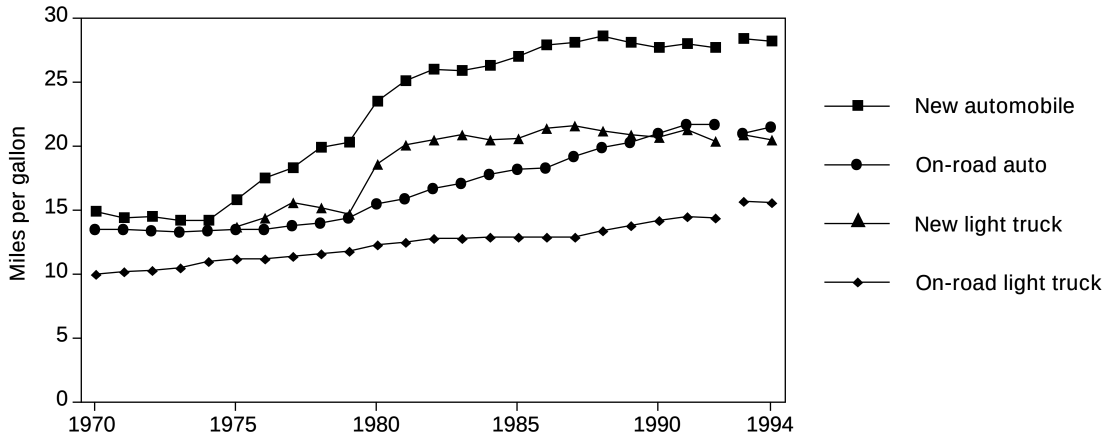
SOURCE: U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(95/10) (Washington, DC: October 1995).

improvements appear to have tapered off or stopped for the largest energy-using modes. In 1991, transportation energy use was about 15 percent lower than it would have been had there been no changes in modal energy intensities or the modal structure of passenger and freight flows since 1972. (Davis 1995) This remained nearly unchanged in 1992 and 1993 (the latest year for which data are available). The slowing of efficiency improvements is true for all major modes. On-road passenger car fuel economy increased about 60 percent between 1975 and 1994, from 13.5 miles per gallon (mpg) to 21.5 mpg in 1994. (Davis 1995) (See figure 4-5.) From 1991 to 1994, however, there was essentially no change. The cause is easy to find: new car mpg has not increased significantly since 1982.

A somewhat more complex story is told by the data for light and heavier trucks. Fuel economy estimates for all types of trucks are collected by the Bureau of the Census every five years as part of the Truck Inventory and Use Survey. These data allow a comparison of mpg trends by truck model year at three different times—1982, 1987, and 1992. Mpg estimates for single- and multiple-trailer combination trucks are shown in figures 4-6 and 4-7. Both show a gradual trend of improving fuel economy from about 5 mpg in the early 1970s to about 6 mpg by 1990. The fact that mpg seems to improve by model year rather than vary with the calendar year of the survey or the age of the truck suggests that the mpg improvements reflect steady technological advances rather than changes in the way trucks are used. The 1992 survey estimates, however, were lower (by a few tenths of an mpg) for model years 1983 through 1986. This may indicate a change in operating or maintenance practices over the five-year period. Whether improvements slowed after 1991 is not possible to tell from these data.

The Federal Highway Administration 1994 estimates for all combination trucks indicated a slight decline in mpg from 5.7 to 5.6 from 1991 to 1993. The most recent estimates, which are based on a revised method, showing a slight increase from 1993 to 1994, from 5.82 to 5.87. Thus, it is not clear whether heavy-truck fuel

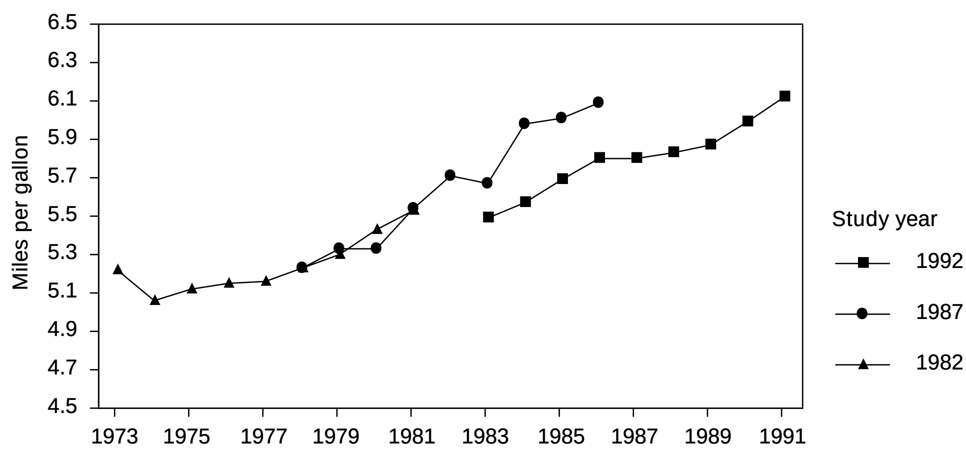
FIGURE 4-5: LIGHT-DUTY VEHICLE FUEL ECONOMY, 1970–94



NOTE: Estimation methods were revised in 1995, making estimates for 1993 and 1994 inconsistent with the historical series.

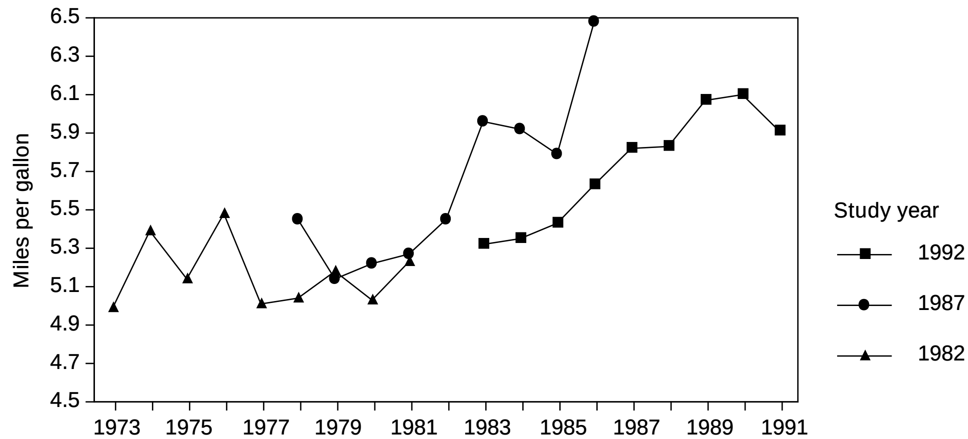
SOURCES: J.D. Murrell et al., Society of Automotive Engineers, "Passenger Car and Light Truck Fuel Economy Trends Through 1980," SAE Technical Series 800853, 1980; J.D. Murrell et al., *Light-Duty Automotive Technical and Fuel Economy Trends Through 1993,* EPA/AA/TDG/93-01 (Ann Arbor, MI: U.S. Environmental Protection Agency, 1993); U.S. Department of Transportation, National Highway Traffic Safety Administration, *Automotive Fuel Economy Program,* 19th Annual Report to Congress, Calendar Year 1994 (Washington, DC: 1995).

FIGURE 4-6: SINGLE-TRAILER COMBINATION TRUCK FUEL ECONOMY, 1973–92 (BY MODEL YEAR)



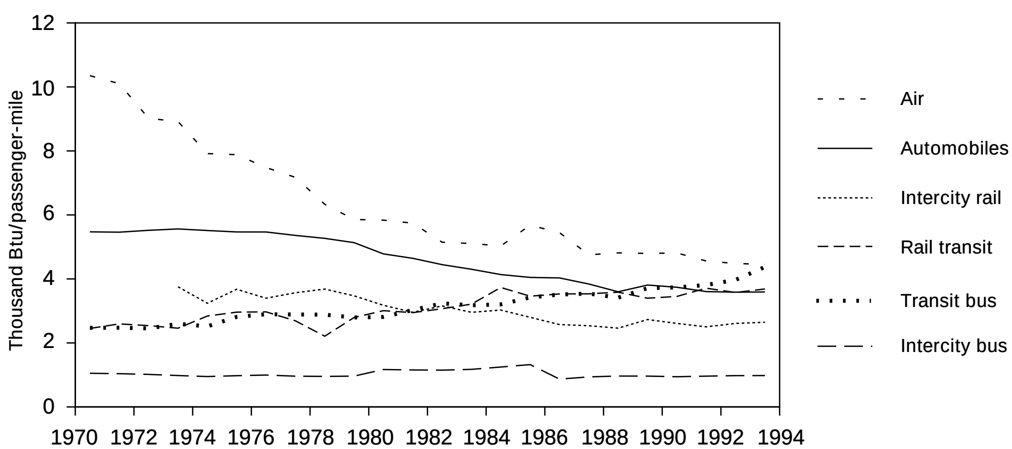
SOURCE: U.S. Department of Commerce, Bureau of the Census, "Truck Inventory and Use Survey," 1982, 1987, and 1992.

FIGURE 4-7: MULTIPLE-TRAILER COMBINATION TRUCK FUEL ECONOMY, 1973–92 (BY MODEL YEAR)



SOURCE: U.S. Department of Commerce, Bureau of the Census, "Truck Inventory and Use Survey," 1982, 1987, and 1992.

FIGURE 4-8: ENERGY INTENSITY OF PASSENGER TRAVEL BY MODE, 1970–93



SOURCE: S.C. Davis, *Transportation Energy Data Book, Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2-15.

economy, which improved by about 20 percent over the past two decades, is continuing to improve or has leveled off.

Trends in energy intensiveness since 1970 reveal three significant phenomena. First, energy per unit of transportation has generally declined, in some cases dramatically (see figure 4-8). For example, the energy intensiveness of commercial air travel was cut by more than 50 percent from 1970 to 1992, falling from 10,351 to 4,482 Btu per passenger-mile. Second, for most modes the rate of improvement in energy efficiency has slowed since the collapse of world oil prices in 1986. Rail freight, however, shows no such deceleration in efficiency gains. Third, dramatic improvements by modes like air passenger and rail freight, combined with increasing energy intensiveness in rail transit and transit bus have produced a convergence of modal energy intensiveness. While substantial differences still remain, modal energy efficiencies differ far less than they did 20 years ago before the first oil crisis. (Davis 1995)

While two or three years are not definitive, the simultaneous stalling of energy efficiency across such dissimilar modes suggests a common cause. The most likely cause is the collapse of oil prices in 1986, when the OPEC cartel abandoned its policy of defending higher prices, and subsequently increased its production of crude oil. The price of oil plummeted; although well above the world oil price before the first price shock of 1973–74, the price was well below the 1974 to 1985 prices (in constant 1987 dollars). (USDOE 1995b, 177)

Motor fuel prices did not change as drastically as oil prices because taxes, refining, and distribution costs comprise the majority of their retail price. Retail gasoline prices, for example, peaked at $2.16 in 1981 (1994 dollars), but are now the same in constant dollars as they were in 1973. Lower prices and stable supplies of oil appear to have signaled the marketplace that further improvements in energy efficiency are not needed.

Efficiency improvements continued well beyond the fall in prices, because of a number of factors including price expectations, government efficiency regulations, the momentum of technological change, and the turnover of the capital stock of transportation equipment. Statistical analyses of oil market responses to price increases and decreases confirm that they have been asymmetric: demand fell more in response to price increases than it rose because of price declines. (Oil demand is perhaps four times as responsive to oil price increases as decreases.) (Dargay and Gately 1994)

If the apparent trend holds up, the stalling of efficiency improvements will mark a significant turning point in world energy markets. The official energy demand projections for OECD countries all assume continued improvements in transportation energy efficiency. The EIA's *Annual Energy Outlook 1995* projects passenger-car and light-truck mpg increasing at the average rate of 1 percent through 2010. Energy use per passenger-mile of air travel is assumed to decline at an average rate of 0.7 percent, while truck and rail freight energy intensities are forecast to decline at about 0.5 percent per year. The International Energy Agency's (International Energy Agency 1994) projections assume similar rates of improvement, as do those of the World Energy Council. (World Energy Council 1995) If these projections prove to be too optimistic, then oil demand will grow more rapidly than expected, as will OPEC's share of the world oil market and, consequently, their market power.

Alternative Fuels

Concerns about the environmental effects of petroleum combustion and the dependence of transportation on oil continue to stimulate interest in alternative fuels. A wide variety of fuels not derived from crude oil are considered alternative or replacement fuels for petroleum under the 1992 EPACT.[4]

At the same time that transportation energy efficiency improvements have stalled, both the use of alternative fuels and the number of alternative fuel vehicles (AFV) are growing. Three

[4] As defined in Section 301 of the Energy Policy Act of 1992 (Public Law 102-486).

federal laws and state and local responses to them are largely responsible for this growth. The 1989 Alternative Motor Fuels Act established a variety of incentives for purchase and use of AFVs and directed federal agencies to purchase AFVs for their fleets.

The CAAA of 1990 required standards for clean fuels, which initially appeared to require the use of alternatives to conventional petroleum fuels. Collaborative research by the automobile and oil industries, however, demonstrated that RFG and diesel fuels could meet the numerical emissions standards specified by the act. The CAAA also allowed the State of California to establish a low-emission vehicle program requiring sales of zero-emission vehicles (for all practical purposes, battery-powered electric vehicles) beginning at 2 percent of all new automobile sales in the year 1998. Other states established a variety of programs encouraging AFVs as a means of meeting their own air quality requirements. As of 1994, at least 13 states have some form of purchase requirements for AFVs in state fleets, and at least 20 have financial incentive programs to promote AFVs. (USDOE 1995c)

In 1992, the EPACT set a national goal of displacement of 30 percent of U.S. petroleum motor fuel use with nonpetroleum fuels by 2010. The EPACT also requires purchases of AFVs by certain covered fleets including federal and state governments, alternative fuel providers, and certain other private fleets to be defined in rulemakings now in progress. A 1993 Executive Order gave the federal government greater responsibility to promote the development and manufacturing of AFVs and increased the federal fleet purchase requirements by 50 percent in 1995 (converging to the original EPACT requirements by 2000) (see table 4-1).

The EPACT requirements and other programs, if carried out, could result in a significant increase in the numbers of AFVs manufactured in the United States and greatly increase the supply and availability of alternative fuels. (USDOE 1995a) Whether the programs will be sufficient to initiate a self-sustaining alternative fuels and vehicles market remains to be seen. If the projections hold up, there will be over 1 million AFVs on the road by the year 2000 and over 5 million by 2005. Although it is not clear which types of AFVs will be selected, it is probable that the mix of vehicles will not be as dominated by a single technology and fuel as today's AFV fleet. Whether AFV plans are pursued as aggressively as the projections indicate depends on advances

Table 4-1: Federal Guidelines or Requirements for Purchase of Alternative Vehicles by Large Fleet Owners

Year	Federal	Federal	State	Fuel providers	Private fleets[b]
	EO	required[a]	required[a]	required[a]	
1993	7,500	5,000	—	—	—
1994	11,250	7,500	—	—	—
1995	15,000	10,000	—	—	—
1996	17,500	25%	10%	30%	—
1997	20,000	33%	15%	50%	—
1998	30,000	50%	25%	70%	—
1999	40,000	75%	50%	90%	20%
2000		75%	75%	90%	20%
2001		75%	75%	90%	20%
2002		75%	75%	90%	30%
2003		75%	75%	90%	40%
2004		75%	75%	90%	50%
2005		75%	75%	90%	60%
2006 on		75%	75%	90%	70%

[a] As called for in the Energy Policy Act of 1992, Section 507.
[b] Can be required up to the specified level.

KEY: EO = Executive Order 12844, Apr. 12, 1993.

NOTE: Numbers indicate number of vehicles; percent indicates percentage of fleet purchases.

SOURCE: Adapted from S.C. Davis, *Transportation Energy Data Book, Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995).

in technology, especially for battery-powered electric vehicles, and consumer acceptance of AFV technologies and fuels.

The most significant result of the CAAA clean fuel requirements has been the development of cleaner gasoline and diesel fuels. Reformulated gasoline, however, contains significant quantities of nonpetroleum constituents, primarily ethanol and methyl and ethyl ethers. These, in combination with oxygenate use for gasoline in areas where carbon monoxide (CO) emissions are a problem and with ethanol use in gasohol, are creating a significant market for nonpetroleum transportation fuels. The CAAA and EPACT programs are creating a small but rapidly expanding market for alternative fuels and vehicles, generating at least some economies of scale in vehicle and fuel production, and fostering advances in technology. How successful these efforts will prove to be in establishing alternative fuels markets in the United States remains to be seen.

TABLE 4-2: USE OF NONPETROLEUM COMPONENTS IN GASOLINE BY U.S. REFINERIES (THOUSANDS BARRELS[a])

Commodity	1994	Percent	As of Oct. 1995	Percent
Fuel ethanol	3,620	6.2%	8,643	9.4%
Methanol	242	0.4%	246	0.3%
MTBE	52,937	90.5%	79,574	86.2%
Other oxygenates	1,676	2.9%	3,876	4.2%
Total oxygenates	58,475		92,339	
Gasoline produced	2,621,006		2,712,672	
Percent oxygenates by volume	2.2%		3.4%	

[a] 1 barrel = 42 gallons.

KEY: MTBE = methyl-tertiary-butyl-ether.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Annual 1994,* DOE/EIA-0340(94)/1 (Washington, DC: 1995), tables 2 and 16; and U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Monthly,* DOE/EIA-0109(95/10) (Washington, DC: October 1995), tables 2 and 28.

Metropolitan areas failing to meet air quality standards for CO have for several years been required to add oxygen-containing compounds, such as ethanol or ethers made from ethanol or methanol to gasoline. The oxygen in oxygenated fuel helps attain more complete combustion, especially during cold months of the year, thereby reducing emissions of CO, a product of incomplete combustion. (Calvert et al 1993; *Automotive Engineering* 1996) Largely as a result of oxygenate requirements for gasoline, use of methyl-tertiary-butyl-ether (MTBE) as a blending component has increased from 100 million to 200 million gallons per year in the early 1980s when it was used solely to enhance octane, to 3.3 billion gallons annually in 1995 (see table 4-2). Production of fuel-grade ethanol, also an octane enhancer (which additionally enjoys an exemption from federal excise tax in some state taxes), has also increased from 80 million gallons annually in 1980 to 2.506 billion gallons in 1995. Most ethanol, however, is blended with gasoline downstream from the refinery to make gasohol. As of October 1995, less than 10 percent of the fuel-grade ethanol produced in the United States was used by refineries to make oxygenated gasoline or RFG. (USDOE 1995h)

The introduction of RFG in January 1995 in response to the clean fuel requirements of the CAAA of 1990 gave additional impetus to oxygenate markets. RFG is required to have an oxygen content of 2 percent by weight, and must also meet limits on vapor pressure and toxic constituents. MTBE and ethanol are the primary nonpetroleum constituents of RFG, but ethyl-tertiary-butyl-ether (ETBE, made from ethanol and butane) and tertiary-amyl-methyl-ether are also candidates. From near zero in December 1994, RFG consumption jumped to almost 2 MMBD in 1995, about 25 percent of total U.S. gasoline consumption in that period (see table 4-3). All but about 15 percent of U.S. RFG demand is satisfied by domestic production.

To date, nonpetroleum components in gasoline constitute a much larger alternative fuels market than that created by all AFVs. RFG (by volume) is comprised of 11 to 12 percent oxygenated components if MTBE is used, 13 to 14 percent if ETBE, and 6 percent if ethanol is the oxygenate. In October 1995, oxygenate inputs to U.S. refineries averaged 3.7 percent of total gasoline product supplied by domestic refineries. In 1995, total use of nonpetroleum constituents in gasoline was expected to amount to about 4.4 billion gallons per year. Because oxygenates have on average about 80 percent of the energy content of gasoline, on a gasoline energy equivalent basis this is about 3.5 billion gallons. This is nearly 10 times the estimated 370 million gallons of gasoline equivalent alternative fuels used by all AFVs in the United States in 1995. (USDOE 1995g[5])

TABLE 4-3: U.S. REFINERY NET PRODUCTION OF GASOLINE BY TYPE (MILLION BARRELS PER DAY)

Type of gasoline	1994	1995
Conventional gasoline	5.93	4.89
Reformulated gasoline	0.24	1.99
Oxygenated	1.43	0.91
Total	7.60	7.79

NOTE: 1995 does not add due to rounding.

SOURCES: U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Monthly,* DOE/EIA-0109(96/02) (Washington, DC: February 1996), "U.S. Year-to-Date Supply, Disposition, and Ending Stocks of Crude Oil and Petroleum Products, January-December 1995"; and DOE/EIA-0109(95/02) (Washington, DC: 1995), table 3, "1994: Products Supplied."

Historical Trends in Transportation Energy Use

When examining any subject in detail there is always the danger of losing sight of the big picture. What are the predominant trends in transportation energy use? Are conditions improving or worsening, and why? This section examines the gross trends in energy use by transportation between 1972 and 1993 with the aim of providing a better understanding of the underlying factors.

The analysis relies on a straightforward mathematical technique called Divisia Analysis, an approach discussed in greater detail in the *Transportation Statistics Annual Report 1995.* (USDOT BTS 1995) The approach makes it possible to decompose trends in a single variable, such as total energy use, into changes in activity levels, changes in the mix of activities, and changes in energy use per unit of activity of each type. Assuming accurate data, the approach makes it possible to assess how much of the change in energy use, for example, is due to the growth of transportation activity, shifts in the modal structure of transportation, and changes in energy efficiency (energy use per passenger- or ton-mile).

Gains in energy efficiency have been much smaller than expected, on the order of 15 to 20 percent for the transportation sector. As a result, transportation energy use was 45 percent higher in 1994 than in 1970. Most of the efficiency gains come from improvements in energy use per vehicle-mile for passenger cars, light trucks, and aircraft. Improved load factors have been key to the enormous efficiency gains of rail freight and commercial air passenger traffic, but declining vehicle occupancy rates have worked against efficiency gains in highway travel. In general, changes in modal structure have played a lesser role but the trend has been toward the more energy-intensive modes.

[5] Singh and McNutt (1993) have taken the analysis a step further to consider all petroleum inputs to the production of oxygenate feedstocks. They find that the total oil requirements for MTBE-based RFG are about 10 percent lower than those of conventional gasoline.

► What Is Divisia Analysis?

The Divisia technique is a mathematical method for analyzing and allocating changes in a variable over time into changes in other variables of which it is composed. For Divisia Analysis to be appropriate, the variable to be analyzed must be expressed as the sum of products of its components. For example, total transportation energy use can be expressed as the sum of the energy use of the various modes of transport. The energy use by any mode can be expressed as the product of its activity level and the rate of energy use per unit of activity. For example, passenger car energy use equals vehicle-miles traveled multiplied by the average number of gallons consumed per mile (the inverse of mpg).

The design of the Divisia Analysis depends partly on the nature of the phenomenon to be analyzed and partly on the data. For example, passenger car energy use can also be expressed as the product of three factors: (passenger-miles) x (passenger-miles/vehicle-mile) x (gallons/vehicle-mile). In this case, the Divisia method can measure the effect of changes in vehicle occupancy, as well as changes in modal structure and vehicle efficiency. Energy trends can be analyzed in somewhat greater detail than emissions (see box 4-1).

When energy trends for the entire transportation sector are analyzed, passenger and freight activity are measured in dollars of expenditure. For separate analyses of passenger and freight modes, the more natural units of passenger-miles and ton-miles are used. Although information on vehicle occupancy rates and load factors is often of uncertain quality, it is judged to be reasonably accurate for discerning trends in all areas except truck freight. Air passenger load factor estimates are very accurate. Thus, it is useful to examine energy trends at the level of individual modes in order to see how efficiency trends and load factors have influenced total energy use. Energy

Box 4-1: How To Interpret the Divisia Method Figures

The mathematical technique known as Divisia Analysis is used here to identify the changes in total transportation energy consumption arising from:

- growth in transportation activity (e.g., passenger-miles, ton-miles, and vehicle-miles traveled);
- changes in rates of transportation energy consumption per unit of transportation activity; and
- changes in the structure of transportation activity (e.g., the relative share of activity by mode).

The results of Divisia Analysis are shown in the figures in the section on Energy Trends. Each figure has two lines: the "actual" line showing total transportation energy consumed and the line showing energy use if 1972 conditions had continued. The difference between the lines is the net effect of changes over time in rates and modal structure. The bars in the figures show how much changes in rates and modal structure contributed to the net effect in a given year. Bars above the horizontal axis push the actual line upward by an amount equal to the length of the bar, while the bars below the axis pull the actual line down by an amount equal to the length of the bar. For example, in 1993 improvements in energy efficiency saved 4.3 quads, while shifts to more energy-intensive modes tended to increase energy use by 0.9 quads. Hence, the net effect was to improve energy efficiency by 3.4 quads compared with what it otherwise would have been had 1972 conditions continued.

For the included factors, Divisia Analysis shows only how much the factor contributes to the transportation trend and not what causes the factor itself. The Divisia method is a tool for dissecting transportation trends over time and suggesting areas for further study. In addition to energy use, Divisia Analysis also can be used to examine changes in emissions from transportation (see chapter 7).

trends are examined in six different categories: 1) total transportation, 2) passenger travel, 3) freight transport, 4) highway passenger travel, 5) air passenger travel and, 6) rail freight. Because key data items for 1994, including air passenger-miles, were not available at the time of writing, the energy Divisia Analysis extends only through 1993.

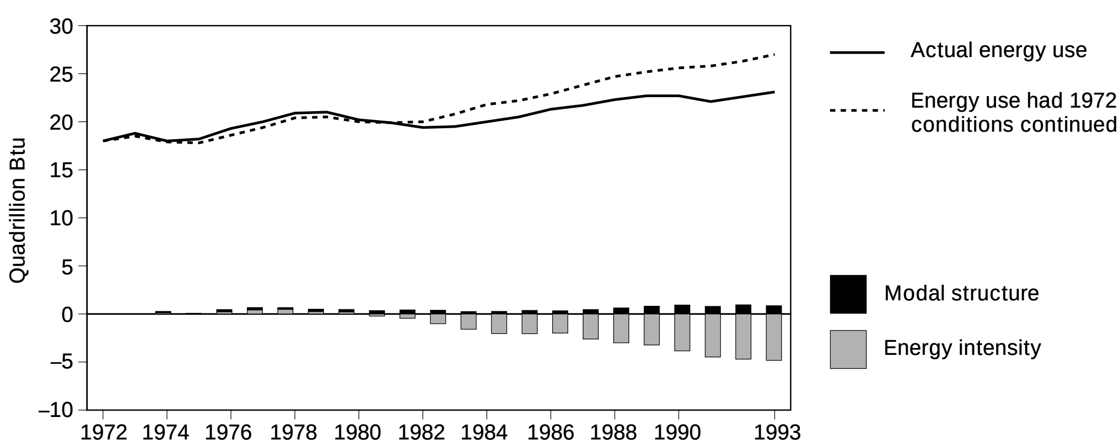
▶ Energy Trends

From 1972 to 1993, transportation energy use increased by 28 percent at an average annual rate of 1.3 percent per year. Oil price shocks in 1974, 1980, and 1991 caused the only periods of decreasing energy use (see figure 4-9). The trend line projects energy use had no change occurred in energy use per dollar of transportation expenditure. Efficiency improvements and changes in modal structure also had an effect.

Energy use attributed to changes in the modal structure of transportation in the United States increased slightly from 1972 through 1993: the cumulative effect over the past two decades was less than a quadrillion Btu (about 4 percent). Changes attributed to energy intensity measured in passenger- and ton-miles within modes, however, reduced energy consumption with a cumulative effect over 20 years of 4.8 quads (just over 20 percent). Modal energy intensiveness increased until 1977, even though the first oil price shock began late in 1973. The four-year delay shows that it takes time to change the capital stock of transportation vehicles. The combined, cumulative effect of changes in energy intensity and modal structure through 1993 reduced transportation energy use by 4 quads, or about 17 percent (see figure 4-9.)

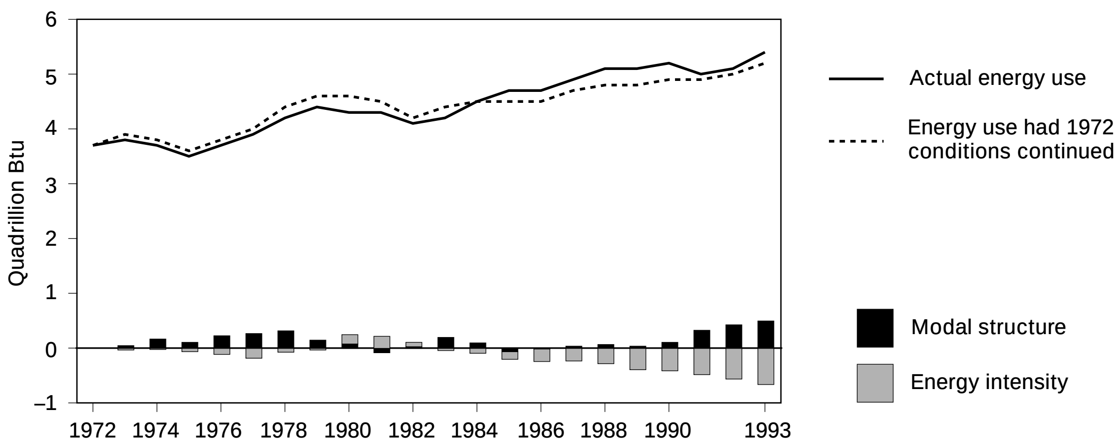
Separate Divisia Analyses of passenger and freight energy use reveal contrasting trends. For passenger travel, the projection showed a 50 percent increase from 1972 to 1993, but the real increase in energy use was only half that amount. Projected freight energy use, on the other hand, is just slightly lower than actual energy use (see figure 4-10). In both cases, changes attributed to modal structure increased

FIGURE 4-9: **CHANGES IN TRANSPORTATION ENERGY USE, 1972–93**



SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.18.

FIGURE 4-10: **CHANGES IN FREIGHT TRANSPORTATION ENERGY USE, 1972–93**



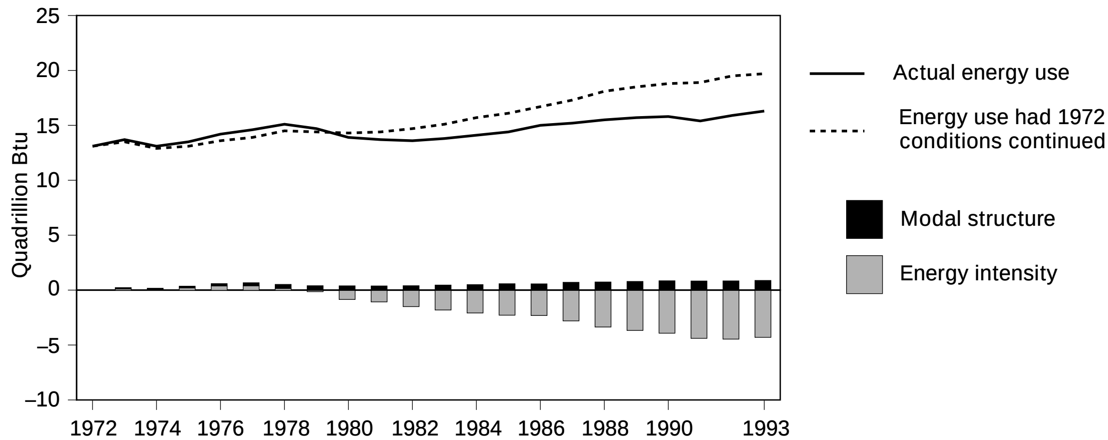
SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.22.

energy use. For freight, shifts to more energy-intensive modes, such as highway and air, outweighed within-mode efficiency gains. In the case of passenger travel, modal efficiency gains, notably in air and highway travel, outweighed structural effects by almost 5:1. It may be significant that energy efficiency gains in all modes of passenger transport, which had been increasing every year since 1977, decreased in 1993 (see figure 4-11). It is premature to call this a trend, but it agrees with other indicators that the energy efficiency of transportation in the United States is no longer improving.

The Divisia Analyses for highway and air transport break out vehicle efficiency gains from changes in occupancy, or load factor (see figures 4-12 and 4-13). The effect of declining vehicle occupancy rates is clearly evident in the highway mode. The Nationwide Personal Transportation Survey (USDOT FHWA 1993) found that the average number of persons per vehicle-mile fell from 1.9 in 1977 to 1.7 in 1983, and again to 1.6 in 1990. This alone accounts for a 20 percent increase in vehicle-miles over the 13-year period. For work trips, vehicle occupancies are approaching the lower bound of 1.0, having declined from 1.3 as recently as 1983, to 1.1 in 1990. In contrast, aircraft load factors (average passenger-miles per seat-mile) have been increasing, as any frequent traveler knows. Whereas experts previously believed that load factors of two-thirds were a practical limit, industry experts now predict load factors in excess of 70 percent after 2010. (Boeing Commercial Airplane Group 1995, Douglas Aircraft Co. 1995) Technological improvements and larger aircraft have been still more important, however, accounting for 70 percent energy efficiency gains of air passenger travel. Had it not been for such gains, air travel would have used more than twice as much energy as it did in 1993: 4.7 quads (instead of 2.3 quads), almost as much as all freight modes combined.

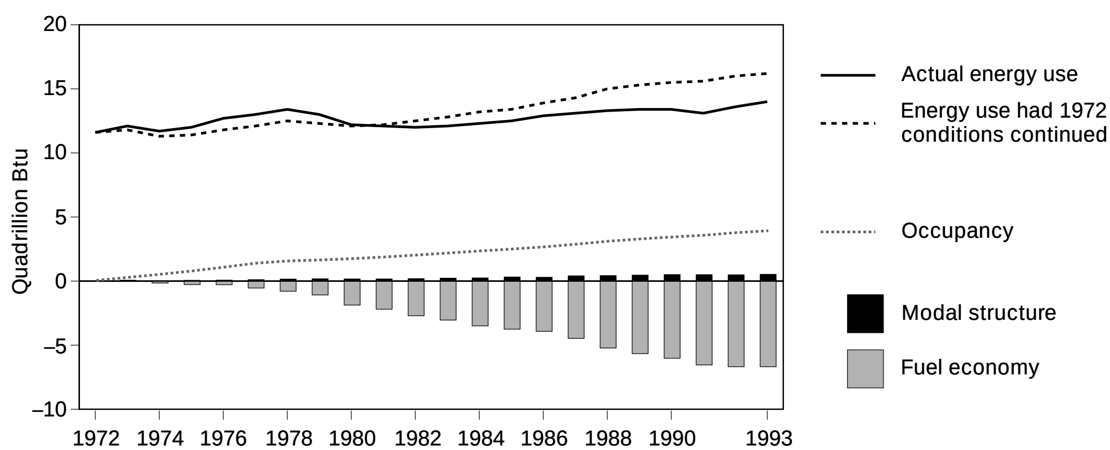
Railroad freight operations also scored enormous efficiency gains, more than halving energy use per ton-mile (see figure 4-14). Unlike the passenger modes, improvements in load factors (ton-miles per car-mile) were the most

FIGURE 4-11: CHANGES IN PASSENGER TRANSPORTATION ENERGY USE, 1972–93



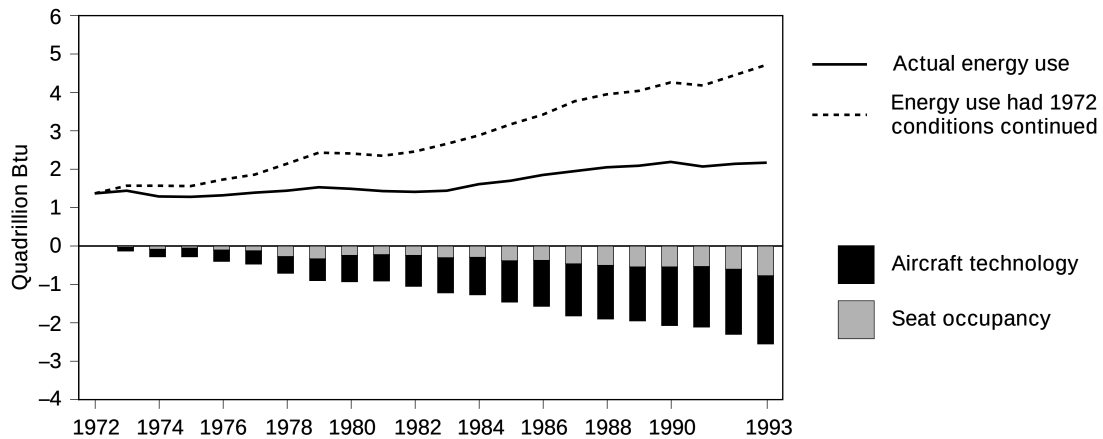
SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.19.

FIGURE 4-12: CHANGES IN HIGHWAY PASSENGER TRANSPORTATION ENERGY USE, 1972–93



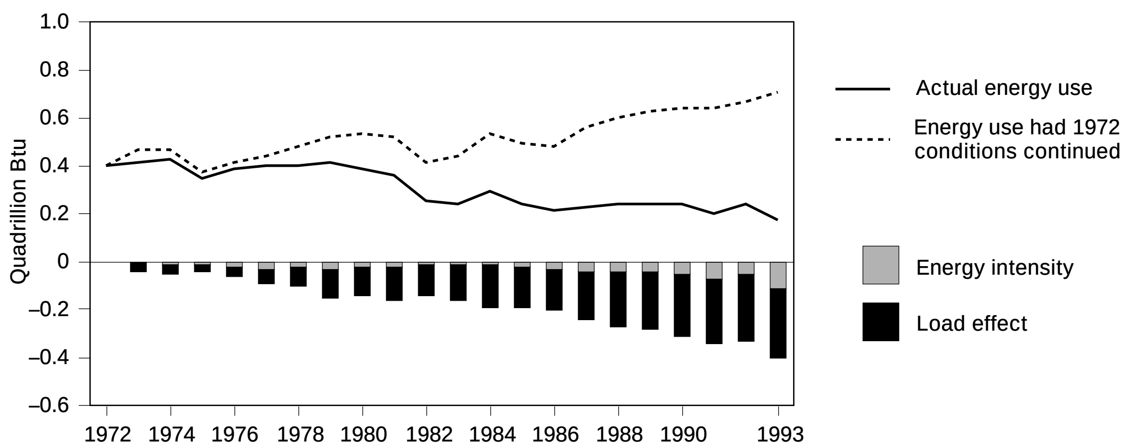
SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15,* ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.20.

FIGURE 4-13: **CHANGES IN AIR PASSENGER TRANSPORTATION ENERGY USE, 1972–93**



SOURCE: S.C. Davis, *Transportation Energy Data Book*, *Edition 15*, ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 2.21.

FIGURE 4-14: **CHANGES IN RAIL FREIGHT TRANSPORTATION ENERGY USE, 1972–93**



SOURCE: David L. Greene and Yuehui Fan, Transport Energy Efficiency Trends, 1972–1992 (Oak Ridge, TN: Oak Ridge National Laboratory, December 1994).

important factor, accounting for three-quarters of the overall reduction in rail freight energy use. Technical efficiency gains are understated by the Divisia method, which compares current energy use per car-mile with that in 1972. With much greater car loadings, energy use per car-mile should increase. Since this is not taken into account, true efficiency improvements are underestimated.

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CHAPTER FIVE

THE STATE OF TRANSPORTATION STATISTICS

CONGRESS CREATED THE BUREAU OF TRANSPORTATION STATISTICS (BTS) TO ESTABLISH A POLICY-RELEVANT KNOWLEDGE BASE FOR DECISIONMAKERS, AND TO INFORM THE PUBLIC ABOUT TRANSPORTATION AND ITS CONSEQUENCES. IN CALLING ON BTS TO REPORT ANNUALLY ON THE STATE OF THE TRANSPORTATION SYSTEM, CONGRESS ORDERED BTS TO PROVIDE "DOCUMENTATION OF THE methods used to obtain and ensure the quality of the statistics presented in the report, and recommendations for improving transportation statistical information." In response, BTS first examined ways to identify needed improvements to the transportation knowledge base. *Transportation Statistics Annual Report 1994* highlighted the needs expressed in congressional mandates, reports of the National Academy of Sciences, and initial customer responses to BTS products. In 1995, BTS published a comprehensive strategy of data-collection and analysis activities for meeting the initial set of needs. In this 1996 edition, BTS reviews the information needs identified to date and the progress made toward meeting those needs.

BTS and its partners are working on a wide range of data-collection, analysis, and dissemination activities to help answer the many questions of decisionmakers.

What We Need To Know About Transportation

BTS seeks to create a knowledge base that serves decisionmakers throughout the transportation community, including federal, state, and local governments, private industry, and quasi-public institutions. Components of the knowledge base are defined by:

- Congressional mandates for specific information, which are summarized in table 5-1;
- Comprehensive assessments in which information needs and resources are cataloged, gaps between the needs and resources are identified, and strategies for filling the gaps are proposed. (See, for example, USDOT (1969) and TRB (1992)); and
- Customer responses to BTS products.

► Extent and Use of the Transportation System

There must be a common understanding of what the transportation system comprises and how the system is used before decisionmakers' questions about the performance or consequences of transportation can be answered. How widespread are transportation facilities? How frequent are transportation services? How are these facilities and services interconnected? How many vehicles go how far? How many people and how much freight move over the system? How are these movements distributed by mode, in time, and geographically? There is no one answer to these questions. The answers vary by mode and intermodal combination, the geography and temporal aspects of travel and goods movement, and the characteristics of the traveler or shipment.

Modal distinctions are very important in transportation because the system is ultimately

TABLE 5-1: MANDATED TOPICS FOR DATA COLLECTION AND ANALYSIS

Topic	Source
Technological, statistical, economic, and other information relevant to domestic and international transportation	DOT Sec. 4a (49 USC 301(4))
Intermodal passenger volume and geography of intermodal flows	ISTEA Sec. 5002 (49 USC 301 note)
Intermodal freight volume and geography of intermodal flows	ISTEA Sec. 5002 (49 USC 301 note)
Air carrier passenger volume and geography of air passenger flows	FAA Sec. 311 (49 USC 329(b))
Public and private investment in intermodal transportation facilities and services	ISTEA Sec. 5002 (49 USC 301 note)
Motor carrier financial, operating, and safety conditions	ICC Sec. 103 (49 USC 14123)
Productivity in various parts of the transportation sector	ISTEA Sec. 6006 (49 USC 111)
Traffic flows	ISTEA Sec. 6006 (49 USC 111)
Travel times	ISTEA Sec. 6006 (49 USC 111)
Vehicle weights	ISTEA Sec. 6006 (49 USC 111)
Variables influencing travel behavior, including choice of transportation mode	ISTEA Sec. 6006 (49 USC 111)
Travel costs of intracity commuting and intercity trips	ISTEA Sec. 6006 (49 USC 111)
Availability of mass transit and the number of passengers served by each mass transit authority	ISTEA Sec. 6006 (49 USC 111)
Frequency of vehicle and transportation facility repairs and other interruptions of transportation service	ISTEA Sec. 6006 (49 USC 111)
Accidents	ISTEA Sec. 6006 (49 USC 111)
Collateral damage to the human and natural environment	ISTEA Sec. 6006 (49 USC 111)
Condition of the transportation system	ISTEA Sec. 6006 (49 USC 111)

SOURCES: DOT = Department of Transportation Act of 1966 (Public Law 89-670); FAA = Federal Aviation Administration Act of 1958 (Public Law 85-726); ICC = Interstate Commerce Commission Termination Act of 1995 (Public Law 104-88); ISTEA = Intermodal Surface Transportation Efficiency Act of 1991 (Public Law 102-240).

made up of motor vehicles, airplanes, and other transportation equipment carrying people and goods over roads, rails, and waterways, through the air, and, in the case of some goods, through pipelines. These components have very different physical and economic characteristics that must be understood before the integration of these components into an intermodal transportation system can be contemplated.

Geographic and temporal variation are important in the transportation equation. Transportation exists because economic and social activities are spread across the land. The distribution of population and economic activity provides the basic demand for transportation facilities and services. The perennial transportation problem—congestion—derives from too many people wanting to arrive at or depart from the same place at the same time.

The characteristics of freight being shipped and travelers are also important. Knowledge about who uses the transportation system is a prerequisite to understanding why demand for transportation facilities and services is evolving, what markets exist for new facilities and services, and who directly benefits from changes in the transportation system. Knowledge of trip purposes, which place very different demands on the system, is also of concern: speed and reliability considerations are very different for emergency medical transport, the routine daily trip to work or school, and discretionary weekend travel. Different types of cargo also place diverse demands on the system. For example, carbon in the form of coal moves in trainloads and shiploads; in the form of diamonds, it moves in briefcases on airplanes and in cars.

The combination of modal distinctions, temporal and geographic variation, and traveler and shipment characteristics means that a great amount of data is required to understand the extent and use of transportation. In most other fields, relatively small samples are sufficient to measure activity. Geographic variation is often adequately represented by sampling from each of the 50 states. In transportation, the flows of people and goods within and among the states require a sample large enough to fill a matrix of 2,500 cells (50 states of origin by 50 states of destination). This is why BTS-sponsored data collections such as the American Travel Survey (ATS) and the Commodity Flow Survey (CFS) are among the largest components of the Economic Census.

► Condition and Performance of the Transportation System

The transportation system's ability to serve travelers and shippers can be measured in physical terms, economic terms, and in terms of unintended consequences. Physical terms refer to two key questions: Does the system get people where they want to go, when they want to get there? How well does the delivery system for goods work? Specifically:

- Do the transportation facilities and services cover existing and anticipated origins and destinations? Quite simply, can you get there from here? How direct or circuitous is the route?
- Does the transportation system have enough facilities, vehicles, and services to serve demand? Is there enough capacity to handle predictable surges in demand, such as holiday travel? Is there enough capacity to handle unexpected surges in demand, such as responses to military threats overseas or natural disasters at home?
- How timely and reliable is the transportation system?
- How comfortable is the trip?

These questions reflect a user perspective rather than the traditional view of a transportation service provider, reflecting the contemporary realization that customer satisfaction is essential to continued survival of both public and private enterprises.

► Economic Dimensions of Transportation

Transportation is both a major consumer and an enabler of economic activity. To understand both aspects, it is important to ask:

- What proportion of the national economy does transportation comprise? How has that proportion changed over time?
- How much do transportation providers spend on material and other inputs from each sector of the economy? How has the quality of transportation service delivered per dollar spent changed over time?
- How important is transportation as a source of employment? What kinds of skills are needed in the transportation sector? How has the quality of transportation service delivered per hour or dollar of labor changed over time? What are the sources of changes in productivity of transportation workers?
- How much does each sector of the economy spend on transportation? How do these expenditures vary over time and by region? How much does transportation contribute to the total cost of a commodity or service? Is transportation being substituted for other costs of production, such as warehousing? To what extent do the availability and cost of transportation affect the labor force?
- How much does each level of government spend on transportation? How much do government expenditures reduce transportation costs for businesses and households? How much do government-supported transportation facilities and services contribute to economic output overall, economic growth, and international competitiveness?

The financial condition of transportation service providers is also relevant. Even in a largely deregulated environment, the financial health of a service provider affects that provider's ability to maintain and improve safety, meet contractual obligations to customers, and purchase more efficient or effective equipment. Financial health is not limited to carriers; for instance, the financial viability of private toll road authorities has become a recent concern.

► Unintended Consequences of Transportation: Safety, Energy Use, and the Environment

Most of the preceding questions involve the intended consequences of transportation: to support economic and social interaction at a minimum financial cost. More hotly debated areas involve transportation's unintended consequences for safety, energy use, and the environment.

- How likely are travelers or bystanders to be harmed or killed in an accident? How does the risk vary by type of trip, mode of travel, type of facility, season, or time of day?
- How likely are shipments or luggage to be damaged, lost, or stolen?
- How much energy is consumed overall and by different modes of transportation? What types of energy are being consumed? How much of that energy is from foreign sources?
- How much damage is done to air quality? How much damage is done to water quality? How much noise and other pollution are created?
- To what extent are wetlands and other sensitive human and natural environments disrupted by transportation facilities and activities?
- What are the economic costs of accidents and environmental damage? Are these costs reflected in the prices paid for transportation?

Can We Answer the Questions of Decisionmakers?

To answer the questions raised by decisionmakers about transportation, it is necessary to turn a question into a measurable concept, fill the measure with data, and use models for conditions that cannot be measured directly or that need to be forecast. The ability to produce credible and timely answers to a question varies significantly by topic, mode, and geographic detail.

▶ Extent and Use of the Transportation System

Prior to passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, the national picture of the transportation system was limited to very coarse, mode-specific maps of facilities and estimates of total vehicle activity by type of vehicle. An integrated, geographically detailed picture of transportation facilities and activity across all modes had not been compiled since the mid-1970s.

Since 1991, BTS has compiled a fairly extensive picture of the components of the transportation system and where they are located. The transportation community is just now beginning to understand how and where the transportation system is used. The state of this knowledge can be divided into four basic layers of information: facilities, services, flows, and context.

- *Facilities data* include the location, connectivity, and use of highways, railroads, airports and air space, ports and waterways, and pipelines. Good data are available on the location and connectivity for about 10 percent of the nation's highways, covering the Interstates and other major roads, most railroads, all rail transit facilities, all public use airports, and ports and all navigable waterways. Facility-specific use data are available for railroads, ports and waterways, airports, and a sample of highways. Data on the use of specific railroad segments can be estimated. The location of truck and rail terminals are known, primarily for those identified by states when defining intermodal connector roads to the National Highway System, but little is known about the use of those facilities. There is only very coarse information about the location, connectivity, and use of pipelines.
- *Services data* include the geographic domains of carriers and the amount and type of service provided within those domains. Data on where commercial airlines and long-distance water carriers operate and what service they provide are available. The ownership and trackage rights of railroads for each part of the rail network are known, but relatively little is known about the levels of service provided on each segment. The Department of Transportation is just now beginning to plot the location of public transit and intercity bus service. Geographic knowledge of truck and intercity bus operations is very limited, and pipeline data are available at best for multistate regions.
- *Flows data* include freight, passenger, and vehicle movements. The CFS covers most domestic freight activity, but must be supplemented by additional information on international, farm, and government shipments to obtain a complete picture. The surface transborder part of information on international movements is provided by BTS through the Census and Customs Bureaus. The ATS will provide information on long-distance passenger flows of U.S. households, but will also require supplements to identify the domestic travel of foreign visitors. Commercial aircraft and ship movements are tracked in great detail, but very little is known about the origin-destination patterns of motor vehicles.
- *Context data* establish the geographic context in which transportation exists including: political boundaries and other major features that help to physically locate transportation; the distribution of population and economic activity that generate transportation activity; and the distribution of environmental conditions and human activity affected by trans-

portation. Much of the population and economic context is provided by the Decennial Census of Population and Housing, which collects a wealth of demographic and economic characteristics of residents at a neighborhood scale. Since the decennial census long form includes questions on place of work, demographic and economic characteristics of workers at their place of work can also be mapped at the neighborhood scale. This provides the only nationwide source of information on economic activity below the county level. Extensive data on land uses and environmental conditions are available at the local level, but are not always comparable from one locality to the next. Definitions of some environmental conditions, such as wetlands, are the subject of extensive debate at both national and local levels.

There are both individual gaps in geographic information on the extent and use of transportation and a lack of consensus on the number of motor vehicles operated in the United States and the distance those vehicles operate. Most commonly cited motor vehicle statistics on the number of vehicles and how far they travel are provided by the states to the Federal Highway Administration and published in *Highway Statistics.* The National Highway Traffic Safety Administration uses alternate numbers from R.L. Polk, Inc. (USDOT NHTSA 1995) The Bureau of the Census also used R.L. Polk data for the Truck Inventory and Use Survey (TIUS). Accurate counts of vehicles by type of vehicle and valid estimates of their travel are essential for understanding changes in travel, accident rates and safety risks, fuel consumption rates, tax burden, and air pollution emissions and other environmental concerns.

► Condition and Performance of the Transportation System

The federal government has produced many reports on the condition and performance of highways, public transit, aviation, and waterways. Certain aspects of system performance, such as on-time statistics for airlines, are available with great geographic and carrier specificity. Extensive work needs to be done, however, to develop effective measures of mobility, accessibility, and congestion.

► Economic Dimensions of Transportation

As indicated in chapter 2, remarkably little is understood about transportation as a consumer of economic resources. A joint program of BTS and the Bureau of Economic Analysis to establish a Transportation Satellite Account will for the first time provide effective measures of the full scope of transportation in the economy. The project will also provide robust answers to questions such as: what contribution does transportation make to the cost of specific goods and industries, and how does that contribution vary over time?

A key element in the Transportation Satellite Account is business use of motor vehicles and aircraft not belonging to for-hire motor carriers or airlines. We know from the TIUS that the total mileage traveled by commodity-carrying trucks is divided roughly equally between trucks belonging to for-hire motor carriers and trucks in other businesses. The TIUS links vehicle activity of trucks, vans, and mini-vans to specific types of industries. There are no equivalent data to identify the number of automobiles, station wagons, and buses used in either for-hire transportation or other business use, nor how much activity can be attributed to each type of industry. Similarly, there is relatively little information about industry-specific use of corporate aircraft and other forms of general aviation. Data on motor vehicles can be obtained by expanding the TIUS to include automobiles, station wagons, and buses. Surveys of general aviation by the Federal Aviation Administration also, in theory, could be expanded to measure business use of aircraft by type of business. The resulting data on physical use could then be used to estimate the economic consumption of motor vehicles and general aviation that is otherwise underrepresented in the input-output tables that describe the structure of the national economy.

While progress is being made on understanding transportation as a consumer of economic resources, significant uncertainty remains about transportation as an enabler of economic activity and a contributor to economic growth. Part II of the *Transportation Statistics Annual Report 1995* included an extensive review of the current knowledge and identified areas for further research to answer questions such as:

- How can the output of transportation be measured in a way that reveals whether inputs of labor and capital are being used efficiently? Is it possible to control for changes in the quality of transportation output when productivity is measured over time?
- How can the capital stock of transportation be measured to determine the value of investments and whether that value is being maintained over time?
- How many jobs are created by expenditures for construction by mode of transportation and type of project?
- How much does transportation spending contribute to national economic growth? Does the type of spending matter? Do restrictions on transportation affect national economic growth?
- How much do transportation spending and regulation affect regional economic growth? Can growth be channeled in areas of need or away from areas where growth is not desired?

Unintended Consequences of Transportation: Safety, Energy Use, and the Environment

Chapters 3 and 4 of this report highlight the current state of knowledge on safety and energy consumption aspects of transportation, while Part II features the environmental consequences of transportation. A common theme of these diverse safety, energy, and environmental subjects is the critical need for robust estimates of the size of the vehicle fleet and the amount of vehicle travel and ton- and passenger-miles by mode. Other data needs include:

- Measures of in-use fuel economy by type and age of highway vehicles. Since the Department of Energy's Residential Transportation Energy Consumption Survey stopped collecting gasoline diary data, there have been no statistics on in-use fuel economy.
- The composition of gasoline sold in the United States (i.e., the proportion of nonpetroleum components, especially alcohols, ethers, and oxygenates, in gasoline).
- A national inventory of land used for transportation infrastructure by type of infrastructure and type of land (e.g., agricultural lands and wetlands).
- Methods to assess transportation's indirect land-use impacts.
- Some measure of the accuracy of emissions statistics, and a method of breaking out transportation and nontransportation (e.g., chain saws and lawnmowers) mobile sources.
- Estimates of noise generation and affected population on a national scale.
- An assessment of the road dust issue. Are roads really the major source of fine particu-

lates? Is road dust the major source of human exposure to fine particulates? How do the impacts of road dust vary depending on its constituents?

- Measures of habitat impacts, such as habitat fragmentation and destruction, and noise and pollution impacts, at a national scale.
- National assessments of water quality impacts of transportation facilities. This would primarily include runoff from roads and other infrastructure, and groundwater.

The BTS Program for Meeting Statistical Needs

BTS and its partners are working on a wide range of data-collection, analysis, and dissemination activities to help answer the many questions of decisionmakers. The Bureau's major partners include its sister operating administrations in the Department of Transportation; other federal agencies concerned with transportation, statistics, and geographic data; and several private sector organizations.

The Bureau's major data-collection efforts to date are the ATS, the CFS, and the Surface Transborder Freight Data program. These efforts, all conducted through the Bureau of the Census, provide basic data on who and what moves among domestic origins and destinations and across the nation's borders. BTS will update the ATS and the CFS every five years, and expand the monthly Surface Transborder Freight Data program to establish a more complete picture of the domestic transportation of international trade. BTS will also supplement other parts of the quinquennial Economic Census to measure the relationships between vehicle activity and the economy.

BTS is expanding its analytical efforts from the *Transportation Statistics Annual Report* to special studies of transportation activity and of the relationships between transportation and the economy. Transportation activity studies include analyses of the data generated by the ATS, the CFS, and the Surface Transborder Freight Data program, in particular to relate those data to other programs such as the Nationwide Personal Transportation Survey, the decennial census, Waterborne Commerce of the United States, and the Rail Waybill Data. With respect to the economy, BTS has initiated a joint effort with the Bureau of Economic Analysis to establish a Transportation Satellite Account.

Providing the transportation community with ready access to authoritative and accurate information about transportation is a key part of the Bureau's mission. Its program is designed to meet continuing growth in demand for products and services within an environment of constrained resources. In its first three years, BTS created and distributed over 100,000 CD-ROMs, printed reports, maps, and other products to a wide variety of users.

Exploiting the potential of electronic media is an important BTS strategy for efficiently offering an expanded range of services and products to its public and private customer base. For example, the BTS Internet Home Page (www.bts.gov) offers ready access to BTS products and transportation information sources. BTS also makes its information and data from the Department of Transportation and other federal agencies available through CD-ROMs. The recently established Office of Airline Information within BTS sped up the process of releasing quarterly passenger origin-destination data. Airlines on-time performance data by city-pair is now widely available to the public through the Internet.

Demand for the mapping and data integration capabilities of the Bureau's Geographic Information Systems (GIS) Center is also growing. The GIS Center will integrate the results of the Commodity Flow Survey and the American Travel Survey with facility and service data, and develop new techniques to represent visually the complex flows identified in those surveys. The GIS Center is continuing to expand its data coordination activities to meet the requirements of Executive Order 12906, *Coordination of Geographic Data Acquisition and Access: The National Spatial Data Infrastructure*.

The restructuring of some federal transportation programs have led to reassignment of data-collection responsibilities to other agencies. The Office of Airline Statistics in DOT's Research and Special Programs Administration is now the Office of Airline Information in BTS. The Interstate Commerce Commission (ICC) was terminated at the end of December 1995. ICC's railroad data programs were transferred to a new DOT entity, the Surface Transportation Board. Motor carrier registrations and insurance oversight were transferred to the Federal Highway Administration. The quarterly and annual reporting of financial and operating data by motor carriers was transferred to BTS.

Another Commerce Department entity, the U.S. Travel and Tourism Administration (USTTA), is scheduled for termination in 1996. USTTA administered programs to count air passengers by nationality and measure travel and spending patterns of foreign visitors to the United States through an on-board survey during international flights. Short-term provisions have been made to continue these programs following termination of USTTA, but a longer term solution has not yet been developed.

Institutional uncertainty is not limited to the future of the Bureau's partners. All authorizations for programs under ISTEA—including the core funding of BTS—expire at the end of fiscal year 1997. Debate about reauthorization is occurring at a time when federal-state relationships are being seriously reevaluated. Proposals to transfer more functions to states, localities, and the private sector will not alter the importance of national data programs, such as those run by BTS, to the broad transportation community. Indeed, additional data-collection and analysis programs may be necessary to serve the informational needs of state, local, and private sector decisionmakers more directly. BTS is considering several issues:

- BTS has focused its initial data-collection efforts on large-scale surveys that provide five-year benchmarks. What types of indicators and additional data sources should BTS develop to track monthly or quarterly changes in transportation and to support short-horizon decisionmaking?
- How can BTS expand its efforts to make federal data more relevant and useful to state and local transportation agencies?
- BTS has attempted to serve the transportation community through a small, Washington-based staff relying heavily on the Internet. What other models for the delivery of information and related services should be considered, such as the state data centers sponsored by the Bureau of the Census?
- How can BTS work with the transportation and trade communities to develop new techniques and technology to collect, analyze, and disseminate data?
- How should federal data programs be reorganized as decisionmaking shifts among levels of government and between the public and private sectors? How can reporting burdens on the states, localities, and private sector be reduced without jeopardizing our ability to collect and use information needed to articulate the importance of transportation?

These questions will be explored through the reauthorization process in 1997.

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Part II

Transportation and the Environment

ENVIRONMENTAL IMPACTS OF TRANSPORTATION

SINCE THE APPLICATION OF STEAM POWER TO SHIPS AND LOCOMOTIVES IN THE EARLY 19TH CENTURY, MOTORIZED TRANSPORT HAS HAD AN INFLUENCE ON NEARLY EVERY ASPECT OF SOCIETY, FROM THE ORGANIZATION OF ECONOMIC ACTIVITIES, TO THE GEOGRAPHY OF CITIES, TO THE PATTERNS OF SOCIAL LIFE. ITS IMPORTANCE CAN BE GAUGED BY THE FACT THAT, AS NOTED IN CHAPTER 2, TRANSPORTATION accounts for about one-ninth of the U.S. economy measured in terms of gross domestic product (GDP). Although transportation is vital to the U.S. economy and an indispensable part of contemporary society, it also generates undesirable byproducts that adversely affect environmental quality and human health. Emissions from transportation vehicles and the production and handling of fuels are two of the leading causes of air quality problems. Carbon dioxide (CO_2) emissions from transportation-related combustion of fossil fuels are increasing the concentration of greenhouse gases, which threatens to alter the earth's climate. Motor vehicles and airplanes are major sources of undesirable noise in metropolitan areas. Discarded motor vehicles are a significant source of solid waste. Crude oil and gasoline leaks and spills pollute water and groundwater resources Moreover, transportation infrastructure not only directly uses land, thereby impacting habitats for flora and fauna, but also

Environmental policies have been quite successful in addressing some impacts associated with increased transportation, while in other cases the results have fallen short of expectations.

supports the transformation of rural land to urban uses, often in the form of urban sprawl.[1]

Most facets of transportation-related environmental impacts—from air pollution to noise pollution to oil spills—have been addressed by some type of policy action. Major public policy responses to transportation-related environmental problems originated in several laws enacted in the late 1960s and early 1970s. Many of the policies implementing these laws have been regulatory: standards specifying allowable rates of pollution or rules encouraging or requiring the use of less polluting technologies. Over the years these laws have been revised and generally strengthened as transportation activities have grown and regulations have been reevaluated (see box 6-1 for a list of transportation-related environmental laws).

Environmental policies have been quite successful in addressing some impacts associated with increased transportation, while in other

[1] In addition to the direct impacts of transportation, "upstream" activities necessary for transportation to take place—including oil field exploration and development, petroleum refining and storage, and vehicle manufacturing—can have significant environmental impacts as well.

Box 6-1: Selected Federal Laws Addressing the Environmental Impacts of Transportation

Broadly Applicable Laws

- Urban Mass Transportation Act of 1964
- National Historic Preservation Act of 1966
- Department of Transportation Act of 1966 (section 4(f), Preservation of Parklands)
- National Environmental Policy Act of 1969
- Airport and Airway Development Act of 1970
- Federal Aid to Highways Act (various years)
- Intermodal Surface Transportation Efficiency Act of 1991

Air Quality

- Clean Air Act (major amendments in 1965, 1970, 1977, and 1990)
- Energy Policy Act of 1992

Noise Pollution

- Housing and Urban Development Act of 1965
- Noise Control Act of 1972
- Airport Noise and Capacity Act of 1990
- Control and Abatement of Aircraft Noise and Sonic Boom Act of 1968

Water Quality (including oil spills)

- Clean Water Act (major amendments in 1972, 1977, and 1987)
- Safe Drinking Water Act
- Oil Pollution Act (1990)

Protection of Environmentally Sensitive Areas, Rare Species, and Wildlife

- Fish and Wildlife Coordination Act of 1958
- The Wild and Scenic Rivers Act of 1968
- The Endangered Species Act of 1973

Marine and Coastal Areas Protection

- Ocean Dumping Act and Amendments (1972, 1982, and 1992, among others)
- Coastal Zone Management Act of 1972
- The Coastal Wetlands Planning, Protection, and Restoration Act (1990)
- The Nonindigenous Aquatic Species Nuisance Species Prevention and Control Act (1990)
- Shore Protection Act of 1988

Transportation of Materials, including Solid and Hazardous Waste

- Resource Conservation and Recovery Act of 1976
- Superfund Amendments and Reauthorization Act of 1986
- Used Oil Recycling Act of 1980
- Hazardous Materials Transportation Act, as amended
- Sanitary Food Transportation Act of 1990

cases the results have fallen short of expectations. Measuring success can be complex; the same body of data can give rise to quite different interpretations of environmental progress, depending on the time period and the environmental indicators selected for examination. In the case of air pollution, for example, the data show that, compared with the 1970s, emissions per vehicle-mile are significantly lower for all regulated pollutants and total transportation emissions are down. These reductions, together with other sectors' successes, have produced measurable improvements in metropolitan air quality. Still, many metropolitan areas fall short of national air quality standards, and emissions of some pollutants have increased recently, leading to concern about whether the clear progress made in the 1980s will continue.

The lack of clear solutions to environmental problems has led some to propose a new goal for transportation: *sustainability*. The World Commission on Environment and Development has defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Whether a practical, operational definition of sustainability can be developed to form the basis of transport-related environmental policy remains to be seen. The intent, however, is to protect the environment and assure adequate resources for society for the indefinite future. The goal of sustainability has encouraged the international community to debate new environmental strategies, including those that seek to enlist market forces in the effort to address environmental quality.

This chapter provides a brief overview of transportation-related environmental impacts. It also discusses a key concept of environmental economics, externalities, which is necessary to understand both existing and potential policy approaches. Finally, this chapter presents a description of data needed to monitor the environmental impacts of transportation, particularly in relation to federal legislation and regulations affecting the transportation sector.

Transportation-Related Environmental Impacts

▶ Air Pollution

Air pollution is the most studied environmental impact of transportation. Burning of fossil fuels in internal combustion engines produces a variety of pollutants, including carbon monoxide (CO), volatile organic compounds (VOCs), and particulates. In addition, internal combustion engines oxidize nitrogen, the principal constituent of air, thereby producing various oxides of nitrogen. During transportation, storage, and refueling, liquid fuels evaporate, further adding to the amount of hydrocarbon emissions. Impurities and additives in fuel result in additional particulate and gaseous pollution.

Carbon monoxide is readily absorbed into the bloodstream where it can reduce oxygen delivery to organs and tissues. Exposure to high levels decreases visual perception, work capacity, manual dexterity, learning ability, and performance of complex tasks. VOCs and nitrogen oxides (NO_x) are the principal precursors to the formation of ozone. Ozone is the major constituent of smog. It is formed in the lower atmosphere by a photochemical reaction promoted by heat and sunlight. Ozone in the lower troposphere contributes to respiratory diseases and reduced lung function. It also causes foliar damage in crops and trees, leading to annual crop losses of several billion dollars in the United States alone. (USEPA 1994)

Particulate matter also contributes to smog. It consists of dust, dirt, soot, smoke, and liquid droplets released directly into the air by sources such as factories, powerplants, fires, and automobiles. Particulate matter also causes damage to materials and soil and is a major cause of visibility impairment in many parts of the United States. Particulate matter that is smaller than 10 microns (PM-10) is more likely to be responsible for adverse health effects. The major effects of these particulates include aggravation of existing respiratory and cardiovascular disease, alterations in the body's defense systems against foreign materials, damage to lung tissue, and in some cases, carcinogenesis. As with most air pollutants, those most susceptible to adverse effects include individuals with chronic obstructive pulmonary or cardiovascular disease, influenza, and asthma, and the elderly and children.

In the United States, lead additives in fuel have been eliminated with the conversion to unleaded gasoline. As a result, airborne lead from the combustion of fuel—once the primary source of airborne lead particles—is no longer significant. Leaded gasoline is, however, still widely used in many developing countries and has yet to be fully phased out in some developed countries. Exposure to excessive amounts of lead can harm both adults and children by causing damage to the nervous system, gastrointestinal tract, and blood-forming tissues.

Some other transportation-related toxic air pollutants include benzene, polynuclear aromatic hydrocarbons, formaldehyde, toluene, ammonia, cyanide, hydrogen sulfide, ethylene, and dioxin. These emissions can cause varying degrees of health problems.

In addition to local and regional environmental impacts, transportation emissions contribute to international environmental problems. These include acid rain, global warming, and stratospheric ozone depletion. Oxides of nitrogen and sulfur contribute to acid rain, which can damage forests and vegetation and adversely affect aquatic species.

When burned, hydrocarbon fuels produce CO_2 and water vapor. Both are greenhouse gases, but only CO_2 accumulates in the upper atmosphere in a way that can affect global climate. Greenhouse gases also naturally occur in the earth's atmosphere and are essential for the continuation of life. They are transparent to short-wave radiation from the sun but absorb and trap long-wave radiation within the atmosphere, which can raise the average global temperature. Scientists have established that the amount of heat trapped is affected by greenhouse gas concentrations, but are uncertain about the exact degree to which these gases will affect global temperatures and precisely what regional climatic changes will occur. Even a slight increase in the global mean temperature would alter natural and agricultural ecosystems by changing the distribution of climatic resources (e.g., patterns of rainfall). In addition, global warming could cause melting of polar ice caps, thereby increasing the sea level and leading to coastal flooding.

Another global environmental problem, stratospheric ozone depletion, is influenced by transportation, primarily because of past use of chlorofluorocarbons (CFCs) in automotive air conditioners. Ozone molecules in the stratosphere act as a protective shield for life on earth by absorbing ultraviolet radiation, a known cause of skin cancer. CFCs destroy ozone molecules, increasing the risk of such impacts. Now subject to an international agreement, CFCs are being phased out and replaced with less damaging compounds.

► Noise

People living near airports, major highways, railroad tracks, and other transportation facilities may be exposed to much noise. The impact of noise depends on the frequency, pitch, loudness, and duration of the sound. Transportation noise can be of a short duration, for example backfires, but is usually persistent. Prolonged exposure to noise can have a range of health effects, contributing to anxiety, depression, and insomnia. For most people, transportation noise does not pose a threat of permanent hearing damage.

Water Pollution

The major source of water contamination from the transportation sector comes from oil and fuel leaks and spills from a variety of sources, including tankers, motor vehicles, and above- and below-ground fuel storage tanks. Oil spills from tankers can have major impacts on nearby ecosystems, aquatic species, wildlife, and birds, but the extent and severity of environmental contamination vary greatly with the location and size of the spill. Even a small amount of petroleum in the groundwater system can contaminate large quantities of water.

Runoff from roads, infrastructure construction, and the deterioration of discarded vehicles also have an impact on surface and groundwater quality. The amount and magnitude of highway runoff depend on traffic characteristics, maintenance activities, and climatic conditions, as well as the location of the road itself. (USDOT FHWA 1987) For example, runoff from roads and parking lots has a higher than normal concentration of toxic metals, suspended solids, and hydrocarbons, which alter the composition of surface and groundwater. (Hahn and Pfeifer 1994) In northern regions, the application of road salts in winter is another concern. Increased sodium levels in water and surrounding soils can damage vegetation.

Moreover, transportation infrastructure may cause changes in the local water table and drainage patterns by increasing the share of rainwater that becomes runoff. This, in turn, affects the soil moisture content of the area, which, in turn, may alter vegetation and wildlife. Although these effects may be localized, transportation-related construction activities are so extensive that they cannot be ignored.

Solid Waste

Solid waste generated from the disposal of obsolete vehicles, paving and other materials, and construction adds to landfills, contributes to air pollutant emissions if incinerated, and contaminates water systems. Although about 75 percent of the weight of an average car is recycled (Holt 1993), about 3.5 million tons from scrapped cars wound up in landfills in 1994. Old tires, lead and acid in batteries, and pavement add to the waste stream from the transport sector. Despite recycling successes, the improper disposal of materials and the inability to recycle all solid waste remains a serious problem. In recent years, advances in lighter weight plastics, ceramics, and composite materials have shifted the composition of motor vehicles to a higher nonferrous content. These advanced materials increase fuel economy by reducing vehicle weight, but also complicate recycling.

Although more than 80 percent of asphalt is reclaimed and used in highways and other transportation applications, it is still a significant source of solid waste. Reclaimed concrete is used less frequently.

Land Use and Habitat

Transportation also has a direct effect on the environment through changes in land use and habitat. In the United States, paved and unpaved public roads occupy 25,000 square miles of land, an area equal to the size of West Virginia. If off-street parking, garages, carports, and driveways are included, the land area increases to 29,000 square miles. (Delucchi 1995) (Because the U.S. transportation system is highly developed, relatively little additional land is converted to new transportation uses each year.) Transportation infrastructure causes modification of vegetation, changes in drainage patterns, the creation of microclimates, and changes in habitat. Indeed, highways, runways, railroad tracks, and some other transportation infrastructure often fragment animal habitats by creating barriers between previously joined areas. The degree to which habitats are affected depends partly on traffic density. Furthermore, slight changes in moisture content of an area can cause the migration or disappearance of some species from that area. Other species that are dependent on or interact with these species may also be affected. In some cases, wetlands are destroyed by development linked to urban sources, including transportation.

Indirectly, transportation also contributes to much more extensive land-use changes. The availability of inexpensive and efficient transportation promotes the conversion of rural land into low-density urban use, often termed urban sprawl. Many people prefer lower population densities and larger home lots even at the price of driving longer distances to work and shop. This preference increases the amount of developed land, contributing to habitat alteration. Moreover, the increase in travel often translates into greater production of residuals. How to balance the benefits of inexpensive, efficient mobility and low-density residential living with its related environmental costs presents a major challenge.

Environmental Damage: The Concept of Externalities

Markets have difficulty assigning monetary values to environmental damage produced by the byproducts of transportation. These costs are external to the price of a good or service and thus are referred to as negative externalities. External benefits also can be attributed to transportation. Appendix B discusses both external costs and benefits in detail.

Although a precise and comprehensive definition of a negative externality does not exist, it can be thought of as a cost (such as damage from air pollution) imposed on society by an activity (such as motor vehicle use), which does not affect the price of a good or service. To the extent that travelers and shippers do not pay for these consequences, they have little economic incentive to consider them in their decisionmaking. In theory, if these external costs were routinely and predictably added to the price of transportation, the market itself would promote more "efficient" production and consumption decisions. In that event, a transportation option that entails relatively little environmental damage could be offered at a lower price than other options that entail more environmental damage. But, ordinarily, this will not happen unless some mechanism exists to force consideration of external costs.

The environmental costs to society of transportation are not trivial but cannot be quantified precisely. Some forms of environmental damage—effects on scenic resources, for instance—are very hard to express in economic terms. National estimates of external costs of transportation-related air pollution range from 0.03 to 1.05 percent of GDP. For Organization for Economic Cooperation and Development (OECD) countries, the costs are estimated at 0.4 percent of GDP, or 0.1 to 0.3 cents per kilometer (the OECD estimate includes pollution from all motor vehicles). (Quinet 1989; Sperling and Shakeeh 1995, 112) At the present time, estimates of external costs of greenhouse emissions are not reliable.

The inability of markets to price these environmental effects in the cost of transportation has been a rationale for government intervention through environmental policies and standards. Federal emissions standards for newly manufactured highway vehicles, initially imposed in the late 1960s and early 1970s, are examples. In response, vehicle manufacturers designed new vehicles that pollute less than their predecessors. In addition, alternative fuels and alternate fuel vehicles significantly lower the per-vehicle-mile rate of emissions. Battery-powered electric vehicles produce no exhaust emissions directly but do so indirectly, from the powerplants that provide the electricity needed to charge their batteries.

Figures 6-1a–d illustrate the impact on air pollution externalities and vehicle-miles traveled under four different market situations. Figure 6-1a represents the market situation when the environment is not a factor. The market supply curve (S) represents the cost of an additional mile of travel at each level of travel, and the market demand curve (D) shows the marginal benefit of an additional mile. The market demand curve slopes downward, indicating that the first few miles traveled are extremely valuable in comparison to the last few. Conversely, the supply or marginal cost curve slopes upward, reflecting the fact that resources must be reallocated from other areas of the economy in order to produce additional transportation. With each additional unit of transportation output, opportunity costs increase as fewer other valued goods can be produced. At the point where the two curves meet, private cost equals private benefit. The intersection of the supply and demand curves occurs at price P1 and quantity Q1.

Markets will only produce maximum societal benefits when private costs and benefits are equal to social costs and benefits. For this to occur, transportation-related pollution costs must be added to the private costs, as illustrated in figure 6-1b—total social cost (S′) of transportation activities is equal to the sum of the private costs plus environmental damage costs.

In theory, when full social costs are considered (e.g., users pay the actual social cost of each mile via some artificial pricing structure), the market system will adjust so that social costs equal social benefits. As shown in figure 6-1c, the higher price of transportation would result in fewer miles traveled, decreasing from quantity Q1 to quantity Q′.

Creating a price structure to reflect full social costs, however, is only one way to deal with external costs. As noted earlier, technology plays an important role in determining the amount of pollution produced by transportation. In particular, pollution control technologies strongly affect the rate of emissions per mile—a key component of total vehicle emissions.

Although highway vehicle travel increased by over 100 percent from 1970 to 1994, several kinds of emissions from highway sources decreased significantly. This trend can be attributed to technological changes required by the previously mentioned federal emissions standards. The effect of reductions on pollution rates is to shift the social cost curve (S″) much closer to the private cost curve (P″), as shown in figure 6-1d. Thus, technology makes it possible to reduce environmental damage and consequently total social cost (P″), with a smaller decrease in the quantity of travel (Q″) than shown in figure 6-1c.

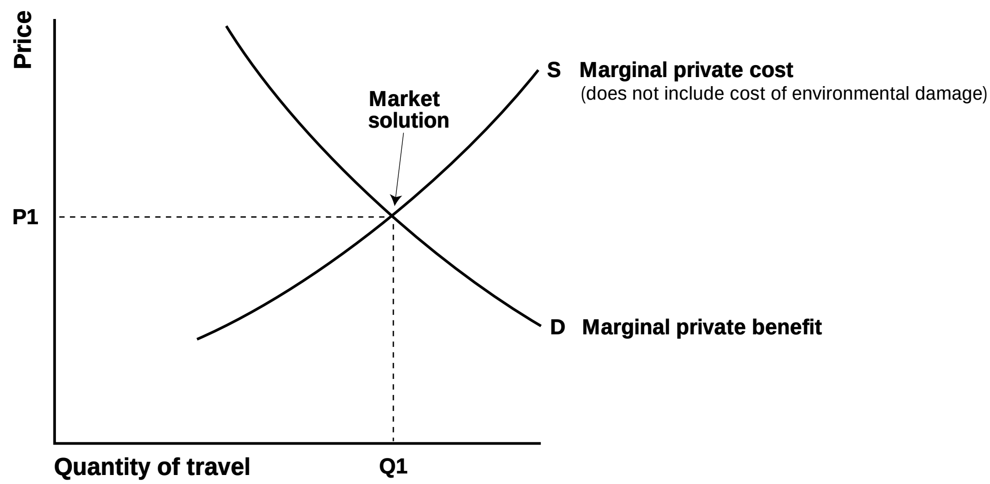
► Internalizing Environmental Effects

Increasingly, U.S. environmental policy entails a mix of market incentives, regulations, and other measures such as information programs. Although all of the measures have the potential to reduce the quantity of residuals produced, thus helping to reduce the cost of environmental damage, each has drawbacks that need to be considered. (US Congress OTA 1995)

Regulatory policies have been the most widely applied approach for addressing environmental problems. Examples include motor vehicle emissions standards, aircraft engine noise standards, and oxygenated fuel requirements.

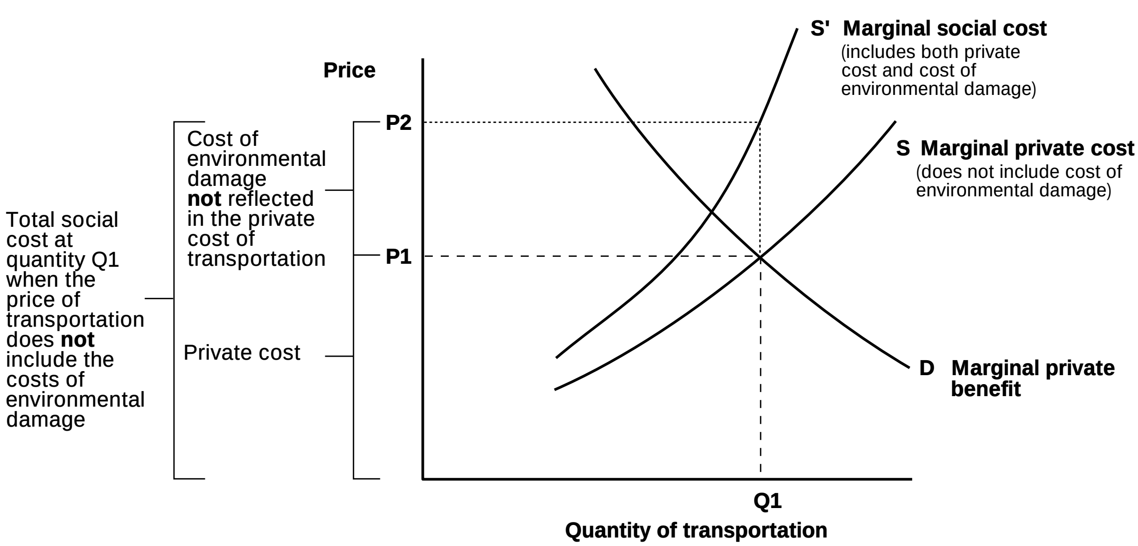
Regulatory measures sometimes lack flexibility, however, and may also be costly to administer and enforce. Automotive emissions standards, for example, apply equal per-mile emissions rates to an entire class of new vehicles (e.g., gasoline passenger cars and diesel light trucks)

FIGURE 6-1A: PRICE AND QUANTITY OF TRANSPORTATION WHEN ENVIRONMENTAL COSTS ARE NOT A FACTOR



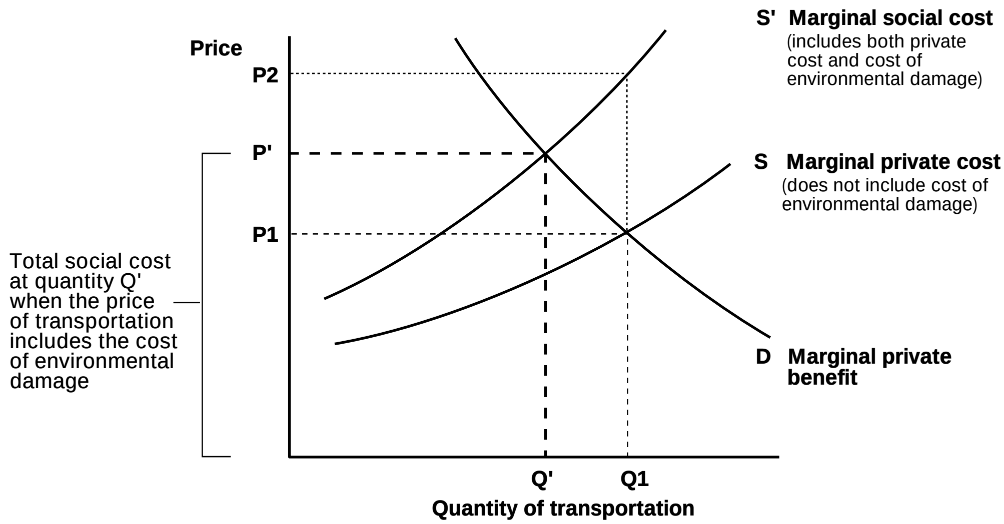
NOTE: Intersection of S and D indicates the market solution at which marginal private cost equals marginal private benefit.

FIGURE 6-1B: COST CURVE S′ REPRESENTING BOTH PRIVATE COST AND COST OF ENVIRONMENTAL DAMAGE



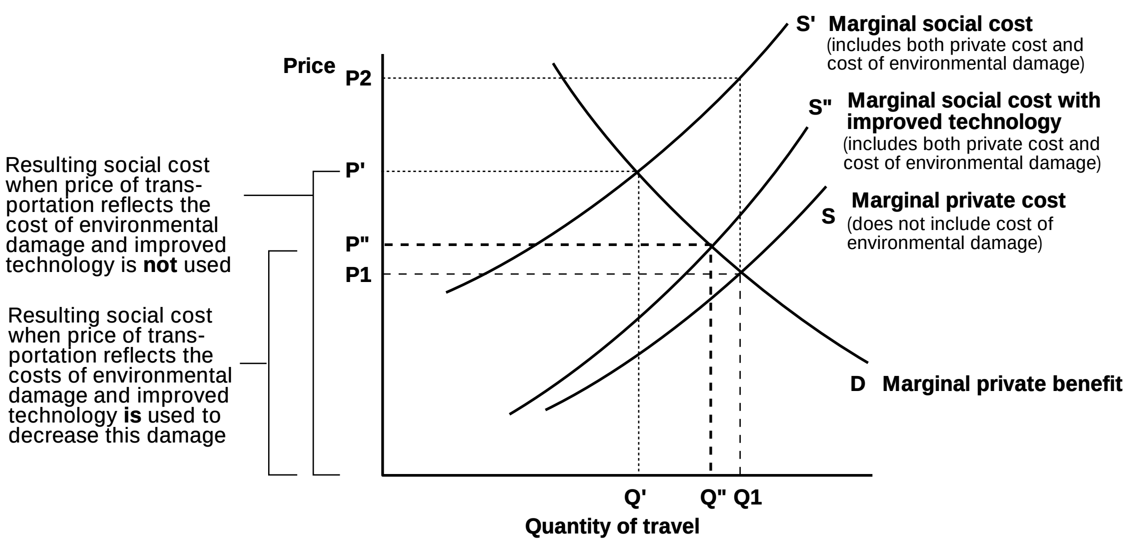
NOTE: The difference between S and S' at quantity Q1 represents the costs of the environmental damage of transportation consumed at quantity Q1.

FIGURE 6-1C: MARKET SOLUTION WHEN COSTS OF ENVIRONMENTAL DAMAGE ARE INTERNALIZED



NOTE: The intersection of D and S' is a generalized representation of the price of transporation that would result if all environmental damage costs were internalized so that users actually paid for this damage. Less transportation results from this change in price.

FIGURE 6-1D: MARKET SOLUTION WHEN IMPROVED TECHNOLOGY DECREASES THE RATE OF ENVIRONMENTAL DAMAGE



NOTE: The intersection of D and S" is a generalized representation of the price and quantity of transportation that might result if technological improvements are used to reduce the rate at which a given amount of travel generates pollution. Transportation's price would be higher and its quantity lower than when the costs of environmental damage are not included in the price of transporation (intersection of D and S). But the social costs associated with a given amount of environmental damage would be lower, and would result in less descrease in travel, than if environmental costs are internalized without the use of improved technology (intersection of D and S').

despite the cost differentials for achieving emissions reduction. In addition, standards apply to emissions measured by fixed procedures under specified laboratory conditions. If real-world conditions are not accurately reflected in the measurement methods, real-world performance is likely to fall short of the regulatory goal. This has become a concern with the federal automotive emissions standards (see chapter 8).

A variety of market-based incentives exist or have been proposed to internalize environmental costs. Some, such as emissions trading or banking, assign property rights to environmental resources. These rights can be bought, sold, traded, or otherwise used by their owner. In theory, emissions trading could help to eliminate exploitation of the environment beyond its efficient use, because the market will account for environmental costs in arriving at the quantity and means of producing transportation services.

In a few cases, assigning property rights for pollution or other residuals already has been used to address environmental externalities in transportation. In the 1970s and 1980s, for example, the Environmental Protection Agency (EPA) authorized credits to refiners for lead removal in gasoline that exceeded a prescribed phase-down schedule. Under this program, credits could be banked or traded with other refiners. EPA estimates that without the program it would have cost refiners an additional $226 million to phase out lead. Fee rebate systems also have been used or proposed to assure proper disposal of batteries, tires, and other solid waste. In addition, a regional clean air incentives market (RECLAIM) was set up in the Los Angeles area in 1994, which includes emissions trading for NO_x and sulfur dioxide. Although primarily oriented toward stationary sources, RECLAIM includes credits for reducing emissions by scrapping old automobiles.

Pollution charges or taxes have also been proposed, and, in some cases, used to address environmental externalities. In theory, a charge or tax equal to the cost of damage would eliminate the difference between societal and private costs.

Devising an optimal tax or charge is often very difficult, however. The tax must be levied directly on the residual's damage in order to elicit the correct responses, including behavior modification and technological innovation. Taxing only vehicle-miles driven is unlikely to produce the desired results, because differences in emissions rates due to differences in technology and driving styles would be unaffected. Moreover, it is difficult to devise a tax that reflects the environmental damage produced by residuals, and not just their quantity. For example, hydrocarbon and nitrogen oxide emissions are more troublesome when weather conditions favor ozone formation (hot, sunny days when the air is stagnant). A fuel tax would differ from the vehicle-miles-traveled tax in that it would also provide an incentive to increase vehicle fuel economy. As discussed above, however, there are conceptual drawbacks to taxes on surrogates.

Many states employ pollution charges or taxes of one sort or another. Their use at the federal level is limited, although there are examples, such as a provision in the 1990 Clean Air Act Amendments that levied a per-pound charge on CFC use, depending on ozone depletion impacts and other pollution charges.

Current Data Needs

Prior to the 1970s, few laws required environmental impact assessments or standards for environmentally safe levels of residuals. Today, more than 20 laws have provisions that address many environmental impacts from transportation. Measures range from broadly applied legislation, such as the National Environmental Policy Act or the Endangered Species Act, to measures that target transportation-related environmental impacts, such as the Clean Air Act and Amendments and the Noise Control Act of 1972 (see table 6-1). To be effective in this complex environment, accurate and comprehensive sources of data and information on the environmental impacts of transportation are needed. Moreover, data need to be understandable and available to the public. To this end some have suggested the development of a series of performance indicators for environmental quality. (President's Council on Sustainable Development 1996)

A good deal of progress in data collection and dissemination has been made over the past 25 years, particularly in the realm of air quality. A nationwide air monitoring system records daily variations in air quality. Moreover, through the Travel Model Improvement Program, the Department of Transportation (DOT), EPA, and the Department of Energy are working to improve travel forecasting procedures in order to respond to environmental and other concerns. (USDOT USEPA USDOE 1996) To advance our understanding of air quality, EPA recently has taken steps to improve its estimation of motor vehicle emissions in real-world conditions.

DOT and EPA are charged with preparing triennial reports on air quality-related transportation programs, called for by Section 108(f)(3) of the Clean Air Act. The studies assess existing state and local programs, including adequacy of funding, and the extent to which DOT air quality-related transportation programs comply with and meet goals of the Clean Air Act. The first report was issued in 1993 (USDOT and USEPA 1993); the second is expected in 1996.

Unfortunately, other aspects of environmental quality are less well documented. Until recently, EPA's inventory of toxic emissions focused on manufacturing, making it of little use for understanding transportation emissions. Data is even scantier, in general, for transportation-related impacts on surface and groundwater resources, animal habitats, and land use. For instance, the nationwide effects of groundwater contaminants from highway runoff—including oil, antifreeze, and salt—are largely unknown. And more needs to be known about the interactions between transportation and land use, particularly in terms of what is dubbed the "costs of sprawl." Impacts of transportation on biodiversity are also poorly understood.

Finally, a weakness of environmental data is that it does not show the real impact of the pollutants produced by transportation. To what extent does transportation pollution damage human health? What are the effects of transportation pollution on crop yields? How and to what extent do transportation activities affect ecosystems? These are difficult questions, but they must be answered in order to assess the actual environmental impact resulting from transportation.

Such an effort will likely be an important part of developing indicators of progress toward sustainability. Proponents of such an approach have proposed goals of sustainability like the conservation of nature, stewardship of natural resources, and health and the environment. One indicator of the conservation of nature might be the amount of wetlands and other habitat loss. Resource stewardship indicators might reflect measures of materials consumption, waste reduction (including recycling), energy efficiency, and renewable resources. Indicators of progress on health and the environment might include estimates of the number of people living with unhealthy air and water.

The environment is only part of the sustainable development equation. The other equally critical component is to encourage development that meets the needs of current and future generations. Hence, some argue that ways need to be found to weigh the unintended consequences of transportation against its benefits. These include not only environmental damage but fatalities and injuries from crashes. For this reason some are now proposing a full-cost accounting in order to measure the full social costs and benefits of transportation (see appendix B). Clearly, this places an even greater emphasis on the ability to collect data on the wide range of transportation impacts. Moreover, full-cost accounting raises difficult issues with regard to costing things such as ecosystem damage, the destruction of species, and people's lives. Yet, such an enterprise, while difficult and expensive, promises to help distribute resources in the most productive and efficient possible way.

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ENVIRONMENTAL TRENDS AND THE U.S. TRANSPORTATION SYSTEM

ALTHOUGH THE ENVIRONMENTAL IMPACTS OF TRANSPORTATION CONTINUE TO BE VERY LARGE, THE UNITED STATES HAS MADE MUCH PROGRESS IN THE LAST 25 YEARS IN REDUCING SOME IMPACTS FAR BELOW WHAT THEY OTHERWISE WOULD HAVE BEEN HAD PAST TRENDS BEEN ALLOWED TO CONTINUE UNABATED. THE PROGRESS IS MOST DRAMATIC FOR AIR POLLUTANTS FROM HIGHWAY VEHICLES THAT are regulated by the federal Clean Air Act (CAA) and its amendments: the concentration of some of these pollutants in urban areas today is much less than it was in 1970, despite a doubling in vehicle-miles traveled (vmt). Much of the improvement is a result of controls on motor vehicle emissions.

Some emissions from transportation, however, have recently increased. Moreover, as is discussed in greater detail in chapter 9, the United States continues to be the world's largest producer of greenhouse gas (GHG) emissions. Transportation's share of U.S. GHG emissions has grown over the last quarter century. (Carbon dioxide (CO_2), the major GHG of concern, is an unavoidable byproduct of fossil fuel combustion.)

As travel and traffic continue to grow, it becomes increasingly important to understand and monitor the relationships between transportation and the environment

The transportation sector also has significant impacts on water quality and many other aspects of environmental quality, such as noise, alteration of habitat for plants and animals, and solid waste generation. Furthermore, transportation affects land use and shapes development patterns in complex ways. As discussed in chapter 6, measures and trend data for transportation and air pollution are far more complete than for other aspects of environmental quality.

This chapter analyzes data on transportation and the environment and discusses trends, information needs, and areas for further research. The analysis covers five areas: 1) air pollution; 2) water and groundwater contamination; 3) noise; 4) solid waste; and 5) land use and habitat modifications. Upstream activities associated with transportation, such as vehicle manufacturing, petroleum extraction and processing, construction of transportation infrastructure, and other processes needed for transportation to take place, have significant environmental impacts, but are not treated in detail here.

Air Pollution Trends

The most conspicuous environmental impact of transportation is its impact on air quality, largely due to burning and evaporation of fossil fuels. Recent and long-term trends for several kinds of air pollution are discussed in the sections that follow.

► Criteria Air Pollutants

The Clean Air Act of 1970 called for establishment of National Ambient Air Quality Standards (NAAQS) to help protect the public health and welfare from known or anticipated effects of air pollutants. (Box 8-1 in chapter 8 discusses the NAAQS.) Under the law, and its subsequent amendments, the U.S. Environmental Protection Agency (EPA) set primary and secondary ambient air quality standards for six air pollutants, known as criteria pollutants. These criteria pollutants are carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), airborne particulate matter of less than 10 microns in size (PM-10), lead, and sulfur dioxide (SO_2). The effects of these pollutants vary, but can include respiratory and cardiopulmonary problems, acid rain, decreased crop yield, defoliation of plants, and decreased visibility, as is discussed in chapter 6.

To assess national criteria pollution trends, two kinds of data are useful: 1) monitoring data about ambient concentrations of criteria pollutants in the atmosphere; and 2) estimates of total nationwide emissions from different classes of mobile and stationary pollution sources (see box 7-1.)

Monitoring data from 4,000 sites across the United States show decreases in the average concentrations of all six criteria pollutants in the 1985 through 1994 period. Decreases in ambient concentrations averaged 28 percent for CO, 12 percent for O_3, 86 percent for lead, 9 percent for NO_2, 20 percent for PM-10, and 25 percent for SO_2. (USEPA 1995a)

The national average concentrations of two criteria pollutants increased between 1993 and 1994, however. In 1994, CO concentrations increased 2 percent and the composite average for NO_2 increased 5 percent over 1993 levels. (Lead and sulfur dioxide concentrations continued to decrease, while PM-10 concentrations did not change.) Furthermore, over 62 million people still lived in counties that had not attained or met the NAAQS for at least one criteria pollutant in 1994. Clearly, pollution problems remain. (USEPA 1995a)

Transportation vehicles are major sources of several criteria emissions. They account for most emissions from mobile sources, which include road vehicles and a diverse mix of mobile nonroad sources and equipment (see box 7-2). In 1994, mobile sources (including both road and nonroad sources) accounted for 78 percent of all

Box 7-1: Measuring Air Quality and Vehicle Emissions Trends

The U.S. Environmental Protection Agency (EPA) monitors ambient air quality trends at 4,000 sites nationwide. Numerous samples are collected at each site throughout the year. Not all pollutants are measured at a site and different air quality indicators are used to characterize each pollutant to determine compliance with air quality standards aimed at protecting public health. The carbon monoxide standard specifies one-hour and eight-hour concentration levels; for an area to attain the standard, these averages could be exceeded only once a year. The ozone standard specifies a maximum daily one-hour average concentration to be met or bettered every day of the year. The lead standard is a maximum quarterly average. The nitrogen dioxide standard is an annual arithmetic mean. For PM-10 and sulfur dioxide, the standards specify average concentrations for the short term (24 hours or less) and long term (annual average).

EPA ranks each pollutant by the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles. The arithmetic average for all sites is reported. Arithmetic averages are reported for sites categorized by location as rural, urban, and suburban. Finally, the areas failing to meet at least one pollutant standard are listed together with an indication of which standards were not attained. These measures do not fully describe the air quality of the United States or even that of a particular site. With so many sites and observations around the country, however, they give a useful indication of national air quality trends.

EPA also prepares annual nationwide estimates of emissions of key pollutants from stationary and mobile sources. Mobile sources include eight categories of on-road vehicles and major categories of nonroad transportation vehicles (e.g., aircraft, boats, and locomotives), and mobile equipment such as lawnmowers and construction equipment. To estimate emissions from on-road vehicles, EPA makes use of several kinds of data, such as Federal Highway Administration data on vehicle-miles traveled, state-level temperature data, and data from the Federal Test Procedure (FTP), which also is used to certify compliance of newly manufactured vehicles with federal emissions standards. Emissions estimates have been prepared for every year from 1970 through the present. EPA sometimes revises its prior estimates of emissions as understanding and information about factors affecting emissions grows. Recent research suggests that emissions estimates based on FTP assumptions have underestimated real-world emissions. This issue is discussed in detail in box 8-2 in chapter 8.

SOURCES: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Quality and Emissions Trends Report, 1994*, EPA 454/R-95-014 (Research Triangle Park, NC: October 1995); and U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994*, EPA-454/R-95-011 (Research Triangle Park, NC: October 1995).

CO emissions, 45 percent of all nitrogen oxides NO_x emissions, and 37 percent of all hydrocarbon (HC) or volatile organic compounds (VOC) emissions. The latter three classes of substances contribute to the formation of ground-level ozone, another criteria pollutant present in smog (see figure 7-1). Although mobile sources still accounted for 32 percent of 1994 lead emissions, vehicular lead emissions are now less than 1 percent of their 1970 levels because lead has been eliminated from motor gasoline. Mobile sources account for less than 3 percent of SO_2 emissions.

Highway vehicle travel accounts for most criteria pollution from the transportation sector. On-road vehicles produced 62 percent of all CO emissions, 32 percent of all NO_x emissions, and 26 percent of all VOC emissions in 1994. Between 1970 and 1994, the highway vehicle fleet grew 80 percent, and annual vehicle-miles traveled nationwide doubled. (USDOT BTS 1995, table 5, 33, 41) Technological changes resulting from the CAA, however, have controlled highway vehicle emissions to a substantial degree (see figure 7-2). In part because of the control of

Box 7-2: Transportation's Share of Mobile Source Pollution

The U.S. Environmental Protection Agency (EPA) divides air pollution sources into stationary sources and mobile sources. Mobile sources are further divided into on-road sources and nonroad sources. EPA prepares emissions estimates each year for the following mobile sources:

On-road mobile sources:
- Light-duty gas vehicles and motorcycles
- Light-duty gas trucks
- Heavy-duty gas vehicles
- Light-duty diesel vehicles
- Light-duty diesel trucks
- Heavy-duty diesel trucks

Nonroad mobile sources:
- Aircraft
- Marine vessels (includes estimates for coal, diesel, and residual oil)
- Railroads
- Other nonroad gasoline and diesel sources, including:
  - recreation
  - construction
  - industrial
  - lawn and garden
  - farm
  - light commercial
  - logging
  - airport service
  - recreational marine vessels (gasoline only)
  - other (gasoline only)

All emissions from on-road sources, aircraft, marine vessels, and railroads can be attributed to transportation. Some other nonroad emissions (such as from airport services and recreational marine vessels) also are transportation-related. Emissions from some nonroad sources (such as lawn and garden equipment) clearly should not be attributed to transportation, and, strictly speaking, only a portion of the emissions from nonroad mobile equipment used in industry, construction, and farming should be attributed to transportation, since the equipment may also be used to process goods and materials.

On-road sources (especially light-duty gasoline vehicles, which have been subject to the most stringent emissions standards) account for most of the progress in reducing emissions from mobile sources over the years. Overall emissions from less regulated mobile sources (both in the on-road and nonroad categories) have increased for some pollutants.

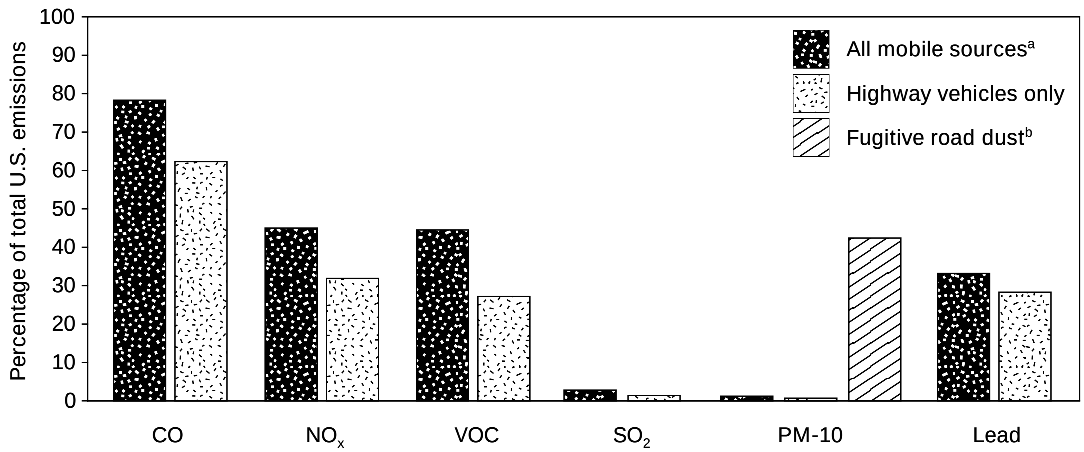
A life-cycle accounting of air pollution from the transportation sector also would need to take into account the fraction of emissions from stationary sources that produce, store, or dispose of raw materials and goods used in transportation. Examples include oil wells, petroleum refineries and storage facilities, and factories for manufacture of materials, parts, and vehicles used for transportation.

road vehicle emissions, the concentration of criteria pollutants in the air has decreased, and ambient air quality is better in most areas (see figure 7-3).

Most of the progress to date in curbing criteria air pollution from transportation can be attributed to: 1) tailpipe or other emissions standards for newly manufactured highway vehicles (see table 7-1 for examples); and 2) requirements that harmful substances be reduced or removed from fuels, or that substances be added to fuels to make them pollute less. (Thus, lead essentially has been eliminated from fuel, and the sulfur content of fuel has been reduced greatly).

As is reported later in this chapter, had nothing been done, tailpipe and other vehicular emissions of criteria pollutants would have more than doubled between 1970 and 1994 because of the growth in travel. Instead, EPA estimates that

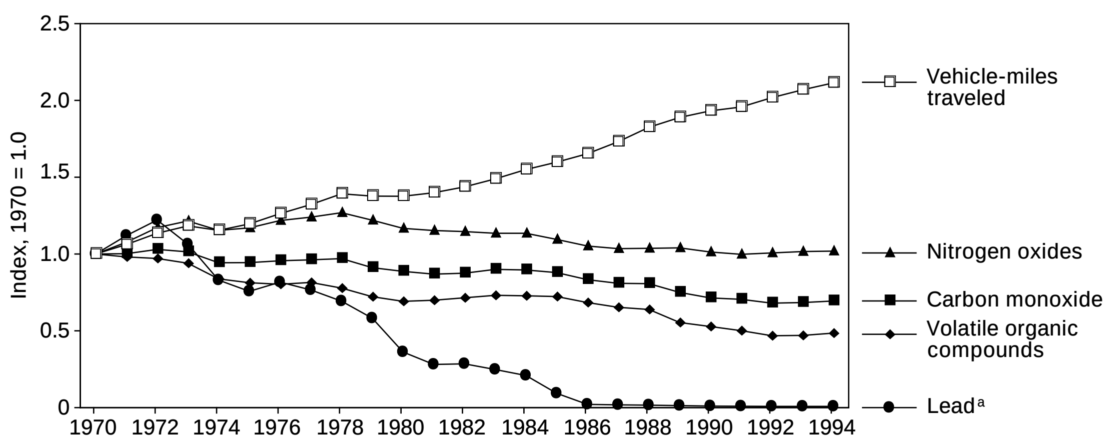
FIGURE 7-1: TRANSPORTATION'S SHARE OF U.S. CRITERIA POLLUTANT EMISSIONS, 1994



[a] "All mobile sources" include highway vehicles, nonroad vehicles, and mobile equipment, some of which may be used in nontransportation applications such as lawn and garden care.
[b] Fugitive road dust is particulate emissions kicked up from paved and unpaved roads. EPA lists road dust as a miscellaneous source of PM-10, not as a mobile source.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1900–1994,* EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), tables A1–A6.

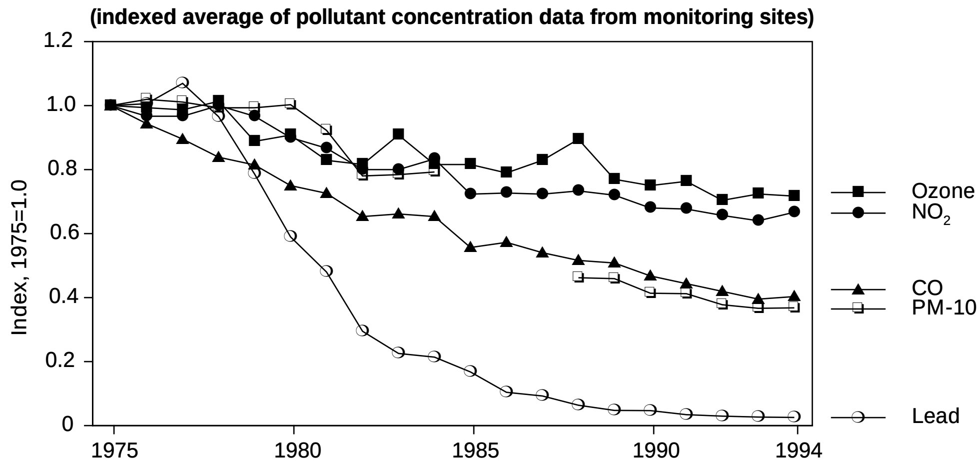
FIGURE 7-2: ROAD VEHICLE AIR EMISSIONS AND MILES TRAVELED, 1970–94



[a]Lead emissions since 1990 have been less than 1 percent of their 1970 levels.

SOURCES: Vehicle-miles—U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics* (Washington, DC: various years). Emissions—U.S. Environmental Protection Agency, Office of Air Quality, Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994* (Washington, DC: 1995), tables A-1, A-2, A-3.

FIGURE 7-3: U.S. AIR QUALITY TRENDS, 1975–94



SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Quality and Emissions Trends Report, 1994, Data Appendix,* EPA 454/R-95-XXX (Research Triangle Park, NC: October 1995), table A-9.

TABLE 7-1: FEDERAL EMISSIONS CONTROL STANDARDS FOR LIGHT-DUTY GASOLINE VEHICLES (GRAMS PER MILE)

	Automobiles				Light trucks			
Year standard set or changed	Hydro-carbons	Carbon monoxide	Nitrogen oxides	Particulates	Hydro-carbons	Carbon monoxide	Nitrogen oxides	Particulates
1976	1.50	15.0	3.1	—	2.00	20.0	3.1	—
1977	nc	nc	2.0	—	nc	nc	nc	—
1979	nc	nc	nc	—	1.70	18.0	2.3	—
1980	0.41	7.0	nc	—	nc	nc	nc	—
1981	nc	3.4	1.0	—	nc	nc	nc	—
1982	nc	nc	nc	0.60	nc	nc	nc	0.60
1984	nc	nc	nc	nc	0.80	10.0	nc	nc
1987	nc	nc	nc	0.20	nc	nc	nc	0.26
1988	nc	nc	nc	nc	nc	nc	1.2	nc
1994	0.25	nc	0.4	0.08	0.25	3.4	nc	nc
1995 on	nc	nc	nc	nc	nc	nc	0.4	0.08

KEY: — = no emission standard in effect; nc = no change from prior year listed.

SOURCE: S.C. Davis, *Transportation Energy Data Book, Edition 15*, ORNL-6856 (Oak Ridge, TN: Oak Ridge National Laboratory, 1995), table 7-14.

highway vehicles emit only half the VOC and 30 percent of the CO as in 1970; motor vehicle emissions of NO_X are higher but by only 2 percent (USEPA 1995b, tables 3-1, 3-2, 3-3). As a result, concentrations of these air pollutants in the atmosphere generally are lower today despite continuing growth in vehicle travel.

Yet, the most recent data on emissions suggest a slowing of the improvements that characterized the past two decades. Steady growth in travel coupled with increased emissions from previously unregulated off-highway sources may overtake the impressive emissions reductions achieved under past standards. Since 1991, for example, NO_X emissions from mobile sources increased 4.5 percent; about one-third of the increase is attributed to on-road vehicles, the remainder to nonroad mobile sources (including nontransportation sources such as lawnmowers as well as marine, air, and rail transportation vehicles). (USEPA 1995b, table A-2)

Tightened emissions standards for new cars and light-duty trucks, as well as requirements for cleaner burning oxygenated and reformulated fuels, were put in place in 1994 and 1995, as called for in the 1990 Clean Air Act Amendments (CAAA) (see table 7-1). New standards for heavy-duty trucks, buses, other transportation modes, and some categories of off-road vehicles and equipment are scheduled to be promulgated in the coming years. Moreover, as is discussed in chapter 8, enhanced inspection and maintenance (I/M) programs, and transportation control measures are in place or under consideration in many metropolitan areas with air quality problems. These initiatives will help to ameliorate air quality impacts from future growth in stationary and mobile source emissions, although perhaps not enough to prevent overall growth in emissions (see chapter 8).

In the long term, technological advances could further reduce criteria emissions. The federal government and some states have sponsored or cost-shared with industry research on cleaner engine technologies, alternative fuels, and advanced emissions control devices. (US Congress OTA 1995a) In time, such research could lead to new vehicles or fuels that are less polluting.

Carbon Monoxide

Highway vehicles accounted for almost 80 percent of the CO emitted from mobile sources in 1994 (table 7-2). (Gasoline vehicles accounted for almost all the highway vehicle emissions—diesel-powered vehicles accounted for only a little over 2 percent.) CO emissions from highway vehicles decreased by 21 percent in the 1985 to 1994 period in spite of the increase in vmt. Much of the decrease is the result of improved engine designs that burn fuel at near-optimum air-fuel ratios and the use of catalytic converters that oxidize most of the CO in engine exhaust to produce CO_2.

Between 1992 and 1994, CO emissions from highway vehicles increased by about 2 percent, however. Many factors will affect the level of highway vehicle emissions in the future. A more stringent CO emissions standard for new light-duty trucks was put in place in 1994. Additional emissions reductions may occur if more areas adopt reformulated and oxygenated fuel programs called for by the 1990 Clean Air Act Amendments. Oxygenated fuel programs are mandated in CO nonattainment areas and can also be implemented on a voluntary basis in areas that are within attainment standards. These and other measures will help offset emissions from growth in travel and other sources—although to what degree remains to be seen.

Nonroad sources contributed over 20 percent of all CO emissions from mobile sources in 1994, up from 15 percent in 1985. (USEPA 1995b, table A-1) Off-highway vehicles with gasoline engines accounted for most of the growth; emissions from these sources increased 14 percent between 1985 and 1994. The category includes a mixture of transportation and non-

TABLE 7-2: CARBON MONOXIDE EMISSIONS BY SOURCE, 1985, 1992, AND 1994 (THOUSAND SHORT TONS)

Source category	1985	1992	1994	Percentage change 1985–94	Percentage change 1992–94
Mobile sources	91,093	74,758	76,727	–15.8	2.6
Highway vehicles	77,387	59,859	61,070	–21.1	2.0
Light-duty gas vehicles and motorcycles	49,451	39,370	39,303	–20.5	–0.2
Light-duty gas trucks	18,960	14,567	15,140	–20.1	3.9
Heavy-duty gas vehicles	7,716	4,569	5,244	–32.0	14.8
Diesels	1,261	1,352	1,384	9.8	2.4
Nonroad vehicles and mobile equipment	13,706	14,900	15,657	14.2	5.1
Nonroad gasoline[a]	11,815	12,883	13,452	13.9	4.4
Nonroad diesel[a]	910	853	954	4.8	11.8
Aircraft	831	980	1,063	27.9	8.5
Marine vessels	44	60	63	43.2	5.0
Railroad	106	124	124	17.0	0.0
Fuel combustion	8,487	5,601	4,884	–42.5	–12.8
Industrial processes	7,216	6,911	7,161	–0.8	3.6
Miscellaneous	7,895	6,774	9,245	17.1	36.5
Total emissions	114,690	94,043	98,017	–14.5	4.2

[a]Includes a mixture of off-highway vehicles used in transportation and mobile equipment used in nontransportation activities. In 1994, emissions from lawn and garden equipment, a nontransportation source, accounted for 40 percent of nonroad mobile source carbon monoxide and 8 percent of all mobile source carbon monoxide emissions.

NOTE: Subtotals may not add due to rounding. Data for 1992 included because carbon monoxide emissions in this year reached their lowest point in the 1985–94 period.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994,* EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-1, pp. A2–A5.

transportation sources, including recreational boats, off-road commercial vehicles, and lawn and garden equipment. The 1990 CAAA established emissions standards for nonroad vehicles and equipment. In 1996, these standards will be applied to new equipment. Thus it will be several years before significant effects on nonroad emissions will be apparent.

Urban Ozone

Ground-level ozone, the major constituent of smog, is formed by photochemical reactions involving sunlight, NO_X, and volatile organic compounds. Urban ozone formation is highly dependent on meteorological conditions, peaking during hot, dry, stagnant summertime weather. Since weather conditions vary, sometimes greatly, from year to year, so too does the formation of O_3. Estimates that account for meteorological variation have found that the O_3 concentration decreased by about 12 percent between 1985 and 1994. The number of O_3 nonattainment areas dropped from 94 in September 1993 to 77 in September 1994. (USEPA 1994, USEPA 1995a)

Mobile sources accounted for nearly 37 percent of all VOC emissions in 1994 (see table

7-3). VOC emissions from mobile sources declined by nearly 25 percent between 1985 and 1994; however, 1994 emissions exceeded those in 1992 (the low point) by 3.9 percent. Of the mobile source emissions, highway vehicles accounted for 73.6 percent, and nonroad gasoline vehicles were responsible for 20.2 percent.

Several measures could further reduce VOC emissions from highway vehicles. These include enhancing or expanding I/M programs, reducing the vapor pressure of gasoline to decrease evaporative emissions, increasing use of oxygenated fuel for more complete combustion, and tightening of tailpipe emission standards.

Nonroad mobile sources of VOC emissions increased by 12.3 percent from 1985 to 1994. Roughly one-third of these nonroad emissions came from a nontransportation use (lawn and garden equipment). Recreational boats were the next largest source, accounting for one-fifth of nonroad VOC emissions from mobile sources.

Upstream emissions of VOCs from the production, refining, transport, storage, and handling of transportation fuels and other petroleum products are substantial. Petroleum production and refining produced 630,000 short-tons of VOCs in 1994, while storage and transport, including service stations, generated 1,773,000

TABLE 7-3: VOLATILE ORGANIC COMPOUNDS EMISSIONS BY SOURCE, 1985, 1992, AND 1994 (THOUSAND SHORT TONS)

Source category	1985	1992	1994	Percentage change 1985–94	Percentage change 1992–94
Mobile sources	11,384	8,231	8,550	–24.9	3.9
Highway vehicles	9,376	6,072	6,295	–32.9	3.7
Light-duty gas vehicles and motorcycles	5,864	3,832	3,921	–33.1	2.3
Light-duty gas trucks	2,425	1,588	1,664	–31.4	4.8
Heavy-duty gas vehicles	716	334	393	–45.1	17.7
Diesels	370	318	317	–14.3	–0.3
Nonroad vehicles and mobile equipment	2,008	2,159	2,255	12.3	4.4
Nonroad gasoline[a]	1,561	1,677	1,730	10.8	3.2
Nonroad diesel[a]	216	203	226	4.6	11.3
Aircraft	165	195	212	28.5	8.7
Marine vessels	30	41	43	43.3	4.9
Railroad	37	43	43	16.2	0.0
Fuel combustion	1,569	1,023	886	–43.5	–13.4
Industrial processes	12,283	12,703	13,054	6.3	2.8
Miscellaneous	562	466	685	21.9	47.0
Total emissions	25,798	22,420	23,174	–10.2	3.3

[a]Includes a mixture of off-highway vehicles used in transportation and mobile equipment used in nontransportation activities. In 1994, emissions from lawn and garden equipment, a nontransportation source, accounted for 9 percent of all mobile source volatile organic compounds emissions.

NOTE: Subtotals may not add due to rounding. Data for 1992 included because volatile organic compounds emissions in this year reached their lowest point in the 1985–94 period.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994* EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-3, pp. A10–A16.

short-tons. If included in the transportation sector, these upstream activities would add 28 percent more VOC emissions to the mobile source totals for 1994.

Nitrogen Oxides

Nitrogen dioxide is a criteria pollutant; therefore, EPA measures NO_2 concentrations in the ambient atmosphere. NO_2 concentrations across the United States decreased an average of 9 percent from 1985 to 1994. From 1993 to 1994, however, NO_2 concentrations increased by 5 percent. (USEPA 1995a) Even so, all monitoring stations in the country met the NO_2 emissions standard in 1994 for the third year in a row. (USEPA 1995a) Control of NO_2 emissions are important for reducing levels of O_3, which exceed NAAQS in many areas.

Tailpipe and other emissions standards have been set for all forms of nitrogen oxides, which include several substances that quickly turn into NO_2 or can themselves contribute to the formation of smog. In 1994, according to EPA, electric utilities and industry accounted for about half of the NO_x emissions; mobile sources accounted for 45 percent. Highway vehicles accounted for 71 percent of mobile source NO_x emissions in 1994 (see table 7-4).

NO_x emissions from on-road vehicles declined by 6.9 percent between 1985 and 1994, while emissions from off-highway vehicles increased by 13.2 percent in the same period. Since 1991, however, NO_x emissions from both highway and nonroad vehicles increased, with highway vehicle emissions increasing by about 2.1 percent. (USEPA 1995a)

Diesel engines have high compression ratios, and therefore produce proportionately more NO_x than gasoline engines. Emissions from diesel-powered vehicles, both road and nonroad (including railroad and marine diesels), account for 45 percent of mobile source NO_x emissions—a much higher share than their modest percentage of the vehicle population and vmt. Emissions from diesel-powered highway vehicles decreased by 17 percent between 1985 and 1994. Railroad diesels contributed 9 percent to the mobile source total in 1994, increasing by 17 percent since 1985. Marine diesels contributed 1.8 percent to the mobile source total in 1994, increasing by nearly 44 percent since 1985. Other off-highway diesel emissions increased by 7 percent over the same period. (USEPA 1995a) Some of the off-highway diesel emissions come from construction equipment used to build or maintain transportation infrastructure.

Lead

At one time, transportation vehicles were the primary source of lead emissions in the United States, contributing about four-fifths of total lead emissions as recently as 1985. Air pollution control programs implemented by EPA, however, have nearly eliminated lead emissions from transportation fuels. Unleaded gasoline, introduced in 1975 to prevent fouling of catalytic exhaust emissions control devices, accounted for 99 percent of gasoline sales by 1993.

Although transportation still contributes 32 percent of total lead emissions, the base is much smaller (see figure 7-4 and table 7-5). Currently, 10 areas exceed the NAAQS for lead—mostly due to point sources such as lead smelters, battery plants, and solid waste disposal. (USEPA 1995a). Some of these facilities provide products or disposal services to the transportation sector.

Particulate Matter

In 1994, more areas were classified as nonattainment for PM-10 than for any other criteria pollutant. The number of nonattainment areas increased from 70 in 1991 to 82 in 1994. (USEPA 1994, USEPA 1995a) (PM-10 concentrations have been separately measured since

TABLE 7-4: NITROGEN OXIDES EMISSIONS BY SOURCE, 1985, 1991, AND 1994 (THOUSAND SHORT TONS)

Source category	1985	1991	1994	Percentage change 1985–94	Percentage change 1991–94
Mobile sources	10,823	10,170	10,625	–1.8	4.5
Highway vehicles	8,089	7,373	7,530	–6.9	2.1
Light-duty gas vehicles and motorcycles	3,806	3,464	3,750	–1.5	8.3
Light-duty gas trucks	1,530	1,339	1,432	–6.4	6.9
Heavy-duty gas vehicles	330	326	333	0.9	2.1
Diesels	2,423	2,244	2,015	–16.8	–10.2
Nonroad vehicles and mobile equipment	2,734	2,796	3,095	13.2	10.6
Nonroad gasoline[a]	113	122	133	17.7	9.0
Nonroad diesel[a]	1,562	1,433	1,673	7.1	16.7
Aircraft	119	139	153	28.6	10.1
Marine vessels	131	174	188	43.5	8.0
Railroad	808	929	947	17.2	1.9
Fuel combustion	10,837	11,382	11,728	8.2	3.0
Industrial processes	891	837	889	–0.2	6.2
Miscellaneous	309	283	374	21	32.2
Total emissions	22,860	22,672	23,615	3.3	4.2

[a]Includes a mixture of off-highway vehicles used in transportation and mobile equipment used in nontransportation activities. In 1994, emissions from nonroad construction vehicles and mobile equipment accounted for 14 percent of all mobile source nitrogen oxides emissions.

NOTE: Subtotals may not add due to rounding. Data for 1991 included because nitrogen oxides emissions in this year reached their lowest point in the 1985–94 period.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994,* EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-2, pp. A6–A9.

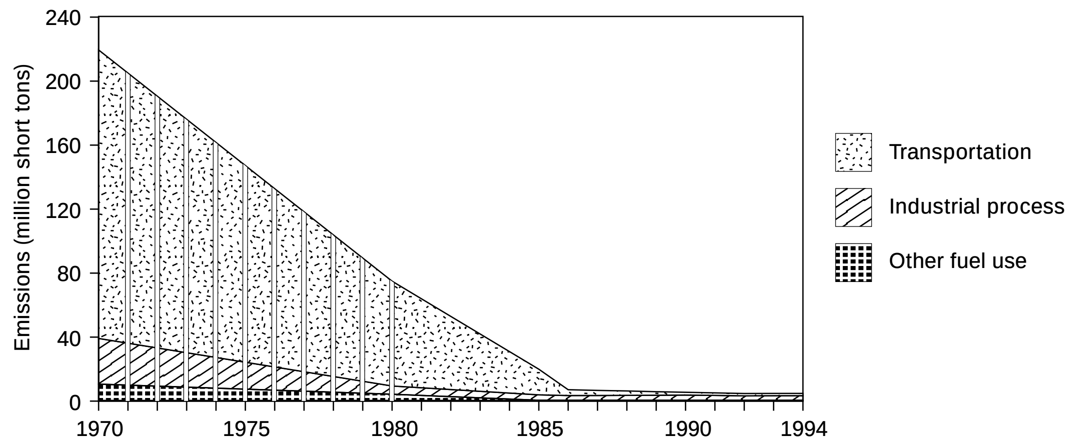
1988; before 1988, PM-10 was not distinguished from larger suspended particulates.)

PM-10 sources include both anthropogenic and natural sources. Most PM-10 originates from diffuse sources that cover large areas (e.g., dust from roads and farms, from fires, and wind erosion). These “miscellaneous” and “natural” sources account for the lion’s share—94 percent—of PM-10 emissions. The remaining PM-10 emanates from discrete or point sources (e.g., transportation vehicles, manufacturing, and other industrial processes).

Of this small share of PM-10 from discrete anthropogenic sources, transportation vehicles contributed 27 percent in 1994. Since 1988, PM-10 emissions from highway vehicles decreased, while emissions from off-highway vehicles increased. Nonhighway diesels, in particular, accounted for one-third of the vehicular PM-10 emissions.

Fugitive road dust—dust kicked up from paved and unpaved roads—is categorized as a miscellaneous, not as a transportation source of PM-10. From 1985 to 1994, dust from paved roads increased by 25 percent, while dust from unpaved roads increased by 11 percent. In 1994, according to EPA, road dust accounted for over 40 percent of all anthropogenic and biogenic

FIGURE 7-4: LEAD EMISSIONS BY SOURCE IN THE UNITED STATES, 1970–94



NOTE: Data between 1970 and 1980 are interpolated.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollution Emission Trends, 1990–1994*, EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-6, pp. A26–A27.

TABLE 7-5: LEAD EMISSIONS BY SOURCE, 1985 AND 1994 (SHORT TONS)

Source category	1985	1994	Percentage change 1985–94
Mobile sources	16,207	1,596	–90.2
Highway vehicles	15,978	1,403	–91.2
Light-duty gas vehicles and motorcycles	12,070	1,048	–91.3
Light-duty gas trucks	3,595	336	–90.7
Heavy-duty gas vehicles	313	19	–93.9
Nonroad mobile sources	229	193	–15.7
Fuel combustion	515	493	–4.3
Industrial processes	3,402	2,868	–15.7
Total emissions	20,124	4,956	–75.4

NOTE: Subtotals may not add due to rounding.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollutant Emission Trends, 1990–1994*, EPA-454/R-95-011 (Research Triangle Park, NC: October 1995), table A-6, pp. A26–A27.

PM-10 emissions. (USEPA 1995b) Road dust also accounted for over 30 percent of emissions of very fine particles—those measuring 2.5 microns or smaller (PM-2.5). (Barnard 1996)

A debate exists about what size and kind of road dust should be used in setting health-based attainment standards for particulate matter. Further research into the relationships between health effects and particle size and composition will be needed to clarify and eventually quantify the specific health effects of road dust particulate pollution.

Sulfur Dioxide

In 1994, 43 areas were classified as nonattainment for sulfur dioxide (SO_2), mostly due to emissions from electric utilities and industrial point sources. (USEPA 1995a) The U.S. transportation sector contributed very little to SO_2 emissions since the demise of the coal-fired locomotive. In 1994, transportation accounted for only 2.7 percent of the nation's total SO_2 emissions—a substantial drop from 1993, when new CAAA regulations required a reduction in the sulfur content of diesel fuel for highway vehicles. Even so, highway vehicles still accounted for half of transportation's SO_2 emissions in 1994. Sulfur oxides from other transportation sources, including marine transport, locomotives, and aircraft, increased between 1985 and 1994.

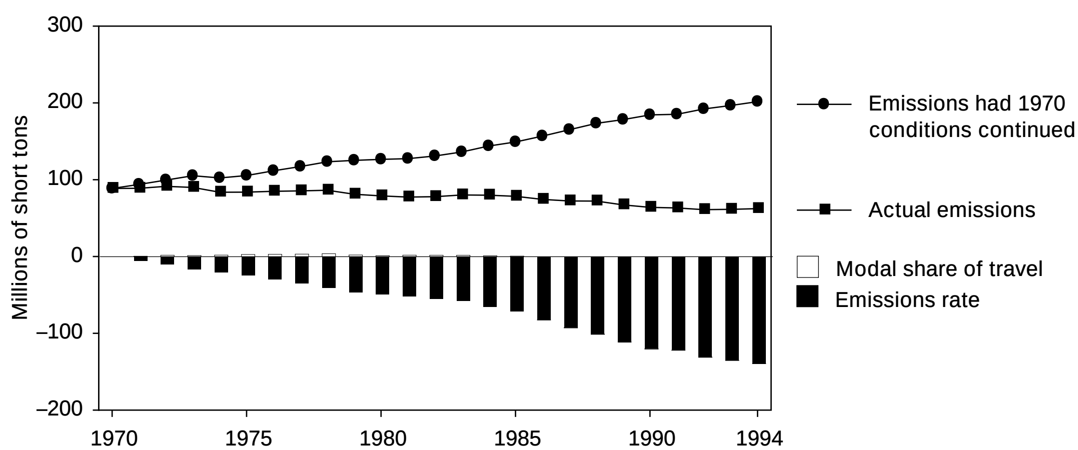
Long-Term Trends in Criteria Emissions

The Bureau of Transportation Statistics (BTS) has applied Divisia Analysis (discussed in chapter 4) to show how rates of emissions per vehicle-mile and changes in modal structure (distribution of travel across modes) affected transportation emissions between 1970 and 1994. The analysis focuses on emissions of three key criteria pollutants—CO, VOC (or HC), and NO_X. Two conclusions emerge from the analysis: 1) without the reductions in emissions rates since 1970, air pollution by transportation would be two to four times what it is today; 2) changes in the modal structure of transportation had virtually nothing to do with this result. (See figures 7-5, 7-6, 7-7).

The analysis makes use of EPA emissions data for six categories (modes) of transportation vehicles: 1) passenger cars and motorcycles, 2) light trucks, 3) heavy-duty highway vehicles, 4) aircraft, 5) railroad vehicles, and 6) marine vessels (not including recreational boats). These categories account for between 70 and 80 percent of all mobile source emissions of the three pollutants, and an even higher proportion of transportation activity. They also are the categories for which adequate travel activity data are available. Activity for highway vehicles is measured in vehicle-miles. Commercial air activity is measured in aircraft-miles for domestic and international flights by U.S. certificated air carriers. Rail is measured by freight car-miles, and marine vessel activity by total tons shipped in domestic and international waterborne commerce. (German 1995)

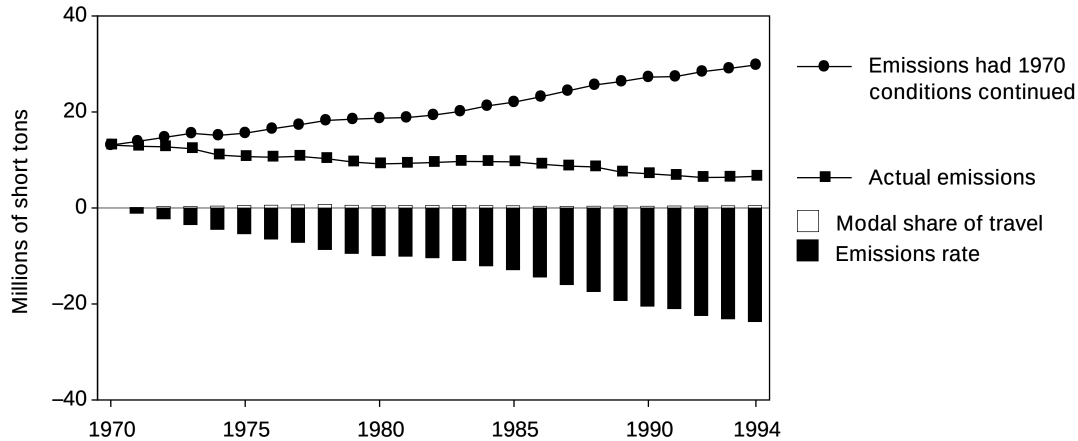
Over the 1970 to 1994 period, actual emissions from these six transportation categories declined significantly in the cases of CO and VOC and increased only slightly in the case of NO_X. During this time period, transportation activity doubled. The Divisia Analysis shows

FIGURE 7-5: **CARBON MONOXIDE EMISSIONS FROM U.S. TRANSPORTATION, 1970–94**



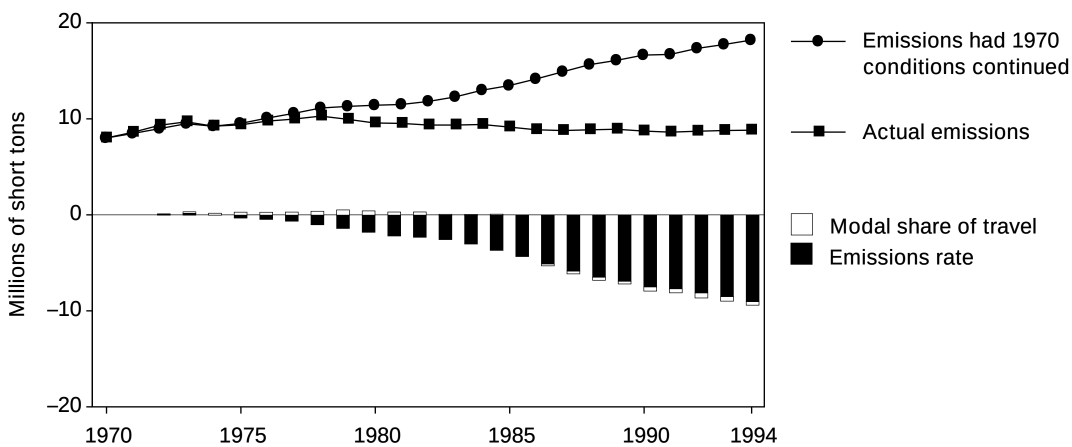
SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, based on analysis of data from the U.S. Environmental Protection Agency.

FIGURE 7-6: VOLATILE ORGANIC COMPOUNDS EMISSIONS FROM U.S. TRANSPORTATION, 1970–94



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, based on analysis of data from the U.S. Environmental Protection Agency.

FIGURE 7-7: NITROGEN OXIDES EMISSIONS FROM U.S. TRANSPORTATION, 1970–94



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, based on analysis of data from the U.S. Environmental Protection Agency.

that without the improvement, VOC emissions from transportation would be 4.5 times what they are today, CO emissions 3.2 times as great, and NO_x emissions 2 times as great.

The improvement in transportation emissions has kept overall U.S. emissions from all sources at a lower level than would otherwise have been the case. For example, the six modes of transportation account for 64 percent of CO emissions from all sources. Without the improvement in transportation emissions, *total* emissions of CO would have been 2.4 times their actual level in 1994. Total VOC emissions, of which these six categories of transportation accounted for 28 percent in 1994, would have been twice as great.

Even total NO_x emissions, of which these six transportation modes accounted for 37 percent in 1994, would have been 40 percent greater had there been no improvements in transportation emissions rates.

As shown in figure 7-7, the improved trend for NO_x emissions did not begin in earnest until about 1980. This marks the beginning of widespread use of three-way catalytic converters in automobiles, which are capable of reducing NO_x as well as oxidizing HC and CO, the tightening of NO_x standards for light trucks in 1979, and the introduction of heavy-duty vehicle standards in 1984.

▶ Toxic Air Pollutants

The 1990 CAAA placed renewed emphasis on regulation of toxic air pollutants (substances known or thought to cause cancer or other serious illness). Although it is clear that vehicles and fuels are major sources of certain toxic pollutants, comprehensive data are not yet available. EPA's Toxic Release Inventory, covering about 600 chemicals, applies to manufacturing facilities and provides little information about transportation emissions. Other national inventories for specific pollutants are under preparation to support studies called for by the 1990 CAAA. These inventories do not cover all toxics, and the collection methods vary. EPA is developing a more comprehensive toxics database which is expected to be available in 1996.

Fuels used by internal combustion engines are the principal sources of the key hazardous air pollutants (HAPs)—benzene, 1,3-butadiene, and formaldehyde—according to EPA estimates. (USEPA 1995b, tables 8-2, 8-3, 8-4) Onroad mobile sources accounted for 45 percent of EPA's estimated benzene emissions, 38 percent of 1,3-butadiene, and 37 percent of formaldehyde. If all nonroad mobile sources were counted as well, the mobile source share would rise to 64 percent of benzene, 79 percent of 1,3-butadiene, and 53 percent of formaldehyde. (This total includes nontransportation sources such as lawnmowers and construction equipment.) Upstream emissions during the production of petroleum fuels are also a source of benzene emissions (4 percent).

Marine vessel loading and unloading operations also can be sources of toxic air emissions, because vapors are released into the air when liquids are loaded into or removed from cargo holds. Such operations may release as many as 60 of the 189 HAPs listed in Title III of the 1990 CAAA, including benzene, toluene, ethylbenzene, and xylenes (BTEX). BTEX emissions have been shown to contribute to cancer, liver and kidney damage, and neurological and developmental effects. In 1990, the total emissions of HAPs from marine vessel loading totaled about 8,800 short tons, less than 1 percent of the total toxic emissions reported by EPA for that year. EPA has proposed regulations that would reduce emissions to about 400 short tons annually. (USEPA 1995b)

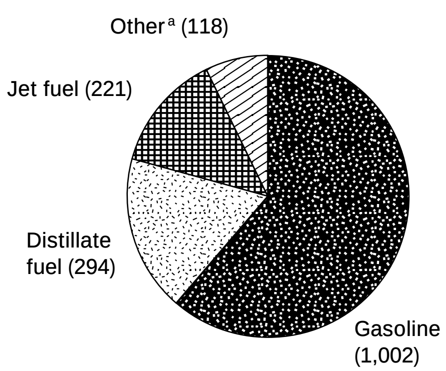
► Greenhouse Gas Emissions

CO_2 is the predominant greenhouse gas released from anthropogenic sources, accounting for about 85 percent of the total emissions, weighted by global warming potential. Methane, nitrous oxides, and other less common gases account for 15 percent of the total global warming potential of greenhouse gases.

Of the 5.12 billion metric tons of CO_2 released from fossil fuel combustion in 1994, transportation was responsible for more than 1.6 billion metric tons (see figure 7-8). While the transportation sector's annual share of these emissions has remained at about 32 percent each year from 1987 to 1994, the actual emissions from transportation increased by 8.6 percent over this period, in line with the 8.9 percent increase for total emissions (see figure 7-9).

Carbon dioxide accounted for all but 3 percent of transportation's 1993 GHG emissions. (USDOE 1995c) Combustion of petroleum fuels accounted for nearly 98 percent of transportation's CO_2 emissions; gasoline contributed more than 60 percent of the CO_2 from transportation. (USDOE 1995d, table C-4, 92)

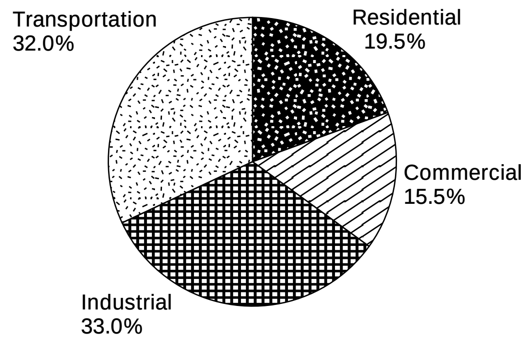
Figure 7-8: Carbon Dioxide Emissions from the U.S. Transportation Sector, 1994 (million metric tons)



[a] These are, in descending order, residual fuel oil (70); natural gas (34); lubricants, liquefied petroleum gas, etc. (10); and electricity (2).

SOURCE: U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1987–1994*, DOE/EIA-0573 (87–94) (Washington, DC: 1995), table C-4.

Figure 7-9: Carbon Dioxide Emissions in the United States, 1994



SOURCE: U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States, 1987–1994*, DOE/EIA-0573 (87-94) (Washington, DC: October 1995), table 5.

Despite significant energy efficiency improvements, transportation activity outpaced efficiency gains, resulting in increased energy use and increased CO_2 emissions. Total transportation energy use increased from 19.7 quadrillion Btu in 1980 to 23.5 quadrillion Btu in 1994. (USDOE 1995c, table 2-1) Transportation emissions of carbon dioxide grew accordingly from 379 million metric tons to 446 million metric tons of carbon. (One ton of carbon equals 3.667 tons of CO_2.)

According to U.S. Department of Energy projections, CO_2 emissions by transportation could increase by 1.3 percent per year through 2010, despite greater use of alternative fuels. (USDOE 1995a) As discussed in chapter 4, gains in energy efficiency have slowed, while vehicle travel continues to grow. Moreover, despite the interest in alternative fuels, petroleum is expected to remain the dominant transportation fuel through at least 2010. Furthermore, most alternative fuels are derived from natural gas or natural gas byproducts. While natural gas and natural gas-based fuels reduce CO_2 emissions relative to petroleum-based fuels, they do not eliminate them. In addition, energy use in upstream processing of alternative fuels reduces their greenhouse gas advantage (see table 7-6). Even battery-powered electric vehicles provide little or no benefit if the electricity is generated from fossil fuels, as is now the case for most U.S. electricity. Unless a widespread switch occurs to cellulosic ethanol (made from woody plants), other renewable-based fuel sources, solar, or nuclear power, even large market penetrations of alternative fuels could have little effect on transportation greenhouse gas emissions.

TABLE 7-6: CARBON DIOXIDE-EQUIVALENT EMISSIONS OF ALTERNATIVE FUELS: LIGHT-DUTY VEHICLES (GRAMS PER MILE)

Fuel/vehicle	Vehicle use	Upstream emissions	Total emissions
Conventional gasoline	344.5	85.9	430.4
Reformulated gasoline	333.7	101.6	435.3
Diesel fuel	325.0	56.8	381.8
Methanol from natural gas	277.4	151.5	428.9
Methanol from coal	277.4	464.7	742.1
Methanol from cellulose	51.4	97.4	148.8
Compressed natural gas	269.0	91.9	360.9
Compressed natural gas from cellulose	64.4	130.2	194.6
Liquid petroleum gas	283.6	36.9	320.5
Ethanol from corn	51.0	481.2	532.2
Ethanol from cellulose	51.0	25.6	76.6
Battery-powered electric vehicles (by primary energy source for electricity generation)			
U.S. mix	0.0	445.6	445.6
Coal-fired plants	0.0	545.6	545.6
Natural gas-fired	0.0	334.4	334.4
Nuclear plants	0.0	29.0	29.0
Solar power	0.0	1.3	1.3

SOURCE: M.A. Delucchi, Argonne National Laboratory, Argonne, IL, "Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity," ANL/ESD/TM-22, vol. 1, 1991, table 9.

► Chlorofluorocarbons and Stratospheric Ozone Depletion

While ozone in the air we breathe is harmful to health, a layer of ozone in the upper atmosphere shields the earth from harmful ultraviolet rays. Chlorofluorocarbons (CFCs) are chlorine containing halocarbons which until recently were widely used in automotive and other air conditioners. When released into the air, CFCs migrate to the stratosphere where they convert ozone to O_2, depleting the ozone layer. In 1987, the United States and most other nations signed the Montreal Protocol on substances that deplete the ozone layer, agreeing to phase out and eventually eliminate CFC production. The 1990 CAAA called for stopping CFC production in the United States by the end of 1994, but an extension was granted to one manufacturer until January 1996.

CFC-12 (dichlorofluoromethane), also known as freon-12, is the CFC previously installed in newly manufactured mobile air conditioners. Although air conditioners in new vehicles now contain a substitute (HFC-134a) that does not contain chlorine, leakage of CFC-12 from the air conditioners of older vehicles slows the progress toward complete elimination of CFC-12 emissions. CFC-12 emissions from all sources have decreased by 38 percent since 1989, and totaled 71 thousand metric tons in 1994. (USDOE 1995d)

CFCs are also potent greenhouse gases with thousands of times the warming potential of CO_2 per molecule. Because they destroy ozone, which is also a potent greenhouse gas, their net effect on climate change is uncertain. The HFC replacement refrigerant also is a greenhouse gas.

Water and Groundwater Contamination

Oil spills and improper disposal of used motor oil and other chemicals from transportation vehicles and facilities are major sources of both surface water and groundwater contamination. Large tanker spills, such as the 10 million gallons of crude oil discharged from the Exxon *Valdez* into Alaska's Prince William Sound in 1989, are the most visible examples. Depending on the concentration and nature of the pollution, the location of the spill, and the environmental resources affected, such spills can have major adverse environmental impacts. Far greater total volumes of oil and petroleum products enter the environment from smaller spills and the improper disposal of used motor oil. For example, it is estimated that the volume of used motor oil improperly dumped into sewers, drains, and soil annually is 15 to 20 times greater than the Exxon *Valdez* spill. From 1982 to 1992, spills from tankers into U.S. waters accounted for only a little more than one-third of all oil spilled. The cumulative effect of these smaller incidents can be significant and costly to clean up.

Other sources of water pollution include leaking above- and below-ground motor fuel storage tanks and pipelines, and runoff from transportation facilities and equipment. In 1993, EPA estimated that one-fifth of the 2 million or so underground fuel storage tanks in the United States that are subject to federal regulation were leaking. According to a 1993 American Petroleum Institute survey, 10 percent of petroleum transportation facilities with aboveground storage tanks reported groundwater contamination. (API 1994)

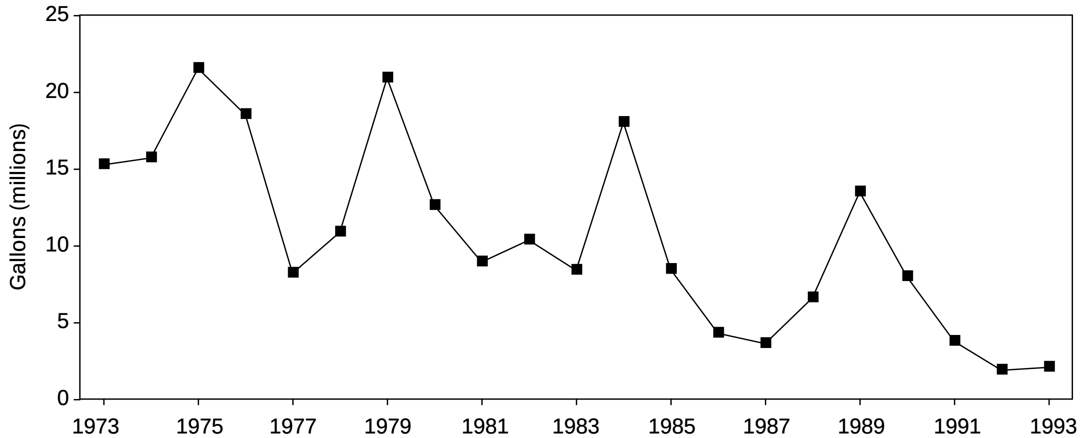
Substantial amounts of oil, grease, antifreeze, fuel, deicing materials, and other contaminants enter the environment from millions of operating vehicles. Additional contaminants come from pavement materials and pollutants from nontransportation sources that settle on highways, parking lots, airport runways, and other transportation facilities. Some of this material is carried by stormwater into rivers or other bodies of water, thus adding to the load of suspended solids, organic compounds, nitrogen, phosphorus, heavy metals, and other contaminants in the water. In general, relatively little is known about the volumes, composition, and impacts of pollution from these smaller, widely dispersed sources.

► Oil Spills into U.S. Waters

In 1994, the U.S. economy consumed 271 billion gallons of petroleum products. (USDOE 1995c, tables 5-8 and 5-11) The United States accounts for 25 percent of the world's oil usage and imports 45 percent of its total oil needs. As a result, 35 percent of the world's petroleum imports are destined for the United States. (USDOE 1995b, table 3-3) Because the transportation sector accounts for two-thirds of U.S. oil use, almost one-quarter of the oil shipped over the world's oceans is for use by the U.S. transportation system.

The median quantity of oil spilled annually in U.S. waters and reported was 9 million gallons or about 0.004 percent of the total amount used. The reported volume of oil spilled has trended downward in recent years despite gradually increasing consumption. The number of reported spills declined from approximately 10,000 per year in the 1970s to approximately 5,000 per year in the late 1980s. Since then, the number of reported spills has increased for spills of less than 1,000 gallons, possibly due to increased reporting under the Oil Pollution Act of 1990. The number of larger spills has continued to decline. While the volume of oil spilled has trended downward, periodic peaks result from large tanker spills (see figure 7-10). Part of the reason for the improvement can be attributed to laws and policies aimed at protecting U.S.

FIGURE 7-10: REPORTED VOLUME OF OIL SPILLED IN U.S. WATERS, 1973–93

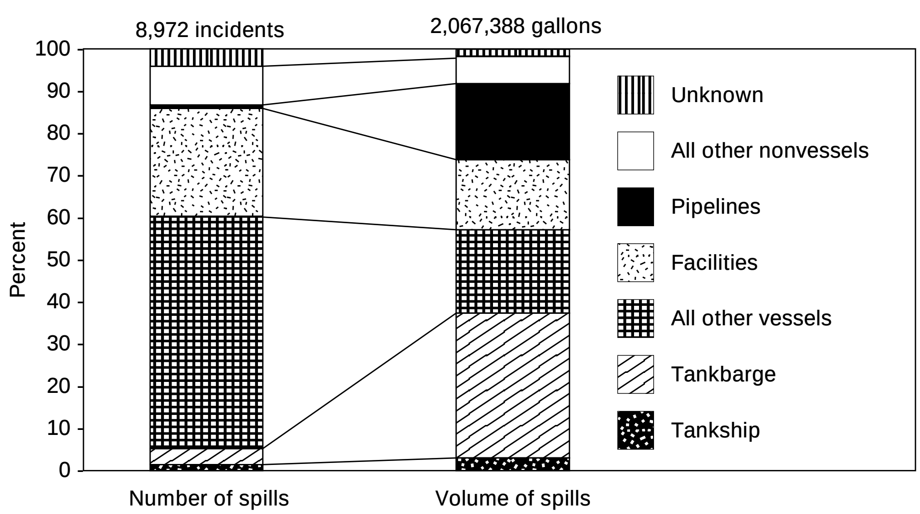


SOURCE: U.S. Department of Transportation, U.S. Coast Guard, *Pollution Incidents In and Around U.S. Waters* (Washington, DC: In press).

waters through fines, tighter regulations, and funding of research for pollution prevention and response.

The peaks shown in figure 7-10 suggest the skewed nature of spills, in which a small percentage of the spills account for most of the volume spilled. Of the 8,972 spills reported in 1993, 19 spills (just 2 percent) accounted for 1.5 million gallons (or 72 percent) of the 2 million gallons of oil entering the water that year (see figure 7-11). Of the remaining spills, 8,470 were less than 100 gallons each. Over the past 20

FIGURE 7-11: OIL SPILLS IN U.S. WATERS BY MAJOR SOURCE, 1993



SOURCE: U.S. Department of Transportation, U.S. Coast Guard, *Pollution Incidents In and Around U.S. Waters* (Washington, DC: In press).

years, oceangoing tanker spills accounted for 30 percent of the volume spilled, but only 5 percent of incidents. Three-quarters of all spills occurred during transportation; the remainder resulted from activities at fixed facilities.

The extent of adverse impact from spills depends on many additional factors aside from the quantity of oil. These include the characteristics of the spilled oil and receiving waters, the environmental sensitivity of the area, and the weather. Most spills occur in protected environments such as rivers, harbors, bays, and sounds, rather than on open seas. Of the approximately 221 million gallons reported spilled over the past 20 years, less than 15 percent were on the open ocean. (USDOT Coast Guard in press) The largest number and volume of spills reported occurred in internal waters.

► Improper Disposal of Used Motor Oil

The improper disposal of used motor oil is a widespread source of groundwater and surface water contamination. Automobile owners who change their own motor oil account for a significant portion of used oil dumping, disposing of up to 200 million gallons of oil annually; of this, as much as 120 million gallons may be dumped onto the ground or into storm drains and another 60 million gallons may be dumped into trash cans. (Novallo 1993) Annually, this is much more than the Exxon *Valdez* spill. (Anderson and Lear 1994)

Although a person may believe that dumping small amounts of oil is of little consequence, one quart of oil can taint the taste of 250,000 gallons of water and can create a 2-acre oil slick on lakes and streams. (Novallo 1993) Oil also contains additives that can oxidize during combustion to form corrosive acids, and used oil is often contaminated with heavy metals, chlorinated solvents, and harmful organic substances. EPA did not list used motor oil as a hazardous waste under the Resource Conservation and Recovery Act. It has promulgated, however, used oil handling standards for generators, transporters, processors, re-refiners, burners, and marketers. The standards only apply after used oil is collected and aggregated by public or private collection services. (Kreith 1994, 9.166)

According to EPA, only about 10 million gallons (5 percent) of the used motor oil generated by do-it-yourself oil changers was recycled in 1988. More recycling could decrease both the amount of used oil released into the environment and the amount of crude oil used for producing motor oil. Motor oil does not wear out; it merely becomes contaminated with residuals of fuel combustion and engine wear. Re-refining removes these contaminants from the oil and returns it to its original quality. (Novallo 1993, 109–112)

► Underground Storage Tanks

Groundwater contamination is often caused by leaks from underground storage tanks, such as those found at neighborhood gas stations. Most underground storage tanks are used by the transportation sector. Of these, about 49 percent are for retail motor vehicle fuels, 47 percent for petroleum storage, and 4 percent for chemical storage. According to EPA, about 1,000 confirmed releases are reported each week, and 20 percent of the 2 million regulated tanks may be leaking. (USEPA 1993, 14–15)

To remediate this type of contamination, the federal government established the Leaking Underground Storage Tanks program, which operates under the authority of Subtitle I of the Hazardous and Solid Waste Amendments Act of 1984 as amended by the Superfund Amendments and Reauthorization Act of 1986. The program's purpose is to achieve rapid and effective responses to releases from underground storage tanks containing petroleum and other hazardous substances.

The Strategic Targeting and Response System (STARS) is used to track releases and cleanup activities for underground storage tanks regulated under Subtitle I. (Other underground tanks are not included within the database.) The STARS database has been in place for a relatively short period of time, and the format of the data has changed somewhat, making it difficult to identify trends. Still, the number of active tanks regulated under Subtitle I has decreased since 1990, while closures and cleanup activities seem to show a peak in 1992–93.

► Aboveground Storage Tanks

In addition to their air emissions, spills from aboveground storage tanks (ASTs) are a source of groundwater contamination. ASTs at transportation facilities serve two primary functions: 1) to provide breakout storage or overflow relief at small pumping stations, or 2) to provide short-term storage at tank farms or distribution facilities. (API 1994) Spills from these facilities are often due to overfill, failure of tank bottoms, improper disposal of tank bottom mixtures, and leakage from piping associated with tanks.

A 1993 American Petroleum Institute (API) survey found improved spill prevention and reduced instances of environmentally unsound disposal practices at refining, marketing, and transportation facilities operated by API member companies. Of the 140 transportation facilities surveyed, 127 responded. This, however, represents only 8.7 percent of the transportation facilities operated by API members.

Mixtures of water and dissolved or entrained hydrocarbons accumulate at the bottom of aboveground storage tanks. These water-bottom mixtures once were routinely drained onto the ground. Now, 71 percent of the respondents said they used procedures to remove, recover, or properly dispose of the water-bottom material. Only 18 percent of the responding transportation facilities had established groundwater monitoring programs. The explanation is that many facilities, such as crude oil facilities, are located away from population centers. Ten percent of the respondents confirmed groundwater contamination.

The survey did not yield information about incident frequencies or accidental release volumes. Such information and more comprehensive surveys would be desirable.

► Runoff

Runoff from streets and parking lots is another source of water and groundwater contaminants. A study by the Federal Highway Administration (FHWA) identified the primary sources and constituents of highway runoff (see table 7-7). (USDOT FHWA 1987) Both the amount and nature of the materials are highly site-specific, depending on such factors as traffic characteristics, highway design, maintenance activities, surrounding land use, climate, and accidental spills. The study also determined that deposition from vehicles is the primary source of pollutants except during periods of ice and snow, when deicing chemicals and abrasives are the primary source. The FHWA study found that metals and sodium concentrations in topsoil next to highways could affect ecosystem processes.

FHWA analyzed runoff from 993 separate events at 31 sites in 11 states across the United States to determine the range of composition of highway stormwater runoff. (USDOT FHWA 1990, table 3) FHWA found that the only statistically significant distinction among the events in their sample was whether they were at rural or urban sites, the urban sites producing greater pollutant concentrations, as one might expect.

TABLE 7-7: CONSTITUENTS AND SOURCES OF HIGHWAY RUNOFF

Constituent	Primary sources
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Autobody rust, steel highway structures (e.g., guard rails), moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides applied by maintenance operations
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Bromide	Exhaust
Cyanide	Anticake compound (ferric ferrocyanide, Prussian Blue or sodium ferrocyanide, Yellow Prussiate of Soda) used to keep deicing salt granular
Sodium, calcium	Deicing salts, grease
Chlorine	Deicing salts
Sulfate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate
Polychlorinated biphenyls (PCBs), pesticides	Spraying of highway rights-of-way, background atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria (indicators)	Soil, litter, bird droppings, and trucks hauling livestok and stockyard waste
Rubber	Tire wear

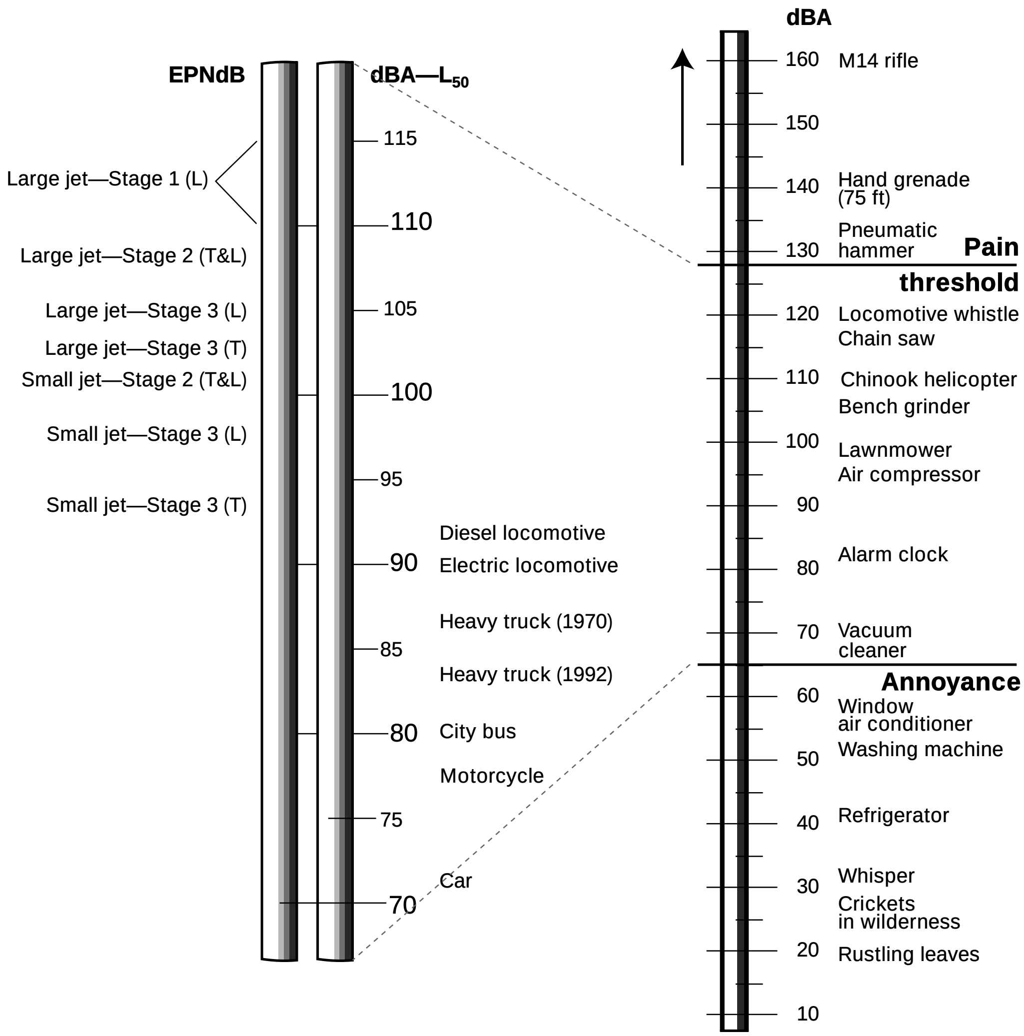
SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Sources and Migration of Highway Runoff Pollutants*, Technical Summary of Report No. FHWA/RD-84/060 (Washington, DC: 1987).

Noise

The transportation system is a pervasive source of noise in the United States. Intrusive noise—unwanted sound—is considered a form of pollution that can degrade the quality of life for those exposed. Sound is most often measured on a nonlinear scale in units of decibels. An adjusted scale, the A-weighted scale, emphasizes sound frequencies that people hear best. The measurement units in this scale are A-weighted decibels (dBA). On this scale, a 10-dBA increase in sound level is generally perceived by humans as a doubling of sound. Examples of sound sources and their typical noise levels are presented in figure 7-12.

The localized occurrence of noise makes it difficult to study national trends. Noise levels can vary drastically from site to site depending on noise sources, structures or natural terrain that block noise, and other factors. According to one estimate in the early 1980s, however, 37 per-

FIGURE 7-12: TRANSPORTATION NOISE LEVELS



KEY: EPNdB = Effective Perceived Noise Level used to measure aircraft flyover noise during a specified 10-second interval. Includes maximum audible sound level. Measurement is not comparable to A-weighted decibel scale.
dBA = A-weighted decibels (see text definition).
dBA—L_{50} = the sound level (measured in A-weighted decibels) that is exceeded by no more than 50 percent of the sample readings in the measurement time period. Peak sound level not necessarily measured. Noise measured at a point 7.5 meters from highway vehicles and locomotives. Unless noted, highway vehicles are 1992 European models.
L = landing noise over reference point 2,000 meters from runway threshold.
T = takeoff noise over reference point 6,500 meters from start of takeoff roll.
Small jet = commercial aircraft up to 100,000 lbs maximum takeoff weight.
Large jet = up to 1,000,000 lbs maximum takeoff weight.
Stage 1 = aircraft certified prior to 1969, before Federal Aviation Administration (FAA) noise regulations.
Stage 2 = aircraft sound level needed to meet FAA 1969 noise regulations. Now being phased out.
Stage 3 = aircraft sound level needed to meet FAA's more stringent 1975 noise regulations.

SOURCE: Aircraft noise—adapted from 14 Code of Federal Regulations, Part 36, appendix C; highway and railroad noise—P.M. Nelson, ed., *Transportation Noise Reference Book* (London, England: Butterworths, 1987); and Truls Berge, "Vehicle-Noise Emission Limits: Influence on Traffic Noise Levels Past and Future," *Noise Control Engineering Journal,* vol. 42, No. 2, March–April 1994; all other adapted from Ann Arbor Science Publishers, Inc., *Environmental Impact Data Book* (Ann Arbor, MI: 1979).

cent of the U.S. population was exposed to noise levels exceeding 55 dBA, 10 percent exceeding 60 dBA, 7 percent exceeding 65 dBA, 2 percent exceeding 70 dBA, and 0.4 percent exceeding 75 dBA. (OECD 1988, 44)

Annoyance, which is subjective, is probably the most prevalent effect of transportation noise. Transportation noise, especially noise from large aircraft, can interfere with sleep, and this, in turn, can adversely impact health. Minimum noise levels that disturb sleep range from 35 to 70 dBA, depending on the sleep stage and the age of the person.

Under the circumstances experienced by most people, transportation noise does not pose a permanent threat to hearing acuity. For hearing loss to occur, a person would have to stand about 10 to 20 feet (3 to 6 meters) from a highway lane carrying approximately 1,000 trucks per hour for 8 hours per day on a daily basis for many years. (Newman and Beattie 1985; USDOT FHWA 1980, 86)

► Highway Noise

Vehicles on the highway are the most pervasive source of noise from the transportation sector. The level of noise generated by highway traffic is a product of three factors: 1) traffic volume, 2) traffic speed, and 3) traffic mix (i.e., the number of trucks in the traffic flow). Noise from cars and light trucks is primarily caused by the sound of tires on the pavement, but noise from heavy trucks is a combination of engine, exhaust, and tire sounds.

Control Methods

Highway noise can be addressed through motor vehicle controls, land-use controls, and highway planning and design. Vehicle controls include quieter engine design, sound enclosures around engines, and better mufflers. Laws or regulations that require vehicle owners to properly maintain their vehicles are also considered vehicle control measures; such measures can produce a 5 to 10 dBA decrease in sound level. The Noise Control Act of 1972 authorizes EPA to regulate major sources of noise emissions, including transportation noise. In 1988, EPA established a noise emission standard for newly manufactured medium and heavy trucks with a gross vehicle weight of more than 4,525 pounds. (USDOT FHWA 1994) (The standard does not apply to vehicles too large to operate on highways.)

Land-use controls are sometimes used to reduce the impact of vehicular noise on residential areas, schools, churches, and other developments. Such controls may limit new development near highways or require soundproofing of buildings, erection of noise barriers, or other mitigation measures. The federal government has little authority to regulate land use, and such controls are usually implemented by state and local governments.

Noise also can be considered in highway planning and design. Studies can be conducted to determine whether an area will be seriously affected by highway construction or vehicle noise. In many cases, alternative routes can be selected if the projected noise levels exceed acceptable levels. By constructing a highway so that the line-of-sight between traffic and populated areas is obstructed, noise impacts can be avoided to some degree.

Noise barriers (solid obstructions erected between highways and areas such as residences, parks, and commercial buildings) impede highway traffic noises, reducing noise levels by as much as 10 to 15 decibels in some cases. (Cohn et al 1993, 69–74) As a result, noise barriers have become a popular method of highway traffic noise mitigation. From 1970 through 1989, 40 states and the Commonwealth of Puerto Rico constructed nearly 750 miles of barriers at a cost of nearly $650 million in 1992 dollars. (USDOT FHWA 1994)

► Aircraft Noise

Aircraft noise became a conspicuous problem in the United States with the advent of commercial jetliners in the 1960s. Research shows that hearing loss is not a cause for concern for aircraft passengers and the flight crew. Studies also show that there is no danger of permanent or even temporary hearing loss due to aircraft flyover. (Newman and Beattie 1985)

Speech interference is the primary source of annoyance from aircraft flyover. In addition to general annoyance, speech interference is a safety issue for crew members in the cockpit of aircraft. In situations where cockpit noises are above 88 dBA, special noise-canceling communications equipment should be used.

Some research shows that aircraft noise has minimal impact on farm animals. Wild animals have shown degrees of agitation when exposed to aircraft noise; however, a study involving wild birds demonstrated that this can be highly species-dependent.

Aircraft/Airport Noise Abatement and Regulation

In 1968, Congress gave the Federal Aviation Administration (FAA) authority to prescribe standards for measurement and regulation of aircraft noise so as to protect the public health and welfare. In 1969, FAA adopted Part 36 of the Federal Aviation Regulations (FARs), which established noise certification standards for turbojet and transport category aircraft. Part 36 required all future-design turbojet and large transport category aircraft to meet Stage 2 noise standards.[1] Current-production planes were excluded from this standard until 1974, when FAA demonstrated the feasibility of retrofitting current production aircraft to meet Stage 2 standards.

While Part 36 helped reduce noise from jet planes, the rapid expansion of commercial jet transport exposed more people to noise impacts. By 1974, for example, as many as 7 million people were severely affected by jet airplane noise. (USDOT FAA 1989) Thus, FAA required operators to install quieter engines or hushkits on Stage 1 aircraft by January 1, 1985. (Hushkits reduce fan and compressor noise by modifying various engine components and by adding acoustic treatment and noise suppressors.)

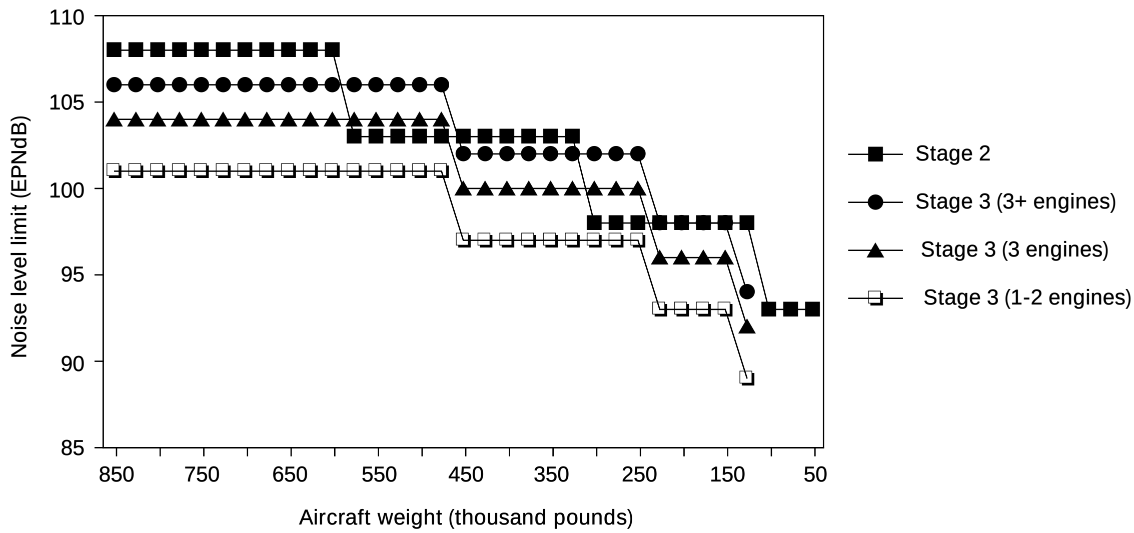
As jet travel increased, more stringent noise standards were adopted. Since March 1977, all newly type-certificated aircraft have been required to meet Stage 3 noise certification requirements where technologically feasible. These standards set limits on aircraft noise based on the number of engines in addition to weight and operation. In most cases, Stage 3 standards are more stringent than those for Stage 2—although there can be exceptions (see figure 7-13). Some airports imposed local operating restrictions to decrease the noise impacts of Stage 2 aircraft (such as phased elimination schedules, nighttime curfews, and noise budget allocations for carriers).

In 1990, Congress passed the Airport Noise and Capacity Act (ANCA), which calls for the phased elimination of civil, subsonic Stage 2 aircraft weighing over 75,000 pounds that use airports in the contiguous United States by December 31, 1999. (USDOT FAA 1994) Under an interim compliance schedule, operators can either reduce the percentage of Stage 2 aircraft or achieve a fleet composition percentage of Stage 3 aircraft by, for example, installing quieter engines or modifying Stage 2 aircraft engines with certified hushkits. ANCA also allows local airport operators to continue to use additional controls to reduce the impact of Stage 2 aircraft prior to the 1999 deadline.

According to FAA estimates, the Stage 2 and Stage 3 regulations have dramatically reduced the number of people exposed to aircraft day-night noise levels (DNL) of 65 dB or above. In

[1] See the key in figure 7-12 for an explanation of the stages of aircraft noise.

FIGURE 7-13: **COMPARISON OF STAGES 2 AND 3 NOISE LIMITS FOR TAKE-OFF**



NOTE: See key in figure 7-12 for an explanation of stages of aircraft noise.

SOURCE: Based on 14 Code of Federal Regulations, Part 36, appendix C.

1975, 7 million people lived within DNL 65 dB contours. By 1990, the number of people within these contours was only 2.7 million. FAA estimates that this number will decrease to 0.4 million by 2000 after the final phase of the Stage 2 ban goes into effect. (USDOT FAA 1994)

Airport noise compatibility planning is another way to reduce noise annoyance for areas around airports and under aircraft flight patterns. The objective of the planning is to help areas near airports take noise impacts into account in their land-use and development decisions.

Under FAR 150, federal grants are available to airports for preparation of airport noise exposure maps and airport noise compatibility programs. FAA has issued criteria to be used by airports that elect to participate in the program. As of November 1995, 173 airports had approved Noise Compatibility Programs, and about 220 airports were active within the Part 150 program. (Hixson 1995)

Solid Waste

Discarded vehicles or parts and obsolete or abandoned infrastructure (e.g., pavement scraped off highways and abandoned rail line materials) account for most of the solid waste generated by the transportation sector. Much of the waste is put in landfills, but a significant amount of scrap from old vehicles, tires, car batteries, and pavement is recycled. In addition to the solid waste generated by transportation, a significant volume of waste (hazardous and otherwise) is shipped by rail, truck, and vessel. Solid waste can also be generated in the maintenance of transportation infrastructure. Examples are silt and other material dredged from ports and harbors to maintain navigation channels. Disposal of this material, especially when contaminated can be challenging (see box 7-3).

Box 7-3: Dredging of Sediments in Ports and Harbors

In 1992, more than 3 billion tons of cargo moved into and out of U.S. ports. Essential for trade and commerce, these ports handle 95 percent (by weight) of all U.S. exports and imports. Ports and port activities, however, affect the nation's coastal, ocean, and freshwater resources. One environmental issue is dredged sediments. In order to accommodate large cargo ships, navigation channels must be dredged and siltation removed from the harbor floor. Although estimates vary widely, one study concluded that about 400 million cubic yards of material are removed each year to maintain the depth of navigation channels and shipping berths. The current permitting process results in the special handling of about 5 percent of dredged material classified as contaminated.

Siltation is a common problem because many of our nation's ports (e.g., New York, New Orleans, Baltimore, and Portland) were built at the mouth of river systems that deliver silt that settles in port channels, making regular dredging a necessity. As ship size and speed have increased, so too have the requirements for channel depth. For example, in the 1970s, a depth of 35 feet was considered adequate to handle most maritime trade. Today, container ships require channel depths of 45 to 50 feet; bulk carriers may require water depths of 60 to 65 feet. For all ports, particularly those with tributary river systems, maintaining channel depth provides a challenge.

Uncontaminated dredged material can be used beneficially for beach nourishment, wetland creation, and as caps for landfills, or it can be dumped in certain disposal sites in open waters. Contaminated material, on the other hand, may have to be treated to reduce its toxicity and managed in special ways, increasing the costs of navigational dredging. Contaminates include heavy metals and other pollutants, such as dioxins and polychlorinated biphenyl, that are or have historically been discharged into water and air. Contributing sources are industrial facilities within ports and upstream, and nonpoint sources such as transportation and agriculture. For example, bottom sediments in many harbors and rivers of the Great Lakes ecosystem have been found to contain bioaccumulated toxic substances from past industrial discharges. Contaminates reduce or injure fish and wildlife populations. Improper disposal of contaminated material can present costly environmental and human health risks.

Dredge material management is a contentious issue. In some instances, the presence of contaminated sediment has delayed dredging, thereby affecting waterborne commerce.[1] Uncertainties exist about how best to determine the extent of contamination in sediments, and there is debate about appropriate management options. Indiscriminate dumping in the ocean was once a common way to dispose of sediment but is no longer permitted. Current alternatives include upland disposal and disposal in confined areas within ports and harbors (such as underwater in covered pits or by constructing islands). Highly contaminated materials may require special remediation to remove or treat the contaminants before disposal. A National Research Council study, expected to be issued in late 1996, is examining best management practices and technologies and other issues relevant to contaminated sediments.

National and state regulations have been developed to address dredging and appropriate sediment management to maintain the environmental integrity of the nation's coastal resources. Under statutes, such as the Clean Water Act (CWA) and the Marine Protection, Research, and Sanctuaries Act (MPRSA), a number of agencies have been given authority for various stages of the dredging and disposal process. Under the MPRSA, for instance, the U.S. Army Corps of Engineers issues permits covering dredged materials disposed in most coastal waters and the open ocean; the Environmental Protection Agency has review authority, designates specific ocean disposal sites, and established the environmental impact criteria used by the Corps of Engineers in the permit review process.

[1] Council on Environmental Quality, Office of the President, *Twenty-Fourth Annual Report* (Washington, DC: U.S. Government Printing Office, 1993).

(continued)

Box 7-3 (cont'd): Dredging of Sediments in Ports and Harbors

Disposal in most freshwater areas and wetlands, estuaries, and coastal waters is regulated under the CWA. Regulations setting quantitative sediment quality criteria have been debated for a decade and were finally proposed in 1994.

Recognizing a need for improvements in the dredging review process, Secretary of Transportation Federico Peña convened an Interagency Working Group on the Dredging Process in October 1993.[2] The Group's *Action Plan for Improvement*, submitted in December 1994, resulted in the establishment of an interagency National Dredging Team and regional teams. The teams are helping to implement the action plan's comprehensive recommendations. The aim is to establish a more timely, efficient, and predictable dredging process.

[2] U.S. Department of Transportation, Maritime Administration, *Report to the Secretary of Transportation, The Dredging Process in the United States: An Action Plan for Improvement* (Washington, DC: December 1994).

► Highway Vehicle Scrappage

Dismantlers have long collected junk cars and spare parts for resale, reconditioning, or recycling. With the introduction of shredding in the 1960s, it has became more cost-effective to recycle vehicles. By 1995, 94 percent of retired vehicles were recycled, and 90 percent were scrapped at shredders. (Curlee et al 1995; AAMA 1995, 55; Holt 1993)

According to Oak Ridge National Laboratory, approximately 12.8 million tons of material were generated from retired automobiles from June 1993 to June 1994. About 73 percent of this material (9.4 million tons) was recycled. The remaining 3.5 million tons was placed in landfills.

The increase in highway vehicle recycling over the last few decades has reduced the volume of waste that would otherwise be placed in landfills. Recent trends in the composition of passenger vehicles, however, have begun to make current recycling practices less viable economically, thereby forcing vehicle manufacturers, recyclers, and other organizations to find new technologies and procedures for recycling highway vehicles.

To improve fuel efficiency, manufacturers reduced the weight of vehicles. Since 1976, the weight of the typical family vehicle decreased from 3,761 pounds to 3,169 pounds, an average decrease of 592 pounds (see table 7-8). Much of this reduction came through less use of steel,

Table 7-8: Composition of a Typical Passenger Vehicle, 1976–94 (pounds of material)

Year	Ferrous	Aluminum	Other nonferrous	Thermoplastics	Thermosets	Other materials	Total
1976	2,785.0	85.5	101.0	87.6	74.9	626.5	3,760.5
1980	2,423.5	130.0	71.0	97.3	97.7	543.5	3,363.0
1985	2,269.0	138.0	62.0	128.3	83.2	506.5	3,187.0
1990	1,985.0	158.5	65.0	128.3	93.7	465.0	2,895.5
1994	2,145.0	182.0	58.0	152.4	92.6	539.0	3,169.0

SOURCE: *Ward's Automotive*, annual editions, 1976–1994.

iron, and other metals, and greater use of such lighter weight materials as plastics and plastic composites. Unfortunately, metals are the most cost-effective materials to recycle, while plastics, rubber, glass, and other materials are most often regarded as "fluff" or "automobile shredder residue" (ASR) and placed in landfills or incinerated. As the amount of recyclable metals decreases, recycling becomes less profitable.

New technologies that could increase the cost-effectiveness of recycling are under development. For example, one Maryland company is developing a computerized dismantling facility. The computer helps determine which vehicles, or which vehicle parts, are economically reclaimable, based on make, model, year of the vehicle, estimated time to remove recyclable parts, and the market value of these parts. (Holt 1993) Oils, lubricants, and other liquids are extracted for off-site reprocessing. Recovered fuels are used on-site for power generation; most plastics, oils, and hydraulic fluids are converted into natural gas and used for fueling the on-site electric cogeneration system. The remaining hulk is separated from hazardous materials and liquids, compressed, and bundled for resale.

Some firms have conducted research to find uses for ASR and to develop processes for recovering these materials in a cost-effective manner. Perhaps, in the future, innovative recycling technology will make a significant impact on the amount of ASR in landfills.

Automobile designers have begun to find ways to make automobiles more recyclable and to use recycled materials in new autos. Much of this effort has been propelled by expectations that Germany and some other European countries may eventually require auto manufacturers to take back their cars for recycling or disposal when their useful life ends. Such proposals, if adopted, could apply to cars imported into Germany or other countries with take-back requirements, as well as to their domestic automakers. (Kinraid 1995)

► Lead-Acid Batteries

Lead-acid batteries from automobiles are another source of solid and liquid waste from the transportation sector. The Battery Council International estimates that, overall, 98 percent of obsolete lead-acid batteries from vehicles were recycled in 1990 and 97 percent were recycled in 1991. (Kreith 1994) Still, the hazardous nature of these batteries suggests that even higher recovery rates would be desirable. It is estimated that lead from automobile batteries accounts for about two-thirds of the lead (by weight) in municipal solid waste sites. (Kreith 1994)

A typical automobile battery has a useful lifetime of three to four years. It contains 18 pounds of lead and lead dioxide, 9 pounds of sulfuric acid (about 1 gallon), 3 pounds of polypropylene plastic casing, 3 pounds of polyvinyl chloride rubber separators, and about 3 pounds of various chemical sulfates and oxides. Lead from used batteries is reclaimed at smelters, which rely on used batteries for more than 70 percent of their lead supply. Sulfuric acid recovered from batteries can be used in fertilizer or neutralized for disposal, and the plastic battery cases can be reused or recycled to form other plastic products.

Lead wastes are hazardous, and can be absorbed through ingestion or inhalation. Lead settles in body organs, often causing liver and kidney damage in adults and neurological damage to children. Lead from landfilled batteries can leach into groundwater or contaminate surrounding soil. For this reason, EPA classified lead-acid batteries as hazardous waste in 1985. Also, as of February 1993, 41 states had passed legislation on lead-acid batteries. Regulations include such measures as banning disposal of lead-acid batteries in landfills and incinerators, establishing requirements for retailers and collection facilities that accept spent batteries, imposing fines to enforce regulations, and requiring deposit fees for the sale of new batteries, which can be recovered on return of the spent battery.

► Tires

Used tires comprise a large part of the solid waste generated by the transportation sector. No industry group or governmental agency monitors scrap tire disposal in the United States. Therefore, estimates of used tire generation are based on tire production. (USEPA 1991)

In 1990, an estimated 188 million tires were placed in landfills or stockpiles, or dumped illegally (see figure 7-14).Tires are a significant problem in landfills. The tires often rise to the landfill surface as other materials around them settle. The uncovered tires can be breeding grounds for mosquitoes and other insects. Piles of tires sometimes ignite and burn, releasing toxic smoke and fumes. Burning tires emit criteria air pollutants, metals, and unburned organics. (USEPA 1991) Burning tires are difficult to extinguish, and the related residue can cause groundwater contamination. Several large stockpile fires in the mid-1980s prompted interest in alternative uses for scrap tires.

It has been estimated that only about 22 percent of the tires that were scrapped in 1990 were recycled. The recycled tires were processed in two primary ways: fuel combustion (26 million) and processed-tire products (16 million). Another 300,000 tires were reused in whole-tire applications. (While there are many uses for scrap tires—crash barriers, retaining walls, artificial reefs, playground equipment, landscaping material, and other applications—they have not developed into widely marketed products.) An additional 12 million tires were exported to other countries (see figure 7-14).

Burned as fuel, tires have an energy content of about 15,000 Btu per pound, somewhat higher than coal (6,000 to 13,000 Btu). Tires are also compact, consistent in composition, and low in moisture content.

Processed-tire applications include pyrolysis products, shredded embankment material, various molded rubber products, and crumb rubber for asphalt paving. Of these, pyrolysis and crumb rubber are the most common.

Pyrolysis thermally breaks scrap tires down into three marketable products—pyrolytic gas, oil, and char. The gas has a heat value similar to natural gas. The oils can be used for gasoline additives and fuel oil, and char can be substituted for carbon black in some applications. EPA maintains that pyrolysis units will have minimal air pollution impacts, because most of the pyrogas generated in the pyrolysis process is burned as fuel, and organic compounds are destroyed during burning. (USEPA 1991)

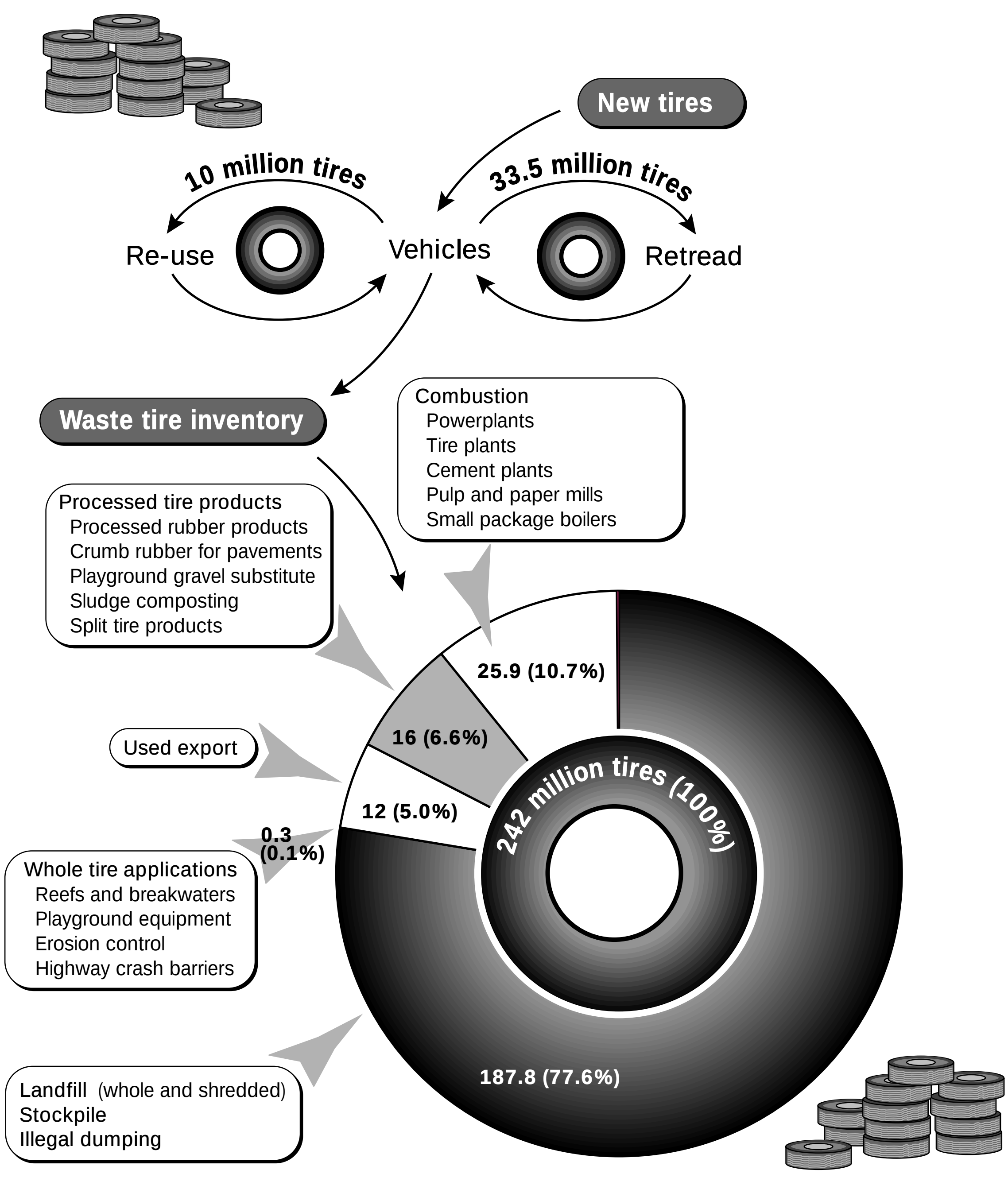
Crumb rubber modifier (CRM) is primarily used to produce asphalt rubber and rubber modified hot mix asphalt (RUMAC). Asphalt rubber is a combination of asphalt cement binder and CRM and is used in sealants, thin surface treatments, and hot mix asphalt (HMA). RUMAC is used in hot mix asphalt only (see next section). (USDOT FHWA and USEPA 1993, 4)

Use of asphalt pavement containing recycled rubber has been encouraged through provisions in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). ISTEA prohibits disapproval of highway projects on grounds of use of asphalt pavement with recycled rubber. It requires studies on the performance and recyclability of asphalt pavement containing recycled rubber and evaluation of the environmental impacts of its use. ISTEA provisions setting minimum utilization requirements for recycled rubber in asphalt pavement were repealed by Congress in the 1995 National Highway System Designation Act.

► Asphalt and Concrete Pavement

Asphalt and concrete pavement removed from roadways constitute a significant portion of the solid waste produced from transportation infrastructure. Fortunately, this material can be reclaimed and used in a number of transportation-related applications. Estimates vary about

FIGURE 7-14: DISPOSITION OF U.S. SCRAP TIRES, 1990



SOURCE: U.S. Environmental Protection Agency, Solid Waste and Emergency Response, *Summary of Markets for Scrap Tires* (Washington, DC: 1991).

the total amount of reclaimed asphalt pavement (RAP) generated each year. A 1994 estimate put the quantity of RAP at about 45 million metric tons per year. A study by FHWA published in 1979 estimated that 90.5 million metric tons were removed annually. (USDOT FHWA 1995, 6) The Environmental Protection Agency estimates that more than 80 percent of removed asphalt pavement is reused in highway applications, and less than 20 percent is placed in landfills. (USDOT FHWA 1995, 6, 13)

Reclaimed Asphalt Pavement

Reclaimed asphalt pavement is used for, among other things, resurfacing, aggregate for roadway and shoulder base, shoulder surfacing and widening, driveway maintenance, surfacing under traffic barriers, ditch linings, and pavement repairs. RAP is typically recycled in three ways: HMA prepared off-site at a plant, hot in-place recycling (HIPR), and cold in-place recycling (CIPR).

An estimated one-third of the RAP generated annually is used in HMA production. (USDOT FHWA 1995, 13) RAP content in recycled HMA produced with conventional technology typically is in the range of 10 to 20 percent. Hot mix materials with a far higher RAP content can be produced, however, without adverse engineering or significant environmental problems. (USDOT FHWA and USEPA 1993, 27)

The initial construction cost of HMA recycling projects can be 15 to 30 percent less than traditional paving approaches. (USDOT FHWA and USEPA 1993, 14) Savings vary depending on project and plant location, materials availability and proximity, and asphalt cement prices. Since most recycling projects are relatively recent, adequate performance data for estimating life-cycle costs is often not available.

According to the National Asphalt Pavement Association, almost half of the HMA producers in the United States used some recycled asphalt in 1986. More recently, FHWA reported that, among state highway agencies that responded to a request for information, the use of RAP for HMA ranged from 7 percent in Texas to 75 percent in Florida. (USDOT FHWA 1995, 6)

HIPR is an on-site process to rehabilitate existing pavement. The existing pavement is heated and milled, mixed with new material, placed, and compacted by the recycling train. Currently, this technique only is used to remedy problems with the surface course on pavement not needing structural improvement.

According to the American Recycling and Reclaiming Association (ARRA), HIPR was used to recycle approximately 545,000 metric tons of RAP in 1991. The cost of using this technique has varied significantly from a 16 percent increase over conventional methods to a 40 percent savings, with recent reports finding cost savings of less than 10 percent. (USDOT FHWA 1995, 16)

In another on-site process, CIPR, the existing pavement is milled, mixed, and placed without added heating. The placed material is then cured, compacted, cured again, and covered with a wearing surface. ARRA estimates that 2,060,000 metric tons of RAP were processed using this technology in 1991. (USDOT FHWA 1995)

Reclaimed Concrete Pavement

About 3 million metric tons of reclaimed concrete pavement are used annually. (USDOT FHWA 1995, 23) It is most commonly used as an aggregate subbase or base course, but at least two states reported use in hot mix asphalt.

▶ Transportation of Hazardous Materials

A large volume of hazardous materials is shipped each year, posing risks of accidents and damage to the environment. For this reason, the government regulates the transport of hazardous materials and monitors spills. Table 7-9 summarizes causes and consequences of hazardous materials incidents in 1994. The number of incidents rose from about 6,000 in 1985 to 16,092 in 1994. The 1994 incidents resulted in 11 deaths, 577 injuries, and $37 million in damages. (The figure for water transportation does not include spills from bulk containers, i.e., tankers and barges.) Although the number of incidents has grown, it is far from certain that the incident occurrence rate is increasing. Improved reporting explains part of the increase in reported incidents. Additionally, the growth in incidents also may be caused by increased economic activity. Both ton-miles and vehicle-miles of freight rose over the past decade. While it is reasonable to assume that shipments of hazardous materials also increased, reliable statistics are not available.

Another factor in the growth of incidents is the rise in nonbulk shipments of hazardous materials, including those by parcel services. Indeed, incidents from bulk shipments have remained flat over time, whereas those from nonbulk shipments have grown steadily. Because incidents include any unintentional release of hazardous materials during the course of transportation, many of the nonbulk incidents were spills that did not spread beyond the vehicle. While the total number of incidents increased, the number of serious incidents remained constant. (In this context, a serious incident is one that involves a fatality, major injury, closure of a major transportation artery or facility, evacuation of six or more persons, or a vehicle accident or derailment.) It is likely that minor incidents were previously underreported and that minor, nonbulk incidents account for at least some of the rise.

The bottom half of table 7-9 shows the consequences of hazardous materials incidents. As with the number of incidents, these numbers have trended upward since 1985, although at a slower pace and more erratically. Most of the numbers

TABLE 7-9: HAZARDOUS MATERIALS INCIDENT STATISTICS, 1994

Causes	Air	Highway	Railway	Water	Total incidents
Human error	787	12,189	539	4	13,519
Package failure	120	1,408	556	1	2,085
Vehicle accident/derailment	0	246	52	0	298
Other	23	156	10	1	190
Consequences					
Incidents	930	13,999	1,157	6	16,092
Deaths	0	11	0	0	11
Injuries	57	425	95	0	577
Number of evacuations	29	255	31	1	316
Number of people evacuated	368	7,984	10,015	25	18,392
Damages	$177,543	$25,248,950	$18,673,002	$92,003	$44,191,498

SOURCE: U.S. Department of Transportation, Research and Special Programs Administration, Hazardous Materials Information System.

are based on information collected within 30 days of the incident, which affects the damage figures. Damages that are not assessed until later are not included, which potentially overlooks costly environmental remediation.

Land-Use and Habitat Effects of Transportation

Transportation has important direct and indirect impacts on land use and environmental habitats: 1) land is used directly for transportation infrastructure, and 2) other development may be stimulated by the construction or expansion of transportation infrastructure. Both of these transportation-related forms of development have the potential to reduce and/or fragment wildlife habitat and disrupt ecosystems.

► Land Requirements for Transportation Infrastructure

The transportation infrastructure of the United States is extensive. The highway system reaches all but the most remote and unpopulated parts of the country; most small cities have a rail line passing though them, and airports of all sizes are common throughout the United States. In addition, ports, intermodal facilities, pipeline facilities (where such facilities are above ground), rail yards, and other transportation infrastructure also require land.

According to one estimate, the land devoted to roads in 1991 totaled approximately 20,627 square miles, and land devoted to parking ranged from 1,910 to 3,035 square miles. (These estimates include only the paved portion of the highway. Other portions of highway right-of-way such as land between divided Interstates and the cleared areas outside the shoulders of highways are not included.) (Delucchi 1995)

Like other forms of development, transportation infrastructure—through direct use of the land and through land fragmentation—reduces the amount of land usable by wildlife and occupied by vegetation. Currently, national-level information about the cumulative impacts of this infrastructure on ecological systems is very limited. Most transportation-related impacts on habitats are studied at the local level. The federal government requires that Environmental Impact Statements be prepared for federally funded development projects that could have a significant impact on the environment. These statements address impacts on mammals, birds, aquatic life forms, endangered species, air quality, water quality, ambient noise levels, cultural and historical sites, and other aspects of the environment. The environmental impact statement process does not prohibit development nor require any specific decision, but relies on full disclosure to identify and assess impacts. Mitigation measures must be considered to minimize impacts and a monitoring program adopted where appropriate.

► Habitat Fragmentation

Transportation infrastructure can form barriers to wildlife, especially highways and rail lines. While highways and rail lines do not occupy much of the area of the land they traverse, their linear nature divides wildlife habitat into smaller, more isolated units of land or creates barriers between functional areas. Impacts such as traffic noise, emissions of xenobiotic substances, artificial lighting, and vehicle-fauna collisions also affect species in fragmented areas. Mitigation measures, such as lowering speed limits to reduce noise levels, erecting warning signs and fences to avoid collisions, and constructing ecoducts (fauna bridges and tunnels) to allow freer movement of fauna between isolated fragments are sometimes used. Also, countries such as the

Netherlands employ compensatory programs to replace destroyed habitats or improve marginal habitats. (Van Bohemen 1995)

► Wetlands

Wetlands can be adversely affected by most kinds of development. In the past, wetlands were widely viewed as unproductive tracts of land and were drained so that they could be put to more "profitable" use. In the last few decades, it has become clear that wetlands perform important functions for humans, fish and shellfish, and wildlife. Wetlands provide flood conveyance, act as erosion, wind, and wave barriers, facilitate sediment replenishment, provide habitat for waterlife, waterfowl, mammals, and reptiles, improve water quality by removing nutrients and some chemical contaminants, and are sometimes a source of timber. They may also have recreational, educational, and historical value. As one study put it: "many of the beneficial functions of wetlands accrue to the larger populace but not to the land-owner who is in a position to capture only a portion of the product of wetlands." (Anderson and Rockel 1991)

In an attempt to decrease the rate of loss of the nation's wetlands, the federal government has implemented a policy aimed at achieving the goal of "no net loss" of wetlands. This is often achieved by requiring some kind of compensatory mitigation such as wetland mitigation banking or fee-based compensatory mitigation. (Environmental Law Institute and Institute for Water Resources 1994)

Mitigation banks have been set up to offset losses of wetlands from construction or other forms of development. Using a system of credits and other marketable instruments, mitigation banking makes it possible for developers to convert wetlands to other uses if corresponding activities take place elsewhere to restore, protect, or create other wetlands of comparable value. As of the summer of 1992, 24 of the 46 existing wetland mitigation banks in the United States were developed for transportation-related mitigation; 18 of these were operated by state departments of transportation to meet continuing needs for compensatory mitigation. (Environmental Law Institute and Institute for Water Resources 1994) Most other transportation-related banks were constructed to offset impacts of waterway/harbor dredging and port facility expansion. Of the 59 banks proposed in 1992, 19 were for transportation purposes.

► Transportation and Land-Use Interactions

Transportation systems can also impact the environment indirectly by affecting how land is subsequently developed and used. Transportation and other forms of land use affect each other, and the relationship between them has important implications for the evolution of urban environments. Chapter 8 discusses the air quality implications of the interaction between transportation and land use in some detail.

By making access between places easier and cheaper, new transportation options can not only encourage relatively rapid changes in travel behavior but can also encourage, and are often a necessary component of, new patterns of industrial, commercial, and residential growth. Businesses may relocate or open new premises, and households may move to new residential areas made more accessible to a region's employment, retail, recreational, and institutional centers of activity. Over time these changes in land use generate new travel demands, possibly accompanied by new patterns of traffic congestion, which in turn encourage additional transportation capacity.

Isolating transportation's role in the land development process is difficult, especially within urban settings. (Southworth 1995) Much of the residential development in the United States since World War II has been low in density and located in the suburbs. It has been spurred by the low cost of driving and the nation's extensive highway building programs. Consequently, our larger urbanized areas expanded considerably. Employment similarly migrated away from congested and high-rent central business districts, and many Americans now live and work within multicentered metropolitan areas.

Between 1982 and 1992, built up and urban land in the United States increased by 14 million acres, according to the U.S. Department of Agriculture. As a result, developed land in the United States totaled 92.4 million acres, roughly 5 percent of the U.S. land area not including Alaska. (US Department of Agriculture n.d.)

Future development patterns will depend in part on societal choices about highways, public transit, and other transportation systems, and the costs of constructing and maintaining these systems. Technological and other changes will also affect choices. For example, the information society could alter the transportation and land-use relationship in the coming century. (US Congress OTA 1995b, 106) A growing number of service and information-based companies already find themselves no longer tied to the geographic location of their key resource inputs or to local markets for their products. Industrial practices such as just-in-time scheduling may also affect the siting needs of companies as well as their use of freight vehicles. How the nation's households and companies will respond to telecommuting, teleshopping, and other potential travel-reducing options remains an open question.

Costs and Benefits of Environmental Controls

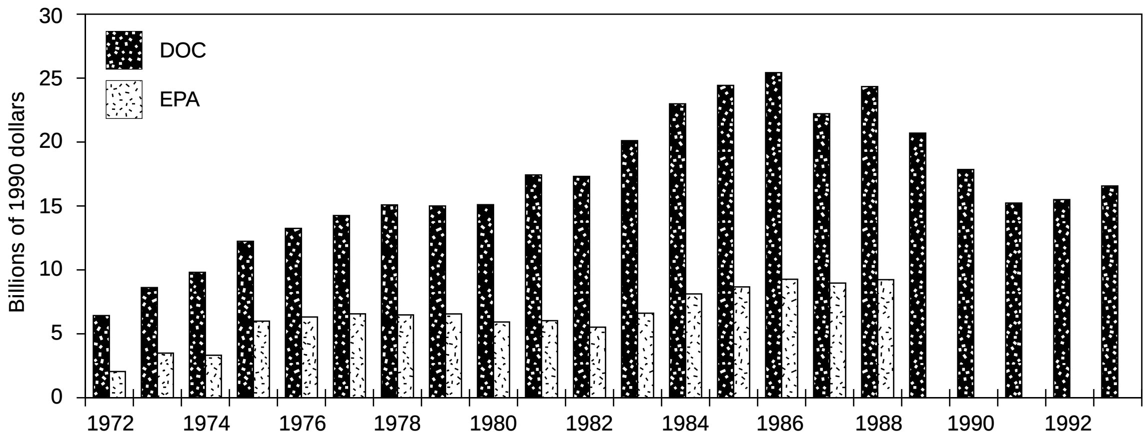
The benefits arising from emissions reductions, noise abatement, and other environmental protection actions are not free. They come at a cost of resources that could be used for personal expenditures by consumers, investments by business, or spending by governments for other objectives such as national defense and medical research. As a result, deciding on a level of environmental protection can require choices between a cleaner environment and other societal goals. As pointed out in chapter 6, the environmental management system that has evolved in the United States increasingly seeks to equate the cost of the next improvement in environmental quality with the benefits it provides. Unfortunately, this is more easily said than done. The benefits of environmental protection, while real, are often very difficult to quantify in economic terms. The direct costs of pollution abatement and control are easier to identify, although estimates vary substantially.

According to the U.S. Department of Commerce (DOC), consumers, businesses, and governments in the United States spent $17.2 billion (in 1994 dollars) on air and water pollution controls for highway transportation in 1993. (Rutledge and Vogan 1995, table 3) (An EPA estimate for 1972 to 1988 was roughly half the DOC number. In part, this difference reflects EPA's estimates of benefits—such as greater fuel economy of vehicles—stemming from government regulations.) (See figure 7-15.)

DOC did not estimate pollution abatement costs for other transportation modes. Upstream costs to control pollution from facilities operated by petroleum refineries or vehicle manufacturers are not included in the $17.2 billion. DOC estimated the petroleum industry's annual capital plus operating costs for environmental protection at $2 billion to $3 billion over the past decade, while the industry estimates its expenditures at up to 80 percent more, depending on the year in question. (Perkins 1991)

DOC attributed $16.6 billion of its $17.2 billion cost estimate to motor vehicle emissions controls. The remaining amount was spent on state and local highway erosion control pro-

FIGURE 7-15: MOBILE SOURCE EMISSIONS CONTROL COSTS IN THE UNITED STATES, 1972–93



SOURCES: U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, *Environmental Investments: The Cost of a Clean Environment,* EPA-230-11-90-083 (Washington, DC: 1990), tables 3-1A and 3-2A; G.L. Rutledge and C.R. Vogan, "Pollution and Abatement and Control Expenditures, 1993," *Survey of Current Business,* vol. 75, No. 5, May 1995, table 3, pp. 36–49; and G.L. Rutledge and C.R. Vogan, "Pollution and Abatement and Control Expenditures, 1972–92," *Survey of Current Business,* vol. 74, No. 5, May 1994, table 3, pp. 36–49.

grams. (Other costs borne by highway transportation for environmental compliance, such as noise abatement, were not addressed.) DOC estimated that businesses paid 42 percent of the $17.2 billion, while consumers paid 54 percent in the form of higher vehicle prices. By dividing the $16.6 billion for motor vehicle emissions controls by the 14.2 million vehicles sold in 1993, a rough estimate of $1,150 per vehicle for emissions control costs emerges. Of course, costs vary greatly by type of vehicle and even by place, because California has stricter vehicle emission standards than the rest of the country.

While the expense of motor vehicle pollution controls is considerable, the benefits are also very large, if more difficult to quantify. As documented earlier in this chapter and in chapter 8, U.S. cities would be far more polluted than they are today had there not been significant reductions in emissions from the transportation sector since 1970. Total CO emissions would be 2.5 times as great, VOC emissions would be twice as great, and NO_x emissions would be 40 percent greater. Nearly all the reduction in emissions from the transportation sector is the result of emissions standards for new highway vehicles and cleaner fuel requirements.

Clearly, U.S. air quality would be far worse had these transportation emissions reductions not been made. To estimate the benefits in a way that is truly comparable to the corresponding cost estimates just presented, three more steps would have to be taken. Emissions would have to be translated into air quality, air quality into impacts on health, flora, fauna, and infrastructure, and these impacts monetized. The Environmental Protection Agency is undertaking a comprehensive analysis of the costs and benefits of the Clean Air Act and is expected to issue its report to Congress in 1996.

Information Needs

This chapter necessarily has relied on data developed to meet the needs of current environmental policies to describe the environmental effects of transportation. For the most part, the current environmental management system continues to treat each kind of pollution separately, even though there are complex interactions among different media. Similarly, most analyses of transportation's environmental impacts focus on individual modes—motor vehicles, aircraft, rails—rather than comparative environmental performance among modes (see box 7-4). Moreover, a complete analysis of the environmental impacts of transportation would need to take into account upstream activities (e.g., oil field development, petroleum refining, vehicle production) that make transportation possible. In conducting such analyses, special care to avoid double counting of impacts would be needed.

As policies for management of the environmental impacts of transportation evolve, so too will information needs. Questions about the costs relative to the benefits of further environmental improvement are increasingly raised, as are concerns about the dampening effects of regulation on the economy. Scientific and technical questions continue to arise concerning the nature of environmental impacts for human health and the ecosystem as a whole, and the technological capacity to address those impacts within acceptable cost-benefit ratios for society. At the same time, there is increasing interest in environmental policies that address such goals as pollution prevention and sustainable development.

Box 7-4: Comparing the Air Pollution Impacts of Different Transportation Modes

Two recent studies in California attempted to compare the air pollution emissions of two different transportation modes. One compares the emissions of truck and rail freight transportation. The other compares emissions from automobile and rail commuting. The results show that rail transportation overall produces less air pollution than motor vehicle transportation, but on a pollutant by pollutant basis the picture is more mixed.

The comparison of truck with rail freight transportation examined emissions of carbon monoxide (CO), hydrocarbon (HC), particulate matter (PM), and nitrogen oxides (NO_x) in California's I-40 corridor. (Barth and Tadi 1996). According to the study, trucks produced 2.6 times the amount of CO, 4.2 times the amount of HC, and 32.5 times the amount of PM to move the same amount of goods as rail freight. Rail produced 1.2 times the amount of NO_X as trucks, however.

The automobile/rail study compares commuting by single-occupant automobile with a rail-based commute (including getting to the train station, whether by automobile, bus, or other means) from Riverdale to downtown Los Angeles. Again, the study results are mixed. At current ridership levels (approximately 300 to 400 passengers a day), the automobile commute contributes 2.5 times more CO and 2.3 times the amount of HC than the train-based commute. The train-based commute contributes 4.7 times more NO_x and 5.5 times the amount of PM than commuting by automobile. The authors calculate that train ridership would have to reach about 2,000 passengers a day to break even on the emission of particulates and between 1,500 to 2,200 passengers to break even on NO_x emissions.

SOURCES: M. Barth and R. Tadi, "An Emissions Comparison Between Truck and Rail: A Case Study of the California I-40," presented at the 75th Annual Transportation Board Meeting, Washington DC, January 1996; and M. Barth et al., "An Emissions Analysis of Southern California's Metrolink Commuter Rail," presented at the 75th Annual Transportation Board Meeting, Washington, DC, January 1996.

Developing the information needed for such broader analyses will require a common metric for comparing different environmental effects. Many disciplines—economics, environmental science, risk analysis, and medical research, for example—would need to work together to translate environmental impacts into dollar values.

As part of a larger effort to understand and estimate the full costs and benefits of transportation, researchers are working on data and methods for costing out transportation's environmental impacts. Still, many conceptual, methodological, and statistical problems must be overcome before transportation's full costs and benefits can be understood quantitatively. Appendix B describes proceedings of a conference on this topic that BTS sponsored in July 1995. The conference addressed theoretical, methodological, and statistical issues. It also brought to the discussion of the full costs of transportation a recognition of the equal importance of transportation's full benefits.

Over the last three decades the United States has primarily applied a technology-based strategy to address the environmental impacts of transportation. So far, that approach has worked well in several areas. In the race between impact mitigation technology and demand for more transportation, however, the future is uncertain. As travel and traffic continue to grow, it becomes increasingly important to understand and monitor the relationships between transportation and the environment.

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CHAPTER EIGHT

Transportation and Air Quality: A Metropolitan Perspective

METROPOLITAN AREAS EXPERIENCE THE MOST ACUTE TRANSPORTATION-RELATED AIR POLLUTION IMPACTS. COMMUTING, SHOPPING, AND OTHER SHORT PERSONAL TRIPS IN HIGHWAY VEHICLES CAUSE MOST OF THESE IMPACTS. THIS CHAPTER DISCUSSES AIR QUALITY TRENDS IN U.S. METROPOLITAN AREAS, ANALYZES FACTORS THAT UNDERLIE THESE TRENDS, SUCH AS TRANSPORTATION ACTIVITY AND emissions rates, and discusses transportation control measures (TCMs) and their potential to mitigate the impact of transportation on air quality in metropolitan areas.

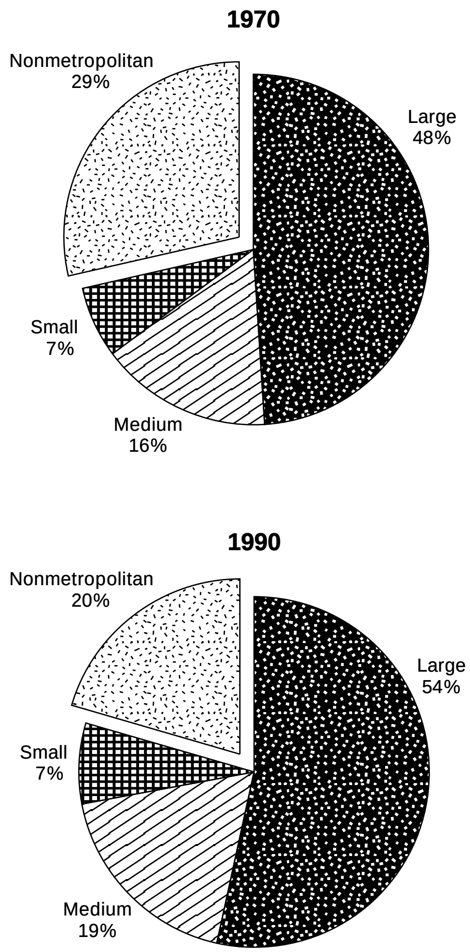
About 80 percent of the U.S. population lived in 268 metropolitan statistical areas (MSAs) in 1990.[1] The MSAs range in size from almost 20 million people (the New York-Northern New Jersey-Long Island consolidated MSA) to less than 200,000 people. (USDOC 1994a, 37, 39–41) A growing proportion of people live in large (population over 1 million) and medium-size (250,000 to 999,999) metropolitan areas (see figure 8-1).

> ***Between 1985 and 1994, some of the fastest growing metropolitan areas (San Diego, Dallas, Houston) had the highest percentage reductions for the primary air pollutants from highway vehicles.***

The central cities of MSAs are focal points for various types of economic and social interactions, such as commuting

[1] The Bureau of the Census defines MSAs as containing a central city of at least 50,000 population and all those surrounding urbanized counties that are strongly linked with it. Large MSAs that include two or more adjacent cities of over 50,000 population are designated consolidated metropolitan statistical areas.

FIGURE 8-1: **U.S. POPULATION LIVING IN METROPOLITAN AREAS BY SIZE AND IN NONMETROPOLITAN AREAS, 1970 AND 1990**



SOURCE: U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1994* (Washington, DC: 1994), table 40.

and shopping trips. Surrounding suburban communities with lower development densities are strongly linked with the central city and with each other. Commuting patterns are a good indicator of the strength of these linkages. Metropolitan areas are usually delineated so that most commuting trips occur within their borders rather than across them.

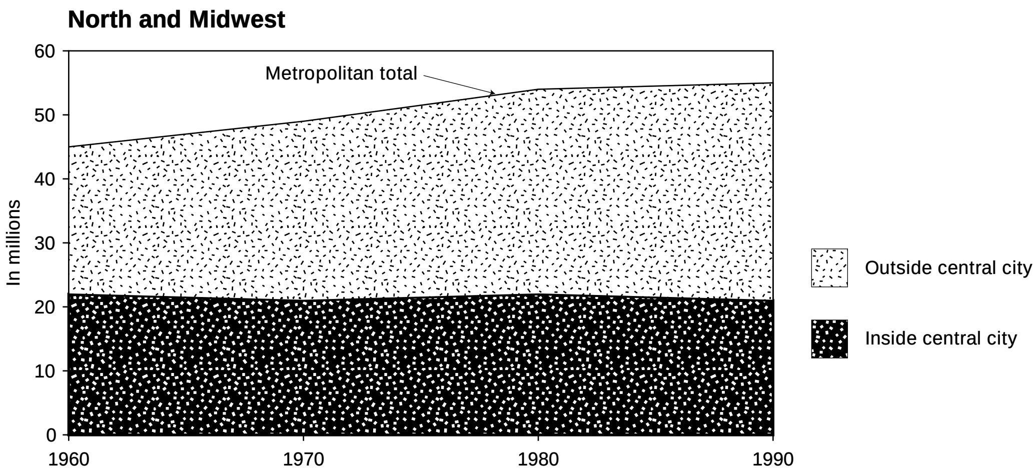
MSAs vary widely in rates of population growth. In general, southern and western metropolitan areas grew rapidly between 1970 and 1990. For example, Miami's metropolitan population grew by 40 percent between 1970 and 1980 and by another 21 percent in the 1980s. Northern cities generally declined or marked much smaller gains in this period. The New York metropolitan area, for instance, declined by 4 percent between 1970 and 1980 but grew by 3 percent between 1980 and 1990.

Most MSA population growth has occurred in the suburbs, with central cities either growing more slowly or declining in population (see figure 8-2). Even in some rapidly growing western metropolitan areas, where central cities have been growing at double-digit rates, suburbs have grown more quickly. Suburbs have also enjoyed relatively greater growth in jobs, retail outlets, and recreational facilities, placing further pressure on the development of the rural periphery. The result is a decline in the density of both population and employment—a trend strengthened by the faster growth in the newer, low-density metropolitan areas of the South and West.

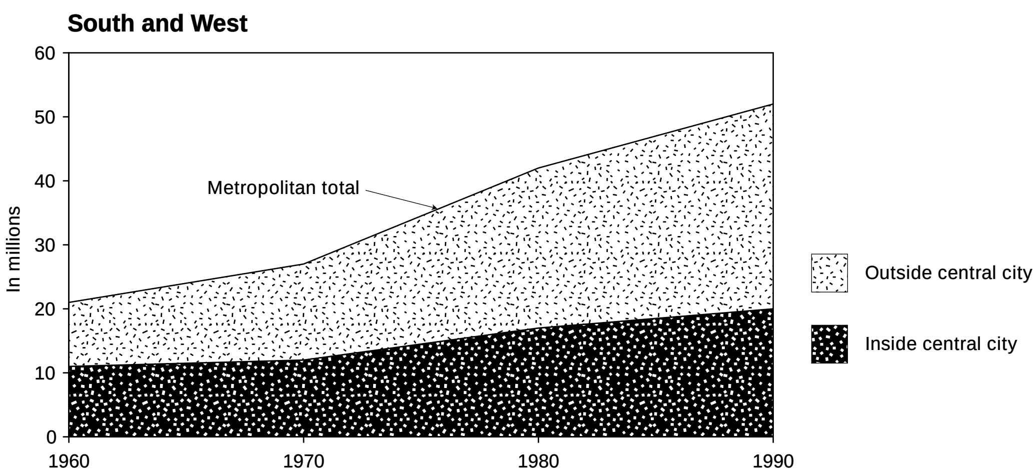
As the metropolitan population share increased and the density of development within metropolitan areas decreased, the proportion of travel occurring within metropolitan areas grew. The urban area portion of automobile vehicle-miles traveled (vmt) increased from 48 percent in 1960 to 65 percent in 1994. Similarly, the urban area portion of truck vmt increased from 35 percent to 54 percent over the same period.[2] (USDOT FHWA various years)

[2] In this case *urban* includes some smaller urbanized areas, but is dominated by the metropolitan areas.

FIGURE 8-2: **POPULATION CHANGE IN CENTRAL CITIES AND METROPOLITAN AREAS, 1960–90**



NOTE: Data are for the 12 largest metropolitan areas in the North and Midwest in 1990.



NOTE: Data are for the 13 largest metropolitan areas in the South and West in 1990.

SOURCE: U.S. Department of Commerce, Bureau of the Census, *State and Metropolitan Area Data Book* (Washington, DC: U.S. Government Printing Office, 1979 and 1991).

Metropolitan Emissions and Air Quality

The Clean Air Act established National Ambient Air Quality Standards (NAAQS) for six pollutants (called criteria pollutants). The standards are used to characterize the relative healthiness of air quality depending on the concentrations of these pollutants in the air (see box 8-1). The U.S. Environmental Protection Agency (EPA), states, and localities have set up a nationwide system of air quality monitoring stations. The stations measure ambient concentrations of the six criteria pollutants, so that peak-levels can be judged for conformity with air quality standards.

Box 8-1: Air Quality Standards and Attainment Levels

The National Ambient Air Quality Standards (NAAQS) are a set of atmospheric concentration levels (not to be confused with emissions levels) for six critical air pollutants: carbon monoxide (CO), lead, nitrogen dioxide (NO_2), ozone (O_3), fine particles (PM-10), and sulfur dioxide (SO_2). These standards are defined by the U.S. Environmental Protection Agency (EPA) as concentration levels above which there is significant damage to public health and welfare. Primary standards protect against adverse health effects, while secondary standards protect against other effects, such as damage to vegetation and buildings. Current primary and secondary standards are shown in the table.

Since there may be significant day-to-day or even hour-to-hour variation in air quality, standards for some pollutants are defined in terms of peak periods. Health impacts are more closely connected with the worst concentration levels than with average levels. For example, the standard for CO is not attained if the eight-hour concentration level is exceeded during any eight-hour period within a year, or if the higher one-hour concentration level is exceeded during any one-hour period. For O_3 the standard is not attained if the maximum one-hour concentration exceeds the standard more than one day a year.[1]

Monitoring of ambient concentrations takes place at over 4,000 monitoring sites, known as the Aerometric Information Retrieval System, operated mostly by state and local agencies. While not all sites monitor each pollutant, each is monitored at 300 or more sites.

Areas where concentrations of one or more pollutants persistently exceed the standards levels are designated as nonattainment areas. A nonattainment area is classified as marginal, moderate, serious, severe, or extreme depending on the number of days and the amount by which the concentration standards are exceeded. In nonattainment areas, steps must be taken to reduce emissions. As of February 8, 1996, there were 182 regions designated as nonattainment areas for one or more of the six pollutants: 75 for O_3, 35 for CO, 43 for

[1] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Quality and Emission Trends Report, 1992*, EPA-454/R-93-031 (Research Triangle Park, NC: October 1993).

National Ambient Air Quality Standards

	Primary standard		Secondary standard	
Pollutant	Type of average	Standard level concentration	Type of average	Standard level concentration
Carbon monoxide	8-hour 1-hour	9 ppm 35 ppm	No secondary standard No secondary standard	
Lead	Maximum quarterly average	1.5 ug/m	Same as primary standard	
Nitrogen dioxide	Annual arithmetic mean	0.053 ppm	Same as primary standard	
Ozone	Maximum daily 1-hour average	0.12 ppm	Same as primary standard	
PM-10	Annual arithmetic mean 24-hour	50 ug/m 150 ug/m	Same as primary standard Same as primary standard	
Sulfur dioxide	Annual arithmetic mean 24-hour	80 ug/m 365 ug/m	3-hour	1,300 ug/m

KEY: ppm = parts per million; ug/m = micrograms per cubic meter.

SOURCE: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Quality and Emissions Trends Report, 1992* (Research Triangle Park, NC: 1993).

Box 8-1 (cont'd): AIR QUALITY STANDARDS AND ATTAINMENT LEVELS

SO_2, 82 for PM-10, 10 for lead, and 1 for NO_2.[2] The great majority of the population living in nonattainment areas is metropolitan.

The number of people exposed to unhealthy air in nonattainment areas is difficult to estimate. A total of 132 million people live within the boundaries of the 182 nonattainment areas. Yet, this is not necessarily a good measure of the number of people currently exposed to unhealthy air. To be reclassified as in attainment, an area must not violate EPA standards for three consecutive years and must have an approved state implementation plan (SIP). Thus, some areas may not have violated air quality standards for one or two years but will still be classified as nonattainment. An estimated 90 million people live within the boundaries of nonattainment areas that currently violate EPA standards. Some of these people have homes located in healthy air pockets, even though the metropolitan region as a whole is in nonattainment. (They may still be affected if they work in areas with unhealthy air.) EPA also estimates the number of people living in counties with unhealthy air in a single year. Data for the most recent year available, 1994, show that 62 million live in counties that violated at least one pollutant standard.[3] This estimate, however, only includes counties that have a monitoring station and does not account for year to year weather variations that can affect air quality. Consequently, this method likely underestimates the number of people who live in areas with unhealthy air.

[2] An updated list of nonattainment areas is available on the World Wide Web at www.epa.gov/airs/nonattn.html.

[3] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Pollution Emission Trends, 1900–1994*, EPA-454/R-95-011 (Research Triangle Park, NC: October 1995).

Estimating the number of people that are exposed to unhealthy air is difficult, however. It is currently estimated that between one-quarter to one-third of the population are affected. Most live in urban areas.

Transportation vehicles—especially highway vehicles—emit large quantities of four pollutants that are directly covered by the NAAQS or are related precursor substances. As detailed in chapter 7, much progress has been made in reducing emissions from highway vehicles. In 1994, however, highway vehicles still accounted for 62 percent of carbon monoxide (CO) emissions, 32 percent of nitrogen oxides (NO_x) emissions, and 7 percent of particulate matter smaller than 10 microns (PM-10) excluding miscellaneous and natural sources. Highway vehicles also accounted for 26 percent of volatile organic compounds (VOCs) emissions, which along with NO_x are the main precursor pollutants to ozone (O_3) formation. (USEPA 1995)

Table 8-1 shows estimates of highway vehicle emissions in 13 MSAs in 1985 and in 1994. Over that period, significant reductions occurred in the primary pollutants, except NO_x which increased in some areas. Some of the fastest growing metropolitan areas (San Diego, Dallas, Houston) were among those with the highest percentage reductions for these pollutants.

Because of differences in transportation patterns and economic structure among metropolitan areas, the proportion of emissions attributable to highway vehicles varies. In San Francisco, for example, 79 percent of estimated CO emissions are attributed to road vehicles, along with 46 percent of both NO_x and VOC emissions. By contrast, only 60 percent of CO, 25 percent of NO_x, and 17 percent of VOC are attributed to road vehicles in Houston, possibly owing to the predominance of petroleum-based industries in that area. (USEPA 1995, table 2-7)

The link between vehicle emissions and concentrations in the air is not straightforward. Local factors, such as variations in weather and topography, affect the rate of emissions dispersal. Moreover, the size of the area over which

Table 8-1: Transportation Emissions for Selected Areas, 1985–94 (thousand short tons per year)

Region	Metropolitan area		VOC	NO_x	CO	PM-10
North	New York-Northern New Jersey-	1985	447	356	3,552	14.6
	Long Island CMSA (partial[a])	1994	301	329	2,620	12.0
		Change (percent)	–32.7	–7.3	–26.2	–17.9
	Chicago-Gary-	1985	267	186	2,249	7.4
	Lake County, IL-IN-WI CMSA	1994	160	168	1,547	6.0
		Change (percent)	–39.9	–9.5	–31.2	–18.9
	Pittsburgh-Beaver Valley, PA CMSA	1985	87	69	737	2.9
		1994	47	51	465	2.0
		Change (percent)	–46.0	–26.1	–36.9	–31.0
	Indianapolis, IN MSA	1985	48	39	396	1.6
		1994	39	40	389	1.5
		Change (percent)	–20.1	3.0	–1.7	–4.9
South	Dallas-Fort Worth, TX CMSA	1985	179	124	1,370	5.3
		1994	96	102	891	4.0
		Change (percent)	–46.4	–17.4	–34.9	–24.7
	Houston-Galveston-Brazoria, TX CMSA	1985	172	124	1,319	5.4
		1994	100	105	956	4.1
		Change (percent)	–41.9	–15.3	–27.5	–34.1
	Miami-Fort Lauderdale, FL CMSA	1985	119	64	841	2.8
		1994	78	68	722	2.6
		Change (percent)	–34.9	6.3	–14.1	–7.1
	Tampa-St. Petersburg-	1985	89	54	633	2.5
	Clearwater, FL MSA	1994	52	53	484	2.2
		Change (percent)	–41.7	–1.6	–23.5	–12.6
West	Los Angeles-Anaheim-	1985	417	329	3,185	15.3
	Riverside, CA CMSA	1994	285	300	2,361	12.5
		Change (percent)	–31.7	–8.8	–25.9	–18.3
	San Francisco-Oakland-	1985	185	165	1,476	7.6
	San Jose, CA CMSA	1994	130	139	1,148	5.7
		Change (percent)	–30.1	–15.8	–22.2	–24.6
	Seattle-Tacoma, WA CMSA	1985	98	96	870	3.9
		1994	70	87	667	3.3
		Change (percent)	–28.3	–8.9	–23.3	–16.8
	San Diego, CA MSA	1985	74	65	563	3.0
		1994	49	55	392	2.4
		Change (percent)	–34.8	–15.2	–30.4	–22.1
	Portland-Vancouver, OR-WA CMSA	1985	42	43	347	1.8
		1994	30	41	268	1.6
		Change (percent)	–28.4	–5.2	–22.7	–12.6

[a]Contains only Fairfield County, Connecticut. 1990 census definition also includes parts of Litchfield and New Haven counties.

KEY: CMSA = consolidated metropolitan statistical area; MSA = metropolitan statistical area.

NOTE: Metropolitan definitions used in this table do not necessarily correspond to metropolitan definitions used to define nonattainment areas. Thus, the emissions numbers in this table cannot be used to assess compliance with federal clean air requirements.

SOURCE: County-level data provided by the U.S. Environmental Protection Agency aggregated up to MSAs according to 1990 census definitions.

emissions are distributed affects concentration levels. Both San Francisco and Houston have very high levels of CO emissions, but relatively low CO concentrations in the air. NO_x and VOC are precursors to ozone, yet St. Louis, with relatively low emissions of both pollutants has a high ozone concentration (see table 8-2).

EPA's pollution standards index (PSI) provides a daily indicator of an area's overall air quality. The index values range from 0 to 500, with values above 100 indicating increasingly unhealthful air quality. Although all criteria pollutants are included in the PSI, high levels of O_3 account for most of the daily PSI values greater than 100. Table 8-3 shows the number of days in which the PSI exceeded 100 in a selection of MSAs.

The most striking aspect of table 8-3 is the general downward trend in unhealthful days for most metropolitan areas. The improvement is evident even in fast-growth areas such as Miami, San Diego, Phoenix, and Denver—indicating that growth in population does not necessarily lead to more days of unhealthy air quality. These downward trends are consistent with the national trends presented in chapter 7.

Variability is also evident in tables 8-2 and 8-3. Los Angeles has high concentration levels for all pollutants and air quality that is unhealthful or worse on roughly half the days of most years, while Miami has concentrations roughly half as high as in Los Angeles and healthful to moderate air nearly all year round.

Table 8-3 also shows that cities with similar peak concentration profiles may be quite different in terms of the frequency of unhealthful air. For example, peak concentrations in Baltimore and in Philadelphia are not very different, yet Baltimore had almost three times as many days with unhealthful air in 1994.

It is important to recognize that not all the environmental impacts of urban transportation are reflected in metropolitan air quality indicators. Other impacts, such as the contribution of NO_x and VOC emitted from road vehicles to the problems of acid deposition and the contribution of CO_2 from vehicles to climate change may affect the environment at the continental and global scales (see discussion of greenhouse gas emissions in chapters 7 and 9).

Road Vehicles and Air Quality

What factors underlie the downward trend in highway vehicle emissions across the diverse cross section of U.S. metropolitan areas shown in table 8-1? As discussed below, levels of emissions from road vehicles are a reflection of two factors: the total amount of driving, and the rate of emissions on a per vehicle-mile traveled (vmt) or per trip basis.

► Transportation Trends

Transportation analysts generally divide the pattern of urban trip-making into four stages: trip generation, trip distribution, mode split, and traffic assignment. Trip generation refers to the number of trips made by residents of each part of the city at various times of the day. Trip distribution refers to the destinations they choose, and thus determines the average length of trips. Mode split refers to the decision to travel by car, carpool, public transportation, bike, or on foot, thus establishing the relationship between passenger-miles traveled and miles traveled by each type of vehicle. Traffic assignment refers to the combined routing of all vehicles onto the roads and rails that make up the urban transportation network. The relationship between the capacity of that network and the number of vehicle-trips assigned to it over any interval of time affects the level of congestion.

The rate of trip generation has been increasing. The Nationwide Personal Transportation Survey (NPTS), which provides the most com-

TABLE 8-2: POLLUTANT CONCENTRATIONS IN SELECTED AREAS, 1994

Region	PMSA[a]	CO (ppm)	NO_2 (ppm)	Ozone (ppm)	PM-10 (ug/m)
North	New York, NY	7	0.046	**0.13**	**53**
	Chicago, IL	8	0.034	0.12	44
	Philadelphia, PA-NJ	8	0.037	**0.13**	**111**
	Detroit, MI	**10**	0.025	**0.14**	49
	Boston, MA-NH	6	0.035	0.12	29
	Cleveland-Lorain-Elyria, OH	8	0.028	**0.13**	**60**
	Minneapolis-St. Paul, MN-WI MSA	6	in	0.08	in
	St. Louis, MO-IL MSA	6	0.028	**0.15**	45
	Pittsburgh, PA MSA	7	0.031	0.12	41
	Cincinnati, OH-KY-IL	5	0.027	**0.13**	32
	Milwaukee-Waukesha, WI	7	0.025	**0.13**	33
	Kansas City, MO-KS MSA	5	0.011	0.11	40
South	Washington, DC-MD-VA-WV	6	0.030	**0.13**	29
	Dallas, TX	5	0.016	**0.14**	29
	Houston, TX	6	0.028	**0.17**	47
	Miami, FL	5	0.014	0.11	25
	Atlanta, GA MSA	5	0.023	**0.13**	32
	Baltimore, MD	7	0.032	**0.15**	33
	Tampa-St. Petersburg-Clearwater, FL	4	0.010	0.10	30
West	Los Angeles-Long Beach, CA	**15**	0.050	**0.24**	47
	San Francisco, CA	5	0.022	0.08	in
	Seattle-Bellevue-Everett, WA	7	nd	**0.13**	28
	San Diego, CA MSA	7	0.024	**0.14**	**51**
	Phoenix-Mesa, AZ MSA	**10**	in	0.12	50
	Denver, CO	8	0.035	0.11	36
	Portland-Vancouver, OR-WA	8	in	0.11	32
	Honolulu, HI MSA	5	0.004	0.06	17
	Anchorage, AK MSA	**11**	nd	nd	in

[a]MSA where noted; definitions are based on Office of Management and Budget definitions effective June 30, 1993.
KEY: PMSA = primary metropolitan statistical area; MSA = metropolitan statistical area; ppm = parts per million; ug/m = micrograms per cubic meter; in = insufficient data; nd = no data.

NOTE: **Numbers in bold** indicate that MSA is a nonattainment area.
Basis of concentration measure:
CO: Second highest maximum non-overlapping 8-hour concentration.
NO_2: Highest arithmetic mean concentration.
Ozone: Second highest daily maximum 1-hour concentration.
PM-10: Highest weighted annual mean concentration.

SOURCE: U.S. Environmental Protection Agency, *National Air Quality and Emissions Trends Report, Data Appendix* (Research Triangle Park, NC: 1994), table A-12.

TABLE 8-3: NUMBER OF PSI DAYS GREATER THAN 100 FOR SELECTED AREAS, 1985–94

Region	PMSA[a]	1985	1989	1994
North	New York, NY	65	18	8
	Chicago, IL	9	4	8
	Philadelphia, PA-NJ	31	20	6
	Detroit, MI	2	10	8
	Boston, MA-NH	3	4	1
	Cleveland-Lorain-Elyria, OH	1	6	4
	Minneapolis-St. Paul, MN-WI MSA	22	5	3
	St. Louis, MO-IL MSA	10	13	11
	Pittsburgh, PA MSA	9	9	2
	Cincinnati, OH-KY-IL	5	3	5
	Milwaukee-Waukesha, WI	5	8	4
	Kansas City, MO-KS MSA	3	2	0
South	Washington, DC-MD-VA-WV	17	8	7
	Dallas, TX	27	7	1
	Houston, TX	64	42	29
	Miami, FL	5	4	0
	Atlanta, GA MSA	9	3	4
	Baltimore, MD	25	9	17
	Tampa-St. Petersburg-Clearwater, FL	6	1	0
West	Los Angeles-Long Beach, CA	208	226	136
	San Francisco, CA	5	1	0
	Seattle-Bellevue-Everett, WA	25	8	0
	San Diego, CA MSA	88	90	16
	Phoenix-Mesa, AZ MSA	88	30	7
	Denver, CO	38	11	2
	Portland-Vancouver, OR-WA	3	6	2
	Honolulu, HI MSA	0	0	0

[a]MSA where noted; definitions are based on Office of Management and Budget definitions effective June 30, 1993.

KEY: PSI = pollution standards index; PMSA = primary metropolitan statistical area; MSA = metropolitan statistical area.

SOURCE: U.S. Environmental Protection Agency, *National Air Quality and Emissions Trends Report, Data Appendix* (Research Triangle Park, NC: 1994), table A-13.

prehensive data about urban trips, found that between 1983 and 1990 the number of person-trips in the United States grew by 11 percent, at a time when the population grew by only 4 percent. (USDOT FHWA 1993, 4-4) Family and personal business (including shopping) were the fastest growing trip categories.

Due in part to the gradual decentralization of metropolitan areas, the trend in trip distribution is toward more distant destinations. Trip length for all purposes in metropolitan areas increased from an average of 8.5 miles in 1983 to 9.3 miles in 1990, a 9.4 percent increase. (USDOT FHWA 1993, 4-42) If the average metropolitan trip length in 1990 had remained at the 1983 level of 8.5 miles, Americans would have traveled 156 billion miles less in metropolitan areas than they did in 1990. Trips associated with earning a living increased in length by 19 percent over this period.

Table 8-4 shows changes in the duration of work trips for 26 metropolitan areas. Since changes in the level of congestion as well as changes in trip length can affect duration, these data are an imperfect indicator of trip length. Trip duration generally increased the most in fast-growth metropolitan areas. There are exceptions, however. Milwaukee, which had slow population growth, had a significant increase in trip duration, while Denver, which had fast growth, had a very small increase.

Mode split is dominated by privately operated vehicles, which accounted for 86 percent of all urban trips in 1990—up from 81 percent in 1983. In the same period, the share of trips made on public transportation fell from 3.4 percent to 2.6 percent and the percentage of trips made by other modes—bicycle, walking, school bus, taxi, airplane, rail, moped—fell from 13.1 percent of all trips to 11.7 percent. Public transportation's share of total trips declined for two reasons: first because the transit share declined for most categories of trips, and second because the fastest growing category of trips—family and personal business—is also the category for which travelers are least likely to use transit. The greatest transit share is in the Boston-to-Wash-

Table 8-4: Mean Travel Times to Work in Selected Areas, 1980–90 (in minutes)

Region	Area	1980	1990	Change (percent)
North	New York-Northern New Jersey-Long Island CMSA	33.7	31.1	–7.7
	Chicago-Gary-Lake County, IL-IN-WI CMSA	26.3	28.1	6.7
	Philadelphia-Wilmington-Trenton, PA-NJ-DE-MD CMSA	24.0	24.1	0.5
	Detroit-Ann Arbor, MI CMSA	22.5	23.4	3.8
	Boston-Lawrence-Salem, MA-NH CMSA	23.4	24.2	3.6
	Cleveland-Akron-Lorain, OH CMSA	21.6	22.0	1.7
	Minneapolis-St. Paul, MN-WI MSA	20.1	21.1	4.9
	St. Louis, MO-IL MSA	22.6	23.1	2.3
	Pittsburgh-Beaver Valley, PA CMSA	22.8	22.6	–1.1
	Cincinnati-Hamilton, OH-KY-IN CMSA	21.8	22.1	1.4
	Milwaukee-Racine, WI CMSA	18.8	20.0	6.2
	Kansas City, MO-KS MSA	20.7	21.4	3.6
South	Washington, DC-MD-VA MSA	27.2	29.5	8.5
	Dallas-Fort Worth, TX CMSA	22.4	24.1	7.4
	Houston-Galveston-Brazoria, TX CMSA	25.9	26.1	0.7
	Miami-Fort Lauderdale, FL CMSA	22.6	24.1	6.5
	Atlanta, GA MSA	24.9	26.0	4.6
	Baltimore, MD MSA	25.3	26.0	2.7
	Tampa-St. Petersburg-Clearwater, FL MSA	20.2	21.8	7.8
West	Los Angeles-Anaheim-Riverside, CA CMSA	23.6	26.4	11.9
	San Francisco-Oakland-San Jose, CA CMSA	23.9	25.6	6.9
	Seattle-Tacoma, WA CMSA	22.8	24.3	6.7
	San Diego, CA MSA	19.5	22.2	13.7
	Phoenix, AZ MSA	21.6	23.0	6.5
	Denver-Boulder, CO CMSA	22.0	22.4	1.9
	Portland-Vancouver, OR-WA CMSA	21.4	21.7	1.5

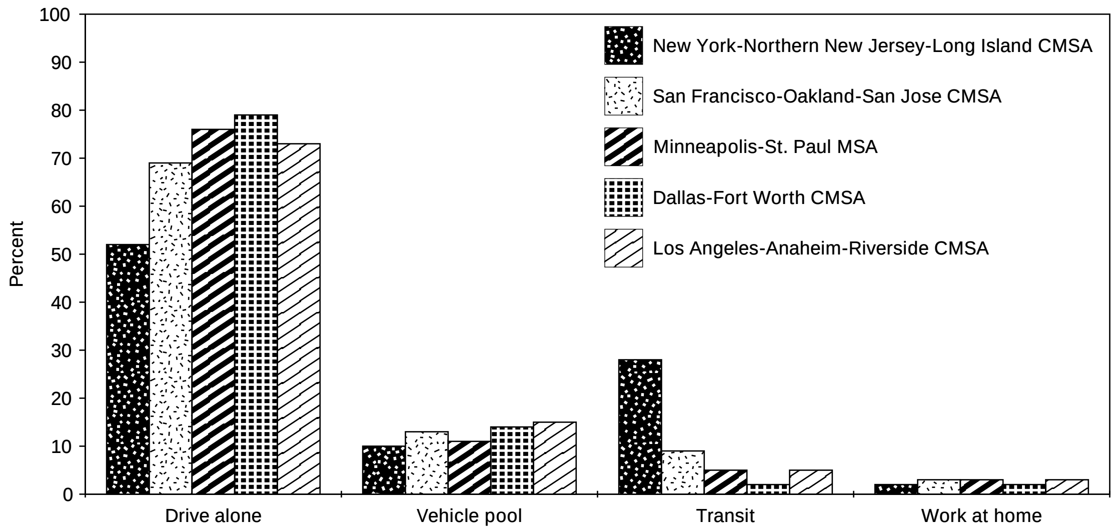
KEY: CMSA = consolidated metropolitan statistical area; MSA = metropolitan statistical area.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Journey-to-Work Trends in the United States and Major Metropolitan Areas, 1960–1990* (Washington, DC: 1993), table 4-13.

ington Corridor and in Chicago. New York has the greatest proportion of commuters who use transit (see figure 8-3).

In the rest of the country, San Francisco is the only major metropolitan area where transit share approaches 10 percent. In Minneapolis and Los Angeles the share is 5 percent and in Dallas only 2 percent. The fact that transit shares are low in rapidly growing metropolitan areas of the South and West reinforces the countrywide shift away from transit. Many people in such southern and western cities as Dallas and Los Angeles ride in

FIGURE 8-3: JOURNEY-TO-WORK MODE SHARES IN SELECTED MSAS, 1990



KEY: CMSA = consolidated metropolitan statistical area; MSA = metropolitan statistical area.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, *Journey-to-Work Trends in the United States and Major Metropolitan Areas, 1960–1990* (Washington, DC: November 1993), table 5-7.

vehicle pools, thus dampening the geographical variation in the drive alone mode share.

The increasing number of trips, distance of trips, and dominance of private modes of transportation have all led to an increase in vmt in privately operated vehicles. In urban areas, vmt increased 34 percent between 1983 and 1990. (USDOT FHWA 1994, 2-5, 2-6) There is, however, significant variation across metropolitan areas in road transportation. Newer, fast-growth areas such as Houston and Atlanta have a vehicle-mile per capita rate more than 50 percent higher than some older metropolitan areas such as Boston and Pittsburgh.

Finally, traffic growth is faster than growth in road capacity, leading to a potential for increased congestion in some areas. Between 1980 and 1992, total urban vmt increased by 61 percent while urban road mileage increased by only 26 percent. (USDOT FHWA various years) Wasted time and fuel are well documented costs of congestion. (Downs 1992) Cars traveling in congested traffic have higher emissions per mile than cars traveling at a moderate speed. CO, the greenhouse gas carbon dioxide (CO_2), and VOC emissions are especially high when cars accelerate or decelerate, and may be significantly higher when a car is idling than when it cruises at a steady speed. (TRB 1995, ch. 3) It is not clear, however, whether relieving congestion necessarily reduces emissions. Congestion is a major deterrence to driving, so reduced congestion may lead to increased vmt. Also, emissions of most pollutants, especially NO_x, increase above moderate speeds.

Empirical evidence on congestion is difficult to construct. Table 8-5 presents the Texas Transportation Institute's (TTI's) congestion index of U.S. cities. As the data show, most large cities have significant congestion problems, although some medium-size cities (e.g., Miami and Seattle) are more congested than some of

TABLE 8-5: ROADWAY CONGESTION INDEX, 1982–90

Region	Urban area	1982	1990	Change (percent)
North	New York	1.01	1.14	13
	Chicago	1.02	1.25	23
	Philadelphia	1.00	1.05	5
	Detroit	1.13	1.09	–4
	Boston	0.90	1.06	18
	Cleveland	0.80	0.97	21
	Minneapolis-St. Paul	0.74	0.93	26
	St. Louis	0.83	0.99	19
	Pittsburgh	0.78	0.82	5
	Cincinnati	0.86	0.96	12
	Milwaukee	0.83	0.99	19
	Kansas City	0.62	0.74	19
South	Washington, DC	1.07	1.37	28
	Dallas	0.84	1.05	25
	Houston	1.17	1.12	–4
	Miami	1.05	1.26	20
	Atlanta	0.89	1.11	25
	Baltimore	0.84	1.01	20
	Tampa	0.94	1.05	12
West	Los Angeles	1.22	1.55	27
	San Bernardino-Riverside	1.09	1.19	9
	San Francisco-Oakland	1.01	1.35	34
	Seattle	0.95	1.20	26
	San Diego	0.78	1.22	56
	Phoenix	1.15	1.03	–10
	Denver	0.85	1.03	21
	Portland	0.87	1.07	23
	Average	0.93	1.10	

NOTE: A value of 1.00 or greater indicates area-wide congestion. *Urban areas* are in some cases smaller than consolidated metropolitan statistical areas.

SOURCE: Texas Transportation Institute, *Estimation of Roadway Congestion, 1990* (College Station, TX: March 1994), table 6.

the largest cities (e.g., Philadelphia and New York). The TTI index indicates increasing congestion between 1982 and 1990 in all but three of the metropolitan areas.

TTI compares traffic count data with road capacity measures to construct the congestion index. Unfortunately, the resulting estimates do not correlate well with self-reported data from the NPTS. In that survey, respondents are asked to report the length and duration of trips. These can be used to calculate the average speed over each trip, which is a proxy for the level of congestion. The NPTS found a general increase in speeds. For instance, in cities of more than 3 million people, the mean work trip speed during the morning peak period for those living outside the central city increased from 28.1 mph in 1983 to 31.8 mph in 1990. The NPTS found similar or larger gains in cities of other sizes and for residents living inside the central city. This change is attributed to a decentralization of employment, which results in diversion of work trips away from those roads that are already most congested. (Gordon and Richardson 1994) There is some evidence to suggest, however, that congestion is not limited to high-density central areas. A recent study of the Chicago metropolitan area found that drivers in new, lower density suburbs were exposed to levels of congestion similar to those experienced by drivers in older suburbs closer to the urban core. (Prevedouros and Schofer 1991)

Given the contradictory nature of the best available data and the critical role of congestion in emissions generation, urban traffic congestion is a key area for further data development.

► Emissions Rates

Aside from the uncertainty about congestion, the preponderance of evidence is that urban driving increased in a period when highway vehicle emissions (other than NO_x) decreased and air quality improved significantly. Cars emit less pollution per mile than they did in the 1970s and early 1980s—reflecting the impact of federal emissions standards for new vehicles. As the stock of old cars turned over, the emissions performance of the in-service vehicle fleet improved. Beginning with the 1996 model year, emissions per mile standards for new cars and light trucks were cut by 39 percent for VOC and 60 percent for NO_x (the CO standard remained unchanged). Standards applying to the 2004 model year will be reduced by an additional 50 percent for all three pollutants, if EPA determines that it is necessary and feasible to do so. It must be noted, however, that past projections have proven to be optimistic. One reason is that real-world driving has produced more emissions than anticipated on the basis of testing data on emissions from new vehicles (see box 8-2).

Real-world emissions also could be affected by inspection and maintenance (I/M) programs. The 1970 Clean Air Act authorized EPA to require I/M programs for states that were unable to meet NAAQS for ozone or carbon monoxide. By 1996, I/M requirements affected 146 urban areas, of which 92 must implement enhanced I/M practices. (USEPA 1996) Over time, EPA changed its I/M guidelines to account for new vehicle technology and improved understanding of vehicle emissions. As a result, I/M procedures now may measure emissions under various speeds and engine loads, and check evaporative control systems. EPA's enhanced I/M guidelines also call for roadside monitoring of on-road emissions, such as by remote sensing devices that can estimate emission rates from passing vehicles. EPA estimates that enhanced I/M programs can reduce vehicle emissions by 31 percent for hydrocarbons and 34 percent for CO compared with no I/M, and by 26 percent and 18 percent, respectively, compared with older I/M procedures. (USEPA 1992, 2) In making these estimates, EPA attempts to account for real-world operating conditions, including the potential for errors in testing and repair.

EPA estimates the cost of enhanced I/M programs to be $460 to $2,000 per ton of VOC reduced, depending on assumptions about the frequency of testing, the allocation of costs to VOC and CO reductions, and other factors. (USEPA 1992, tables 6-4, 6-5, and 6-10) Other estimates are as much as 5 to 10 times higher, reflecting, among other things, different assumptions about the effectiveness of the I/M program and other emissions control programs in effect. (Anderson and Lareau 1992, McConnel and Harrington 1992)

Changes in the composition of fuel also have contributed to emissions reductions. Federal regulations require use of oxygenated gasoline during the winter months in 40 major metropolitan areas. Increasing the oxygen content in gasoline reduces CO and VOC emissions in laboratory tests (this has been verified in at least one field test). (Harley 1995)

Other gasoline reformulations may help address ozone problems. In response to the 1990 CAAA, refiners and automobile industry officials developed reformulated gasoline (RFG). These fuels are designed to meet limits on vapor pressure and toxic constituents, as well as oxygen requirements. (Lidderdale 1994) In 1995, RFG was introduced in nine cities with the highest ozone levels, as well as other ozone nonattainment areas that opted to participate in the program.

In the long term, technological advances could further reduce criteria emissions. The federal government and some states have sponsored or cost-shared research with industry on cleaner engine technologies, alternative fuel vehicles, and advanced emission control devices. (US Congress OTA 1995a) In time, such research could lead to new vehicles or fuels that are less polluting.

A critical question is whether technological advances will continue to reduce emissions, or at least hold them in check, for the foreseeable future. Recent nationwide data show increases in some criteria emissions from transportation between 1991 and 1994, as is discussed in detail in chapter 7. Whether these increases will continue, thus reversing the downward trend in the 1970s and 1980s, remains to be seen. A study by

Box 8-2: Real-World versus Expected Emission Rates

Studies of real-world vehicle emissions show that past estimates used in U.S. Environmental Protection Agency (EPA) models underestimated carbon monoxide (CO) and volatile organic compounds (VOC) emissions from motor vehicles.[1] EPA has since revised its emissions estimates upward. There are several reasons why real-world emissions have been higher than expected:

1. *Turnover of the vehicle fleet is slower than it once was*. In 1970, only 12 percent of cars and 29 percent of the light trucks were 10 or more years old. In 1993, by contrast, 30 percent of cars and 36 percent of light trucks were 10 or more years old. Old vehicles embody older, less effective technology than newer cars.

2. *Emissions controls become less effective as vehicles age.* EPA estimates that a properly operating 1995 vehicle after 50,000 miles of use will emit 2.3 times as much CO, 2.0 times as much VOC, and 1.3 times as much nitrogen oxides (NO_x) as when new.[2]

3. *Tampering with, or failing to maintain, emissions controls reduces their effectiveness.* Vehicles with disconnected catalytic converters emit 7 to 10 times as much CO and VOC. Tampering rates increase with vehicle age, from 1 to 7 percent for one-year-old cars to over 50 percent for nine-year-old vehicles.[3]

4. *Some vehicles, called "super-emitters," pollute much more than expected even when new.* The most recent studies show that 10 percent of vehicles emit almost 60 percent of the CO; and 10 percent (but not necessarily the same 10 percent) are responsible for 60 percent of VOC emissions.[4] This problem is not limited to the oldest vehicles. Among four-year-old cars, about two-thirds of CO emissions appear to come from the 10 percent of vehicles with malfunctioning emission controls.[5]

5. *The Federal Test Procedure (FTP)—used to certify newly manufactured vehicles for compliance with emissions regulations—does not fully reflect real-world driving conditions and behavior, thus creating a gap between the test and actual performance.* One problem is that certain speeds, acceleration rates, and other factors affecting vehicle emissions, are not represented in the FTP test cycle. One group of researchers estimates that over the lifetime of a 1993 model year car, about 46 percent of its CO and 7 percent of its hydrocarbon (HC) emissions will be due to such off-cycle operations. Emissions under these conditions are largely ignored by the regulatory process. Manufacturers, therefore, have been free to employ an engine-control strategy known as "command enrichment" under high-speed and high-acceleration off-cycle driving. Command enrichment provides excess fuel to the engine to improve drivability and reduce the chance of knocking under high load conditions. Some of this fuel exits the engine unburned. The catalytic converter's efficiency also is adversely affected. As a result, during command enrichment episodes, CO emissions per mile increase greatly.

6. *Other discrepancies between test assumptions and the real-world, such as the assumed effect of air conditioner use on emissions and the number of cold starts, lead to a performance shortfall.* EPA found that air conditioner use in vehicles has a greater effect on NO_x emissions than previously believed. In simulations of air conditioner operation in new vehicles at temperatures of 95°F, EPA found that NO_x emissions are an average of

[1] National Research Council, *Rethinking the Ozone Problem in Urban and Regional Air Pollution* (Washington, DC: National Academy Press, 1991), p. 300.

[2] U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources, Test and Evaluation Branch, *Compilation of Air Pollutant Emission Factors, Vol. 2, Mobile Sources,* AP-42 (Ann Arbor, MI: 1985).

[3] National Research Council, *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use,* Special Report 245, Transportation Research Board (Washington, DC: National Academy Press, 1995), p. 60 and table 2.

[4] B. Naghavi et al., "Remote Sensing Means, Medians, and Extreme Values: Some Implications for Reducing Automobile Emissions," *Transportation Research Record* No. 1416: Energy and the Environment, Transportation Research Board (Washington, DC: National Research Council, 1993), pp. 53–61.

[5] M. Ross et al., *Real-World Emissions from Model Year 1993, 2000 and 2010 Passenger Cars* (Washington, DC: American Council for an Energy Efficient Economy, 1995), p. 25.

Box 8-2 (cont'd): REAL-WORLD VERSUS EXPECTED EMISSION RATES

80 percent higher with an air conditioner in use.[6] At present, the FTP represents the effect of air conditioner use as a fixed percentage, giving manufacturers little incentive to optimize air conditioner designs for efficiency and emissions. Another discrepancy results from the amount of times a vehicle is started cold. For a cold start, excess fuel is added so that enough fuel vapor is present for steady combustion. While cold-start conditions are a part of the FTP, real-world driving surveys reveal that trips are shorter and cold starts more frequent than previously thought. Thus, more driving takes place before engines and catalysts reach normal operating temperatures than represented on the FTP. As a result, HC and CO emissions per mile are greater than previously believed.[7]

Although some of the causes of these discrepancies are still under study, EPA has proposed rules to address the discrepancy between FTP and real-world driving patterns and other factors, such as the effect of air conditioners. Documenting the extent of this problem and analyzing its causes and possible cures remains an important area for further research.

[6] J. German, "Off-Cycle Emission and Fuel Efficiency Considerations," paper presented at the 1995 Conference on Sustainable Transportation Energy Strategies, Asilomar Conference Center, California, July 31–Aug. 3, 1995.

[7] U.S. Environmental Protection Agency, Office of Radiation, *Federal Test Procedure Review Project, Preliminary Technical Report,* EPA-420-R-93-007 (Washington, DC: May 1993).

the Transportation Research Board of the National Academy of Sciences projected that, even with full achievement of all technological improvements mandated by current law, aggregate emissions of CO, VOC, and NO_x would increase if vmt grows just 2 percent per year. (TRB 1995) Higher rates of vmt growth (such as continuation of the 3.5 percent annual increase that occurred over the last decade) would lead to a more rapid increase in emissions.

A couple of notes of caution are in order. First, technological improvements other than those mandated in federal legislation may come into use in the coming years. The second is that demographic trends may lead to lower rates of growth in vmt. (See chapter 1 for a discussion of demographic trends). Nevertheless, the possibility exists that technological improvements will need to be complemented with other measures (such as TCMs) if continued progress is to be made in reducing emissions of most pollutants from highway vehicles.

► The Policy Context

Three federal laws significantly affect transportation planning to reduce emissions in metropolitan areas: The Clean Air Act and its 1990 Amendments (CAAA), the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), and the Energy Policy Act of 1992 (EPACT).

Under the CAAA, all metropolitan areas that do not meet the NAAQS are classified as marginal, moderate, serious, severe, or extreme nonattainment areas. (Once nonattainment areas meet standards they are classified as maintenance areas.) Nonattainment areas are required to take action to address their air pollution problems within a specified time period, depending on the relative severity of their problem. Thus, areas classified as marginal for ozone were given three years from the 1990 base year to attain standards, areas classified as moderate were given six years, areas classified as serious were given nine years, areas classified as severe were given 15 to 17 years, and the one extreme ozone nonattainment area (Los Angeles) was given 20 years. Those areas classified as moderate or worse were required to submit plans to reduce ozone precursors by 15 percent from the 1990 base within six years, and by 3 percent per year thereafter until standards are met. For severe or extreme nonattainment areas, these plans must include transportation control measures. (These measures are defined and described in the next section.)

Somewhat different rules apply for areas that are in nonattainment only for CO. Since CO is so closely linked with highway vehicles, these rules call for the adoption of TCMs when growth in vmt exceeds allowable levels. The sanctions for nonattainment areas that fail to comply with these rules include withholding of federal highway funds. (TRB 1995, 16–17) In addition, the CAAA requires state and metropolitan officials to demonstrate that all new transportation infrastructure projects in nonattainment and maintenance areas contribute to reductions in emissions.

ISTEA emphasizes integrated planning of different transportation modes, consideration of environmental impacts in plan assessment, and efficient provision of transportation services. (Gifford et al 1994, and Lyons 1994) ISTEA highlights the importance of metropolitan areas as planning units. It places new responsibilities on metropolitan planning organizations (MPOs), which represent local governments and public agencies within the metropolitan areas. To qualify for federal funds, each MPO must submit a long-range plan that includes environmental and intermodal considerations, and a transportation improvement program (TIP) with policy instruments and management tools to accomplish the plan's goals.

One objective of EPACT is to reduce U.S. dependence on imported petroleum by promoting use of alternative fuel vehicles. While EPACT is not, strictly speaking, environmental legislation, the effect of its requirements could be to reduce emissions in metropolitan areas.

Transportation Control Measures

Measures to reduce travel demand, improve traffic flow, divert travel away from peak periods, or mitigate harmful impacts of existing traffic are known collectively as transportation control measures. Metropolitan transportation planners have used TCMs in their efforts to reduce congestion for many years. The CAAA and ISTEA identified TCMs as important elements in an overall strategy to reduce emissions of pollutants from vehicles, especially in nonattainment areas. Some TCMs that reduce congestion, such as shifting trips to off peak, may have uncertain effects on emissions, however.

TCMs are used to encourage: 1) changes in mode choice—primarily to shift trips from single-occupancy vehicles (SOVs) to high-occupancy vehicles (HOVs) or transit; 2) changes in work day or work week trip scheduling by commuters; 3) flow improvements to reduce congestion levels without changing the number of vehicle trips; and 4) changes in vehicle stock to improve emissions performance. The first two address the level and pattern of travel demand, and are therefore known collectively as travel demand management (TDMs) measures, while the second two rely on improved systems management practices and vehicle technology.

TCMs can be implemented through several mechanisms. Information and education is used to publicize TCM programs and to prepare guidelines. Economic incentives may be used to promote desirable actions or discourage undesirable activities (see box 8-3). TCM implementation also can entail investment in public facilities, the transportation infrastructure, and systems management. Finally, regulations may be used to prohibit undesirable actions or require desired activities.

Table 8-6 classifies 15 kinds of TCMs according to the four categories of changes and implementation mechanisms described above.

Box 8-3: Congestion Pricing

Of all transportation control measures (TCMs), congestion pricing is often estimated to have the greatest potential to reduce volatile organic compounds (VOC) emissions. Also, unlike most TCMs, it can in theory not only reduce congestion levels, but lead to *optimal* congestion levels. It is not surprising, therefore, that it has been the subject of a great deal of interest and research in recent years.

In economist's language, congestion occurs as the result of a negative externality, which is an adverse impact that one person's behavior has on another person, and for which there is no compensation (see chapter 6 and appendix B for theoretical discussions of externalities). If a driver decides to take a trip, her presence in the flow of traffic will contribute marginally to the congestion delay that every driver on the road experiences. She is not required, however, to compensate the other drivers for the cost of the delay imposed by her presence. In other words, she is undercharged for the privilege of using the road. As is always the case, when a resource is underpriced, it is overused. Thus, an excessively large number of drivers choose to use the roads, and inefficient levels of congestion ensue. By setting a price that is equal to the marginal social cost, congestion pricing seeks to *internalize the externalities* in order to bring about efficient driving behavior.

If only the time costs of congestion are considered, the marginal social cost is equal to the total cost of delay (based on some estimate of the value of time) to *all* drivers on the roadway imposed by each additional driver. When environmental externalities are considered, calculation of the marginal social cost becomes considerably more complex. First, the social cost of emissions includes such disparate matters as health impacts and reductions in visibility. To calculate such costs, values would have to be assigned to human life and visual aesthetics—difficult and controversial matters. Furthermore, the relationship between the level of congestion and air quality is complex. Vehicles generally emit more at low and high speeds, so a reduction in congestion may have a deleterious effect beyond a certain point. For this reason, congestion pricing may only reduce emissions in a limited range of traffic situations.[1] Finally, the effects of changes in the rate and location of emissions on ambient air quality measures, such as ozone concentrations, is difficult to predict.

In addition to the problem of price setting, congestion pricing has practical drawbacks. People are always reluctant to pay a new tax. The case must be made that, despite the extra costs, commuters themselves would benefit from reduced congestion, and all urban residents would benefit from cleaner air. A second problem is how to collect such a tax. New technology allows the passage of a car over particular roadways to be recorded "on the fly" and the toll charged to the driver's account.[2] This technology is now used for congestion-sensitive pricing along a recently opened private toll road in Orange County, California.

Given both its potential and its problems, practical experience with road pricing is needed to assess the role it can play in mitigating urban air quality problems. The Intermodal Surface Transportation Efficiency Act of 1991 established a Congestion Pricing Pilot Program authorizing the Department of Transportation to enter into cooperative agreements with up to five state and local governments or other public authorities to establish, maintain, and monitor congestion pricing pilot projects. "Preproject" studies, including public outreach, project design, and related activities, can be supported with program funds. There are currently 10 congestion pricing projects funded under this program. Two of these are expected to lead to implementation of congestion pricing projects in the near future (San Diego, California, and Lee County, Florida). One project is monitoring and evaluating the privately constructed and operated variable toll facility in Orange County, California. The remaining seven projects are preproject studies examining alternative pricing approaches, including assessment of potential impacts and public participation in proposal development and project design. Several of these could proceed to implementation in the late 1990s.

[1] R. Guensler and D. Sperling, "Congestion Pricing and Motor Vehicle Emissions: An Initial Review," *Curbing Gridlock, Volume 2*, Transportation Research Board, Special Report 242 (Washington, DC: National Academy Press, 1994).

[2] K. Bhatt, "Potential of Congestion Pricing in the Metropolitan Washington Region," *Curbing Gridlock, Volume 2*, Transportation Research Board, Special Report 242 (Washington, DC: National Academy Press, 1994).

TABLE 8-6: TRANSPORTATION CONTROL MEASURES (TCMs)

TCM	Implementation mechanism	Examples
Commuter trip reduction	Information, education, and regulation	Ridesharing incentives, vanpool programs
Area-wide ridesharing	Information and education	Commuter-matching programs and databases
Rail transit improvement	Public facilities improvement	Light-rail system, expanded underground system
HOV lanes	Public facilities improvement	Lanes restricted to vehicles with three or more passengers
Park-and-ride lots	Public facilities improvement	Peripheral lots at transit stops or as car and vanpool staging areas
Bicycle/pedestrian facilities	Public facilities improvement	Pedestrian and bicycle lanes, bicycle lockers at transit stops
Parking pricing	Economic incentive	Charging full parking costs, parking "cash-back" program
Congestion pricing	Economic incentive	Charge for entering congested zone, congestion-based road pricing
Emissions/vmt tax	Economic incentive	Charged on gasoline or through differentiated registration fee
Buy-back of older cars	Economic incentive	Purchase of gross polluters above market value for scrapping
Compressed work week	Information and education	Employees work more hours on fewer days
Telecommuting	Information and education	Employees work at home or at "satellite" offices
Signal timing	Public facilities improvement	Timed lights to reduce accelerations and control access ramps
Incident management	Public facilities improvement	Automated monitoring, overhead signs to warn of incidents ahead
Land-use planning	Public facilities improvement, economic incentives, regulation	Increased density, nodal development, transit-oriented development

KEY: HOV = high-occupancy vehicle; vmt = vehicle-miles traveled.

SOURCE: Adapted from Apogee Research, Inc., *Cost and Effectiveness of Transportation Control Measures (TCMs): A Review and Analysis of the Literature*, prepared for the National Association of Regional Councils (Washington, DC: September 1994).

The final TCM in table 8-6 is land-use planning to reduce the need for automobile trips, decrease average trip lengths, and facilitate nonmotorized transportation. This longer term strategy is addressed in detail below.

The potential of TCMs to reduce total automobile emissions in metropolitan areas is disputed. Some critics argue that the benefits from TCMs may not justify the inconvenience to travelers. (Giuliano 1992) Furthermore, many analyses of TCMs have focused on their ability to reduce congestion (COMSIS Corp. 1993), which is not necessarily proportional to their ability to reduce emissions.

Apogee Research, Inc. recently reviewed the literature on use of TCMs to reduce VOC emissions, and their related costs. (Apogee Research, Inc. 1994) Table 8-7 shows key results of the study. Apogee identified what it considered to be a realistic maximum percentage reduction in trips, vmt, and VOC for each TCM. It evaluated information about the total capital, administrative, and operating costs of each TCM to estimate the cost per ton of VOC reduction. (The estimates do not include the full cost of tolls, taxes, and charges, or the costs of travel delay or lost productivity that might be associated with some TCMs.)

Where possible, the estimates were based on experience with TCMs. For example, data from California's South Coast Air Quality Management District (see box 8-4) were used to develop estimates of trip reductions arising from actions by employees. There has been, however, little or no application in North America of TCMs for congestion pricing, parking pricing, emissions/vmt taxes, telecommuting, signal timing, and incident management. In these instances, Apo-

TABLE 8-7: EFFECTIVENESS AND COST OF TRANSPORTATION CONTROL MEASURES (RANKED BY COST PER TON)

	Vmt reduction (percent)		**Trip reduction** (percent)			
TCM	**Range of study estimates**	**Apogee estimate**	**Range of study estimates**	**Apogee estimate**	**VOC reduction** (percent)	**1994 cost per ton**
Emissions/vmt tax	0.2–0.6	0.4	0.1–0.9	0.7	4.1	near 0
Buy-back of older cars	na	na	na	na	0.4	3,000[a]
Area-wide ridesharing	0.1–2.0	0.4	0.5–1.1	0.3	0.4	16,000
Signal timing	<0.1	<0.1	<0.1	<0.1	0.4	23,000[b]
Parking pricing (work)	0.5–4.0	3.0	0.4–4.0	2.5	2.8	47,000
Congestion pricing	0.2–5.7	5.0	0.4–4.2	3.8	8.2	66,000
Incident management	(0.1)–0.0	–1.0	(0.1)–0.0	–1.0	0.8	83,000[b]
HOV lanes	0.2–1.4	1.4	0.5–0.6	0.5	1.1	109,000
Park-and-ride lots	0.1–0.5	0.5	0	0	0.3	146,000
Major rail transit improvement	0.0–2.6	1.0	0.6–2.5	0.8	0.9	272,000
Commuter trip reduction	0.2–3.3	1.0	0.1–4.1	0.8	0.9	281,000
Bicycle/pedestrian facilities	<0.1	<0.1	<0.1	<0.1	<0.1	289,000
Parking pricing (nonwork)	3.1–4.2	4.2	3.9–5.4	5.4	4.6	in
Telecommuting	0.0–3.4	1.1	0.0–2.8	1.0	1.0	in
Compressed work week	0.0–0.6	0.8	0.0–0.5	0.7	0.7	in

[a] For 1990.
[b] For 1997.

KEY: TCM = transportation control measure; vmt = vehicle-miles traveled; VOC = volatile organic compounds; na = not applicable; HOV = high-occupancy vehicle; in = insufficient data.

SOURCE: Based on Apogee Research, Inc., *Cost and Effectiveness of TCMs: A Review and Analysis of the Literature,* prepared for the National Association of Regional Councils (Washington, DC: January 1994).

gee used projections. As a result, caution should be used in interpreting the findings.

Some TCMs (including employee trip reduction, transit improvement, and bicycle/pedestrian facilities) were found to have relatively little potential for emissions reductions and were not cost-effective. Signal timing and incident management were relatively cost-effective, but also had little impact. Economic incentives (congestion pricing, parking pricing, and emissions/vmt taxes) ranked high in both potential reductions and cost-effectiveness. This conclusion, however, is based on projections rather than experience. Also, while taxes, tolls, and charges may have low systemwide costs, they have high direct costs to some individuals, and are likely to meet with political resistance.

The researchers concluded that TCMs aimed at inducing mode switches were ineffective because of the high premium that commuters place on driving alone. Also, existing TCMs focus on the journey to and from work, which limits their overall potential for emissions reduction. The study also was based on the application of TCMs in isolation from one another. In practice, more than one TCM might be implemented. For example, regional vanpool and parking cash-out programs might be applied together, as they have the common goal of reducing SOV commuting. It is not clear whether the combined emissions reductions would be greater (because of synergies) or less (because of overlap) than the sum of their individual effects. Also, imple-

Box 8-4: South Coast Air Quality Management District

Of all U.S. metropolitan areas, Los Angeles is the most severely affected by transportation-related air quality problems. Public concern over smog (of which ozone is a primary constituent) led to the establishment of the first air pollution control district in Los Angeles County in 1946. In 1976, the California legislature created the South Coast Air Quality Management District (SCAQMD). Its legal responsibility is to devise and implement plans to meet federal and state air quality standards in the region comprising Los Angeles, Orange, San Bernardino, and Riverside Counties—an area of over 12,000 square miles and the second most populous urban area in America.

SCAQMD has a legal mandate to achieve air quality objectives through a combination of planning, regulation, compliance assistance, enforcement, monitoring, technological advancement, and public education. Faced with such a heavy task, it is innovative in a number of ways. It collects a large proportion of its annual revenue of nearly $100 million through mechanisms to "make the polluter pay," including pollution fees and permits, and its mobile source programs are funded mostly from surcharges on vehicles. SCAQMD also pioneered the implementation of market-based pollution control mechanisms, including an emissions trading scheme for stationary sources.

Part of SCAQMD's effort focuses on *indirect sources* of air pollution—buildings or facilities that attract large numbers of highway vehicle-trips. Just as direct stationary sources are compelled to reduce their emissions, indirect sources, which include all major employers, are required to reduce emissions from the mobile sources that they attract. One of the most controversial of the efforts to regulate indirect sources was an employer trip reduction program known as Regulation XV. First implemented in 1987, but now rescinded, it required firms with over 100 employees to develop a plan to reduce single-occupancy vehicle trips in order to meet average vehicle ridership (AVR) targets within 24 months. Substantially higher than prevailing values, AVR targets varied from 1.3 riders per vehicle for firms located in rural fringe areas to 1.75 riders per vehicle near or in downtown Los Angeles. Firms were given flexibility to use measures to promote carpooling/vanpooling, transit use, and walk/bike options, as well as complementary measures such as parking cash-out, flexible schedules, and compressed work weeks. Roughly 6,000 firms with 2 million employees participated in Regulation XV programs.

Critics of Regulation XV contend that it interfered with business decisionmaking and that its contribution to emissions reductions did not justify its costs to the employers. Some held that SCAQMD overstated the potential for reduction in vehicle-miles traveled through trip reduction policies.[1]

In 1995, the California Legislature prohibited SCAQMD from enforcing mandatory trip-reduction programs, thus effectively rescinding Regulation XV. Under a new SCAQMD policy (Rule 2220), firms of more than 100 employees are given additional ways to achieve emissions reductions targets aside from AVR programs. For example, they could buy and scrap old vehicles belonging to their employees or subsidize the purchase of clean fuel vehicles. They can also pay $60 per employee to an Air Quality Investment Program in lieu of achieving the emissions target. Thus, a program based exclusively on trip reduction was replaced with a broader selection of transportation control measures and market-based instruments.

[1] C-H.C. Bae, "Air Quality and Travel Behavior: Untying the Knot," *Journal of the American Planning Association,* vol. 59, No. 1, 1993, pp. 65–75.

menting one TCM might affect the cost of implementing another.

When compared with the potential emissions reductions to be achieved through technological means, the contribution of TCMs appear modest. Some might conclude that TCMs are relatively unimportant and should therefore be given less emphasis than they now receive. It could be argued, though, that more effective TCMs need to be devised since emissions gains from technological improvements may be offset by even modest growth in vmt.

TCMs and technological progress are not, of course, mutually exclusive options. Moreover, a new class of technological innovations known collectively as intelligent transportation systems (ITS) may aid in the implementation of TCMs. These innovations include automated transaction systems that can charge tolls, transit fares, and parking fees without slowing down traffic; sophisticated systems management technologies that can adjust ramp controls and signal timing based on current sensor information about traffic conditions and incidents, and traveler information systems that provide current traffic conditions on an ongoing basis so that travelers can adjust the route, time, or mode of travel to avoid congestion delay. (US Congress OTA 1995b) These technologies could reduce the cost and inconvenience of implementing TCMs based on economic incentives, such as congestion pricing. They also could make TCMs relying on information exchange, such as ridesharing, more effective.

The overall impact of ITS on emissions is difficult to evaluate. A goal of ITS is to make the transportation network more efficient by reducing congestion and delays. Since vehicles emit fewer pollutants per gallon in steady or free-flow conditions than in stop-and-go conditions, these systems may reduce emissions rates. It is also possible that, if ITS improves driving conditions, people may drive more than they would under congested conditions and/or stop using high-occupancy vehicles.

The CAAA calls for the adoption of TCMs in nonattainment regions. Box 8-5 describes the process of TCM assessment for the strategy currently being applied to bring Washington, DC, in line with federal air quality standards. This example reinforces the observation that, despite the cost-effectiveness of certain TCMs, their contribution to emissions reduction is relatively small.

Urban Form, Infrastructure, and Air Quality

Urban form is the spatial configuration of fixed elements in a metropolitan area. These include land-use elements, such as buildings, parks, and public facilities, and transportation network elements, such as railways, roads, bridges, and terminal facilities. Urban form greatly influences transportation flows within metropolitan areas. Commuting patterns, for example, can be partly explained by the relative location of homes and workplaces and the roads and transit routes connecting them. Urban form does not, however, *determine* the pattern of flows.

One can envision two very different patterns of commuting flows taking place within the same urban form: in the first, people by and large commute short distances to employment districts close to their residences; in the second, people make longer commutes, bypassing nearby employment districts for more distant ones. In the first case, the minimization of commuting distances influenced residential and employment choices, while in the second, other factors would be more important. Empirical studies from a number of U.S. metropolitan areas indicate that many people make long commutes despite the fact that there are housing units that suit their needs in locations much closer to their workplaces.[3] (Giuliano 1995)

Urban form evolves over time, reflecting the locational decisions of many households and firms, the actions of developers and landowners, and planning decisions and incentives provided by various levels of government. Since the process is slow and place-specific, it is difficult to make empirical generalizations about the environmental costs and benefits of different patterns of urban development. This section

[3] One possible explanation is that convenience of commuting plays a relatively small role in determining a household's location choice. Other factors such as remoteness, prestige, and a preference for newer housing are at least as significant.

Box 8-5: National Capital Region: Strategies for Conforming to Federal Clean Air Standards

The Washington, DC, metropolitan area, which contains parts of Maryland and Virginia, is one of the fastest growing areas on the East Coast. Its most rapid growth is occurring on the metropolitan periphery. Vehicle-miles traveled are projected to grow by 76 percent by 2020, substantially faster than projected growth in either households or jobs.[1]

The metropolitan area is designated a serious nonattainment area for ground-level ozone pollution. For this reason the National Capital Region Transportation Planning Board (TPB), which serves as the metropolitan planning organization (MPO) for the region, was required under the Clean Air Act Amendments of 1990 to submit a plan to achieve a 15 percent reduction in emissions of volatile organic compounds (VOC). As part of the planning process, TPB analyzed the potential to reduce emissions and the relative costs of 59 transportation control measures (TCMs).[2]

The TCMs finally included in the plan had potential to reduce emissions, were relatively low in cost, and could be implemented quickly to meet reductions deadlines. One immediate TCM action was to allow right turns on red throughout the metropolitan region—a step estimated to reduce VOC by 0.39 tons per day at a cost of only $236 per ton.

Another TCM, funded for the 1996 to 2001 transportation improvement plan (TIP), is a ridesharing incentive program to upgrade the existing "Ride Finder" matching system and to establish satellite ridesharing associations at major employment centers. This measure is projected to lower VOC and nitrogen oxides emissions by 0.07 and 0.16 tons per day, respectively, at costs of about $13,000 per ton.

Projected Transportation Emissions for the COG-Modeled Area

	1990	2020 technology	2020 technology and TCMs[a]	TCMs alone
HC (tons/day)	225.47	123.82	121.52	–2.30
CO (tons/day)	2,148.25	1,338.22	1,303.13	–35.09
NO_x (tons/day)	272.11	236.05	239.02	2.97

[a] Includes elements of both the 1996–2001 Transportation Improvement Plan and the Constrained Long Range Plan.

KEY: COG = Council of Governments; TCM = transportation control measure.

SOURCE: National Capital Region Transportation Planning Board, *Conformity Determination of the Constrained Long Range Plan and the FY96-2001 Transportation Improvement Program for the Metropolitan Washington Region with the Requirements of the 1990 Clean Air Act Amendments* (Washington, DC: July 19, 1995), exhibit 16b.

Another TIP measure will promote telecommuting through educational programs, technical assistance, and five new regional telecommuting network centers. The measure is projected to lower VOC emissions by 0.32 tons per day and NO_x emissions by 0.66 tons per day at costs of $6,500 and $3,500 per ton, respectively. A further measure approved for inclusion in the long-range plan is increased speed limit enforcement, which could reduce NO_x emissions by about 1.25 tons per day. (NO_x emissions tend to increase with speed.)

The table summarizes emissions forecasts for the year 2020 under a base scenario and a scenario that takes account of adopted TCMs. The reductions that can be attributed directly to TCMs are small compared with those that are attributable to changes in vehicle technology and emissions standards. Also, emissions of NO_x are projected to be higher with the TCMs than without them, perhaps due to increased average vehicle speeds. TPB is considering measures to address this problem. These include employer outreach for travel demand management measures, guaranteed ride home programs, and programs to remove older vehicles and increase the use of alternative fuel vehicles.

[1] Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, *Conformity Determination of the Constrained Long Range Plan and the FY96-2001 Transportation Improvement Program for the Metropolitan Washington Region with the Requirements of the 1990 Clean Air Act Amendments* (Washington, DC: July 1995), exhibit 11: 22.

[2] Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board, *Transportation Control Measures Analyzed for the Washington Region's 15% Rate of Progress Plan* (Washington, DC: July 1994).

reviews the relationship between urban form and transportation emissions in three ways: urban sprawl, changes in the road network, and local planning and design options that influence transportation choices.

▶ Urban Sprawl

Urban sprawl refers to the general deconcentration of population and employment in metropolitan areas. It is characterized by 1) an outward expansion of the metropolitan boundary that separates urban from rural land uses, 2) a general decline in intensity of urban land uses, as measured by population and employment densities, 3) highway or other transport networks that provide high connectivity among points, even in peripheral parts of the city, and 4) the segregation of residential from other land uses, with the greater part of residences locating in peripheral suburbs.

The term is most often associated with automobile-dependent suburban development in the post-World War II era. Americans with cars no longer needed to locate close to their jobs or to transit corridors. Certain elements of public policy, such as the construction of commuter roads and the tax deduction for mortgage interest, are also credited with promoting sprawl, although the general trend to deconcentration was evident before they came into force.

Sprawl has had a number of benefits. It made home ownership affordable to a larger segment of society and provided a highly mobile and flexible lifestyle away from the congestion and pollution of central cities. It also has its costs. For example, it is generally more expensive to provide infrastructure to low-density development. One recent study concluded that these incremental costs are not fully borne by suburban residents. (US Congress OTA 1995b)

Since low-density development and the segregation of land uses implies longer average

TABLE 8-8: AVERAGE VEHICLE-MILES TRAVELED AT DIFFERENT LEVELS OF DENSITY

Density (pop/sq mile)	**Change in density** (percent)	**Vehicle-miles traveled** (vmt)	**Change in vmt** (percent)
1,280	–	6,500	–
2,688	110	6,500	0
6,400	138	5,500	–15
14,700	130	4,500	–18
33,280	126	2,500	–44

SOURCE: R. Dunphy and K. Fischer, “Transportation, Congestion, and Density: New Insights,” paper presented at the 73rd annual meeting of the Transportation Research Board, Washington, DC, 1994.

trips, it may lead to increased energy use and emissions by automobiles. As shown in table 8-8, residents of high-density zones travel fewer miles annually than residents of low-density zones. These data, however, should be interpreted with caution. There may be socioeconomic differences affecting travel behavior between people living in high-density and low-density neighborhoods. Hence, it does not necessarily follow that the travel of suburbanites would fall to the level of city residents if suburban residential densities increased. Also, the densities at which a rapid decline in vmt are observed are quite high compared with the national average of 2,500 people per square mile in urbanized sections of metropolitan statistical areas. Furthermore, reductions in vmt do not necessarily translate into proportional reductions in emissions, since the number of trips also has an effect on emissions. (TRB 1995, 195-197)

Over the past 20 years, a number of studies looked at the question of whether sprawl leads to increased energy use and emissions. One influential study (Real Estate Research Corp. 1974) assessed the transportation requirements for a hypothetical new town under low- and high-density spatial design scenarios. It found that a high-density scenario was more energy efficient and less polluting than a low-density scenario. Further evidence was provided by studies assessing alternative growth scenarios for specific urban areas, which also indicated significant energy savings, especially in transportation, from higher density development. (Carrol 1977, Roberts 1977)

More recent studies include cross-sectional studies of groups of cities and case studies on individual cities. (Anderson et al 1996) An international comparison of per capita gasoline consumption for 32 major cities concluded that a very high proportion of variation in gasoline consumption is explained by population density. (Kenworthy and Newman 1990) Despite methodological criticism (Gomez-Ibañez 1991), this study is frequently cited in support of arguments for denser urban development. A metropolitan case study of driving behavior in Perth, Australia, found that, despite the negative impact of congestion on fuel efficiency, people living in low-density areas used the most fuel per capita because they took more and longer trips. (Newman and Kenworthy 1988)

A simulation study on the Greater Toronto Area (IBI Group 1990) assessed the energy, environmental, and financial implications of various scenarios for the spatial distribution of urban growth. Its results indicate a strong positive relationship between the extent of sprawl and both energy consumption and environmental emissions. A different conclusion was reached by a simulation study of alternative transportation scenarios in Denver. (May and Scheurenstuhl 1991) It concluded that the benefits of denser development were largely offset by higher congestion.

Most of the studies were based on simulations of land-use scenarios in real or hypothetical cities, not experience. (Exceptions are Newman and Kenworthy 1988, Kenworthy and Newman 1990) Also, some only measure transportation energy consumption, which is an imperfect proxy for emissions.

While most studies contend that sprawl increases emissions, there is a counter argument that says that, in the long run, decentralized development could lead to *lower* emissions. The strong trend of decentralization in employment is resulting in a growing number of suburb-to-suburb commutes and a relative decrease in the proportion of suburb-to-central city commutes. (US Congress OTA 1995b) The pattern will vary among MSAs, but, in some MSAs, the average distance between homes and workplaces could decrease, especially where there are employment clusters in the metropolitan periphery. (Garreau 1991) Because commutes occur on less congested roads, commute duration may decrease even if commute distances do not (Gordon and Richardson 1994), and cars traveling in less congested conditions, and therefore traveling at higher average speed, will produce less emissions per mile (up to certain speeds and except for NO_x). (TRB 1995) Furthermore, a more dispersed pattern of driving will distribute emissions into a larger airshed, leading to lower pollutant concentrations. Although this may reduce some of the negative health effects, this does not necessarily imply that the total cost of damage from such pollution will be lower. Moreover, concentrated or dispersed emission of some pollutants, such as CO_2, makes little difference outside of the MSA as their impact is felt at the global scale. And while this argument is supported by evidence showing increasing average speed of commutes, and, hence, less congestion, it is questionable given the continued growth in the average length of commutes and the fact that sprawled development discourages alternatives to the SOV travel mode.

► Highway Infrastructure

The construction of new roads, or the expansion of existing roads, may affect emissions both directly and indirectly. Direct effects include both changes in the level of congestion, which affect emissions per vmt and increases in vmt.

Indirect effects relate to the long-term impact of road infrastructure on land-use patterns, whereby new roads may accelerate peripheral development and thus increase overall vmt.

If the number and pattern of trips in a metropolitan area could be held constant, new highway infrastructure would reduce congestion. This is true both for the expansion of existing roads and the construction of new roads. In general, reducing congestion can contribute to a reduction in emissions because of the high rates of emissions in stop-and-go situations. This general observation is tempered by two factors. The first is that cold start and hot soak emissions, which account for roughly half of VOCs emitted, are not affected by changes in traffic flow. The second is that NO_x emissions tend to increase as average speed increases. Given the ambiguity about the effect of new roads on emissions, the CAAA requires an analysis of the net impact of all infrastructure projects in nonattainment areas.

There is considerable research on the effects of expanding road infrastructure on peak period congestion and vmt. These studies suggest that growth in traffic is usually less than capacity added, even for long periods. (TRB 1995) Still, some of the increased road capacity is quickly taken up by new traffic during peak periods. Drivers may switch routes or change their commute from off-peak periods. Some may drop out of carpools or stop using public transportation. (Downs 1992) Other drivers, who previously elected not to travel because of congested conditions, may decide to make a trip when new capacity becomes available—a phenomenon called *induced demand.*

A recent study concluded that, given the difficulty of relating emissions to traffic flow and the counteracting effects of induced demand, current analytical models are not able to determine whether a new highway has a positive or negative impact on emissions, even in the short run. (TRB 1995) Whether this points to the need for better models (Replogle 1995) or whether it means that the problem is too complex to permit definitive analysis remains unclear.

Over the longer term, the addition of new road capacity may encourage new housing subdivisions or other development at the metropolitan periphery that generate more traffic and vmt. (Wegener 1986) A number of approaches have been taken to assess the magnitude of this effect. These include studies that relate changes in land use and land values to proximity to new highways, and studies that compare development patterns in areas where new roads have been added with areas where they have not. These studies face a number of methodological difficulties because of the time lags involved, the difficulty of making apt comparisons, and the fact that numerous factors affect land-use patterns simultaneously. There is also a cause and effect problem: do new roads promote new development or does new development create a political demand for new roads? Taken together, the results of these studies are mixed, with earlier studies (in the 1950s and 1960s) indicating greater impacts than more recent studies. (TRB 1995) Assessing the indirect impacts of new highways on emissions, rather than just land-use patterns, would be even more difficult.

The general question of how new highways affect emissions and air quality is a significant issue, especially given the federal role in highway funding and in air pollution control. Once a highway is built, any negative environmental impacts could be felt for decades to come. If the environmental effects are small, however, restraint of new highway construction could impede economic growth and incur high congestion costs. This is an important area for further research.

► Land-Use Planning and Design

Land-use planning and design is sometimes regarded as a transportation control measure because the layout of new development and the rehabilitation of existing built-up areas may affect travel behavior, and thus vmt and trips, and, ultimately, emissions. Given the complex and long-term nature of changes in land-use patterns, it is difficult to evaluate emissions reductions potential or cost-effectiveness of land-use planning as a TCM. The previously discussed Apogee study on TCMs concluded that over the long run, significant changes in land-use patterns had a greater potential for reducing travel than any of the conventional TCMs. (Apogee Research, Inc. 1994, 28)

A number of communities are now adopting planning principles that break with the standard pattern of suburban development. While conventional plans employ low densities and segregation of land uses, these new principles stress higher development densities with access to green spaces and mixed land uses. The motivations for this shift include the need to reduce municipal service costs, the desire to protect agricultural and open-space areas, and the desire to recreate the ambiance of traditional urban or small town communities. One of the most important motivations is to reduce the dependence of suburban residents on automobile travel, thereby reducing emissions. (Bank of America 1995)

Land-use planning and design measures are not specifically called for as ways to reduce emissions under the CAAA. Land-use control has traditionally been viewed as a local matter. Also, the magnitude of the effect of land-use measures on emissions is uncertain. To the extent that such planning can reduce emissions, the reduction will come over a period of several decades. Land-use measures may require cooperation of many local government authorities, and may place significant restrictions on the activities of land developers. As such, they are often controversial and difficult to implement from a political perspective. Still, land-use planning approaches are being examined in various locales.

Transit-oriented development (TOD) is a general class of plans for urban and suburban areas that allow residents to meet their daily mobility needs by travel modes other than SOVs. One critical element of TOD is density. Most people will not walk more than about one-quarter mile from their homes to a bus stop. The more widely spaced the homes, the fewer commuters that live within a reasonable walking radius of each stop.

Density, however, is not the only concern. The layout of streets in conventional suburban residential subdivisions makes extensive use of curved roadways and cul-de-sacs. Although cul-de-sacs reduce traffic on certain roadways, they also make it difficult to establish direct bus routes to serve new residential areas. For this reason, some California jurisdictions prohibit cul-de-sacs in new subdivisions. (Dyett 1991)

A goal of TOD is to lay out high- to medium-density residential areas in ways that maximize access to rail transit routes and stations. In addition to promoting the use of transit for commuting trips, TOD may encourage walking and bicycle trips for service and recreational activities. This can help reduce the number of short automobile trips which, because of cold start and hot soak emissions, can have a large impact on emissions. Shops, schools, parks, and public service facilities are located within short distances of homes, and may be clustered around transit stations. Walking and bicycling are also encouraged by design features of roadways and the design of “pedestrian-friendly” commercial areas rather than the typical suburban plaza with its large parking lots. (Calthorpe 1993) Critics argue, however, that with shorter distances trip-making is less costly in terms of time, so residents who do not switch to non-auto modes may actually make more trips. (Bae and Richardson 1994)

While TOD is too new to permit direct analysis of its impact on travel behavior, its supporters point to comparisons of older neighborhoods that conform with TOD principles with newer, low-density suburban neighborhoods. For example, researchers in the San Francisco Bay Area have compared older suburban town centers, which embody many TOD characteristics, with suburban tract developments. They found that households in the older neighborhoods made 9 trips per day versus 11 in the tract developments. In the older neighborhoods, 64 percent of trips were by car, 19 percent were by bicycle or walking, and 17 percent were by transit. The corresponding proportions in the tract development were 86 percent by car, 11 percent by bicycle or walking, and 3 percent by transit. (Calthorpe 1993, 48) (This comparison should be viewed with some caution as it does not control for socioeconomic differences between residents.)

The success of TOD will depend first on its ability to deliver the kind of change in travel behavior implied by this comparison, and second on its acceptance in the marketplace. A detached house on a large lot is the housing goal of many Americans. It is not clear how many suburban residents will opt for multifamily dwellings or smaller yards. Evidence will soon be available as many TOD projects come to completion, especially in California. San Diego and Sacramento have both incorporated TOD design guidelines into their regional plans, and there are a number of TOD projects at various stages of development. Also, the Portland, Oregon, metropolitan area is currently considering adoption of a long-term plan in which TOD principles are central (see box 8-6 at the end of this chapter).

The design of housing developments around transit services can only be successful if the residents have jobs that are accessible by transit. Most employers outside central cities locate either independently or as part of an industrial park on a large site surrounded by parking areas. These sites often are arranged in linear patterns along major roadways. Thus, the average distance between each place of employment and its nearest neighbor is great. By contrast, urban employment zones traditionally served by public transportation may have dozens of places of employment within an easy walk of each transit stop. Providing service to dispersed workplaces is possible through use of small shuttles that stop at every company's door. Such shuttles, however, are relatively slow and have high labor costs, since the ratio of drivers to riders is higher than in regular buses.

If workplaces are clustered into suburban employment centers, it may become possible to lay out efficient transit routes and serve a large number of employers with each stop. If such centers could be laid out along light-rail lines, and included shopping and recreational facilities, some demand for the transit service during off-peak periods might be generated. (Cervero 1991)

It is probably too early to say how effective land-use planning and design can be in reducing automobile emissions. One reason for this is that these changes are incremental by their very nature. It is very difficult to change the land-use patterns in an existing built-up area. Thus, even fundamental changes in the design of new developments would have only small changes in the overall density and structure of the metropolitan area. (Downs 1992, 80) Only after many years could changes in land-use planning and design be expected to have a major impact on aggregate metropolitan emissions. Because urban environmental problems are likely to be around long into the future, more research is needed to find out whether planning can play a major role in a long-term strategy.

Conclusions

Federal environmental laws encourage many local governments and MPOs to apply TCMs to supplement technology-based strategies to restrain emissions. The information that is currently available suggests that the contributions of TCMs to emissions reductions in most metropolitan areas may be modest when compared with the major reductions that have occurred because of the tighter emissions standards that have been achieved through technology. There is, however, still some uncertainty in this conclusion. Most current analyses take the form of projections based on limited experience and empirical data. More analyses of situations where TCMs have been implemented is needed. Also, more analyses are needed of the potential emissions reduction from the simultaneous application of several TCMs, since synergies or overlaps between measures could affect outcomes.

The TCMs that have received the greatest attention are short- to medium-term measures. There are a number of longer term integrated land-use and transportation planning measures that may also figure in the reduction of emissions in the next century. Highway construction, or the decision not to build a highway, can be seen as a TCM in the sense that it affects the volume and distribution of traffic, and thereby aggregate emissions. Assessment of the emissions impacts of highways is required under the CAAA. The current state of analytical modeling can only address the direct, short-term impacts of highways on vmt, however, and even then imperfectly. The longer run impacts that emerge from the interaction of highway networks and land-use patterns are much more difficult to gauge.

Elements of land-use planning may also affect travel patterns and emissions. On a broad scale, overall development may affect trip lengths, mode split, and congestion. At a more localized scale, transit-oriented development has been proposed as a means to reduce the dominance of the SOV mode. The impact of these measures is uncertain at this time. It is likely, however, that novel approaches to land-use development will soon be applied in a number of metropolitan areas, creating the possibility for empirical analyses.

Finally, evidence that individual TCMs have relatively modest impacts does not necessarily imply that they will not play an important role in the long-term strategy for emissions reduction. Complementary TCMs, taken together, may have higher (or lower) impacts than current research indicates. Also, it should not be assumed that the preferences of the current generation of Americans, such as the preference for large suburban lots and SOV transportation, will be carried over into future generations. Demographic changes and changes in tastes and attitudes may increase the popularity of such options as transit-oriented development at some future date.

Box 8-6: Portland, Oregon: Exploring the Transportation/Land-Use Link

Portland, Oregon, is a relatively fast-growing metropolitan area. Its population increased by over 13 percent between 1980 and 1990, and further increases are projected well into the next century. In the late 1980s, regional authorities proposed the construction of a major circumferential highway, the "Western Bypass." The purpose of the highway was not to alleviate existing congestion problems, but to provide access for the projected increase of 160,000 people in as yet undeveloped areas of Washington County on the western periphery of the metropolitan area. The anticipated development was expected to follow the conventional pattern of low-density residential subdivisions with a high degree of segregation from commercial and other land uses.

An environmental advocacy group, 1000 Friends of Oregon, opposed the Western Bypass on the grounds that it violated the Urban Growth Boundary established around Portland under Oregon state law. In the wake of litigation that followed, the Oregon Department of Transportation asked 1000 Friends of Oregon to propose an alternative plan to accommodate the projected growth in the metropolitan area. The result is a demonstration research project called "Making the Land-Use, Transportation, and Air Quality Connection." The project, which was to become known by the acronym LUTRAQ, received financial support from the U.S. Environmental Protection Agency, the Federal Highway Administration, and a number of private foundations.

The goal of LUTRAQ was to design a regional development plan for Washington County that would provide new residents with adequate transportation access to employment and other services without construction of the Western Bypass. The design strategy focused on transit-oriented development (TOD) principles and economic incentives to discourage single-occupancy vehicle travel.

The proposed plan includes a major light-rail transit corridor extending west from downtown Portland. Feeder buses would serve this corridor, along with a demand responsive "dial-a-ride" system for areas not served by fixed route transit. Limited expansion of existing arterial roads is also part of the plan.

The most innovative aspects of LUTRAQ relate to land-use development. The goal is to create a more structured, transit-supportive land-use pattern without violating the suburban character of the region. Four types of nodal developments are included in the plan: mixed-use centers developed at existing town centers through redevelopment and infill; urban TODs located on previously undeveloped sites along the light-rail corridor; neighborhood TODs connected to the light rail by feeder buses; and secondary areas located no more than one mile from TODs that apply more traditional suburban planning. Mixed-use centers and urban TODs both have an average density of 15 houses per acre, the neighborhood TODs have an average density of eight units per acre, and secondary areas have typical suburban densities.[1] The TOD design also incorporates elements to promote a pedestrian-friendly environment, in order to reduce local automobile trips and vehicle-miles traveled (vmt).[2]

Market analysis was conducted to ensure that the housing mix envisioned by LUTRAQ fit the demand profile of people likely to move into Washington County. To be consistent with market demands, 37 percent of the housing units were planned as multifamily and 67 percent as single-family. It was projected that with appropriate zoning, permit allocations, and fiscal incentives, all the multifamily units and 55 percent of single-family units could be located within mixed-use centers and urban and neighborhood TODs. The balance of single-family homes would be in the secondary areas.[3]

The LUTRAQ plan also includes two financial incentives to discourage SOV travel. The first is a mandatory $3.00 per day parking charge at workplaces and the second is the provision of free transit passes for commuters.

[1] For a review of TOD concepts, see Peter Calthorpe, *The Next American Metropolis* (New York, NY: Princeton Architectural Press, 1993).
[2] Parsons, Brinckerhoff, Quade, and Douglas, Inc., "The Pedestrian Environment," prepared for 1000 Friends of Oregon, December 1993.
[3] Market Perspectives, Hebert/Smolkin Associates, Inc., *Market Research: Volume 3A*, prepared for 1000 Friends of Oregon (Portland, OR: 1992).

(continued)

Box 8-6 (cont'd): Portland, Oregon: Exploring the Transportation/Land-Use Link

One of the main tasks of the project was to compare the projected transportation behavior and emissions under the LUTRAQ proposal with what would be expected if the Western Bypass were constructed. Some estimates for travel behavior effects are presented in table 1. Here LUTRAQ I and LUTRAQ II refer to the plan with and without the financial incentives, respectively. It is interesting to note that the difference in mode share between the Bypass scenario and the LUTRAQ scenario is highly dependent on the inclusion of financial incentives. The analysis also indicates that the LUTRAQ option results in a reduction in vmt and trips, but an increase in peak vehicle-hours of delay. The LUTRAQ project shows that land-use planning and other transportation control measures can be used together to identify and plan potentially viable alternatives to major transportation infrastructure expansion. The expected changes in travel behavior are, however, relatively minor in light of the extensive land-use changes proposed under the plan.[4]

Table 1: Mode Shares Under Western Bypass and LUTRAQ Scenarios

	Mode share (percent)		
Type of trip	**Bypass**	**LUTRAQ I**	**LUTRAQ II**
Home-based work trips			
Walk	2.5	3.5	3.5
Single-occupancy vehicle	75.1	72.7	63.9
Carpool	13.6	13.8	19.7
Transit	8.8	10.0	12.8
Total home-based			
Walk	4.9	5.7	5.7
Automobile	85.4	84.2	83.4
Transit	9.7	10.2	10.9
Total nonhome-based			
Walk	0.3	0.5	0.5
Automobile	99.0	98.8	98.8
Transit	0.7	0.8	0.8
All trips			
Walk	3.7	4.5	4.5
Automobile	89.0	87.6	87.0
Transit	7.3	8.0	8.6
Daily vehicle-trips per household	7.68	na	7.09
PM peak vehicle-miles	679,390	na	586,660
PM peak vehicle-hours	19,920	na	18,380
PM peak vehicle-hours delay	1,670	na	1,950

NOTE: na = not available.
SOURCE: Genevieve Giuliano, "Land Use Impacts of Transportation Investments: Highway and Transit," *The Geography of Urban Transportation*, Susan Hanson (ed.) (New York, NY: Guilford, 1995), ch. 13, tables 13.6 and 13.7.

While LUTRAQ was only a demonstration research project, at least some of the land-use and transportation principles that it endorsed are being adopted in the Portland metropolitan region. Portland was a marginal nonattainment area for ozone, and a moderate nonattainment area for carbon monoxide (CO). Federal emissions standards, along with local initiatives for vapor recovery and vehicle inspection have now brought the region into maintenance status for both pollutants. Given a projected annual growth rate of 2.2 percent for vmt, emissions are expected to increase by the end of the decade. In response to the danger that Portland would be unable to maintain attainment status, a state task force devised a plan to reduce emissions of volatile organic compounds (VOC) and nitrogen oxides (NO_x) by 37.1 percent and 20.6 percent, respectively, by the year 2007 (these are reductions from projected emissions under federal emissions restrictions). Some of the reductions would be achieved by requiring pedestrian-, bicycle-, and transit-friendly land use for all new construction. The majority of the projected

[4] Genevieve Giuliano, "The Weakening Transportation-Land Use Connection," *Access*, vol. 6, 1995, pp. 3–11.

Box 8-6 (cont'd): PORTLAND, OREGON: EXPLORING THE TRANSPORTATION/LAND-USE LINK

reductions are due to vehicle inspection and maintenance programs, with emissions fees and mandatory employer trip reduction also contributing to significant reductions.[5]

More extensive use of integrated transportation and land-use planning is now under review as part of a long-term plan for metropolitan Portland called "Region 2040." As a result of a 1992 referendum, Portland's Metro Planning Department was asked to develop a plan for accommodating growth without sacrificing the quality of life, natural areas, air quality, and water quality. As part of this process, Metro analyzed four land-use and transportation scenarios to accommodate an additional 1.1 million residents by the year 2040. The Base Case scenario represents the growth patterns that would occur if recent development patterns were to continue. It includes dispersed and segregated land-uses and major highway construction (including the Western Bypass). This scenario, however, would not be permitted under recently enacted land-use regulations. Concept A is a scenario for dispersed development—requiring a significant extension of the Urban Growth Boundary—which complies with current land-use rules. Concept B is a dense, transit-oriented growth scenario, which does not violate the current Urban Growth Boundary. It incorporates many of the same design criteria as LUTRAQ. Concept C restricts most growth to the Urban Growth Boundary, but also opens up several "satellite cities" for development.[6] Concept B

[5] State Task Force on Motor Vehicles Emissions Reduction in the Portland Area, *Final Report: Volume 1 Findings and Recommendations* (Portland, OR: Oregon Department of Environmental Quality, February 1993).

[6] Metro Planning Department, *Region 2040 Concepts for Growth: Report to Council* (Portland, OR: June 1994).

(continued)

TABLE 2: COMPARISON OF REGION 2040 GROWTH CONCEPTS

Category	1990	Base Case	Concept A	Concept B	Concept C
Buildable acres	53,736	154,974	104,325	65,006	78,574
Growth outside urban growth boundary (percent)	–	17	29	0	37
Density (people per acre)	8.9	7.9	9.8	12.4	9.2
Single-family/multifamily (percent)	70/30	70/30	74/26	60/40	69/31
Average vmt per capita	12.4	13.04	12.48	10.86	11.92
Auto/transit/walk-bike (percent)	92/3/5	92/3/5	91/4/5	88/6/6	89/5/6
Lane-miles	5,304	6,777	6,377	5,557	6,116
Transit service hours	4,965	9,575	12,322	13,192	12,553
Congested roadway-miles (am peak)	150.5	505.6	682	642.6	403.9
Emissions (kg/day)					
Carbon monoxide: winter	835,115	614,451	613,537	579,579	569,091
Carbon monoxide: summer	574,708	528,601	525,133	496,017	487,188
Hydrocarbon: summer	177,857	70,700	69,810	66,375	65,745
Nitrogen oxides: summer	80,452	94,024	90,987	83,817	86,988

KEY: vmt = vehicle-miles traveled; kg/day = kilograms per day.

SOURCE: Metro Planning Department, *Region 2040 Concepts for Growth: Report to Council* (Portland OR: June 1994), p. 88.

Box 8-6 (cont'd): **PORTLAND, OREGON: EXPLORING THE TRANSPORTATION/LAND-USE LINK**

incorporates the most transit-oriented transportation infrastructure plan, while Concept A incorporates the most roads-oriented plan, with Concept C in an intermediate position.[7]

The concepts were evaluated on a number of factors, including air quality. As a result of federal, state, and local emissions control policies, estimates of CO and VOC emissions for all scenarios were below the 1990 levels (see table 2). However NO_x estimates for all four scenarios are higher than the 1990 levels. The least dispersed scenarios (concepts B and C) had the best estimated performance. A summary of the results of this analysis was distributed to every household in the Metro Region. It is now up to Metro Council to decide which of the three concepts (or what combination of elements of the three) to adopt as its long-range growth plan.

[7] Metro Planning Department, Regional Transportation Planning, *Region 2040: Transportation Analysis of the Growth Concepts* (Portland, OR: July 1994).

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CHAPTER NINE

AN INTERNATIONAL COMPARISON OF TRANSPORTATION AND AIR POLLUTION

MOBILE SOURCES ACCOUNT FOR A SIGNIFICANT SHARE OF URBAN AIR QUALITY PROBLEMS WORLDWIDE. MOTOR VEHICLES ARE A MAJOR SOURCE OF CARBON MONOXIDE (CO), NITROGEN OXIDES (NO_X), AND VOLATILE ORGANIC COMPOUNDS (VOC) EMISSIONS IN ALL ADVANCED INDUSTRIAL COUNTRIES. IN DEVELOPING COUNTRIES, DESPITE LOWER LEVELS OF TRANSPORTATION-RELATED AIR POLLUTANT emissions on a national basis, many mega-cities have severe air quality problems from the increased use of cars and trucks and the limited use of emissions controls. In all countries, of course, industrial and other emissions from stationary sources also affect urban air quality.

There were over 615 million motor vehicles in the world fleet in 1993, and rapid growth is expected. How this growth affects air quality and the global climate is drawing attention.

Moreover, the large quantities of gasoline and diesel fuel consumed by the transportation sector raise concerns about the addition of carbon dioxide (CO_2), a greenhouse gas, to the atmosphere and its potential for global climate change. The United States and other industrialized countries account for 65 percent of mobile source greenhouse gas emissions. Developing countries' contributions, however, are expected to grow appreciably in the future as per capita use of highway vehicles increases in these nations.

Air pollutants do not respect geographic or political borders: the more that is learned about emissions, the harder it is to identify impacts that are purely local in nature. Lead, for example, has been found thousands of kilometers from its source. Thus, transportation-related air pollution is increasingly debated at the international level.

Important lessons can be learned by evaluating other countries' experiences in dealing with transportation-related environmental issues. Although pollution control strategies may be site specific, understanding their strengths and weaknesses can be helpful in adapting them for use elsewhere. In addition, sharing information about air pollution trends can contribute to improvements in measurement techniques.

This chapter focuses on international trends in air pollution from motor vehicle use—the transportation mode for which the most information is available. It presents emissions data (principally, for CO, VOC, NO_x and CO_2) for Organization for Economic Cooperation and Development (OECD) countries,[1] including the United States, France, the United Kingdom, Japan, and western Germany).[2] The chapter also discusses motor vehicle trends affecting air quality in non-OECD countries, although the information is much more limited. The chapter often uses the generic term "developing countries" to refer to non-OECD countries, although the state of economic development among this group varies widely. Where possible, this chapter follows the often-used convention of categorizing the diverse countries of the world as low-, lower middle-, upper middle-, and high-income economies. When the data permits, information about the former East Bloc (FEB) countries in Eastern Europe and the former Soviet Union is provided separately. Otherwise, FEB data is included with non-OECD countries.

This chapter is divided into four sections, beginning with a discussion of global trends in motor vehicle use. The second section provides a comparative discussion of some motor vehicle emissions in key OECD countries. Section three covers non-OECD countries. The final section discusses CO_2 emissions from transportation in both OECD and non-OECD countries.

Conventional air emissions from motor vehicles are a major but, by no means, the only important environmental effect of transportation. A comprehensive international comparison would examine transportation's contributions to other forms of hazardous air pollution.[3] It would also need to examine other modes of transportation (comparing modal shares of transport by country) and other important direct and secondary impacts of transportation activities, such as contributions to water pollution, impacts on land use and habitat modification, and natural resource issues. This broader array is beyond the scope of this chapter.

Global Trends in Motor Vehicle Use and Emissions

The impact of motor vehicles on air quality depends on many factors. These include, among others, the number of vehicles in use; how far and how fast they are driven; road traffic volume; the kind and extent of use of emissions controls; what kind and how much fuel is used; and the local climate and topography. These fac-

[1] OECD is an intergovernmental organization founded in 1960. Its primary goal is to promote economic policies that stimulate growth, employment, and the expansion of trade among its members. The organization's current member countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. Mexico joined OECD in 1994. As most of the data in this chapter predates 1994, statistics for Mexico, when available, are included here with non-OECD data.

[2] Germany is referred to as "western Germany" in this chapter because the trend data used for analysis covers only what was, prior to reunification in 1991, West Germany.

[3] Lead, covered here, can be classified as a hazardous air pollutant. So are many VOCs. For example, benzene is a carcinogen. Particulate matter can also contain carcinogens.

tors interact in complex ways that complicate international comparisons.

The very rapid worldwide growth in the number of motor vehicles and in road traffic has prompted considerable concern about air quality impacts. The number of motor vehicles in the world more than doubled in the last two decades (see figure 9-1). In 1993, the world fleet consisted of 469 million passenger cars and 148 million freight vehicles.[4] (OECD 1995b, 215–219) Between 1970 and 1993, the average annual increase in the number of motor vehicles was 2.6 percent in the United States, 4.4 percent in other OECD countries, and 6.5 percent in the rest of the world (see table 9-1). The U.S. share of the world's motor vehicle fleet decreased from 44 percent in 1970 to 31 percent in 1993.

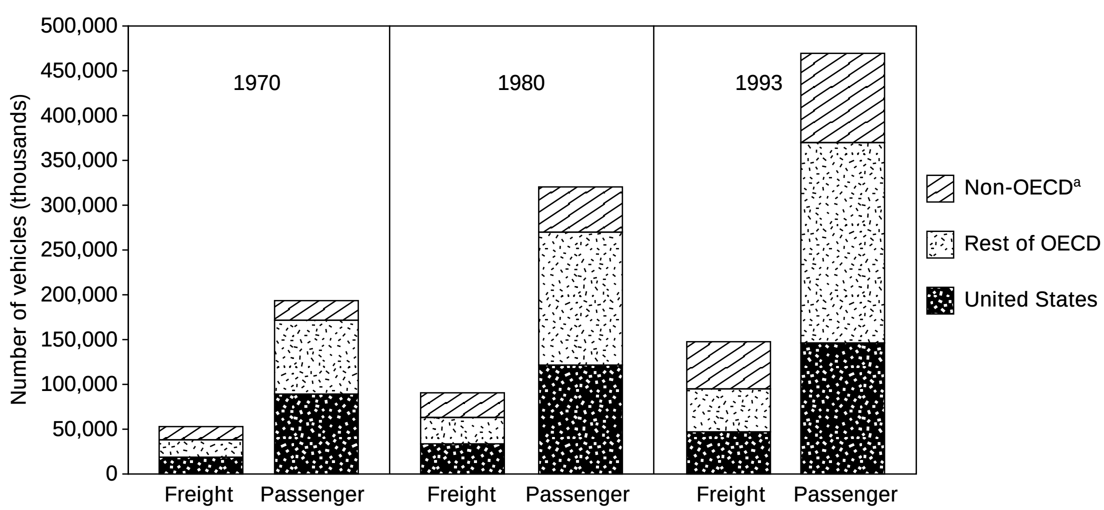
During the same period, the share of the world's motor vehicle fleet held by non-OECD countries increased from 14 to 24 percent. Previously used vehicles imported from OECD countries account for much of the fleet growth in these countries. (Michaelis et al 1996)

Of the 1993 stock of passenger cars, 81 percent were in OECD countries. Per capita car ownership in developing countries is still far below that in OECD countries. While there are two to three people for every car in many OECD countries, in low-income countries, such as Nigeria and Pakistan, there are more than 100 people per car. In China, there were 616 people for every car in 1992. If some Asian countries continue to sustain high rates of economic growth, however, explosive rates of motorization could result. An OECD report suggests the global fleet could exceed 800 million units by 2000. (OECD 1995c, 38)

Road traffic growth reflects, among other things, the combined effects of growth in population, gross domestic product (GDP) per capita, and the number of vehicles per capita. For such OECD countries as the United States, France, and

[4] Unless otherwise specified, motor vehicles include passenger cars, trucks, buses, coaches, and other road vehicles with at least four wheels.

FIGURE 9-1: PASSENGER AND FREIGHT VEHICLES, 1970–93



[a] Includes Mexico 1970–93.

SOURCE: Organization for Economic Cooperation and Development, *OECD Environmental Data: Compendium 1993;* and *OECD Environmental Data: Compendium 1995* (Paris, France: 1993 and 1995).

TABLE 9-1: WORLD MOTOR VEHICLE FLEET, 1970–93

Country or region	1970: Number of vehicles (thousands)	1993: Number of vehicles (thousands)	Shares of total (percent)		Annual growth rate (percent) 1970–1993
			1970	1993	
OECD	**211,686**	**469,233**	**86**	**76**	**3.5**
United States	108,418	194,063	44	31	2.6
Other OECD	103,268	275,170	42	45	4.4
Non-OECD	**34,692**	**147,854**	**14**	**24**	**6.5**
Total (world)	246,378	617,087	100	100	4.1

NOTE: Data for Mexico are included with non-OECD data.
SOURCES: Organization for Economic Cooperation and Development, *OECD Evironmental Data: Compendium 1993* (Paris, France: 1993), p. 221; and *OECD Environmental Data: Compendium 1995* (Paris, France: 1995), p. 215.

the United Kingdom, traffic growth also reflects a greater intensity of car use. Table 9-2 compares road traffic volume for selected OECD countries for passenger and freight vehicles. Passenger vehicle road traffic volume grew much more rapidly between 1970 and 1993 than population and, in some cases, slightly faster than the growth in vehicle stock. Similarly, freight road traffic volumes grew faster than GDP for the same period. Similar trends occurred in some non-OECD countries. For example, Poland's road travel volumes increased from about 13 billion to 91 billion vehicle-kilometers (8 billion vehicle-miles traveled—vmt—to 56 billion vmt) from 1970 to 1991, for an annual growth rate of 9.7 percent. (OECD 1993a, 227) The International Energy Agency (IEA) reports that, in India, passenger-kilometers traveled by road increased significantly faster than GDP. (IEA 1995, 185)

OECD countries still account for over 70 percent of the world's driving. Major emissions control efforts in the United States, Japan, and several other countries have kept their share of several key pollutants lower than their share of vmt. OECD countries, however, still accounted for 48 percent of the CO, 59 percent of the VOC, and 64 percent of the NO_x emitted by the global motor vehicle fleet in 1990. (OECD 1995c)

Most developing countries (as well as many OECD countries) lag far behind the leaders in adopting and enforcing emissions control and cleaner fuel standards. The non-OECD countries share of emissions, especially VOC and CO, is out of proportion to their share of vehicle fleets and usage. Several non-OECD countries, however, are taking promising actions to address transportation needs in more environmentally sustainable ways.

OECD countries were responsible for 65 percent of the 1993 mobile source CO_2 emissions. For the previous two decades, OECD countries held a 70 percent share. The recent decline may signal a shift toward increasing shares by non-OECD countries. CO_2 emissions from FEB countries actually fell in the 1980s because of severe economic declines. Among other non-OECD countries, emissions grew 133 percent between 1971 and 1993. During the same period, OECD countries' emissions grew only 45 percent.

The United States is the world's largest contributor to CO_2 emissions from transportation. U.S. emissions grew more slowly than in other OECD countries where car ownership and annual highway travel are climbing closer to U.S. levels. The lower U.S. growth rate may have been partly driven by larger gains in passenger car fuel efficiency in the United States during this period.

TABLE 9-2: ROAD TRAFFIC VOLUME IN OECD COUNTRIES, 1970–93

PASSENGER CAR	Vehicle-km traveled (vkt) (billions)			Annual growth rates (percent)	
Country	1970	1980	1993[a]	1970–93 vkt	Passenger cars 1970–1993
United States	1,434	1,789	2,652	2.7	2.2
Japan[b]	120	241	429	6.5	6.9
France	165	245	343	3.2	3.0
Western Germany	216	297	425	3.0	3.6
Italy	123	191	356	4.7	4.8
Great Britain	141	197	334	3.8	3.2
Netherlands	38	61	81	3.4	3.8
OECD	2,584	3,604	5,473	3.3	3.4
FREIGHT	Vkt (billions)			Annual growth rates (percent)	
Country	1970	1980	1993[a]	1970–93 vkt	Freight vehicles 1970–1993
United States	346	619	1,039	4.9	4.1
Japan[b]	100	142	272	4.4	4.1
France[c]	32	49	94	4.8	3.9
Western Germany	37	32	46	3.6	2.0
Italy[d]	23	33	52	3.6	4.9
Great Britain	35	41	64	2.7	2.2
Netherlands	6	8	16	4.4	3.4
OECD	656	1,086	1,807	4.5	4.1

[a] Provisional data.
[b] Excludes light vehicles.
[c] Excludes freight vehicles over 15 years old with load capacity greater than or equal to 3 metric tons.
[d] Includes three-wheel vehicles.

SOURCE: Organization for Economic Cooperation and Development, *OECD Environmental Data: Compendium 1993,* and *OECD Environmental Data: Compendium 1995* (Paris, France: 1993 and 1995).

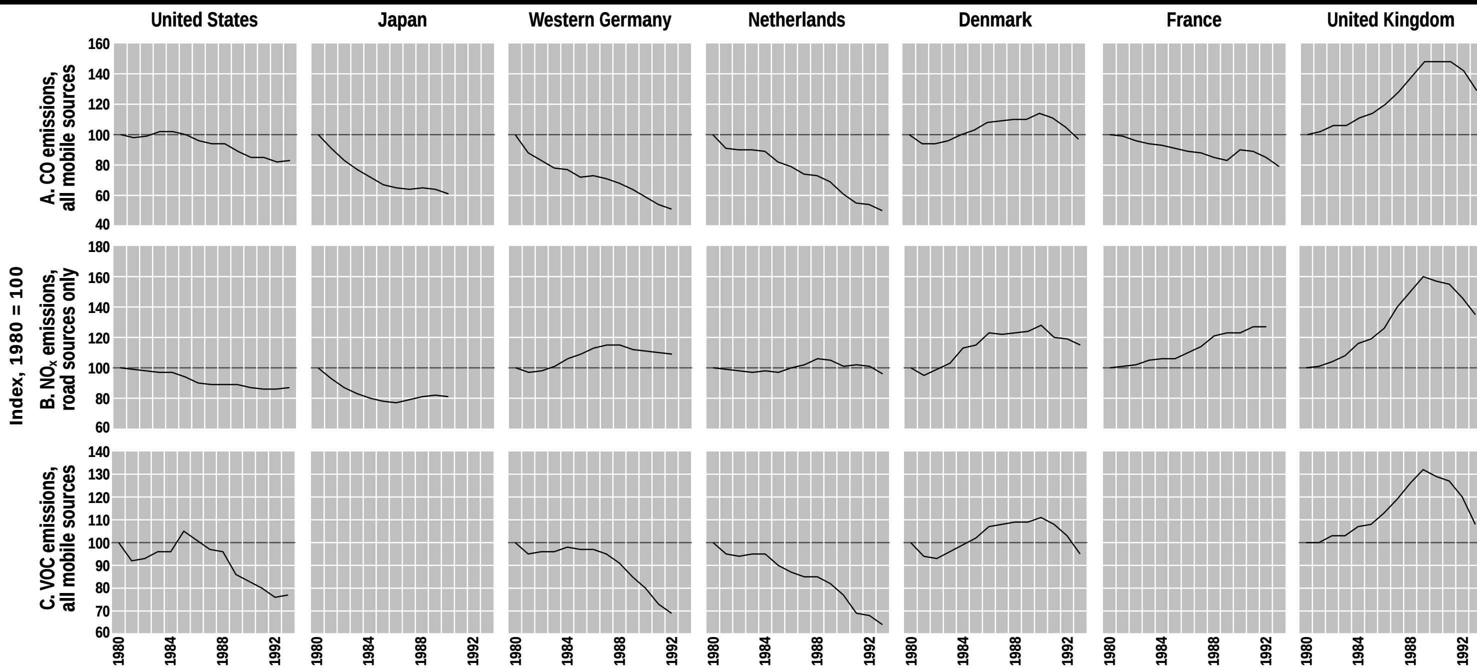
Air Emissions in OECD Countries

Despite more than 20 years of effort in combating emissions, air quality remains a problem in OECD countries.[5] In the summer of 1995, 16 pollution alerts were triggered by high ozone levels in Paris. In the United States, about 62 million people still lived in counties that failed to attain one or more national ambient air quality standards in 1994. Furthermore, while the United States has made much progress in reducing transportation-related air pollution, mobile sources still accounted for 78 percent of CO, 37 percent of VOC, and 45 percent of NO_X emissions in 1994.

Figure 9-2 shows how mobile source emissions of CO, VOC, and NO_X changed between 1980 and 1993 in several high-income OECD countries. It includes most European countries for which OECD has compiled relatively complete data covering these years and pollutants (western Germany, France, Denmark, the Netherlands, and the United Kingdom). The U.S. emissions data

[5] Unless otherwise noted, U.S. data in this section are based on USEPA 1995, and data for other countries are from OECD 1993a, OECD 1995b, and OECD 1995c.

FIGURE 9-2: MOBILE SOURCE AIR EMISSIONS IN SELECTED OECD COUNTRIES, 1980–93



KEY: CO = carbon monoxide; NO_x = oxides of nitrogen; VOC = volatile organic compounds.

NOTE: No data are available for VOC emissions in Japan and France.

SOURCES: U.S. data are from U.S. Environmental Protection Agency, *National Air Pollutant Emission Trends, 1900–1994,* EPA 454/R-95-011 (Research Triangle Park, NC: 1995); data for other countries are from Organization for Economic Cooperation and Development, *OECD Environmental Data: Compendium 1995* (Paris, France: 1995).

are from the most recent estimates published by the U.S. Environmental Protection Agency (EPA) for these years. (USEPA 1995) Trends for NO_x and CO emissions in Japan are also portrayed. Japan has been one of the most aggressive countries in controlling air pollution from cars, but the OECD data on Japan does not include all years in the time series, and does not include VOC.

The trend data should be interpreted cautiously, as there are differences among countries in the way emissions are measured. Although efforts to develop more consistent emissions data have been underway in Europe since 1985, the OECD data reported here are not necessarily internally consistent. (USEPA 1995, 7-1)

The OECD data for NO_x emissions are reported for highway vehicles alone. The OECD data for CO and VOC, however, cover all mobile source emissions. Countries may define mobile sources and collect data in different ways. The United States, as is discussed in chapter 7, includes many categories of nonroad sources in its mobile source data, including such nontransportation sources as lawn and garden equipment.

The timing and nature of control measures greatly influence emission trends. Most OECD countries have set emission standards for new vehicles. Some countries and cities have introduced a variety of other measures, as discussed in box 9-1. (U.S. programs are discussed in chapters 7 and 8).

There can be significant delays between promulgation of emission standards and actual implementation. For example, it was not until the 1981 model year that newly manufactured cars in the United States were required to fully meet emissions standards initially set for 1975 by the 1970 Clean Air Act. Japan, which had adopted standards similar to those in the United States, was the first country to produce new vehicles that met the initial standards. Several European countries set standards some years before fully implementing them in the late 1980s and early 1990s.

Other factors, such as the types of fuels in use and modal mix, also affect trends. Americans, for example, drive more than western Europeans, in part because of the large land area of the United States, the relatively low density of U.S. cities, and the more limited availability of alternatives to cars for urban travel. (OECD 1995d, 71) People in Japan drive less because of high-density cities, fewer highways, and metropolitan areas served by a well-developed rail system.

Of the countries in figure 9-2, the United States has one of the better records in curbing mobile source emissions. Despite rapidly growing freight and passenger transport, new passenger cars and light trucks in the United States today emit far less pollution than similar vehicles in the early 1970s (see chapters 7 and 8). Indeed, the majority of passenger car air pollution emissions in the United States today are produced by old and/or improperly maintained vehicles, or result from operation of vehicles under conditions not currently covered by current standards (see box 8-2 in chapter 8).

Although data are more limited, Japan also has had much success in curbing mobile source air pollutants. A 1994 OECD evaluation of Japan's environmental performance judged its success in meeting stringent emission requirements for automobiles as remarkable. (OECD 1994a, 123)

► CO Emissions

Transportation is the major source of CO emissions in OECD countries. In 1993, transportation's share of CO ranged from 64 to 92 percent in the countries shown in figure 9-2a. Most of these countries, however, have decreased transportation-related CO emissions over the last 15 years.

Despite increased road traffic, the United States lowered CO emissions from all mobile sources (including lawn and garden equipment) by 17 percent between 1980 and 1993. Some

Box 9-1: Transportation Approaches in Several European Cities

The growth in motor vehicle use in the urban areas of Europe has caused congestion and increases in air pollution. Some European cities are attempting to mitigate these problems with policies that seek to maintain or increase use of public transportation and nonmotorized transporation options and discourage motor vehicle use.

Milan introduced an emergency measure to improve air quality in 1990. It restricts vehicle use on days when the city's pollution levels exceed a reference level. Alternate day use restrictions have helped keep pollution levels below a second reference level that would trigger a prohibition. Complementing the car use policy, Milan has a program to improve and extend public transportation services.

Stockholm adopted a comprehensive transportation package in 1991. The agreement committed the three leading political parties to mitigation of environmental and congestion problems in the region over the next 15 years at a cost of about $4.6 billion. The plan is roughly divided between roads and public transport. It provides for more regional rail lines, track improvements, better coordination between services, and more park-and-ride facilities. The metro system is to be completely modernized and a new rapid tram line constructed around the inner city. Highway proposals are designed to improve accessibility while reducing car traffic in the city. A toll system will be used to steer traffic to peripheral routes. Only low-emissions vehicles will be allowed in the inner core area. Expectations are for a 25-percent reduction in traffic in the inner areas and a 50-percent reduction in air pollution. CO_2 emissions, however, will remain about the same.

In **Helsinki**, use of public transportation remains level although its share of total travel is diminishing. While the region is investing in roads to keep up with the growth in car ownership, a number of measures are helping to promote public transportation. Included are generous subsidies to keep fares low, dedicated bus and tram lines with priority at traffic signals, improved rail services and extensions to the metro system, and special easy-to-use ticketing and information systems. As a complement to these measures, parking is controlled in the city.

After years of planning, **Grenoble**, was able to increase public transportation use substantially as the city grew, but public transportation's modal share increased only modestly. Grenoble attempted an integrated approach to transportation that included highway planning, better public transportation, and more facilities for pedestrians and cyclists. Special bus lanes were designated, pedestrian precincts established, and an extensive cycleway program introduced. A new tramway system is complemented by measures to restrict parking and improve traffic circulation. Despite these measures, increases in road traffic may be eroding earlier reductions in noise and pollution.

SOURCE: Organization for Economic Cooperation and Development, European Conference of Ministers of Transport, *Urban Travel and Sustainable Development* (Paris, France: 1995), pp. 214–220.

other OECD countries with similar or higher growth rates in road traffic achieved larger percentage reductions during the same period. CO emissions decreased by 48 percent in western Germany and 50 percent in the Netherlands, for example. Emissions in Japan fell by 39 percent between 1980 and 1990.

In the United Kingdom, CO emissions rose by 29 percent over the 1980 to 1993 period, although improvement has occurred since 1989. The United Kingdom's poor performance on CO (and other) emissions probably can be attributed to the fact that it only recently required catalytic converters on new cars.

VOC Emissions

Among the six OECD countries in figure 9-2b, VOC emissions from mobile sources accounted for 33 to 41 percent of total VOC emissions in 1993. Transportation's share of VOC emissions was smaller in 1993 than it was in 1980 in these countries, with the exception of a slight increase in the United Kingdom.

Sharp declines in VOC emissions occurred in western Germany and the Netherlands between 1980 and 1993—31 and 36 percent, respectively. Emissions in the United States also declined appreciably—by 23 percent. Denmark's emissions declined 5 percent. The United Kingdom's VOC emissions rose 8 percent, although they began to decline after 1989.

NO_X Emissions

Figure 9-2c displays NO_X emissions trends for road transportation in eight countries. Road transportation is a more accurate measure of motor vehicle emissions than the broader mobile source category. Road transportation's 1993 share of all NO_X emissions in these countries ranged from 32 percent in the United States to 72 percent in France.

The control of NO_X emissions from transportation sources requires sophisticated catalytic technology (the three-way converter) and control measures. Japan and the United States were among the first to require such controls in new automobiles. Most European countries have been slower in adopting such requirements. The effect of this delay (and higher use of diesel fuels in Europe) shows in the trend lines in figure 9-2c.

The United States and Japan were the only countries in which road transportation's share of total NO_X emissions declined between 1980 and 1993. Elsewhere, road transportation's increased share reflects both increases in highway vehicle emissions and declines in stationary source emissions.

NO_X emissions have recently begun to increase even in Japan and the United States, however. In the United States, NO_X emissions from road transportation declined 14 percent between 1980 and 1991, before starting to rise again (by 2 percent) in subsequent years. Japanese road transportation emissions declined by 23 percent between 1980 and 1986, but rose by 6 percent in the following four years. Despite Japan's early achievement, large metropolitan areas in Japan have had difficulties in attaining full compliance because of truck emissions. (OECD 1994b)

Particulate Emissions

Countries measure particulate emissions in different ways. For example, the United States normally reports on PM-10, particulates of only 10 microns or less in diameter, because of their more likely health effects. Other countries may use the more inclusive measures, total suspended particulates (TSP) or suspended particulate matter (SPM).[6] Particulate emissions data may also include road dust from paved and unpaved roads.

Of the five countries reporting mobile source particulate emissions trend data to OECD, only the Netherlands showed a decline between 1980 and 1993. During the same period, the United States reported a 20 percent increase in TSP (while mobile sources of PM-10 declined by 1 percent). Western Germany, France, and the United Kingdom reported increases.

The increase in particulates in Europe may be explained partly by greater use of diesel fuel. Diesel engines without particulate controls emit much more particulate matter than gasoline-powered vehicles with catalytic converters that are fueled with unleaded gasoline. (World Bank 1995a, 34) Diesel fuel consumption increased at a much faster rate than gasoline consumption in

[6] To be consistent with the data sources used in this chapter, this section focuses on SPM or TSP rather than PM-10.

Europe. Most of the increase was for freight road transport, but the number of diesel passenger cars also increased. (OECD 1995d, 67) Diesel passenger car registrations in Europe increased from 14 percent of all car registrations in 1990 to 21 percent in 1993. Diesels account for less than 1 percent of U.S. passenger car registrations. (IEA 1995, 275) OECD countries in Europe consume about half of the diesel fuel attributed to OECD as a whole.

► Lead and Sulfur Dioxide Emissions

Lead and sulfur dioxide emissions occur when motor vehicle fuels contain sulfur or lead compounds. To reduce these emissions, some countries have set fuel content requirements that limit the amount of these materials in fuels.

Use of lead as a gasoline additive has declined because of health concerns and the introduction of catalytic converters, which malfunction when leaded gasoline is used. The amount of lead added to gasoline declined 75 percent worldwide from 1970 to 1993. Still, as late as 1989, gasoline combustion accounted for an estimated 62 percent of worldwide lead emissions. Leaded gasoline is still in wide use in many developing and in some OECD countries.

As table 9-3 shows, unleaded gasoline as a share of total gasoline consumption varies considerably by country. Among OECD countries, Japan, the United States, and Canada have either phased out leaded gasoline entirely or are very close to achieving complete phase out. According to the World Bank, the sharp reduction in lead content of fuels in many OECD countries has lowered lead levels in the bloodstream. (World Bank 1992) In the United States and Japan, average blood lead concentrations are now only one third of those reported in the mid-1970s. In 1993, however, leaded gasoline still commanded a substantial share of consumption in Spain, Italy, and New Zealand, and to a lesser extent in the United Kingdom, Australia, and France.

Table 9-3: Unleaded Gasoline as a Percentage of Motor Gasoline Consumption in Selected Countries, 1993

Country	Unleaded gasoline
Japan	100
Brazil	100
South Korea	100
Canada	100
United States	99
Germany	89
Netherlands	75
United Kingdom	53
Australia	45
France	41
Mexico	30
China[a]	30
New Zealand	30
Italy	24
Poland	12
Venezuela	10
Spain[a]	6
Russia	5
India[b]	0
Saudi Arabia	0
Nigeria	0

[a] Data for 1992.
[b] Introduced unleaded gasoline in 1995.

SOURCES: Organization for Economic Cooperation and Development, *Control of Hazardous Air Pollutants in OECD Countries* (Paris, France: 1995), p. 22; and Odil Tunali, "Lead in Gasoline Slowly Phased Out," *Vital Signs 1995: The Trends that are Shaping Our Future*, Lester Brown et al. (eds.) (New York, NY: W.W. Norton, 1995), p. 126.

SO_2 emissions from all mobile sources in OECD countries are generally far less than from stationary sources, such as industrial facilities and utilities. (OECD 1995b, 19–23) In some countries, nonroad mobile sources emit more SO_2 than road transportation. Among European countries reporting road transportation emissions over the period 1980 to 1993, SO_2 emissions increased in the United Kingdom (40 percent), while decreasing in western Germany (39 percent) and Denmark (71 percent). According to EPA data, SO_2 emissions in the United States declined slightly less than 1 percent between 1980 and 1993. (USEPA 1995, table A-4)

Air Pollution and Transportation in Non-OECD Countries

► Air Quality

Air pollution data, especially trend data about motor vehicle emissions, are not available for most non-OECD countries. Still, it is clear that air pollution is a significant problem in many developing countries where rapid economic growth has stimulated the consumption of fossil fuels in industry and transport. (World Bank 1995a, xi) Energy-intensive industries are growing as a proportion of their economies, and these countries, by and large, are only beginning to address their environmental problems.

Air pollution problems are acute in large cities in developing countries, where high population densities increase risk of exposure to pollution (see box 9-2). Air quality in the least polluted cities in low-income economy countries was, on average, worse than that of the most polluted cities in high-income countries. (World Bank 1992) Air quality problems are acute in Asia, which includes five of the seven cities in the world with the worst air pollution: Beijing, Calcutta, Jakarta, New Delhi, and Shenyang. (World Bank 1993, 11) About 26 percent of Latin America's urban population is exposed to dangerous levels of motor vehicle-related air pollution, according to the Pan American Health Organization.

Serious health risks arise from exposure to lead and SPM. Airborne lead poses serious health risks, especially where lead is still used as a fuel additive. The problem is particularly acute in towns and cities where the number of motor vehicles is growing rapidly in the absence of lead control programs.

Some newly industrialized or advanced developing countries have converted to unleaded fuel or are in the process of phasing out lead to reduce adverse health impacts and to prevent fouling of catalytic converters. Examples include Brazil, Singapore, Malaysia, Mexico, and Thailand.

Suspended particulate matter is a major air quality problem for urban areas in developing countries. According to the World Bank, in the mid-1980s, about 1.3 billion people, mostly in developing countries, lived in towns or cities with a population of more than 250,000 that failed to meet World Health Organization standards for SPM. (World Bank 1992) SPM has been linked to respiratory problems; these problems could be exacerbated by poor health and nutrition in developing countries.

According to the World Bank, SPM levels in low-income cities increased during the 1980s, while OECD cities and middle-income cities experienced a decline. SPM levels are rising in most Asian cities, regardless of income level. (World Bank 1993, 11)

Concentrations of SO_2 were, on average, lower in low-income countries than in middle- and high-income countries in the late 1970s. As concentrations declined in the cities of the latter group of countries in the 1980s, they rose in low-income country cities. (World Bank 1995a, 44) The increase in SO_2 emissions in developing countries reflects the use of higher sulfur content fuels by the transport sector, as well as coal by industry. Twelve of the 15 cities with the highest levels of sulfur dioxide are in Asia.

BOX 9-2: URBANIZATION AND MOTOR VEHICLE USE

Motor vehicles are concentrated in large metropolitan areas. Nearly 50 percent of automobiles in Mexico, Iran, and Thailand are located in the capital cities. About 25 percent of Brazil's vehicle fleet operates in the Sao Paulo metropolitan area; and in India, nearly one-quarter of the nation's vehicle fleet circulates in five cities (Bombay, Calcutta, Delhi, Madras and Bangalore).

Over the last two decades, populations of cities in developing countries grew faster than cities in OECD countries. Urban populations in developing countries increased from 753 million people in 1970 to 1,755 million in 1992. Still, the move to the cities is not proceeding at an equal pace everywhere: 70 percent of today's population in OECD countries and Latin America is urban, but only 35 percent in Africa and 30 percent in Asia live in cities.

Of the 16 cities with populations greater than 10 million in 1992, only four are in OECD countries: Tokyo-Yokohama, New York, Osaka, and Los Angeles. Between 1970 and 1995, the annual growth rates of these cities averaged 1.5 percent, while the growth rate of the 12 cities in non-OECD countries averaged 3.7 percent. In 1995, New Delhi, India, joined the list of mega-cities.

High density is a feature of large urban centers in developing countries. Higher densities result in greater numbers of people exposed to air pollution. In 1992, population densities of the four OECD mega-cities ranged from 9,000 people per square mile in Los Angeles to 28,000 people per square mile in the Osaka-Kobe-Kyoto metropolitan area. By contrast, the *lowest* population density among the largest cities in non-OECD countries was 22,000 people per square mile (in Buenos Aires). Population densities in the other non-OECD mega-cities ranged from 28,000 to 134,000 people per square mile.

SOURCES: A. Faiz, "Automotive Emissions in Developing Countries—Relative Implications for Global Warming, Acidification and Urban Air Quality," *Transportation Research*, vol. 27, No. 3, May 1993; and World Bank.

At the present time, CO and NO_x emissions probably pose a less immediate health hazard than lead, particulates, and sulfur oxides emissions for developing country populations, although this could change. In the early 1980s, urban CO concentrations in developing countries were similar to those in OECD countries, while urban NO_x concentrations in developing countries were slightly lower than in OECD countries. Emissions per mile of travel, however, were much higher in developing countries than in OECD countries.

► Transportation Emissions

Lack of data limits analysis of emissions trends in most non-OECD countries. (Trend data are starting to emerge from some FEB countries that now report to OECD.) Transportation in developing countries contributes more to some worldwide emissions of conventional air pollutants than their one-quarter share of vehicles might suggest. In the early 1990s, motor vehicles in non-OECD countries produced about 52 percent of worldwide CO emissions, 41 percent of VOC emissions, 36 percent of NO_x emissions, and 29 percent of CO_2 emissions. (OECD 1995c) These shares may increase in the future due to the rapid growth of motor vehicle fleets in developing countries. In fact, more recent CO_2 data already show increases.

Fossil fuel emissions from residential and industrial applications can dwarf CO emissions from the transport sector in some non-OECD countries. South Korea's relatively low percentage of CO emissions from the transportation sector in 1987 arose, in part, from low per capita car ownership. While car ownership is growing rapidly, it was still low by OECD standards in the early 1990s at 63 vehicles per 1,000 persons. (OECD 1995d, 210) South Korea tried to reduce the growth of vehicle use with the introduction of a new underground rail system in the Seoul metropolitan area, where 40 percent of South Koreans live. The system did not attract as many people as expected, however. (OECD, 1995d, 210)

The transportation sector is a significant source of VOC emissions in many non-OECD countries. Along with the lack of catalytic converters, a possible reason is vapor emissions during vehicle refueling. Although evaporative emissions can be a small percentage of total VOC emissions, the quantity is determined by the vapor pressure and composition of motor fuel and by ambient temperatures. (OECD 1993b) Motor vehicles in warmer climates tend to have higher rates of evaporative emissions. The United States and some other OECD countries have initiated various strategies, such as controls during fueling operations, to reduce evaporative emissions.

Developing countries generally use proportionally more diesel fuel than OECD countries, which can affect the nature of emissions. (World Bank 1995a, 7) Thus, while the transportation sector worldwide is not an important source of SO_2 emissions in OECD countries, the picture is different in some non-OECD countries. The reasons include higher sulfur content fuel and more diesel fuel vehicles for passenger transport. Mexico City's public transportation system, for example, has been estimated to account for 25 percent of the city's air pollution. A general trend away from high sulfur fuel is expected to reduce transportation's share of SO_2 pollution. (IEA 1995, 108)

Little data are available on lead emissions in non-OECD countries. Unleaded gasoline, however, is being phased in (see table 9-3) and the level of lead content reduced in a number of countries. As of 1993, for example, unleaded gasoline held 100 percent of the market in Brazil and South Korea and 30 percent in Mexico and China. (Tunali 1995, 126) In Russia and India, unleaded gasoline is available only in cities, as is the case in China. Many countries in the Middle East and Africa use only leaded gasoline.

► Emissions Control Efforts

Motor vehicles in developing countries tend to be older and less well maintained than in the higher income OECD countries. Vehicles are less likely to be equipped with emissions control devices. Unleaded fuels often are not available. And, vehicle fleets in developing countries tend to be less energy efficient. Further, with the higher densities of development, much less of the urban area is allocated to road space in cities of developing countries, leading to congestion and more concentrated pollution. Many developing countries do not have effective emissions control programs. Without such efforts, increased motor-vehicle emissions will expose hundreds of millions of urban dwellers to dangerously polluted air by the year 2000. (Faiz 1993)

Several newly industrialized countries and rapidly growing developing countries have begun to take action to combat air pollution. Singapore has long been one of the most active countries in addressing air pollution. Its integrated transportation policy, initiated in the early 1970s, is described in box 9-3 By 1990, other countries, including Brazil, Mexico, Chile, Hong Kong, South Korea, and Taiwan, had adopted motor vehicle emission control programs. Some other countries, such as Indonesia, Malaysia, the Philippines, and Thailand, have modest programs. (OECD 1995c, 38) Ultimately, the degree of success among these non-OECD countries will depend on a number of factors, such as the enforceability of standards, availability of unleaded fuels, and related issues such as proper maintenance for vehicles and their control devices.

Solutions to some air quality problems caused by motor vehicles may have to await further per capita income growth in developing countries. The low turnover rate of the vehicle stock in developing countries is primarily responsible for their slower fuel efficiency improvement compared with industrialized

Box 9-3: Singapore's Integrated Transportation Policy

Singapore, an island nation of 2.8 million people occupying a land area smaller than New York City, is one of the wealthiest and fastest growing economies in Asia, with a 1992 per capita income of $16,500. Since the mid-1970s, it has adopted several successively more stringent measures to mitigate congestion caused by its motor vehicle fleet, now numbering 300,000 passenger cars and 130,000 commercial vehicles.

To constrain passenger car use, Singapore has imposed extraordinarily high fees on vehicle ownership and use that would be politically unpalatable in many other countries. Duties on imported automobiles (imports account for essentially all of Singapore's cars) and vehicle registration fees were 195 percent of automobile import values in 1994; road taxes are also imposed, with the tax increasing with engine capacity. Under an area licensing scheme, first adopted in 1975 and expanded in 1989 and 1994, drivers must purchase stickers for display on windshields to access the central business district during specified hours. An electronic toll system is to be put in effect in 1996. Drivers who register their cars primarily for weekend use can get a rebate on import duties and registration fees. (These drivers can also purchase weekday use licenses for specific dates).

Singapore has an extensive public transport system, and a population density of 11,574 people per square mile. Half the population is within a kilometer of a rapid transit system. It also has invested extensively in its road infrastructure, and has computerized its traffic signal system in much of the central business district. Finally, its new settlements are planned to colocate residential, commercial, and employment centers.

For all the measures taken, demand for new vehicles among Singapore's citizens continues to be high. In 1990, a monthly quota system was imposed to limit the number of new vehicles. In the first three years of the program, the number of new vehicle registrations fell appreciably, but in 1993 exceeded the 1990 level significantly. Still, the Singapore measures have had an effect. It is estimated that Singapore's 1990 fuel consumption would have been about 40 percent higher without the constraints on automobile use.

SOURCES: Most of the information in this box is taken from Laurie Michaelis et al., "Mitigation Options in the Transportation Sector," in *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses,* Contribution of Working Group II to the Second Annual Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge, England: Cambridge University Press, in press), p. 707

countries. Low turnover also slows the addition of vehicles with catalytic converters, since they are required only for new vehicles. For example, 38 percent of Mexican vehicles were more than 10 years old in 1983; catalytic converters began to be phased in only with the 1989 model year. Half of Brazil's automobiles in 1991 were still running after 18 years, 20 percent after 24 years. For older vehicles, energy efficiency can be improved and emissions reduced through proper maintenance. A car tuning program in Pakistan led to energy savings of 5 to 6 percent. (IEA 1995, 272)

► Motorization Trends

Motorization trends will have a major influence on transportation-related air pollution in non-OECD countries. Future rates of motorization in developing countries will be affected by many factors, including population growth, economic and income growth, and urbanization patterns. Other factors, such as degree of use of nonmotorized transportation and two- or three-wheel motorized vehicles, also will play a role.

Per capita ownership of passenger cars is far lower in developing countries than in OECD countries (see table 9-4). On average, however,

Table 9-4: Vehicle Registrations and Population in Selected Countries

	Total car registrations		Total commercial registrations		Annual growth rate (percent)			Population per car
					Car	Comm. vehicles	Population	
	1970	1992	1970	1992	1970–92	1970–92	1970–92	1992
Low-income economies					9.4w	9.9w	2.3w	290w
India	609,612	2,806,533	471,722	2,396,738	7.2	7.7	2.2	316.0
Nigeria	81,000	800,000	52,000	625,000	11.0	12.0	1.3	111.0
Pakistan	172,260	731,500	50,682	213,000	6.8	6.7	0.3	166.0
China	133,000	1,900,000	480,000	4,500,000	12.8	10.7	2.0	616.0
Indonesia	238,632	1,574,806	125,552	1,513,845	9.0	12.0	2.2	124.0
Lower middle-income economies					9.6w	8.3w	2.5w	28.4w
Peru	225,700	422,262	133,718	249,223	2.9	2.9	2.4	54.0
Colombia	178,363	800,000	116,321	670,000	7.1	8.3	2.2	43.0
Algeria	142,806	4,417,882	81,625	1,552,893	16.9	14.3	4.1	7.4
Thailand	204,076	890,821	167,903	2,125,632	6.9	12.2	2.2	65.0
Turkey	147,014	2,111,354	168,949	803,496	12.9	7.3	2.4	28.0
Chile	176,066	1,007,713	149,754	206,790	8.3	1.5	1.5	13.0
Upper middle-income economies					7.2w	5.5w	2.4w	11.6w
South Africa	1,653,000	3,488,570	462,000	1,899,721	3.5	6.6	3.4	12.0
Brazil	2,234,500	12,974,991	1,305,200	1,371,127	8.3	0.2	2.3	12.0
Malaysia	279,410	2,214,974	82,623	618,137	9.9	9.6	2.5	8.3
Venezuela	614,616	1,532,572	239,084	449,135	4.2	2.9	3.2	13.0
Mexico	1,233,824	7,300,000	558,044	3,600,000	8.4	8.8	2.8	13.0
Argentina	1,563,000	4,417,882	794,000	1,552,893	4.8	3.1	1.4	7.4
South Korea	60,677	3,461,057	52,504	1,769,837	20.2	17.3	1.5	13.0
High-income economies					3.3w	4.1w	0.9w	2.1w
United Kingdom	11,792,500	23,008,342	1,910,000	3,643,398	3.1	3.0	0.2	2.5
Italy	10,209,045	29,497,000	929,363	2,763,050	4.9	5.1	0.3	2.0
Canada	6,602,176	13,322,457	1,481,197	3,688,433	3.2	4.2	1.1	2.1
France	12,290,000	24,020,000	2,114,750	5,040,000	3.1	4.0	0.6	2.4
Germany	14,376,484	39,086,000	1,228,406	2,923,000	4.7	4.0	1.4	2.1
United States	89,279,864	144,213,429	19,127,442	46,148,799	2.2	4.1	1.1	1.8
Japan	8,778,972	38,963,793	8,802,871	22,694,351	7.0	4.4	0.8	3.2

KEY: w = weighted average for all countries in income category, not just for those listed here.

SOURCES: American Automobile Manufacturers Association, *World Motor Vehicle Data* (Detroit, MI: 1971), pp. 10–11 and (Detroit, MI: 1994), pp. 25–27; and World Bank, *World Development Report 1994: Infrastructure for Development* (New York, NY: Oxford University Press, 1994); and World Bank, *World Development Report 1995: Workers in an Integrating World* (New York, NY: Oxford University Press, 1995).

the number of motor vehicles in non-OECD countries grew 6.5 percent annually, nearly twice as fast as in OECD countries, between 1970 and 1993 (see table 9-1). Some countries had much more rapid growth. Between 1987 and 1992, annual car and truck sales in Mexico more than doubled, from 246,000 to 696,000. (IEA 1995, 106) In India, the number of passenger vehicles grew more than fourfold between 1970 and 1992. Car registrations in China grew more than tenfold in the same period. (World Bank 1995a, 7)

Shifts in transportation modes can have a significant effect on overall energy efficiency and, thus, on emissions. (IEA 1995, 272) According to OECD, as countries industrialize, their vehicle mix shifts first to two- and three-wheel motorized vehicles, then to four-wheeled vehicles. Worldwide, the numbers of two- and three-wheel vehicles grew twice as fast as cars or buses from 1970 to 1990. Such vehicles consume less than 1 percent of the gasoline used in the United States, but up to 50 percent used in Taiwan, 30 percent in Thailand, and 45 percent in India. They are less popular in Latin America, consuming only 8 percent of gasoline in Bolivia and 2 percent in Brazil. One study reported that two-wheel vehicles with two-stroke engines have emissions (largely unburned gasoline) 10 times greater and fuel efficiencies 20 to 25 percent lower than four-stroke engines of equal power. (US Congress OTA 1992, 166)

Some developing country cities, such as Curitiba in Brazil, have adopted innovative ways of meeting their transportation needs through public transportation (see box 9-4). Another counterweight in developing countries to ever-increasing motor vehicle fleets is, as discussed in box 9-5, to enhance and encourage nonmotorized transportation, where appropriate. Nonmotorized goods transport is still important in developing countries, especially in rural areas.

Growth of Road Networks

Road networks in developing countries are also growing. Between 1970 and 1992, the growth rate of paved road ranged between 2 and 12 percent in developing countries, but less than 2.5 percent in high-income countries (except for Japan, which had a growth rate of nearly 8 percent). (World Bank 1994 and 1995c)

Road networks in developing countries are still far less dense than in the United States, Canada, Europe, and Japan. Paved road density in 1992 in these latter countries was many times higher than in even upper middle-income developing countries. The large gap between road densities in developed and developing countries suggests a potential for continued increase in road density in developing countries.

Given the very high population densities in the cities of developing countries, often much less of the urban area is allocated to road space than was true of western cities during the early phase of motorization. When New York City was at its most dense in terms of population per square mile in 1910, roads made up 15 percent of the urban land area of Manhattan. The corresponding figure for road space in Chinese cities today is often less than 10 percent. (Grakenheinor 1994)

Transportation and Greenhouse Gases

In 1990, the world's transportation sector was responsible for almost one-fifth of total world CO_2 emissions. Table 9-5 shows the 20 countries in the world that consumed the most transportation fuel (and thus produced the most CO_2 emissions from transportation) in 1990. (Michaelis et al 1996) The United States tops

Box 9-4: A Surface Subway: Curitiba, Brazil

Curitiba, a city of 1.6 million people in southern Brazil, illustrates one way to manage the damaging environmental effects of rapid population and transportation growth. To cope with the transportation needs of a population that tripled in a little over 20 years, Curitiba built a highly accessible, fast, and relatively inexpensive bus system. The buses are widely used: in 1993, they carried 1.5 million passengers a day, more than ride buses in New York City and four times the number that ride the subway in Rio de Janeiro, a city of 10 million. Although Curitiba has the second highest rate of car ownership in Brazil (33 automobiles per 100 people), 75 percent of its commuters use buses daily compared with 57 percent in Rio and 45 percent in Sao Paulo. Partly as a result, Curitiba's per capita gasoline consumption is 30 percent lower than in eight comparable Brazilian cities.

When developing its bus system in the early 1970s, the city bought or condemned land along five transportation radials that converge on the city center. Each radial is surrounded by a two to four block corridor that is zoned for high-density, low-income housing. Bus lanes were constructed in the median of each radial. Express buses use the lanes to shuttle people downtown or to factories on the urban fringe. Other buses continually loop through the less densely developed neighborhoods to take people to the express bus terminals. Another set of buses travel between outlying districts allowing passengers to travel between them without passing through the center. To speed loading and unloading, tubular bus shelters have been installed. People pay before the bus arrives and board through sliding glass doors synchronized with those on the bus. Some of the busiest routes are now served by three-car buses able to carry 270 passengers. Because of these features, some have called the system a "surface subway," although city officials like to point out that it cost approximately one three-hundredth of a subway system and can be constructed in a fraction of the time. The system is supported by passenger fares. Buses are owned and operated by private companies but regulated by city government, which sets fares, assigns routes, and pays each contractor by the number of passengers carried and kilometers traveled. Fares also cover the cost of road and terminal construction and maintenance and system planning by the city.

SOURCES: Kris Herbst, "Brazil's Model City: Is Curitiba Too Good to be True?" *Planning*, September 1992, pp. 24–27; and Todd Lewan, "Curitiba, Brazil: Model Metropolis Greens as it Grows," *Safety and Health*, April 1994, pp. 44–48.

the list; its transportation energy use is equal to that of the next 10 countries combined. Developing and FEB countries comprise half the countries on the list.[7]

The *Transportation Statistics Annual Report 1995* comprehensively reviewed the status of transportation's contribution to greenhouse gases, as represented by CO_2 emissions. (USDOT BTS 1995, 65-82) The review, over the period 1965 to 1992, compared U.S. data with that of six other OECD countries: Canada, western Germany, France, the United Kingdom, Japan, and Italy. Because CO_2 emissions are directly related to the amount and intensity of energy use, the report also discussed the many factors that drive transportation energy use in these countries. Among those factors are: the increasing magnitude and evolving modal composition of passenger and freight flows, the changing energy intensity of different transportation modes, the shifting vehicle mix in road transportation, the increasing personal propensity for travel, and changing vehicle occupancy rates and load factors.

[7] As noted earlier, Mexico is included in the non-OECD countries. OECD statistics included here have been adjusted to reflect that division.

Box 9-5: Nonmotorized Transportation

Nonmotorized transportation, including bicycles, rickshaws, and walking, remains the most important form of mobility in many developing countries. Beijing, China, residents, for example, in the early 1990s owned 400,000 motor vehicles but 7 million bicycles. In Guangzhou, China in 1989, two-thirds of trips were made by nonmotorized transportation—36 percent by walking and 30 percent by bicycle—and only one-third by motor vehicles including buses, vans, ferry boats, private automobiles, taxis, and motorcycles. In large African cities such as Kinshasa and Dar es Salaam, two-thirds of total trips are made on foot. In Delhi, India, 29 percent of trips were made by walking and 18 percent by bicycle in the early 1980s. Nonmotorized transportation is not merely for personal travel. It has been estimated that cycle rickshaws account for 10 to 20 percent of urban freight movement in many Asian cities. In Bangladesh nonmotorized vehicles accounted for 36 percent of freight ton-miles in 1985.

Nonmotorized transportation is cheap, efficient for relatively short distances, and has very little impact on the environment. In many places, particularly those with rising income levels, conflicts between nonmotorized and motorized modes are becoming increasingly pronounced. The greater use of motor vehicles, especially automobiles, results in less street space for cyclists and pedestrians, greater danger, and over time changes in urban form rendering nonmotorized modes less viable. In Guangzhou, where the number of motor vehicles increased tenfold between 1980 and 1990 it is thought that some have switched to motor vehicles because of the increased danger associated with cycling and walking.

Government policies have generally encouraged motorization and in some cases actively discouraged nonmotorized options, often seen as backward, inefficient, unsafe, and the cause of traffic congestion. The city government in Jakarta, Indonesia, for example, confiscated and destroyed over 100,000 cycle rickshaws in the 1980s in an attempt to eliminate them from the city. Dacca, Bangladesh, in the late 1980s banned pedicabs from the city because of safety problems. In 1995, Calcutta announced plans to ban human-pulled rickshaws.

Following the example of developed western countries, governments in less developed countries, often supported by the World Bank, have provided subsidies and capital investments to support motorization. More recently, however, the World Bank has begun to reformulate its policies toward more sustainable transportation options including mass transportation and nonmotorized modes. In Accra, Ghana, for example, the World Bank is sponsoring the construction of dedicated cycle paths to connect neighborhoods with commercial districts. In other places there is a growing view that to focus purely on motorization will damage mobility by creating untenable levels of congestion, hence the need for balancing and intergrating both motorized and nonmotorized transportation. In Chinese cities, for example, to reduce the conflict between motorized and nonmotorized modes, planners have suggested better traffic control measures, the separation of modes, perhaps with bicycle-only roads, and the better integration of nonmotorized modes with mass transportation.

SOURCES: John F. Burns, "A Tradition Facing the End of the Road: Striving for a More Upscale Image, Calcutta's Officials Target Rickshaws," *New York Times*, Oct. 4, 1995, p. A4.

C. Jones, "To Spiff Up Its Image, Jakarta Does Away with Traditional Taxis: Officials Say Three-Wheelers are an Eyesore in Indonesian Capital," *Christian Science Monitor*, Aug. 19, 1988.

William H.K. Lam et al., "Urban Transportation Planning and Traffic Management in China," *Transportation Research Record No. 1372*, 1992, pp. 11–17.

V. Setty Pendakur, "Urban Transportation in China: Trends and Issues," *Transportation Research Record No. 1372*, 1992, pp. 3–10.

Michael Replogle, "Bicycles and Cycle-Rickshaws in Asian Cities: Issues and Strategies," *Transportation Research Record No. 1372*, 1992, pp. 76–84.

Michael Replogle, "Sustainable Transportation Strategies for Third World Development," *Transportation Research Record No. 1294*, 1991, pp. 1–8.

Carol Thomas et al.). "Policy Implications of Increasing Motorization for Nonmotorized Transportation in Developing Countries: Guangzhou, People's Republic of China," *Transportation Research Record No. 1372*, 1992, pp. 18–25.

World Bank, *Mainstreaming the Environment: The World Bank Group and the Environment Since the Rio Earth Summit* (Washington, DC: 1995).

TABLE 9-5: CO_2 EMISSIONS FROM TRANSPORTATION ENERGY USE IN SELECTED COUNTRIES, 1990

	Exajoules[a]	Carbon dioxide (million metric tons, estimated)
United States	20.3	1,523
Russia	3.5	263
Japan	3.2	240
Germany	2.5	188
United Kingdom	1.9	143
France	1.7	128
Canada	1.7	128
China	1.7	128
Italy	1.5	113
Brazil	1.4	105
Mexico	1.3	98
India	1.1	83
Spain	1.0	75
Australia	0.9	68
Ukraine	0.7	53
South Korea	0.6	45
Thailand	0.5	38
South Africa	0.5	38
Netherlands	0.4	30
Indonesia	0.4	30
Rest of world	7.9	593
TOTAL	54.7	4,103

[a]Includes transport fuel sales, excluding marine bunkers.
[b]Converted at 75 million metric tons carbon dioxide per exajoule.

SOURCE: Laurie Michaelis et al., "Mitigation Options in the Transportation Sector," in *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses,* Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge, England: Cambridge University Press, in press), p. 683.

Because adequate data on transportation energy use were not available, CO_2 emissions by non-OECD countries were not included in last year's analysis. The two sections that follow recap and update, where possible, last year's discussion on OECD countries and provide data and information on non-OECD countries. This year the discussion is centered on the period 1971 to 1993, allowing for comparison across these two sets of countries.

Greenhouse gas emissions in OECD countries are primarily related to energy use. In developing countries, by contrast, emissions have been tied to changes in land use (e.g., deforestation). As noted earlier, however, motor vehicle use is increasing dramatically in many non-OECD countries, as is industrial use of energy. Developing countries (including Mexico) accounted for 52 percent of all forms of CO_2 emissions in 1992, compared with 45 percent in 1980. (On a per capita basis, however, energy use is far higher in OECD countries).

The picture is quite different when only CO_2 emissions from transportation are considered. In 1993, OECD countries produced 65 percent of CO_2 emissions related to transportation; non-OECD countries, 35 percent (see table 9-6). Transportation produced 28 percent of OECD's CO_2 emissions in 1993 but only 14 percent within non-OECD countries. The energy and industrial sectors in non-OECD countries in 1993 emitted more tons of CO_2 (6,936 million metric tons) than did the same sectors of OECD countries (5,826 million metric tons).

Conventional automotive technology cannot reduce emissions of CO_2—a necessary byproduct of fossil fuel combustion—except by improvements in fuel efficiency or the use of alternative fuels. (See chapter 4 for further discussion of alternative fuels.)

► OECD and CO_2 Emissions

The factors contributing to CO_2 emissions from transportation are complex and interrelated. *Transportation Statistics Annual Report 1995*, in comparing the United States with selected other OECD countries, found a growing convergence among the OECD countries as

TABLE 9-6: MOBILE SOURCE CO_2 EMISSIONS BY REGION, 1971–93 (MILLION METRIC TONS)

	1971	1980	1993	World total (percent) 1971	World total (percent) 1993
United States	1,079.7	1,251.4	1,489.8	39	34
Canada	88.1	129.6	129.9	3	3
OECD-Europe	575.8	611.3	873.8	21	20
Japan	150.2	160.3	244.1	5	6
Australia/New Zealand	46.2	59.0	79.1	2	2
OECD total	**1,940**	**2,211.5**	**2,816.7**	**70**	**65**
Non-OECD Europe	79.9	86.5	68.2	3	2
Former Soviet Union	276.9	351.8	298.8	10	6
Asia	141	166.0	365.9	5	9
China	[a]	83.1	168.1	—	3
Latin America[b]	200.7	260.9	340.3	7	8
Africa	45.8	91.5	117.6	2	3
Middle East	105.3	88.8	158.4	4	4
Non-OECD total	**849.6**	**1,128.6**	**1,517.3**	**30**	**35**
Non-OECD without Europe and former Soviet Union	492.8	690.3	1,150.3	18	27
World total	2,789.6	3,340.1	4,334.0	100	100

[a] Data not available for 1971.
[b] Data for Mexico is included in non-OECD Latin America.

SOURCE: Organization for Economic Cooperation and Development, *OECD Environmental Data: Compendium 1993* (Paris, France: 1993), p. 33, and *OECD Environmental Data: Compendium 1995* (Paris, France: 1995), p. 41 (revised); and personal communication.

the differences between per capita GDPs, in terms of purchasing power parities, decreased.

Among OECD countries, transportation energy use and CO_2 emissions grew faster than total energy use and total CO_2 emissions. This is also true on a per capita basis, although rates of growth differ. In France, transportation's share of total CO_2 emissions per capita doubled between 1965 and 1992, as did the United Kingdom's. France had the highest per capita emissions by 1992. Transportation's share of CO_2 emissions in the United States and Canada grew at a slower rate.

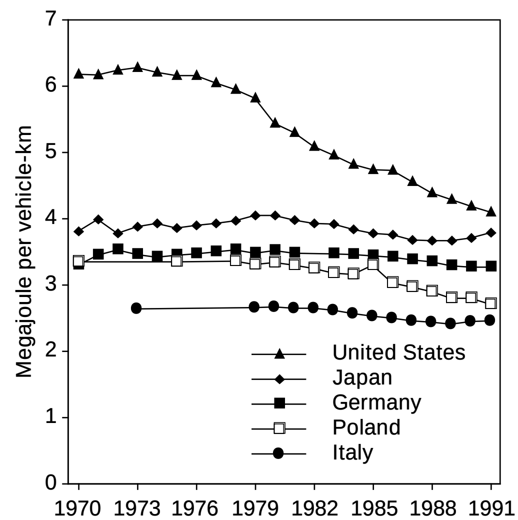
As incomes have risen in OECD countries, so has car ownership and propensity to travel. The mean annual per capita travel of European OECD countries moved from about one-third of the U.S. levels in 1965 to about one-half by 1992. The United States still has higher income, car ownership, and per capita travel than other OECD countries, explaining in part, the much higher per capita transportation energy consumption and CO_2 emissions of the United States.

OECD also found a relationship between prices of fuel and vehicle efficiencies and miles driven. Italy, for example, has the highest fuel taxes and gasoline prices and most fuel-efficient stock of cars in the European Union (8.4 liters of gasoline per 100 kilometers, or 28 miles per gallon). The United States, which has the least expensive fuel among OECD countries, averages 30 percent more vehicle-kilometers per capita annually than Germany, the Netherlands, and France, and 70 percent more than Italy. (IEA 1995, 125) The differences in fuel costs largely reflect different tax policies. For example, French gasoline taxes in 1993 were more than seven times higher than those in the United States. (IEA 1995, 86)

As figure 9-3 shows, the average fuel consumption of passenger cars in the United States improved significantly in the last two decades. During the same period, the averages in Japan and Germany showed only minor changes. Today, the once wide gap between fuel efficiency of U.S. and European cars has narrowed considerably. CO_2 emissions from transportation would be considerably higher today in the United States if there had not been such an improvement in automotive fuel efficiency.

The shift from rail and water transport to air and road transport in OECD countries increased CO_2 emissions from transportation. Steeper increases were observed in Japan and European OECD countries than in the United States. In the last decade, the United States has had one of the lowest growths in CO_2 emissions from mobile sources (19 percent) within OECD and in comparison with non-OECD countries.

FIGURE 9-3: LIGHT-DUTY PASSENGER-VEHICLE ENERGY INTENSITY



SOURCE: Laurie Michaelis et al., "Mitigation Options in the Transportation Sector," in *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses,* Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge, England: Cambridge University Press, in press), p. 683.

► CO_2 Emissions and Non-OECD Countries

Over the past two decades, much of the growth in worldwide CO_2 emissions occurred in non-OECD countries, such as China, Brazil, India, and South Korea. Rapid economic growth and associated increases in energy use occurred in many non-OECD countries. Between 1970 and 1992, CO_2 emissions from energy use in developing countries grew 89 percent. In contrast, OECD energy use emissions increased by 15 percent during the same period. Around 1984, developing countries surpassed OECD countries in the release of CO_2 emissions from energy use.

While non-OECD countries increased their share of total emissions of CO_2, their share of the world's mobile source CO_2 emissions remained at about 30 percent until recently. By 1993, the non-OECD countries' share of mobile source emissions had risen to 35 percent. Between 1971 and 1993, mobile source CO_2 emissions in these countries increased 79 percent. Over the same period, OECD countries' emissions grew 45 percent.

The growth in non-OECD CO_2 emissions is even more pronounced if the FEB economies are not considered. The FEB countries experienced such severe economic setbacks beginning in the 1980s that CO_2 emissions from transportation fell 21 percent in Eastern Europe and

15 percent in the former Soviet Union over the period 1980 to 1993. Thus, if FEB data are excluded, the remaining non-OECD countries' transportation-related CO_2 emissions grew 67 percent from 1980 to 1993.

While FEB countries have, in the past, relied more heavily on rail transport, there has been a significant shift toward less efficient road travel. Passenger rail in 1993 was down almost 43 percent from 1989, partly because of a fall in incomes and partly because of greater competition from private cars. Freight traffic by rail also declined in favor of road transport. (OECD 1994a, 67)

Africa is the region of the world that makes the smallest contribution (3 percent) to transportation-related CO_2 emissions. From 1971 to 1993, however, the region's mobile source emissions grew by 157 percent. Future emissions will be tied to economic growth. Research covering nine nations in eastern Africa found that the transportation sector consumes only 5 percent of total energy use, resulting in 9 million metric tons of CO_2 emissions in 1990. (Mackenzie et al. 1992) Two of the countries, Uganda and the Seychelles, experienced annual GNP growth rates over 3 percent; the balance have negative or near zero growth rates.

Transportation fleets in developing countries tend to use energy less efficiently, releasing more CO_2 per unit of output. (Chatterjee and Han 1994) IEA estimates specific fuel consumption in non-OECD countries to be nearly 30 percent higher than the OECD average. Several factors explain this inefficiency: the average vehicle is old and poorly maintained, cities are congested, and the transportation infrastructure is poor. (IEA 1995, 274) Problems differ across regions, however. Vehicles tend to be less energy intensive in Asia than in Latin America and Africa. Car and engine size are smaller in India, China, and South Korea than in Venezuela.

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Appendices

An Overview of the U.S. Commercial Airline Industry

Since its modest beginnings in the 1920s, the U.S. commercial airline industry has developed into a robust airline system noted for speedy, reliable, and safe movement of people and goods. The extent and density of its network, the level of passenger traffic, as measured by revenue passenger-miles (RPMs)[1] generated, are at historic highs (see figure A-1).

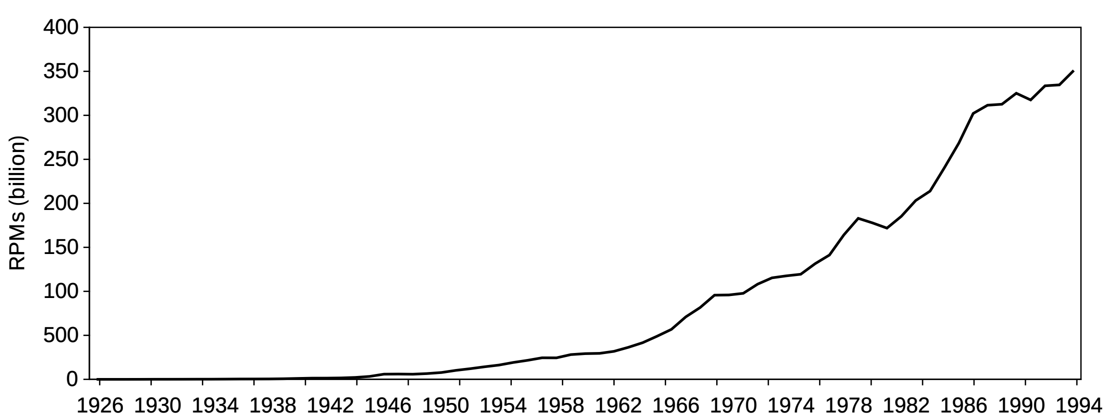
The U.S. commercial airline industry has grown dramatically since the end of World War II, with impressive gains occurring in the post-1979 era. For example, in 1945, U.S. trunk carriers[2] flew 3.3 billion domestic RPMs; in 1979, 205 billion. By 1994, domestic RPMs for the majors had climbed to almost 352 billion. Moreover, the United States has more airports (18,343 in 1994) than the rest of the world combined. Of this number, over 400 are primary airports (with Federal Aviation Administration control towers), which account for more than 99 percent of all passenger enplanements on air carriers. (USDOT FAA 1995) In 1994, 515 million passengers boarded U.S. airlines, 42 percent of the 1.2 billion airline passengers in the world. In the same year, U.S. airlines produced 511 billion RPMs or 39 percent of the world's 1.3 trillion RPMs.

Between 1979 and 1994, growth of air passenger travel (domestic and international) in the United States kept pace with that of the world

[1] A revenue passenger is defined as one who has paid a fare, as distinct from a carrier employee who travels free. A revenue passenger-mile is defined as one passenger transported one mile.

[2] Trunk carriers provided service to major city markets. After passage of the Airline Deregulation Act of 1978, the formal definitions of carriers changed. Carriers that earn more than $1 billion annually are now referred to as majors. See 14 CFR 121.

FIGURE A1: DOMESTIC REVENUE PASSENGER-MILES OF MAJOR AIRLINES, 1926–94



KEY: RPMs = revenue passenger-miles.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

TABLE A1: **U.S. SHARE OF TOTAL INTERNATIONAL AND WORLD PASSENGER TRAFFIC AND REVENUE PASSENGER-MILES, 1979–94**

	1979	1984	1989	1994
Total passengers				
World total passengers (millions)	755	841	1,117	1,225
U.S. total passengers (millions)	314	333	451	515
U.S. share of total world passenger traffic	42%	40%	40%	42%
International passengers				
World international passengers (millions)	159	184	263	343
U.S. international passengers (millions)	24	29	44	53
U.S. share of international passenger traffic	15%	16%	17%	15%
Total revenue passenger-miles (RPMs)[a]				
World total RPMs (billions)	659	789	1,110	1,300
U.S. total RPMs (billions)	262	298	431	512
U.S. share of total world RPMs	40%	38%	39%	39%
International revenue passenger-miles (RPMs)[a]				
World international RPMs (billions)	274	344	516	708
U.S. international RPMs (billions)	49	64	105	142
U.S. share of international RPMs	18%	18%	20%	20%

[a] RPMs are converted from International Civil Aviation Organization (ICAO) revenue passenger-kilometers at 1 kilometer equal to 0.6214 miles. ICAO's RPMs for the United States used in this table are different from U.S. Department of Transportation's RPMs used throughout this appendix. ICAO RPMs are used in this table for comparison with ICAO's estimate of world RPMs, which are reported in kilometers.

SOURCE: International Civil Aviation Organization, *Civil Aviation Statistics of the World* (Montreal, Canada: 1980,1984,1989,1994).

(see table A-1). Total world passenger traffic grew by 62 percent from 1979 to 1994 compared with a 64 percent growth rate in the United States over the same period. The corresponding growth in RPMs for the world and the United States was 97 percent and 96 percent respectively.[3]

[3] In 1994, there were 342.5 million international scheduled passengers in the world, of which the United States generated 52.7 million or 15 percent. In the same year, the United States produced 20 percent of all international passenger RPMs; the higher share in RPMs reflects the distance most passengers traverse over the Atlantic and Pacific Oceans. The growth rates in international passenger traffic in the last 15 years in the United States and the world were higher than total passenger traffic rates. International scheduled passenger traffic grew in that period by 116 percent; international RPMs rose 159 percent for the world and 189 percent for the United States.

In 1994, the most recent year for which data are available on world airline passenger and cargo operating revenues, the total world airline revenues were $247.5 billion. The U.S. airlines generated 35 percent ($87.4 billion) of this amount. Between 1989 and 1994, however, U.S. airlines operating revenues as a percent of the world total declined from 38.9 percent. (Aerospace Industries Association of America 1995; Aviation Week Group 1996; USDOT)

This appendix provides an overview of the U.S. commercial airline industry, focusing on the 1979 to 1994 period. It begins with a brief historical survey of the evolution of the nation's airline system and the federal government's role in facilitating the development of aviation technology and air transport industries, ensuring the safety and security of the system and its passengers, and reducing related environmental impacts. This discussion is followed by a brief review of airline industry deregulation and the domestic airline industry's response to a deregulated market. The appendix also examines trends in average airfares for the top 20 origin and destination (O&D) city-pairs and the factors contributing to declining average airfares. Finally, it describes passenger and freight traffic growth and reviews the finan-

TABLE A2: COMMERCIAL PASSENGER AND FREIGHT AIRLINES IN THE UNITED STATES, NOVEMBER 1995

Majors (revenues over $1 billion)	**Nationals** (revenues over $100 million to $1 billion)		**Large regionals** (revenues $20 million to $100 million)	
Passenger	**Passenger**		**Passenger**	
America West	Air Wisconsin	Horizon Air	Air South	MGM Grand
American	Alaska	Kiwi International	Air Transport International	Miami Air
Continental	Aloha	Markair	Amerijet International	North American
Delta	American International	Mesa Airlines	Atlas Air	Reeve Aleutian
Northwest	American Trans Air	Midwest Express	Buffalo Airways	Rich International
Southwest	Arrow Air	Reno Air	Executive Airline	Spirit Air Lines
Trans World	Atlantic Southeast	Simmons Airlines	Express One	UFS, Inc.
United	Business Express	Southern Air	Fine Airlines	Valujet Airlines
USAir	Carnival Air	Sun Country	Florida West	Western Pacific
	Continental Express	Tower Air	Frontier Airlines	Zantop International
	Continental Micronesia	Trans States	Kitty Hawk Airlines	
	Evergreen International	US Air Shuttle		
	Hawaiian Air	World Airways		
Freight	**Freight**		**Freight**	
Federal Express	DHL Airways		Challenge Air Cargo	Polar Air Cargo
United Parcel Service	Emery Worldwide		Northern Air Cargo	

NOTE: The carriers listed here represent 95.6 percent of total industry revenues, 95.4 percent of passenger revenues, 94.5 percent of operating profits, 99.4 percent of enplanements, and 99.6 percent of revenue passenger-miles.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data, 1995.

cial performance of the nation's largest three air carrier groups: majors, nationals, and large regionals (see table A-2).

Domestic Commercial Aviation: Historical Overview

Commercial air transport is essential to American personal mobility, commerce, and national security. Per capita air travel has increased sharply, in terms of annual RPMs, doubling from 1,110 in 1980 to 1,990 miles in 1994. In addition, gross domestic product (GDP) *originating* in the air transport service sector more than doubled from $19.2 billion in 1980 to $44.8 billion in 1993 (in 1987 dollars), the latest year for which data are available. (USDOC BEA 1995, 47)

The evolution of the nation's airline system has been fundamentally influenced, directly and indirectly, by federal government involvement. Early in the nation's aviation history, U.S. Postal Service contracts provided the impetus for the development of aircraft and the establishment of routes to ensure the delivery of mail by air. Subsequently, federal research and development accelerated the pace of technological developments in communications and navigation equipment, aircraft engines, and the design and construction of airframes. Moreover, the availability of military transports after World War II provided the airline industry with inexpensive aircraft that could be adapted for cost-effective commercial service. During this period, aircraft manufacturers successfully made the peacetime transition from producing military aircraft to building commercial aircraft that incorporated advances in aircraft design and performance gained from military aviation programs. Also immediately following World War II, individual airlines with the support of the federal government began to expand their route systems throughout the United States.

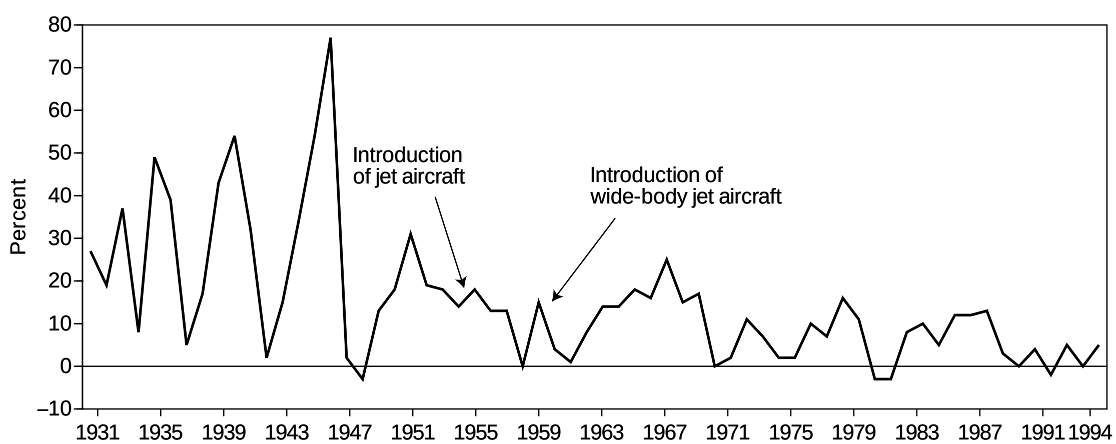
The federal government began regulating the economic activities of the nation's airlines as early as 1938. In that year, Congress passed the Civil Aeronautics Act, which created the Civil Aeronautics Board (originally called the Civil Aeronautics Authority) to oversee economic regulation of airlines. The intent of this legislation was to ensure the adequate provision of air transport services. The Civil Aeronautics Act was superseded by the Federal Aviation Act of 1958, which established the Federal Aviation Administration (FAA) and continued economic regulation of airlines until deregulation in 1978.

The major features of economic regulation under the Federal Aviation Act were: 1) control of market entry by requiring new airlines to obtain a government certificate of public convenience and necessity to operate, 2) control of cargo rates and passenger fares, 3) provision for the payment of direct government subsidy to airlines, and 4) control of intercarrier relations such as mergers and agreements.

The primary reason for adopting a regulatory approach was to preclude unconstrained market entry. Some argued that the competition resulting from unconstrained market entry could adversely affect the industry's ability to attract capital for needed investment.

During the period of airline economic regulation (1938 to 1978), the quality and availability of airline service steadily improved, and the average price of air transport relative to all other goods and services declined. The industry provided an ever-widening and increasing quality of service, and enjoyed, predictably, an expanding market. Because of its reliability, speed, and convenience, the airline industry began dominating the intermediate and long-distance passenger travel market and eventually outpaced their modal competitors in long-haul markets. Figure A-2 shows historical changes in domestic RPMs for trunk carriers (prior to 1979) and major airlines. As shown in the figure, the largest growth spurt occurred immediately following the end of World War II. The introduction of jet aircraft in the late 1950s

FIGURE A2: ANNUAL CHANGE IN DOMESTIC REVENUE PASSENGER-MILES FOR MAJOR AIRLINES, 1931–94



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

and wide-body aircraft in the early 1960s spurred growth and increased productivity. Wide-body jets travel at greater speeds, which results in higher utilization rates and lower costs per passenger-mile.

Passenger travel continued to grow in the mid- to late 1970s as the economy expanded and personal income rose. Interest in investigating the potential benefits of less economic regulation of the airline industry gained an expanded audience during this time. The Civil Aeronautics Board (CAB) experimented with relaxed regulatory constraints by granting airlines more fare flexibility and permitting new and existing airlines to more easily enter and exit new markets.

As early as the 1950s, economists were critical of airline regulations based on their appraisal of the industry and the implications of constrained market entry on prices and services. (Meyer et al 1959; Caves 1962; Levine 1965) Economists speculated that cessation of CAB market entry and fare regulation would increase competition on the most heavily traveled routes, resulting in market-driven decisions on fares and quality of service. Their speculations were based on comparisons of the regulated CAB market with intrastate markets in California and Texas, which were not regulated by CAB. (Levine 1965) Intrastate markets in California were regulated by the Public Utilities Commission, which allowed unconstrained market entry for airlines. (TRB 1991)

These criticisms, coupled with growing public disillusionment with the effects of economic regulation in the trucking and railroad industry, culminated in the Airline Deregulation Act of 1978. (USCAB 1975, 6–7) Under this legislation, businesses that met fitness requirements were free to enter and exit domestic air transport markets at will and set fares in response to market demand.

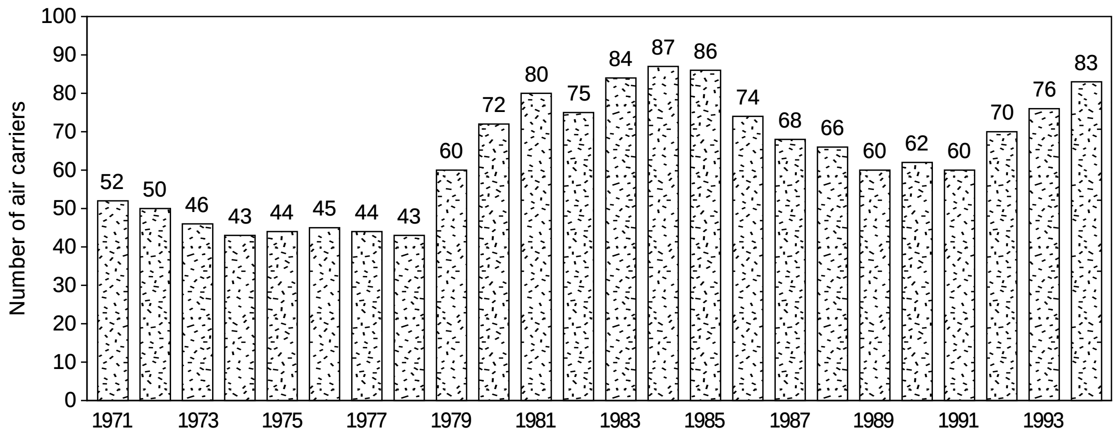
At the heart of the question was the expected performance and potential competitiveness of a deregulated industry. Increasingly, arguments were advanced that competition would produce greater efficiencies, a wider variety of services, and lower fares. Because of the relatively low costs of entry and exit and the high mobility of capital, some economists suggested that any airline trying to levy monopoly prices would be quickly contested by new airlines entering the market to offer services at a lower cost. According to this *contestability* theory, the threat of entry would have the same price-moderating effect as actual entry. (Bailey and Baumol 1984, and Baumol et al 1982) This theory was partially responsible for the way in which deregulation occurred and the relative ease under which airline industry mergers were approved. Subsequent research conducted throughout the 1980s (Bailey et al 1985, Hurdle et al 1989) showed that the theory was not applicable to all airline routes and that the ease or threat of entry will not necessarily restrain prices. In spite of the fact that many city-pair markets are not contestable, deregulation significantly impacted airfares (see below).

The Post Deregulation Period: 1979 to 1995

The 1978 Airline Deregulation Act altered significantly the environment in which airlines operate. The advent of airline deregulation ushered in an era of fierce competition with the arrival of new entrants, some of whom were former intrastate carriers, local service providers, and charter operators. Discount fares multiplied, price wars ensued, and overall traffic soared absolutely and relative to population. Today, average passenger fares (when adjusted for inflation) are lower in most markets and flight frequency is greater.

Shortly after deregulation, the number of new service providers jumped sharply (see figure A-3). New entrants made serious inroads into

FIGURE A3: **AIR CARRIERS SUBMITTING U.S. DOT FORM 41 REPORTS, 1971–94**



NOTE: U.S. air carriers use Form 41 Schedules to report financial and traffic information to the U.S. Department of Transportation.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

market shares of trunk lines,[4] and the share of total traffic accounted for by the largest carriers fell from 94 percent to 77 percent between 1978 and 1985. (TRB 1991) To counter competition, major airlines used a variety of strategies that effectively raised the cost of market entry for new and smaller airlines and developed economies of scope that affected consumer choices in favor of major established airlines. (Economies of scope result when airlines offer a wider variety of services while allocating overhead costs over an increasing number of services.) The most common strategies included building extensive hub-and-spoke route systems and developing marketing programs that would increase carrier loyalty and expand carrier services, such as computer reservation systems (CRSs), frequent flyer programs, and codesharing with commuter airlines.

Airlines' efforts to mitigate some of the negative effects of deregulation were complicated by some long-term secular trends in the economy and special events occurring at the same time. Among the latter were the 1979–80 Organization of Petroleum Exporting Countries (OPEC) petroleum price increases, which led to operating cost increases, and subsequently a fall in air transport demand. Another disruptive event was the operating constraints imposed by the air traffic controller strike in 1981.

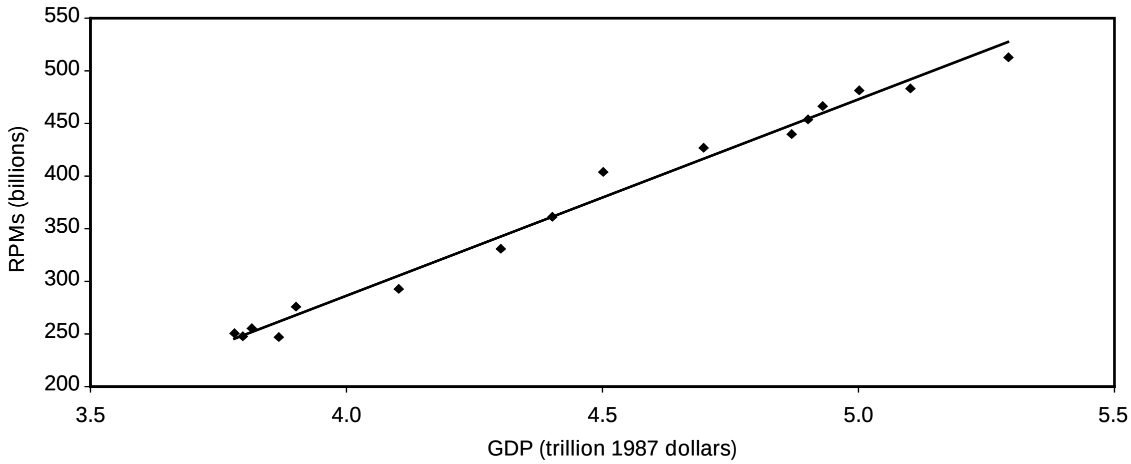
Ultimately, most new entrants, as well as some older established airlines, failed to survive in this new, highly competitive environment. Because of the shrinking number of carriers, the market shares of the three largest airline groups (majors, nationals, and large regionals) have increased. In 1994, the major, nationals, and large regional carriers accounted for 99.4 percent of total passenger traffic (see table A-2).

Traffic Growth

The demand for airline service is income elastic and appears to be price elastic. As real income rises, passengers spend more money on air travel. Conversely, as fares rise, passengers

[4] A trunk line is an air carrier's main route, usually between two major airports.

FIGURE A4: RELATIONSHIP BETWEEN REVENUE PASSENGER-MILES AND GDP, 1979–94



NOTE: The estimated regression is RPM = –430.6 + .18* GDP R^2 = .98.

KEY: GDP = gross domestic product; RPMs = revenue passenger-miles.

SOURCE: Revenue passenger-miles data are from U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information; GDP data are from U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: 1995).

spend less on air travel. Both business and tourist travel are price elastic but the tourist market is far more so, explaining why many discount fares target tourists.

Air traffic growth mirrors trends in the national economy. Figure A-4 shows the close statistical relationship between RPMs and inflation-adjusted GDP from 1979 to 1994. From 1979 to 1994, the number of enplaned passengers grew by 3.6 percent annually. Also, the trend in O&D passenger traffic continued upward, closely paralleling the growth in inflation-adjusted GDP[5] (see figure A-5).

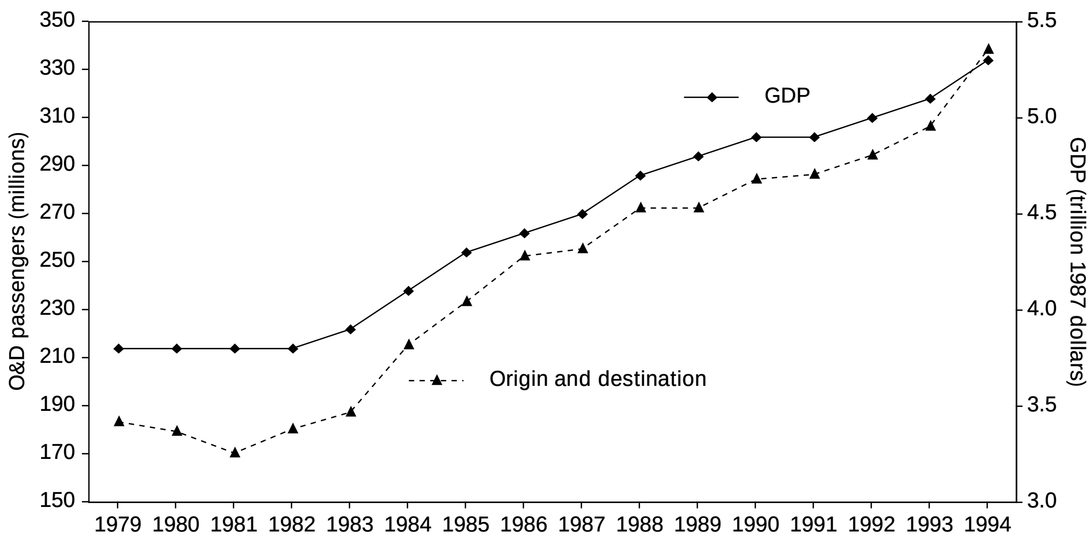
Traffic growth has not been uniform for all categories of carriers in the industry: major airlines have enjoyed substantial growth since 1979 (an 89 percent increase in enplanements); national air carrier growth has remained flat; and the large regionals have experienced phenomenal growth—in excess of 500 percent. (USDOT OAI) Continued growth of large regional carriers is dependent, in large part, on their marketing partnerships with major airlines. Regional carriers provide service to markets that could not be economically served by major airlines operating larger aircraft. The nature of service in smaller markets that provide feed traffic to larger hubs is short-haul, nonstop service.

Despite market entry limitations imposed by foreign governments, U.S. airlines experienced growth in international markets (see figure A-6). Between 1987 and 1993, the number of passengers traveling on U.S. airlines between the United States and foreign destinations increased by 47 percent, while domestic traffic increased by only 6 percent. (USGAO 1995, 2)

As shown in figure A-7 and table A-3, RPMs increased sharply, by about 105 percent between 1980 and 1994. During this period, the U.S. pop-

[5] The effect of the economy on airline traffic is reflected in two direct measures of traffic growth: enplaned passengers (the total number of passengers boarding aircraft for one-stop and multiple-stop flights) and O&D passengers (the number of passengers flying from an intended origin to an intended destination); both increased substantially between 1979 and 1995. O&D count is a better measure of actual passenger traffic because it eliminates double counting, which is inherent in passenger enplanement numbers.

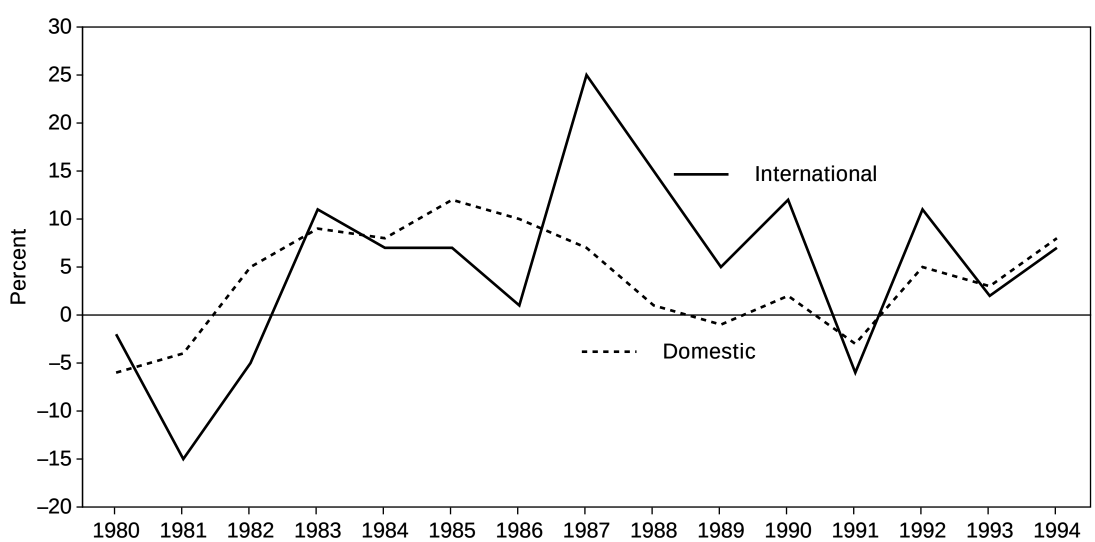
FIGURE A5: SYSTEMWIDE ORIGIN AND DESTINATION PASSENGERS AND GDP, 1979–94



NOTE: Systemwide refers to domestic plus international.

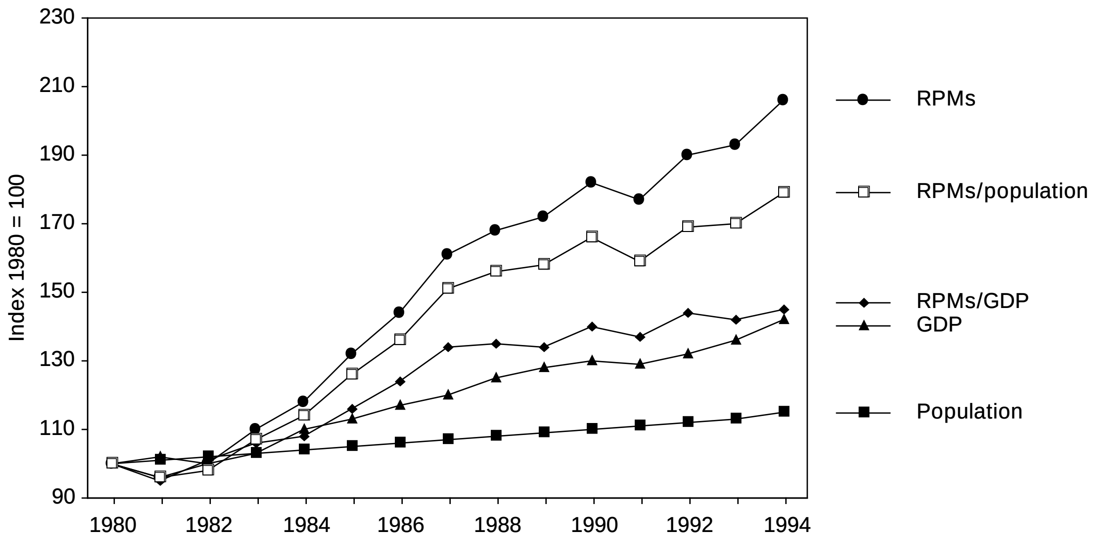
SOURCE: Revenue passenger-miles data are from U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information; GDP data are from U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: 1995).

FIGURE A6: ANNUAL CHANGE IN DOMESTIC AND INTERNATIONAL PASSENGER ENPLANEMENTS, 1980–94



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

FIGURE A7: **PASSENGER TRANSPORTATION TRENDS, 1980–94**



NOTE: GDP is in 1987 dollars.

KEY: GDP = gross domestic product; RPMs = revenue passenger-miles.

SOURCE: Revenue passenger-miles data are from U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information; GDP and population data are from U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: 1995).

ulation grew by only 14.5 percent. Hence, there was an increase in personal travel by air; the number of enplanements per capita increased by 55 percent (see figure A-8). Also the average length of the air trip increased from 854 miles to 985 miles. (USDOT OAI) The rapid growth in demand for air service as the preferred mode for intermediate and long-distance travel can be attributed to its speed, declining cost (in inflation-adjusted terms), and convenience. Between 1980 and 1994, RPMs per unit of GDP increased. This shows the increasing contribution of air travel to GDP (see table A-3).

Air freight transportation trends parallel those in the passenger sector (see figure A-9 and table A-4). Because of structural shifts in the economy, such as the shift away from material-intensive to knowledge-intensive production (dematerialization), the freight and express package business has been a growth industry in recent years. As shown in figure A-9, revenue ton-miles per GDP increased over the 1980 to 1994 period. Again, this trend shows the shift in the economy toward higher value per unit weight production.

Competitive Airfares

Are air passengers paying lower fares today than they did in 1980? The answer is yes. Figure A-10 shows that yields declined between 1980 and 1994. During this period, airline passengers paid less (in inflation-adjusted terms) for air travel.[6] Several factors influenced the trend in average airfares. The most significant of these

[6] Yield per mile is calculated by dividing passenger revenues by revenue passenger-miles.

TABLE A3: PASSENGER TRANSPORTATION TRENDS, 1980–94

Year	Population (millions)	GDP (billion 1987 dollars)	Revenue passenger-miles (RPMs) per capita	RPMs per thousand 1987 dollars of GDP
1980	227	3,776	1,110	67
1981	229	3,843	1,062	63
1982	232	3,760	1,238	67
1983	234	3,907	1,184	71
1984	236	4,149	1,266	72
1985	238	4,280	1,396	77
1986	240	4,405	1,515	82
1987	242	4,540	1,675	89
1988	244	4,719	1,738	90
1989	247	4,838	1,761	89
1990	249	4,897	1,845	93
1991	252	4,868	1,774	91
1992	255	4,979	1,883	96
1993	258	5,135	1,895	95
1994	260	5,344	1,994	97

NOTE: GDP = gross domestic product.

SOURCE: Revenue passenger-miles data are from U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information; GDP and population data are from U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: 1995).

are energy and other operating costs, airline dominance on a route, and national economic trends. Other less influential but important factors are airport limitations on take-offs and landings, level of airport congestion, codesharing agreements, market share of route traffic and share of gates on a route, the use of CRSs, operating costs of the least-cost airline on a route, and price sensitivity of passengers (business versus leisure).

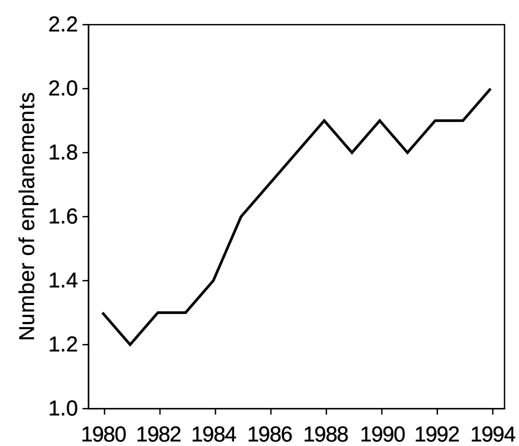
Historically, technological advances also have had an impact on airfares. For example, advances in aircraft design, materials, and construction, aircraft engines, and operating procedures increased productivity per dollar spent on aircraft in the 1980s. (Meyer and Oster 1987, Gordon 1990) Increases in productivity led to reductions in per-seat-mile costs and permitted reductions in airfares.

Shortly after deregulation of the airline industry in 1978, energy costs rose to record-setting levels as a result of the 1979–80 oil crisis. Not surprisingly, fuel is a critical and large expenditure of the airline industry and thus has a significant impact on fares. As shown in figure A-10, real yields rose dramatically, partly in response to increases in total operating costs, and then declined steadily after 1981 as energy prices stabilized and the economy recovered from a recession.

During the 1980s, new carriers entered markets at the same time existing airlines were attempting to expand their market shares. In the early 1980s, established airlines were forced to compete with low-cost carriers for a limited pool of travelers by offering reduced fares.

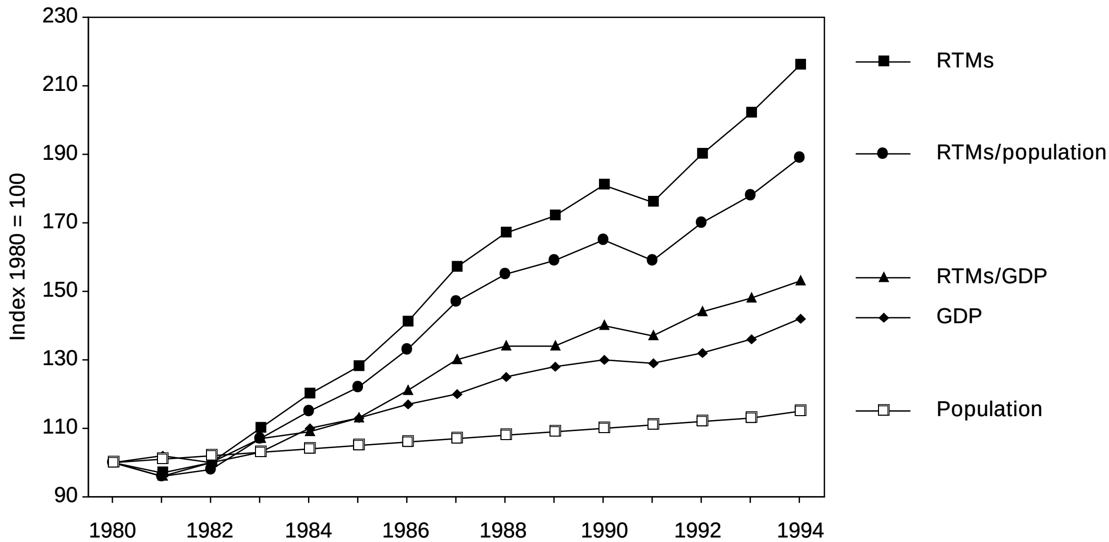
The development of the hub-and-spoke route structure also had an impact on airfares. This structure offered airlines economies of scale such as centralized operational facilities, flexi-

FIGURE A8: PASSENGER ENPLANEMENTS PER CAPITA, 1980–94



SOURCE: Passenger enplanement data are from U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information; population data are from U.S. Department of Commerce Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: 1995).

FIGURE A9: FREIGHT TRANSPORTATION TRENDS, 1980–94

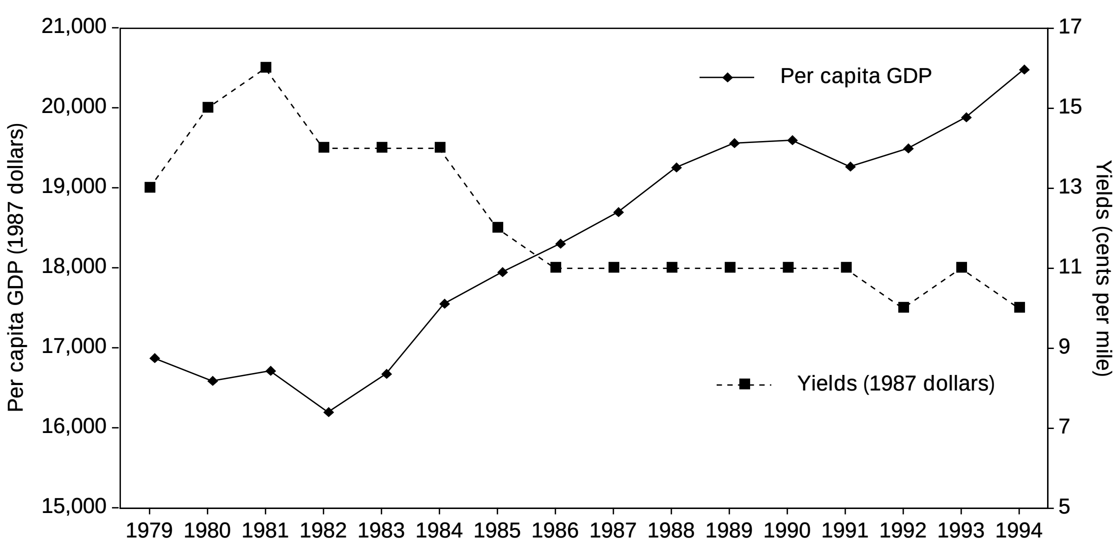


NOTE: GDP is in 1987 dollars.

KEY: GDP = gross domestic product; RTMs = revenue ton-miles.

SOURCE: Revenue ton-miles data are from U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information; GDP and population data are from U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: 1995).

FIGURE A10: PER CAPITA GDP AND SYSTEMWIDE YIELDS, 1979–94



KEY: GDP = gross domestic product.

SOURCE: Passenger fares and yields data are from U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information; GDP and population data are from U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States,1995* (Washington, DC: 1995).

TABLE A4: FREIGHT TRANSPORTATION TRENDS, 1980–94

Year	Total RTMs (billions)	RTMs per capita	RTMs per thousand 1987 dollars of GDP
1980	32.1	141.4	8.5
1981	31.2	136.2	8.1
1982	32.0	138.3	8.5
1983	35.4	151.4	9.1
1984	38.4	162.9	9.3
1985	41.1	172.9	9.6
1986	45.2	188.3	10.3
1987	50.4	207.8	11.1
1988	53.6	219.3	11.4
1989	55.3	224.2	11.4
1990	58.2	233.4	11.9
1991	56.5	224.2	11.6
1992	61.2	239.9	12.3
1993	64.7	251.2	12.6
1994	69.5	267.0	13.0

KEY: RTMs = revenue ton-miles; GDP = gross domestic product.

SOURCE: Revenue ton-miles data are from U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information; GDP and population data are from U.S. Bureau of the Census, *Statistical Abstract of the United States, 1995* (Washington, DC: 1995).

bility in route patterns, increases in frequency of service, and the ability to serve more points and people with a given fleet of aircraft. As new hubs developed and competition among hubs proliferated, fares were reduced further.

The health of the national economy is a major factor influencing airfares. During the second half of the 1980s, the economy grew as did demand for air transport. Airline costs, however, rose faster than inflation, thus increasing fares. By the late 1980s, new airlines had either failed or merged with surviving carriers. Consolidation among the carriers did not result in fare increases because fewer airlines served more city-pair markets and overlapped other carriers service areas. The net result of these factors was that competition among hubs rose and, consequently, average real yields declined rapidly between 1981 and 1986, did not recover, and in 1994 were slightly below their 1986 level (see figure A-10).

Overall, competitive airline pricing brought about by deregulation and other factors lowered fares on many routes for air travelers. Using total third quarter O&D passenger information for the top 20 domestic city-pair markets, average fares declined by 31 percent, from $128 in 1979 to $88 in 1994 (see table A-5). The decline in average fares occurred in spite of pressure to increase fares from energy price hikes and other operating cost increases, reflecting the intense price competition on many routes.

By 1994, more than 75 percent of passengers traveled in markets that had inflation-adjusted fare reductions. Travelers in some short-distance markets dominated by low-cost airlines enjoyed drastically reduced promotional fares. Indeed, today almost 40 percent of domestic passengers travel in markets where low-cost carriers compete. As shown in table A-5, however, three of the top 20 O&D city-pairs (Los Angeles-San Francisco, Boston-New York, and New York-Washington, DC) experienced increased inflation-adjusted fares. Historically, passengers flying longer distance have enjoyed greater fare reductions than those in medium- and short-distance markets.

Hub-and-Spoke Pattern

In the early 1980s, major carriers changed their route structures from a linear point-to-point network, in which airplanes flew through a series of points collecting passengers along the route to a hub-and-spoke network. The advantage of the hub-and-spoke network is that it permits airlines to serve many points without having all points directly interconnected. The

Table A5: Passengers and Fares for the Top 20 Domestic Origin and Destination Markets, Third Quarter Period, 1979–95

Total quarterly O&D passengers and fares (1987 dollars) ordered by percentage change in fares

From	To	1979	1982	1986	1990	1994	1995	Change in fares 1979–95
Los Angeles	Phoenix	80,000 $140.46	118,620 $66.83	354,140 $34.06	356,070 $36.19	333,260 $37.27	307,550 $39.89	–72%
Honolulu	Los Angeles	114,920 $367.94	288,990 $118.14	232,940 $170.28	308,250 $116.50	222,840 $133.23	274,950 $127.49	–65%
Los Angeles	Oakland[a]	360 $97.71	137,950 $57.28	127,680 $80.50	120,540 $58.25	309,140 $43.62	410,850 $40.67	–58%
New York	San Juan	323,970 $196.95	382,580 $142.00	412,220 $124.87	330,000 $136.80	318,350 $119.75	308,690 $121.24	–38%
New York	Palm Beach	74,800 $152.67	178,200 $121.72	186,610 $115.58	244,360 $97.97	253,550 $82.47	202,090 $100.90	–34%
Las Vegas	Los Angeles	153,870 $58.02	168,180 $65.63	264,580 $55.73	148,620 $74.14	424,740 $42.82	440,990 $41.45	–29%
Miami	New York	372,950 $137.40	316,020 $152.74	377,910 $121.78	433,750 $100.62	483,140 $88.03	423,050 $100.90	–27%
Chicago	Detroit	141,600 $73.28	149,470 $91.89	204,780 $91.85	400,230 $41.48	347,530 $54.72	355,290 $56.32	–23%
Dallas	Houston	91,550 $64.12	645,820 $34.61	459,640 $47.47	535,330 $45.90	532,320 $48.37	510,880 $50.84	–21%
Ft. Lauderdale	New York	336,610 $131.30	271,390 $142.00	334,630 $115.58	383,220 $96.20	413,940 $83.27	300,550 $104.81	–20%
Honolulu	Lihue, Kauai, HI	218,870 $35.11	162,060 $20.29	143,300 $36.12	431,880 $28.24	428,400 $30.93	510,250 $28.94	–18%
Chicago	New York	487,160 $140.46	506,370 $188.54	620,790 $149.64	534,500 $195.94	716,020 $95.96	701,390 $116.54	–17%
Honolulu	Kahului, Maui	184,660 $33.59	209,480 $17.90	207,800 $37.15	534,810 $28.24	712,370 $30.13	743,660 $28.16	–16%
Los Angeles	New York	603,700 $210.69	582,110 $255.37	644,440 $204.33	660,240 $214.47	579,670 $181.60	566,830 $180.68	–14%
New York	San Francisco	371,110 $224.43	359,730 $261.34	424,000 $201.24	410,920 $215.36	383,090 $200.63	422,970 $193.98	–14%
New York	Orlando	196,720 $114.50	177,830 $133.65	339,660 $101.14	496,630 $86.50	456,210 $84.85	362,160 $100.90	–12%
Atlanta	New York	195,610 $145.04	200,080 $171.84	336,940 $130.03	296,450 $173.87	411,580 $112.61	381,660 $142.35	–2%
Los Angeles	San Francisco	324,340 $42.75	471,050 $57.28	506,850 $74.30	518,520 $58.25	410,770 $58.68	380,230 $57.88	35%
Boston	New York	503,490 $65.65	697,370 $59.67	763,280 $58.82	614,890 $92.67	576,330 $77.72	566,680 $80.56	23%
New York	Washington, DC	495,370 $70.23	503,110 $68.02	620,910 $60.89	571,920 $94.44	460,980 $83.27	460,490 $80.56	15%
Total passengers **Average fare**		5,271,660 $128.09	6,526,410 $117.23	7,563,100 $105.36	8,331,130 $102.68	8,774,230 $83.48	8,631,210 $87.81	–31%

[a]Direct airline service from Los Angeles to Oakland, California started in the 1970s.
SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information, airline origin and destination data.

hub-and-spoke system also obviates the need to change airlines, thereby reducing the possibility of losing baggage.

Airlines have a strong incentive to increase their control at their connecting hubs. This has encouraged geographic expansion and resulted in intensified service competition in many city-pair markets.

Although major carriers tend to dominate at the largest hubs, consumer choices have increased significantly since deregulation. More city-pair markets and passengers enjoy competitive service from competing carriers than ever before.

Innovative Marketing Strategies

The advent of deregulation forced airline management to develop new approaches for marketing air transportation. Several strategies emerged: sophisticated discounting practices, marketing arrangements with travel agents relying on computer reservations systems, incentive commission programs, frequent-flyer programs, and close operating agreements with smaller air carriers.

Discount airfares were used to counter low-fare offerings of new, low-cost, often non-union, carriers. Over time, established carriers developed yield management systems in conjunction with CRSs, permitting air carriers to focus on selling, at a discount, seats that would have gone unsold. Airlines use computer-based yield management systems to efficiently market discount fares to different customers such as tourists and business-class and first-class passengers. Yield management systems permit the airline industry to take advantage of the different price sensitivities among classes of passengers so that each flight may have a mix of full-fare, partially discounted, and fully discounted tickets. Furthermore, CRSs permit carriers to target competitors' seat availability with minimum impact on prices for their own seats.

In recent years, the airlines elevated the importance of travel agents, a major distribution channel for tickets. American Airlines and United Airlines pioneered the use of CRSs that enabled travel agents to track frequent changes in service and fares and to reserve flights. Economic incentives were provided to travel agents who reserved flights on CRS carriers even though other carriers were available. Eventually, these two airlines claimed affiliations with nearly 80 percent of automated travel agencies. Travel agents are given further incentives to reserve a seat with a particular airline through the provision of high booking fees—called commission overrides, which are given for achieving specific volumes in ticket sales.

Frequent-flyer programs aimed at promoting carrier loyalty proved to be a powerful marketing tool. Introduced in 1981 by American Airlines, frequent-flyer incentives spread throughout the industry as an important way to retain business travelers who are less able to take advantage of deep discount fares, but who might opt for lower fares offered by competitors. The importance of offering frequent-flyer benefits is heightened by the fact that roughly 5 to 6 percent of passengers account for approximately 40 percent of all trips. (TRB 1991, 55)

Frequent-flyer programs have been criticized for a variety of reasons. Some have argued that the airlines pay the cost of frequent-flyer programs by charging higher fares to all passengers. Another criticism is that frequent-flyer programs lessen the competitive pressure of deregulation; passengers may reject the lowest fare airline for a frequent-flyer plan in order to get points toward a future free flight.

Marketing affiliations, known as codesharing, were originally initiated between large and small carriers. These alliances have proliferated throughout the domestic industry and spread to the international arena (e.g., USAir-British Airways, 1993; Delta-Swissair, 1993; Northwest-KLM, 1993; United-Lufthansa, 1994; American-

Canadian Airlines International, 1995; United-Air Canada, 1995). These arrangements have developed into a succession of relationships, from intercarrier agreements to joint operations to partial ownership in some cases. Codesharing allows airlines to sell tickets and provide service to points beyond their immediate route network.

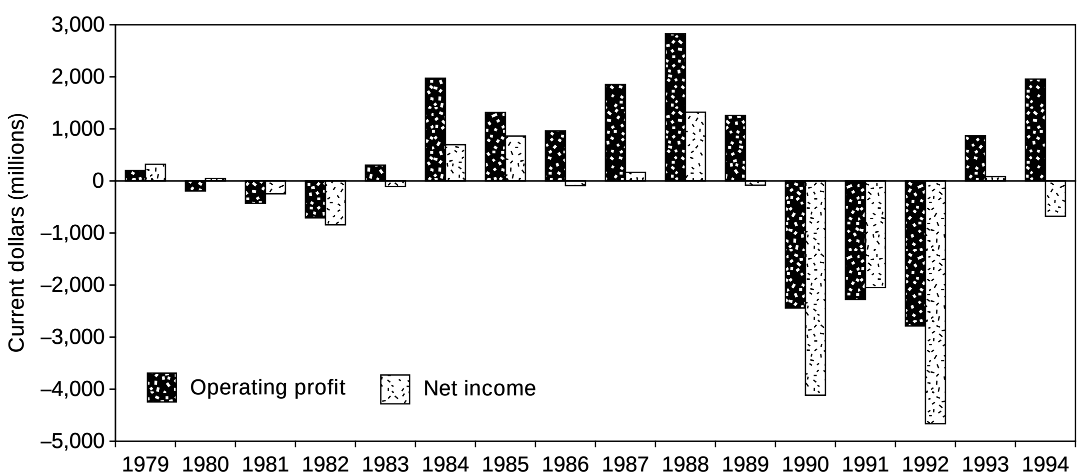
Industry Financial Performance

The strength of the industry's financial condition determines its ability to withstand periods of recession and attract enough capital to replace and expand its fleets. Its financial condition also affects its ability to comply with environmental and energy standards. To date, the airline industry's financial performance has been mixed.

Figure A-11 shows the airline passenger industry's operating profit and net income from 1979 to 1994 for the nation's three largest air carrier groups. Between 1990 and 1992, the airline passenger industry recorded its highest losses in history, but has since rebounded. Similarly, the financial condition of the cargo industry has improved. Figure A-12 shows the passenger and cargo industries' combined cumulative operating profits[7] and net income from 1979 to 1994. As shown in the figure, cumulative operating profits were $16.9 billion, and cumulative net losses were $15.4 billion. These results stemmed from sporadic profitability from 1979 through 1992, which can be traced to cycles in the national economy driving demand for air travel, the inability to maintain yields in the face of competition, and periods of excess seat capacity. By 1994, industry growth and stable yields resulted in the improved financial performance of most carriers. The rebound can be attributed

[7]Cumulative operating profits and net losses are obtained by summing the annual change in operating profits and losses.

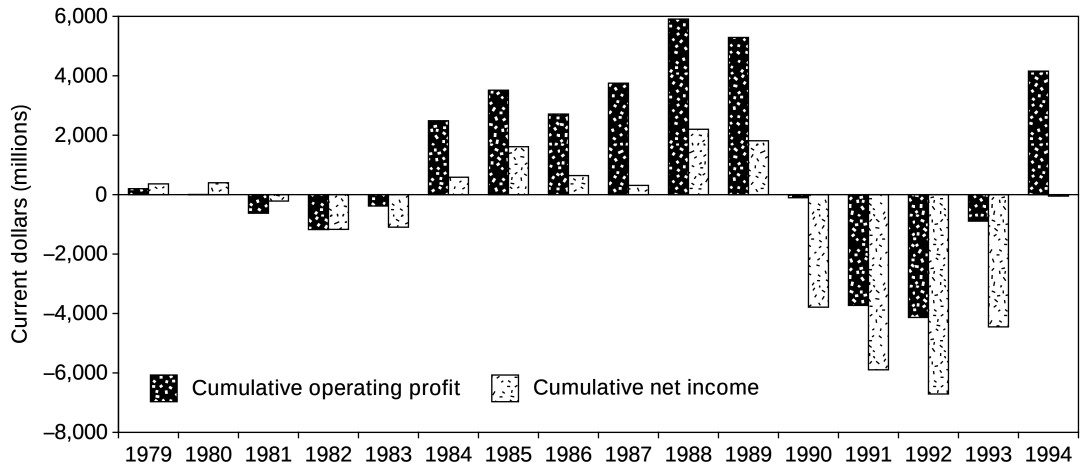
FIGURE A11: AIRLINE PASSENGER INDUSTRY OPERATING PROFIT AND NET INCOME, 1979–94



NOTE: Operating income is obtained from a company's Statement of Income and is derived by subtracting total operating expenses from total operating income. Net income is derived by deducting income and expenses of nonflight operations (interest, capital gains or losses, depreciation, and taxes) from total transportation revenues.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

FIGURE A12: PASSENGER AND CARGO INDUSTRY CUMULATIVE OPERATING PROFIT AND NET INCOME, 1979–94



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

FIGURE A13: CORPORATE RETURN ON INVESTMENT FOR MAJOR PASSENGER AND FREIGHT AIR CARRIERS, 1979–94

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

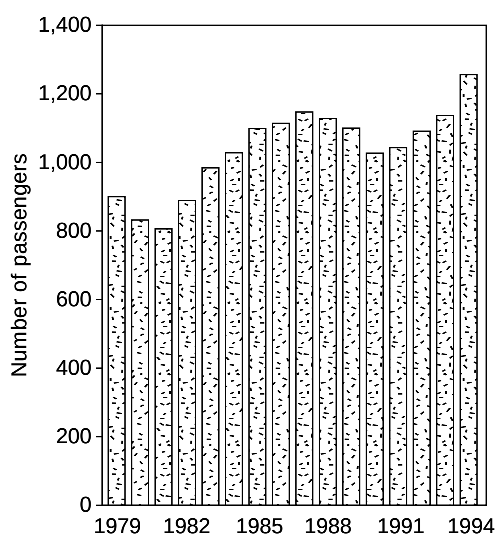
to robust growth in traffic, minimal overall capacity expansion, and better management of the full-fare passenger segment.

Since 1979, industry load factors averaged between 58 and 67 percent. After a sharp drop between 1979 and 1980, load factors rose and reached 66 percent by 1994. As a consequence of these factors corporate return on investment remained unstable for both the passenger and freight sectors of the industry (see figure A-13).

Labor Performance

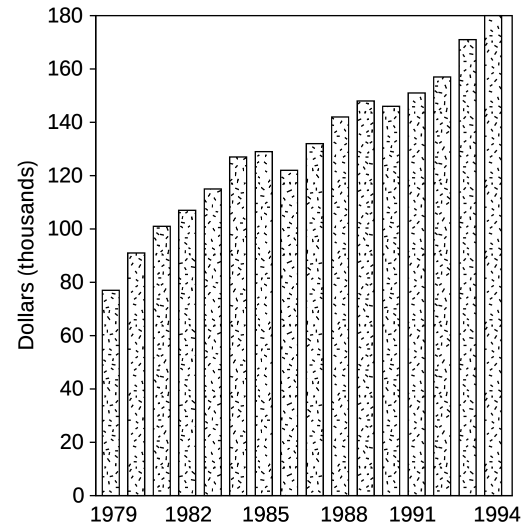
Airlines are using fewer employees to provide services to a growing number of passengers and volume of freight activity. Between 1980 and 1994, total enplanements increased by about 78 percent, but airline employment grew by only 18 percent. Thus, the ratio of enplaned passengers per employee rose by 51 percent over this period (see figure A-14). This striking increase in output per employee arises, in part, from the use of larger and faster aircraft, the computerization of passenger reservations, the hub-and-spoke structure, changes in work rules and practices, and changes in flight personnel requirements. Various yield management techniques adopted by the airlines after deregulation also may have improved labor productivity. Also during the period, operating revenues per employee significantly increased (see figure A-15).

FIGURE A14: ENPLANED PASSENGERS PER EMPLOYEE FOR MAJOR AND NATIONAL AIRLINES, 1979–94



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

FIGURE A15: OPERATING REVENUES PER EMPLOYEE FOR MAJOR AND NATIONAL AIRLINES, 1979–94



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information data.

Fuel Efficiency

The airline industry is a major consumer of jet fuel and to a lesser extent aviation gasoline. Between 1979 and 1994, airline fuel efficiency greatly improved. Although total jet fuel use increased, the available seat-miles per gallon—a measure of fuel efficiency—increased from 38 to 52; a 38 percent increase in fuel efficiency. Also, available ton-miles per gallon increased by 38 percent from 5.3 to 7.3. The reduction in fuel usage per unit of output arises from more efficient engines and operating procedures. Perhaps as important, less fuel consumption per unit of output translates into lower environmental impacts.

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Conference on the Full Social Costs and Benefits of Transportation

A comprehensive description of the U.S. transportation system should include answers to a number of broad and open-ended questions: What are the important measures of the performance of transportation? Is the system's performance getting better or worse? What is the relative magnitude of the problems to be addressed and how much of society's resources should be devoted to solving them? Is the transportation system efficient? Does it satisfy our standards for equity and social justice? Who pays and who benefits?

In July 1995, the Bureau of Transportation Statistics (BTS) held a conference on measuring the full social costs and benefits of transportation. BTS brought together an international group of transportation researchers and analysts from government, industry, academia, and nonprofit institutions. (The list of conference participants is presented at the end of this appendix.) Its purpose was to define concepts and advance the state-of-the-art for estimating, analyzing, and interpreting the social costs and benefits of transportation and to assist BTS in developing useful measures of transportation's consequences. BTS, whose mission is to compile, analyze, and make accessible information on the nation's transportation system, has a mandate to advance comprehensive understanding of transportation's role in society and its effects on the environment.[1] The conference was part of this process.

T.R. Lakshmanan, Director of BTS, identified three types of information needed to measure transportation's full costs and benefits.

1. General and comprehensive **performance indicators** for the transportation system.
2. Measures of transportation's **contribution to the economy.**
3. Measures of the **unintended consequences** of transportation, including external costs.

Fourteen papers were presented on several topics, including social costs and economic efficiency, total costs and benefits, and issues in measuring the full cost of transportation. These papers have been peer reviewed and will be published by Springer-Verlag in late 1996. (The list of papers is presented at the end of this appendix.)

This appendix presents an overview of the topics addressed at the conference. Emphasis was given to theoretical and conceptual issues, which form the foundation for measuring and evaluating full social costs and benefits. Three broad motivations for measuring full social costs and benefits were identified. Each of these motivations can lead to different concepts and measures of costs and benefits.

1. To **compare alternative situations.** Comparisons could be as hypothetical as comparing greenhouse gas emissions under alternative scenarios or as concrete as analyzing the full range of costs and benefits of a major infrastructure investment.
2. To **evaluate the economic efficiency** of transportation, particularly in assessing the external costs and benefits that are not reflected in the price of transportation.

[1] Section 6006 of the Intermodal Surface Transportation Assistance Act of 1991 established BTS.

3. To address **fairness and equity issues,** including horizontal equity and vertical equity concepts. The horizontal equity concept addresses whether those who benefit from transportation infrastructure pay appropriately for it. The vertical equity concept examines whether various segments of society such as the poor, aged, or handicapped receive adequate benefits from public expenditures and investments in transportation.

The conference also focused on empirical issues in full cost estimation, such as how to measure the economic costs of air pollution, how to quantify traffic congestion costs, and how to account for infrastructure costs when valuing the costs of oil dependence. Much of the discussion dealt exclusively with external costs, reflecting current interests and practices of researchers. Participants noted, however, that future research must also focus on how to fully measure the benefits of transportation.

Finally, the conference addressed the implications of full costs and benefits issues. Conferees noted the need to give equal weight to identifying and measuring benefits and the importance of understanding the dynamic spatial effects of transportation systems. Discussions centered on alternative views of transportation as a provider of accessibility or of mobility and the implications of substitution and complementarity of transportation and telecommunications. Although there were many areas of agreement, many important areas of disagreement or uncertainty remain. These include the relevance and importance of external or social benefits of transportation, conceptual uncertainties about which costs and benefits are or are not external to private decisionmaking, and whether relevant costs and benefits can be adequately characterized as externalities. In general, substantial theoretical and methodological questions remain about what needs to be measured and how.

Why Measure Full Social Costs and Benefits?

In 1994, the U.S. transportation system carried travelers more than 4.2 trillion miles and in 1993 hauled 3.7 trillion ton-miles of freight. Not surprisingly, it comprises a major share of the economy. As noted in chapter 2, transportation produces about 11 percent of the U.S. gross domestic product ($712.7 billion in 1994). One in every 10 Americans (12.4 million) are employed in transporting people or goods, manufacturing, selling, or maintaining transportation vehicles and infrastructure, or supplying other critical elements of the transportation system. Yet the influence of transportation on society is even more pervasive than these numbers suggest.

Transportation technologies shape the geography of society by influencing the location and intensity of land uses. Changes in land use, in turn, have far-reaching effects on patterns of production and consumption. The cost and speed of transportation are major determinants of the density of development. Fast, low-cost transportation has supported the increasing independence of home and workplace locations.

The U.S. transportation system has large unintended consequences. In the United States, 43,750 lives were lost and over 3.25 million people were injured in transportation accidents in 1994. In the 50 largest U.S. cities, traffic congestion and delays in 1991 resulted in estimated total economic losses of over $45 billion.[2] Motor vehicles produce from one-third to four-fifths of the major constituents of urban air pollution. Especially in cities, transportation vehicles are a major source of unwanted noise. The transportation sector accounts for two-thirds of total U.S. oil consumption and hence contributes to our

[2] Schrank et al. (1994, table 35) assumed a vehicle occupancy rate of 1.25, calculated in 1994 dollars.

nation's dependence on oil imports. Finally, the combustion of fossil fuels by transportation produces about one-third of U.S. greenhouse gases, which have the potential to alter the world's climate in the next century. Given transportation's importance to society, it is reasonable to ask whether these unintended consequences have been appropriately taken into account in market decisions and public policy initiatives.

All levels of government play important roles in our nation's transportation system. Governments invest in highways, airports, and other infrastructure for all transportation modes. They promulgate and enforce rules and regulations that sometimes encourage and at other times discourage competition throughout the sector. Government regulations on public safety and the environment have been the primary mechanisms for dealing with the unintended social costs of the transportation system.

Conceptual Frameworks for Measuring and Valuing Social Costs and Benefits

Most of the literature on full social costs of transportation attempts to address negative externalities—the unintended damage imposed on others that is not reflected in the price of a good or service. For example, pollution emitted from a motorist's automobile is not fully reflected in the costs of owning and operating a vehicle. Thus, this cost is said to be external to a motorist's economic decisionmaking. (The motor vehicle pollution example is treated in greater detail in chapter 6.) Other acknowledged transportation externalities include surface and groundwater pollution, noise, greenhouse gas emissions, traffic congestion, and impacts on land use and wildlife habitats.

Economists have recognized for decades that negative externalities cause markets to arrive at "inefficient" production and consumption decisions from the standpoint of the greatest possible social welfare. (Pigou 1938) Using the motor vehicle pollution example, the market, acting without public policy intervention, would use overly polluting technology to produce more travel than might otherwise occur, which would then have an adverse impact on clean air.

It is useful to measure the damages done by transportation externalities in order to know whether more, or less, should be done. If it is found that more needs to be done, actions could be considered to encourage markets to recognize and account for external costs. Such measures are sometimes said to "internalize" externalities. For example, some economists propose a tax on negative externalities, on the theory that such measures might promote market decisions that would achieve greater social benefits. In many situations, however, directly taxing an externality is not politically feasible and is difficult to levy and implement. Thus, other public policy actions may be more practical. These include establishing standards for the production of externalities or taxing activities related to the production of externalities.

As chapter 7 demonstrates, public policy tools have been widely used to deal with the environmental impacts of transportation. For more than three decades, increasingly stringent regulations have limited motor vehicle emissions. Regulations also define allowable noise limits for aircraft and require the repair of leaking fuel storage tanks. To some degree, these measures have resulted in the internalization of some externalities. Internalization of the full range of external environmental costs, however, has seldom, if ever, been achieved. Moreover, some of the most significant nonenvironmental costs of transportation, such as traffic congestion, have been largely unaddressed by public policy. (National Research Council 1994)

This and other issues concerning the implications of external costs for economic efficiency were addressed by conference participants. Motor vehicle exhaust emissions were used as an example of an external cost that is difficult to tax directly. Although emissions control technology is a standard feature of all U.S. cars, improperly functioning emissions control technology can cause the rate of emissions per mile to vary by an order of magnitude. In addition, recent research shows that driving practices (e.g., speed, acceleration) greatly affect emissions rates of all vehicles. Furthermore, the damages done by emissions vary over time and space. The effect of emissions on air quality changes with the season and with the concentration of other pollutants already present. The damage done by poor air quality depends on the number of people exposed and their initial health, as well. Rather than attempting to directly tax the external costs of motor vehicle emissions, current policies set regulatory standards for emissions from new vehicles and the composition of fuels.

Regulatory standards affect the rate of emissions per mile, but have little direct effect on the number of miles traveled. (To the extent that the cost of pollution control equipment is passed on to the car buyer, regulations will affect the size of the vehicle stock, scrappage rates, and other factors that indirectly affect the amount of vehicle travel.) Ideally, to achieve the greatest social benefit, both the rate and quantity of emissions must be adjusted. Theoretically, regulatory standards, when used, could be set at such a level to achieve a $1 reduction in damages from the last $1 spent on control equipment. Even this step would be unlikely to completely eliminate pollution by motor vehicles because external damages continue to be created by vehicle-miles traveled. Theoretically, an economically efficient outcome could be achieved if a tax were imposed on vehicle-miles at a rate equal to the remaining external cost per mile. It was pointed out that even if regulations were too stringent, that is, they required more emissions controls than were justifiable based on the reduction of external costs, a tax on vehicle-miles equal to the remaining external cost per mile would still result in an economically efficient outcome from a social benefits standpoint. Thus, even when emissions control regulations are in place, information on the external costs of transportation is still relevant for two purposes: 1) to evaluate the cost-effectiveness of the regulatory standards, and 2) to assess whether the price of travel adequately internalizes the remaining external costs.

Per-mile damage estimates vary greatly by vehicle type and level of emissions control. It is clear that dramatic reductions in per-mile damages have been made, and still further reductions are possible. For example, one report estimated damages of 6.6 cents per mile for a 1977 model year car, compared with half the damages (3.3 cents per mile) produced, on average, by 1992 automobiles. (Small and Kazimi 1995) Vehicles meeting California's new car standards for 1993 were estimated to generate ½ cent per mile in pollution damage; low-emission vehicles and ultra-low-emission vehicles produce only ¼ cent per mile in pollution damages. It is important to note that these estimates are highly uncertain.

Damage estimates from motor vehicles in one city cannot be applied uniformly to cars in all cities. Los Angeles, for example, has the worst pollution in the United States and may have the greatest share of pollution caused by motor vehicles. Also, internalizing air pollution costs would have a noticeable impact on vehicle travel in the Los Angeles region today, but that impact would decrease in the future.

All costs of transportation not directly paid for by transportation users are not necessarily externalities, an important point sometimes overlooked in studies of the full social costs of transportation. The conference addressed the question of what is and is not an externality. Discussions focused on recent studies that examined off-street free parking, accidents, and energy security as external costs. It was noted that free parking provided by employers and retail stores was a case of product bundling rather than external costs. (Lan and Kanafani 1993) For example, if one goes to a shopping mall to buy a shirt, the cost of the free parking provided is paid for in the price of the shirt. Because all shoppers pay the same price for the shirt, regardless of their use of parking, one can argue that shoppers who do not use parking subsidize those who do. In this example, the issue is whether it is more appropriate to view free parking as an external cost, or as a form of price discrimination by a shopping mall that provides a bundled benefit that is valued by some customers but not others. Whether or not this form of price discrimination seriously affects economic efficiency depends on how much it distorts transportation decisions and on the consequences of those distortions.

The view that transportation accident costs are externalities was also questioned at the conference. For example, drivers assume a safety risk and impose a safety risk on others (both personal and property damage apply). If motorists systematically underestimate the risks to themselves, then the failure would appear to be caused by imperfect information or possibly irrational behavior, rather than a case of external cost. The risk to others may be reflected in the cost of liability insurance and by the potential to be held legally liable for damages to others. There is some evidence to suggest that insurance and legal actions do not fully compensate for damages caused by motor vehicle accidents. Estimates of the total costs of motor vehicle accidents were presented at the conference. One estimate indicated that from one-quarter to one-third of the total costs of motor vehicle accidents were borne by society as a whole and not by those involved in the accidents. This suggests that costs imposed on others by transportation accidents are very substantial and not accounted for in private individuals' travel decisions. Tangible and intangible losses to surviving family members are large components of this estimate. Whether such costs should be classified as externalities has been the subject of debate.

More than one-quarter of all drivers in fatal highway crashes have at least some alcohol in their systems. Although drunk drivers impose enormous costs on others, it is not clear that this problem is best viewed as a case of external costs. Some argued that drunk driving is an inherently irrational behavior and may therefore fall outside the realm of welfare economics.

The cost of oil dependence has been classified as an external cost of transportation in several studies. It may be more appropriately regarded, however, as a different kind of economic problem. Recent studies have adopted sometimes internally inconsistent perspectives on the cost of oil dependence. Some have included military and strategic petroleum reserve costs in their analyses. Others view the problem primarily as an exercise of monopoly power by the Organization of Petroleum Exporting Countries (OPEC), resulting in price shocks and generally higher oil prices to the United States. From this perspective, the problem is not so much that the consumption of an additional barrel of oil increases OPEC's market power (though part of the problem can be viewed this way), but rather that OPEC has partial monopoly power in world oil markets in the first place. Using this interpretation, the source of economic inefficiency is the lack of full competitiveness in world oil supply and not an externality associated with the consumption of oil.

External costs like environmental pollution are a significant source of inefficiencies in transportation markets, but not the only source. Imperfect competition, inadequate or inaccurate information or perceptions, and irrational behavior all appear to be significant sources of economic inefficiency. In the case of free parking, the fact that a service for transportation users is partially paid for by others may or may not be economically inefficient. Certainly, all social costs of transportation are not externalities. Some can be attributed to other types of market failures while still others appear to fall substantially outside the realm of economic behavior. Each has different implications for public policy.

Social Benefits of Transportation

What are the full social benefits of transportation? Typically, this question elicits the response, "Compared to what?" Indeed, it is meaningless to compare the current transportation system to none at all. In doing a comparison, two questions need to be answered: what benefits should be considered, and how should they be measured. Again, the appropriate answers depend on the context of the questions. If the concern is economic efficiency, then external benefits (benefits that accrue to individuals who are neither buyers nor sellers of transportation) must be addressed. If the context is measuring the performance of transportation or evaluating infrastructure investments, then the full range of benefits, external or not, may be included. Admittedly, the benefits of transportation were not adequately addressed at this conference. Indeed, many participants strongly urged that any future conference should devote equal time to understanding the full social benefits of transportation.

Just as with external costs, the existence of external benefits of transportation would tend to cause an inefficient use of society's resources. There appears to be a general consensus among transportation researchers that external benefits created by the additional use of the transportation system are negligible. (Button and Nijkamp 1994) Instances when driving or flying another mile, or shipping another ton of freight, will generate meaningful benefits for parties other than the buyer and seller of transportation services are truly minor. Therefore, there seems little reason to worry that the existing transportation infrastructure will not be adequately used because of external benefits.

On the other hand, many agree that there are significant external benefits attributable to transportation infrastructure, such as roads, railways, airports, and ports. In the United States, the major impact of transportation infrastructure improvements is on economic development. By reducing the costs of obtaining goods and services, transportation improvements increase demand, which leads to economic growth. In this way, transportation improvements confer benefits on users and nonusers alike.

There are other less direct but no less important effects. One participant noted that transportation improvements can lead to increased competition among firms in different geographical locations, producing greater economic efficiency overall. For example, reductions in transportation costs could transform the pricing policies of firms from monopolistic to competitive by removing separation in space as a barrier to competition. Also, expansion of transportation infrastructure can enhance competition among producers with fixed geographic locations and may expand competition among transport firms as well.

The completion of the Interstate Highway System, the development of a widespread network of airports, and the development of intermodal systems served to intensify competition within and among freight modes. Greater competitiveness within the freight industry facilitated the move to deregulate transport modes, leading to additional efficiency gains. "Just-in-time" production is an example of how improved transportation services can change the organization of production, permitting more efficient production practices. Research that explicitly measures the benefits of such mechanisms is scarce, however. As a result, we have few insights into how such benefits should be incorporated into infrastructure investment decisions.

Advances in transportation technology and infrastructure can enable a transformation of methods of production and consumption. The effect of the automobile on American society is undoubtedly the best known and most studied example of the transformational effect of transportation technology. Yet, there are many others, from steamships and canals to railroads to jet aircraft. Each changed not only the cost of passenger travel and freight transport but also the geography and nature of production and consumption. In the last century, canals and railroads helped open up the West, accelerating westward migration and creating opportunities for economic development.[3] In general, transportation alone does not cause change, but transportation in concert with other technologies does. Railroads, in combination with the telegraph, made it possible to direct and control business enterprises from afar, enabling the creation of the modern corporation. In the past few decades, the combination of new information technologies and transportation logistics have produced major structural changes in production, replacing inventories and buffer stocks with just-in-time deliveries of customized products produced by agile manufacturing.

The fact that a great deal of transportation infrastructure is provided by governments as a public good is sometimes a source of confusion about the existence of external benefits. Strictly speaking, because public goods are not provided by markets, any external benefits can only be external to public decisionmaking. In other words, if a government took into account the benefits to economic development from building a new road, then the benefits cannot be considered external. If a government did not, then the benefits are external. In either case, the benefits still exist. By ignoring them, however, the government is likely to build too few roads.

[3]For a detailed discussion of the role of transportation in the U.S. economy, see *Transportation Statistics Annual Report 1995*, Part II: The Economic Performance of Transportation. (USDOT BTS 1995b)

Who Pays for Transportation?

Who pays for the costs of the transportation system and who benefits are questions that have frequently led to a muddling of economic efficiency and equity issues.[4] Intuition may suggest that an efficient system for financing transportation infrastructure and charging for its use would also be a fair system, but this is not necessarily the case. There are many possible concepts of equity, but most include the notions that beneficiaries should pay a fair price for what they receive and that when damage is done to others, the perpetrators should compensate the victims. While the strategy of taxing external damages to correct for market failure is somewhat similar to concepts of equity, in general the criteria for economic efficiency and social justice are not identical. It may seem just that motorists pay the full cost of damages done by the air pollution they create. Economic efficiency, however, requires that they pay the marginal cost (the cost of damage done by the last unit of pollution produced) for every unit of pollution.

Assuming highways, airports, and other transportation infrastructure are considered public goods, it is not clear that users should always pay the full cost of these facilities. Several participants pointed out that the economically efficient provision of public goods does not require that users pay the full cost of public facilities. Rather, efficiency requires only that the correct amount and appropriate type of transportation

[4] For example, a recent study by the European Federation for Transport and Environment (Kågeson 1993) defines internalization of transportation's social costs as making those giving rise to the damage and injuries financially liable by levying commensurate taxes or other charges on them. This and several other studies (Diekmann 1995; Litman 1994; and Hook 1994) also assert that all infrastructure costs should be paid by users in order to ensure efficient supply of transportation.

be provided. Who pays for public goods can be a matter of equity, but it is not a question of efficiency. Moreover, determination of the efficient amount must take into account the willingness of all economic agents to pay, whether or not they are users. Thus, if a retail store is willing to pay for transportation improvements because demand for its products will increase, or if firms are willing to pay because labor costs will decrease, businesses' demands for transportation infrastructure must be included.

Furthermore, according to one definition of fairness (known as Lindahl fairness), all agents should be taxed according to their demand for public infrastructure, whether they are users or not. In the United States, for example, transportation user charges directly pay for about 75 percent of the expenditures on transportation by all levels of government. (USDOT BTS 1995a) In this light, using real estate or sales taxes to pay part of the cost of highways or public transport is no longer an obvious subsidy; it could possibly be a Lindahl fair charge for a public good. Much theoretical and methodological, as well as empirical, work remains to be done before these issues can be sorted out.

How one defines the meaning of costs and payments and user and nonusers can make a difference between concluding that transportation users (or beneficiaries) do or do not pay their fair share of systems' costs. European studies have shown that because of high motor fuel taxes, transportation users (defined as travelers and shippers) generally pay more in taxes than governments spend on building, maintaining, and operating highway systems. The inclusion of external costs and subsidies (the definition of which is also a topic of debate) can, however, reverse the conclusion.

Evaluating Transportation System Performance

Measures of the full social costs and benefits of transportation should inform us about the role of transportation in society in a variety of ways. Full cost and benefit measures should tell us how the system is performing: are problem areas improving, are benefits increasing? They should also inform us about the relative sizes of problems and benefits of the transportation system in general. In addition, full costs and benefits measures can be useful in understanding questions of equity—the distribution of burdens and benefits to different groups within the population. Finally, cost and benefit measures can provide critical information about the effects of public policies on the efficiency of the transportation system. As economic theory instructs, however, efficiency is determined by conditions at the margin—the costs and benefits of the next unit of transportation activity—rather than total or average costs and benefits.

The final session of the conference discussed how BTS could develop improved measures of transportation's full range of costs and benefits. BTS reiterated its priorities for improving a knowledge base to support its information gathering and analytical activities. Measures of full costs and benefits were identified as indicators of the performance of the transportation system. Three categories of indicators were highlighted as the agency's priority: 1) inputs (what goes into the production of transportation), 2) outputs, and 3) outcomes (did the outputs really achieve the desired results?). Currently, most of the data available describe the supply of transportation (the outputs). There are fewer data on the performance of transportation (the outcomes), a situation that must be remedied. In particular, better measures of the economic contribution of transportation are needed. Finally, society needs better indicators of the unintended consequences of transportation, such as injuries, deaths, and related costs, environmental impacts, and energy dependence.

Conclusion

The need to develop a better understanding of the full benefits of transportation was widely supported by conference participants. Several participants pointed out that what might be called the products of transportation have not been well defined or measured. For example, is the key output of passenger transportation mobility per se, or access to opportunities such as employment, health care, recreation, shopping and social visits? Since locational decisions have consequences for transportation and vice versa, one suggestion was that BTS work on developing accessibility and mobility measures that recognize the relationship between transportation outputs and the geographical context in which they occur.

Conference participants also generally agreed on the need to better understand and measure the transformational effects of transportation technology and infrastructure. For example, what role did investments in transportation infrastructure, such as the Interstate Highway System, jet airports, and intermodal terminals, play in increasing competition among and within transportation modes, thereby making it possible to largely deregulate transportation in the United States. Not only would it be useful to describe and measure such effects, but also to be able to predict the transformational effects of public infrastructure, research and development, and regulatory policy. The coming revolution in intelligent transportation systems, for example, is almost certain to have transformational effects throughout the economy. Is it possible to fully assess the benefits and costs of such a change without understanding its transformational effects?

The panelists agreed there was a need to clarify concepts of equity and to distinguish them from evaluations of economic efficiency. Transportation and the mobility that it provides play a critical role in enabling participation in the economic mainstream. The fact that about 11 percent of all U.S. households and an even higher percentage of black and Hispanic households (30 percent and 19 percent, respectively) do not own a motor vehicle creates a vertical inequity with respect to access to public highway infrastructure and its related benefits. (Pisarski 1996) If equity is recognized as an issue in its own right, apart from economic efficiency, then several criteria must be used to determine fairness in transportation. Whether or not transportation users pay the full cost of transportation is only one factor in determining equity.

Moreover, better information about the full costs and benefits of both transportation infrastructure and its use are likely to be critical to reaching efficient and equitable transportation decisions. Innovations in the technologies of vehicles and fuels will alter relationships between transportation activities and air pollution, noise, and other environmental impacts. Technological changes in vehicles and infrastructure will also alter relationships between travel and safety risks. Technologies now emerging could be used to implement sophisticated road pricing schemes, creating the potential for correcting inefficiencies due to externalities such as traffic congestion and motor vehicle emissions. Whatever changes occur in the transportation system, the need to consider a full range of costs and benefits in public decision-making will continue.

Around the world, transportation researchers are engaged in an ambitious effort to understand the full effects of transportation on society in order to quantify its full costs and benefits. The impetus for this endeavor derives from the significant impacts of transportation on the environment and on society and from governments' central roles in providing transportation infrastructure and regulating transportation systems. To date, most studies of full costs and benefits focus on costs rather than benefits and are predominantly concerned with issues of economic efficiency. The papers presented at this conference reflected this fact. Yet the conference also served to point researchers in new directions, recognizing that full benefits are equal in importance to full costs. Moreover, full cost and benefit measures are not only relevant to issues of economic efficiency but also are important and meaningful indicators of the overall performance of the transportation system. The conference challenged researchers to help develop the concepts and theory necessary to derive a comprehensive set of performance indicators for transportation and to create methods for measuring them.

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Papers Presented at the BTS Conference on Measuring the Full Social Costs and Benefits of Transportation

- David Anderson and Herbert Mohring, University of Minnesota, "Congestion Costs"
- Ulrich Blum, Dresden University of Technology, "What Benefits of Transportation Must Be Considered and When?"
- Mark A. DeLucchi, University of California, Davis, "The Critical Issues in Full Cost Estimation"
- A. Myrick Freeman III and William D. Shipman, Bowdoin College, "Residual Damages, Surrogate Taxes and Economic Efficiency"
- David Gillen, University of California, Berkeley and Wilfrid Laurier University, "Efficiency and Transportation Infrastructure"
- José Gomez-Ibañez, Harvard University, "Pitfalls in Defining Externalities"
- David L. Greene and Donald W. Jones, Oak Ridge National Laboratory, "Measuring the Full Social Costs and Benefits of Transportation"
- David A. Hensher, University of Sydney, "Travel Time Costs"
- Alan J. Krupnick, Resources for the Future, "Costs of Air Pollution"
- Douglass Lee, U.S. Department of Transportation, "Uses and Meanings of Full Social Cost Estimates"
- Paul N. Leiby, David L. Greene, and Donald W. Jones, Oak Ridge National Laboratory, "Social Costs of Energy"
- Ted R. Miller, National Public Services Research Institute, "Motor Vehicle Crashes"
- Emile Quinet, Ecole Nationale des Ponts et Chausees, "Full Transportation Cost Estimation in the European Community"
- Donald C. Shoup and Mary Jane Breinholt, University of California, Los Angeles, "Parking: Costs, Pricing, and Effects on Mode Choice"

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APPENDIX C

LIST OF ACRONYMS

AAMVA	American Association of Motor Vehicle Administrators
AAR	American Association of Railroads
AASHTO	American Association of State Highway and Transportation Officials
ABS	anti-lock brake system
AFV	alternative fuel vehicle
ANCA	Airport Noise and Capacity Act
ARRA	American Recycling and Reclaiming Association
ASM	available seat-miles
ASR	automobile shredder residue
ATS	American Travel Survey
AVR	average vehicle ridership
BAC	blood alcohol concentration
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
BTEX	benzene, toluene, ethylbenzene, and xylenes
BTS	Bureau of Transportation Statistics
Btu	British thermal unit
CAA	Civil Aeronautics Act
CAA	Clean Air Act
CAAA	Clean Air Act Amendments of 1990
CAB	Civil Aeronautics Board
CAFE	corporate average fuel economy
CASs	crash avoidance systems
CES	Consumer Expenditure Survey
CFCs	chlorofluorocarbons
CFR	Code of Federal Regulations
CFS	Commodity Flow Survey
CIPR	cold in-place recycling
CMSA	consolidated metropolitan statistical area
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CRM	crew resource management
CRM	crumb rubber modifier
CRS	computer reservation system
CWA	Clean Water Act

dB	decibels
dBA	A-weighted decibels
DNL	day-night noise level
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPACT	Energy Policy Act of 1992
ETBE	ethyl-tertiary-butyl-ether
EV	electric vehicle
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCI	Functional Capacity Index
FEB	former East Bloc
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
FTP	Federal Test Procedure
G-7	group of 7 large industrial economies
GATT	General Agreement on Tariffs and Trade
g/dl	grams per deciliter
GDP	gross domestic product
GES	General Estimates System
GHG	greenhouse gas
GIS	geographic information system
GVW	gross vehicle weight
GWP	global warming potential
HAPs	hazardous air pollutants
HC	hydrocarbon
HCFCs	hydrochlorofluorocarbons
HIPR	hot in-place recycling
HMA	hot mix asphalt
HOS	hours-of-service
HOV	high-occupancy vehicle
ICC	Interstate Commerce Commission
IEA	International Energy Agency
I/M	inspection and maintenance
IRI	International Roughness Index

ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITS	Intelligent Transportation System
km	kilometer
LPG	liquid petroleum gasoline
LUTRAQ	Land-Use Transportation and Air Quality
M	Richter Magnitude
MARAD	Maritime Administration
MMBD	million barrels per day
mmt	million metric tons
mpg	miles per gallon
MPO	metropolitan planning organization
MPRSA	Marine Protection, Research, and Sanctuaries Act
MSA	metropolitan statistical area
MTBE	methyl-tertiary-butyl-ether
NAAQS	National Ambient Air Quality Standards
NAFTA	North American Free Trade Agreement
NEPA	National Environmental Policy Act
NHS	National Highway System
NHTSA	National Highway Traffic Safety Administration
NIPA	National Income and Products Account
NO_2	nitrogen dioxide
NO_X	nitrogen oxides
NPTS	Nationwide Personal Transportation Survey
NTSB	National Transportation Safety Board
O_3	ozone
OAI	Office of Airline Information
O&D	origin and destination
OECD	Organization for Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
ORNL	Oak Ridge National Laboratory
Pb	lead
PCB	polychlorinated biphenyl
PM-10	particulate matter of 10 microns in diameter or smaller
PMSA	primary metropolitan statistical area
pmt	passenger-miles traveled
ppm	parts per million
ppmv	parts per million volume
PSI	pollution standards index

RAP	reclaimed asphalt pavement
RCI	Roadway Congestion Index
RECLAIM	regional clean air incentives market
RFG	reformulated gasoline
RPMs	revenue passenger-miles
RSMs	revenue seat-miles
RTMs	revenue ton-miles
RUMAC	rubber modified hot mix asphalt
SCAQMD	South Coast Air Quality Management District
SIC	Standard Industrial Classification
SO_2	sulfur dioxide
SOV	single-occupancy vehicle
SPM	suspended particulate matter
STARS	Strategic Targeting and Response System
TAME	tertiary-amyl-methyl-ether
TCM	transportation control measure
TDM	travel demand management
TIP	transportation improvement plan
TIUS	Truck Inventory and Use Survey
TMIP	Travel Model Improvement Program
TOD	transit-oriented development
TPB	Transportation Planning Board
TRB	Transportation Research Board
TRI	Toxic Release Inventory
TSA	Transportation Satellite Account
TSAR	*Transportation Statistics Annual Report*
TSP	total suspended particulates
TTI	Texas Transportation Institute
ug/m	micrograms per cubic meter
UV	ultraviolet
vmt	vehicle-miles traveled
VOC	volatile organic compounds
WATS	Warehousing and Trucking Survey
ZEV	zero-emission vehicle

APPENDIX D

U.S./Metric Conversions and Energy Unit Equivalents

U.S. to Metric

Length (approximate)

1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

Area (approximate)

1 square mile (sq yd, yd^2) = 2.6 kilometers (km^2)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)

Mass/Weight (approximate)

1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lbs) = 0.9 tonne (t)

Volume (approximate)

1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)

Energy Units (approximate)

1 British thermal unit (Btu) = 250 calories = 1,055 joules
1 calorie (cal) = 4.186 joules[a]
1 barrel of oil = 42 U.S. gallons (gal) = 0.16 cubic meters (m^3)
1 quadrillion Btu (quad) = about 170 million barrels of crude oil

[a] Exact conversion.

Metric to U.S.

Length (approximate)

1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yard (yd)
1 kilometer (km) = 0.6 mile (mi)

Area (approximate)

1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

Mass/Weight (approximate)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

Volume (approximate)

1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)

Energy

1 joule = 0.24 calorie (cal)
1 exajoule = 10^{18} joules

SOURCES: U.S. Department of Commerce, National Institutes of Standards and Technology, "Units of Weight and Measures," Miscellaneous Publication 286; and U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1994* (Washington DC: U.S. Government Printing Office, 1995), table B1, p. 360.

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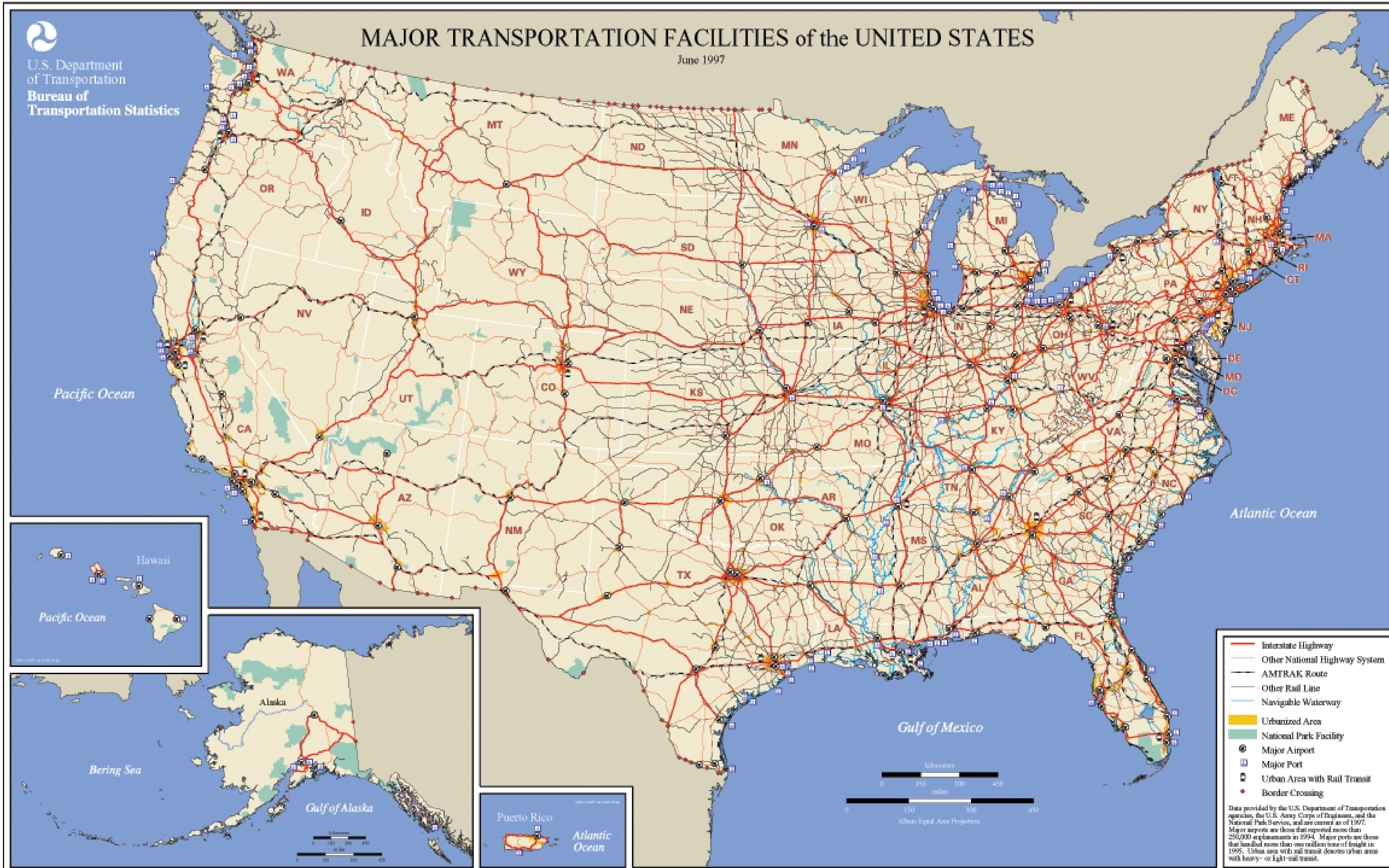
MAJOR TRANSPORTATION FACILITIES of the UNITED STATES
June 1997
U.S. Department of Transportation
Bureau of Transportation Statistics
Pacific Ocean
Atlantic Ocean
Gulf of Mexico
WA
OR
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Gulf of Alaska
Puerto Rico
Atlantic Ocean
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miles
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300
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Albers Equal Area Projection
Interstate Highway
Other National Highway System
AMTRAK Route
Other Rail Line
Navigable Waterway
Urbanized Area
National Park Facility
Major Airport
Major Port
Urban Area with Rail Transit
Border Crossing
Data provided by the U.S. Department of Transportation agencies, the U.S. Army Corps of Engineers, and the National Park Service, and are current as of 1997. Major airports are those that reported more than 250,000 enplanements in 1994. Major ports are those that handled more than one million tons of freight in 1995. Urban area with rail transit denotes urban areas with heavy- or light-rail transit.

The *Transportation Statistics Annual Report 1996* is a summary of the state of the nation's transportation systems and the state of transportation statistics. This edition includes a thematic treatment of the effects of the transportation system on the environment.

Created under the Intermodal Surface Transportation Efficiency Act of 1991, the Bureau of Transportation Statistics (BTS) is an operating administration of the U.S. Department of Transportation. BTS responsibilities include:

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