CHAPTER 3

Transportation Management and Technologies

Photo credit:American Consulting Engineers Council

Contents

Boxes

Figures

Tables

CHAPTER 3
Transportation Management and Technologies

We're repairing everything at once because they all need it.[1]

Passengers and goods can move virtually anywhere on the transportation networks in the United States. But much of the basic transportation infrastructure has been in place for at least 20 to 40 years-long enough to need substantial repair or rehabilitation, especially in heavily traveled corridors. In jurisdictions where maintenance has been neglected, deteriorated and congested rail, highway, water, and air facilities slow travel, hinder national productivity, and increase costs. In many metropolitan areas, complete corridor reconstruction or major modification will be required to ensure safety, alleviate congestion, and improve intermodal connections.

Federal responsibility for transportation rests on the government's constitutional mandate to support interstate commerce and provide for the public safety. Transportation infrastructure includes highways, bridges, rail and bus transit systems, freight and passenger railroads, ports, waterways, airports, and airways. Federal assistance for this infrastructure has always been modally oriented, with separate programs providing assistance for intercity passenger rail; mass transit; bridges, highways, and highway safety; water; maritime shipping; and aviation. The Federal agencies that oversee transportation programs are, for the most part, in the Department of Transportation (DOT), although the U.S. Army Corps of Engineers has primary responsibility for harbor dredging and the condition of inland waterways.

Most State DOTS were originally formed to administer Federal highway programs during the 1960s. During the 1980s, State DOTS expanded and diversified, taking on additional responsibilities as Federal infrastructure programs shrank. State spending for transportation rose from $22 billion to $39 billion,[2] and many DOTS took on some responsibility for airports and mass transportation; some States now aid ports and railroads as well. (See table 3-1 for the major transportation components and figure 3-1 for the share of passenger and freight transportation for each mode.) However, highway departments still dominate State DOTS, and almost all administer and finance transportation programs by separate modes to be compatible with Federal grant programs. Counties and local governments are also important players in operating, managing, and financing transportation infrastructure, particularly roads and airports. Finally, quasi-public, independent, regional authorities operate many major ports and airports.

With so many different entities responsible for different aspects of transportation infrastructure, it is understandable that the transport system does not always function smoothly. This chapter outlines the issues and problems that characterize the present national transportation system and describes the status of management and technologies specific to each transportation mode. It also identifies changes to Federal programs and other approaches that could make the system work more efficiently and productively.

Transportation Issues

Fast, convenient travel for passengers and cargo depends on a well-maintained, smoothly functioning intermodal system with the capacity to handle most of the demands placed on it. Yet, historically, Federal planning, funding, regulation, and policy support in the United States have fostered competitive, modal systems. Modal interdependence, inequalities in maintenance practices, and traffic bottlenecks (capacity problems) that affect total system performance are not addressed in Federal grant programs. Intermodal data collection, planning, and coordination are largely ignored, and successful efforts to integrate land-use planning and transportation requirements are rare.

Because institutional frameworks and funding policies vary for each mode, substantially different

[1] Lucius J. Riccia, New York City transportation commissioner, ss quoted in Andrew L. Yarrow, "Late Repairs Increase Traffic Jams in Region," New *York Times,* Sept. 24, 1990, p. A-1.

[2] U.S. Department of Transportation Economic Studies Division, *Federal, State and Local Transportation Financial Statistics, Fiscal Years 1978-1988* (Washington, DC: March 1990), p. 24.

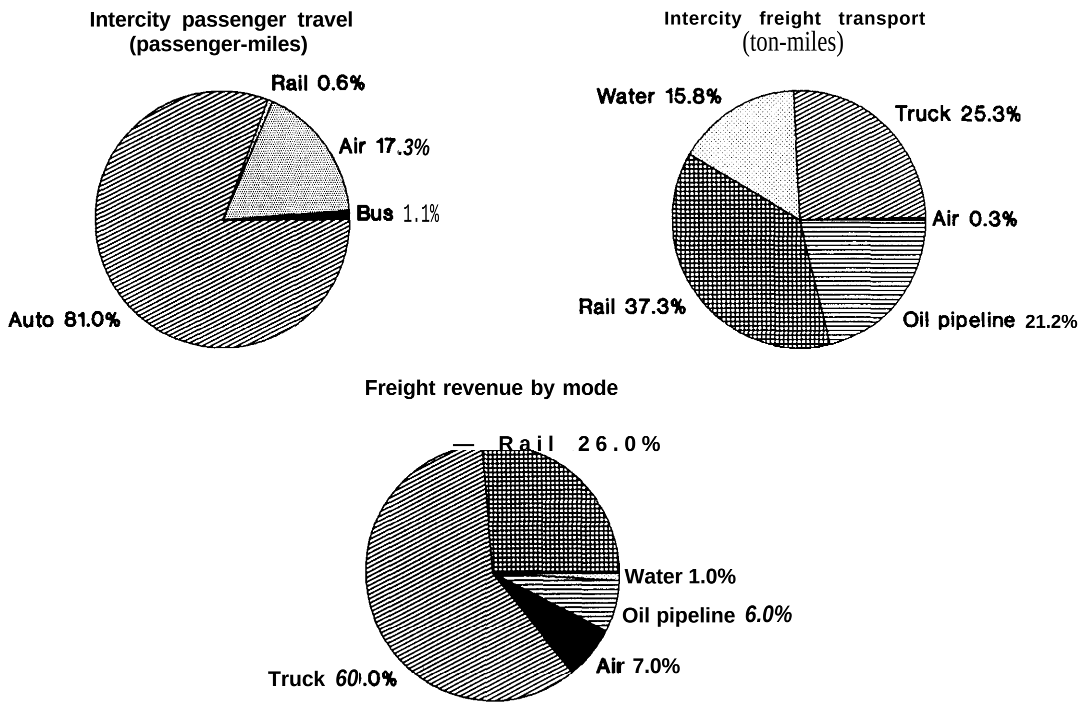
Table 3-l—Transportation System Characteristics

Mode	Major components	Facilities	Vehicles	Traffic volume: Passengers (billions of passenger-miles)	Traffic volume: InterCity freight (billions of ton-miles)
Highways	InterStates	43,000 miles	144,375,000 cars and taxis	1,445	712
	Principle arterials	138,000 miles	42,524,338 trucks		
	Total public roads	3,874,000 miles	615,669 buses		
Airports and airways	Public airports	5,680 airports	5,028 commercial aircraft	351	9
	Private airports	11,647 airports	209,500 private aircraft		
	Airways	384,691 miles			
Mass transit systems	Motor bus	2,671 systems	60,388 buses	41	N/A
	Rapid and light rail	27 systems	11,370 railcars		
	Commuter rail	12 systems	4,649 raiicars		
	Demand response	2,582 systems	16,100 vans, minibuses, etc.		
Railroads	class I	141,000 miles	Freight:	13	1,048
	Regional	16,000 miles	1,239,000 freight cars		
	Local	15,000 miles	19,647 locomotives		
	Switching/terminal lines	4,000 miies	Amtrak:		
	Amtrak	700 miies[a]	1,742 passenger cars		
			312 locomotives		
Waterborne	Ports	177 deepwater ports	754 U.S. flag vessels	N/A	438[b]
		175 shallow pOrtS	5,188 tows and tugs		
	Harbors	757 commercial harbors	31,089 barges		
	Inland waterways	178 loals			
		25,777 miles			

[a]Amtrak also includes 23,000 miles of leased track.
[b]Domestic ton-miles only; about 2 billion tons of cargo transfer through U.S. ports.

SOURCE: Office of Technology Assessment, 1991, based on a variety of data summaries.

Figure 3-l-Passenger and Freight Travel, by Mode



SOURCE: Office of Technology Assessment, 1991, baaed on information provided by the U.S. Department of Transportation and the Eno Foundation.

infrastructure problems characterize each model portion of the transportation system (see table 3-2). Details relating to these difficulties are provided later in this chapter in the appropriate modal sections. However, a number of issues are applicable to the system as a whole.

Intermodal Transport

Efficient intermodal operations have become critical to shippers, many of whom rely on ‘just-in-time” deliveries made possible by speedier and more consistent door-to-door service. Freight transfers between ship, truck, rail, and barge involve physical challenges, such as loading, unloading, and storage of cargo, as well as complex intercompany, interjurisdictional, and even international agreements. Industry has addressed many of these challenges through innovations. Containers permit cargo transfer between modes without repackaging, and automatic equipment identification, electronic data interchange, electronic fund transfers, and computer-aided operations all speed freight movements.

Intercity travelers and urban commuters also use multiple modes for daily commutes, business trips, and vacations. Because passengers and freight moving through airports, marine ports, and rail stations rely on trucks and automobiles for most connections, traffic jams on local roads are often key sources of delay.

Congestion problems increase personal trip times, hurt productivity, and add to industry and individual costs. However, the fractured transportation management framework makes successful programs to combat congestion extremely difficult to develop and implement. To a large extent, surface traffic congestion problems are products of decisions made by governments and individuals and are outside the control of a single industry or level of government. During the 5-year period from 1982 to 1987, traffic congestion in our major cities, as measured by volume of traffic per lane of travel, increased by an average of 17 percent.[3]

More effective, comprehensive regional transportation and land-use planning spanning modes and jurisdictions is essential to efficient intermodal

[3] OTA calculation based on Texas Transportation Institute, “Roadway Congestion in Major Urban Areas 1982 to 1987,” Research Report 1131-2, 1989.

Table 3-2—Major Issues and Problems in Transportation Public Works

Transport mode	Condition	Capacity	Environment	Management and investment
Highways and bridges	10 percent of roads and 42 percent of bridges rated deficient.	Congestion and delays increasing in many urban and suburban areas; excess capacity in rural areas.	Air quality; land use; noise.	Life-cycie management needed; large capital investment would be required to expand urban roadways to meet demand-a temporary solution, at best.
Mass transit	Structural deterioration of rail systems in older urban areas.	Excess capacity available in most rail and bus systems.	Bus emissions.	Roadway management enhancement needed to improve bus transit; life-cycle management and financing for rail transit; little recent R&D investment.
Rail	Generally good for large railroads, problems due to deferred maintenance on some regional and shortline railroads.	Excess capacity on most lines.	Waste disposal on Arntrak trains; noise and land use for high-speed trains.	Federal operating subsidies for Amtrak; Amtrak capital equipment needs.
Ports and waterways	With a few exceptions, locks, dams, protective works, and channels are generally in good rendition.	Locks are the bottlenecks on the iniand waterways; delays can exceed 2 days at a few locks.	Dredging and dredged material disposal; noise, land use, and surface traffic problems at ports.	Transportation users, especially on the inland waterways, require much greater General Fund subsidy than other transport modes; no cost sharing by nontransportation beneficiaries of navigation projects.
Airports and airways	The condition of airport and airway facilities rarely impedes traffic.	The number of available runways at the busiest airports is the greatest capacity constraint. The staffing levels and technological capabilites of certain airway sectors can be sources of delay.	Aircraft noise in communities surrounding airports; surface traffic congestion due to airports.	Constructing new airports or physically expanding existing airports will be difficult for most immunities. Technology advances could effectively expand existing capacity by up to 20 percent.

SOURCE: Office of Technology Assessment, 1991.

Photo credit: American Consulting Engineers Council

Intermodal operations of all kinds have long characterized ports. Increased international trade and just-in-time delivery have made intermodal transport essential for many shippers and air, land, and water carriers.

travel. Using double-deck railcars or increasing vehicle frequency to expand mass transit capacity is useless unless intermodal connections, such as bus feeder lines and suburban park-and-ride lots, are provided. The program described inbox 3-A typifies the kinds of major improvements needed to facilitate intermodal transportation.

Physical Condition

The condition of any part of transportation infrastructure reflects management and investment decisions-planning, design, construction, operations, maintenance, and rehabilitation--that span a system's lifetime, or "life cycle. " The waterway and airway systems are generally in good condition because the Federal Government has primary responsibility for them and manages and maintains the systems as investments. Systems for which a number of separate governmental or private entities share responsibility, such as highways, bridges, and railroads, are much more likely to have major segments in poor condition, usually because of neglect due to fiscal constraints felt by one or more of the owners.

Capacity

The present transportation system in the United States has plenty of excess capacity-but it is **not** available on the busiest routes and at terminals at the times most people want to travel. Transportation demand fluctuates across time and location, and periods of heavy demand create what are called "peaking" problems. To ensure adequate capacity, infrastructure must be designed and built to accommodate traffic volumes somewhat greater than average, However, since facilities can rarely be built to be both cost-effective and large enough to handle smoothly the greatest "peaks,' designs reflect a trade-off between costs of delay and congestion and costs to build, operate, and maintain the infrstructure.

Most infrastructure for transportation is supplied and managed by the public sector. When demand exceeds supply, delays and safety problems occur

Box 3-A—Intermodal Transportation Improvements in Southern California

The proposed Alameda Corridor Transportation Authority (ACTA) project in southern California is a $500-million program[1] of highway and railroad improvements that will facilitate freight movement between the Ports of long Beach and Los Angeles and downtown Los Angeles, where rail yards of three major carriers--the Union Pacific, Southern Pacific, and Santa Fe Railroads-are located TIM project is intended to improve port access and mitigate the impacts of port-related traffic on highway congestion, air pollution, grade crossing delays, and train noise in residential areas. It will involve construction of double tracks for the main rail line between the ports and downtown, grade separations, and street widening along a route running parallel to the rail line. On-dock, ship-to-rail container loading facilities will be expanded to reduce truck traffic out of the ports. ACTA officials estimate that the rerouting of trains of all three carriers onto a single double-track corridor and the elimination of grade crossings will bring a 90-percent reduction in train-related traffic delays, or a total of about 6,300 vehicle-hours per day.

The improvements will be carried out under ACTA, a joint powers authority that consists of representatives of some 13 local, regional, and State agencies. Over $300 million of the total cost will be sought from Federal highway funds. State contributions, totaling $80 million in bond issues, and funds from the Los Angeles County Transportation Commission, the railroads, and the ports will cover the balance of the cost of the project.[2]

The Port of Long Beach's $80-million Intermodal Container Transfer Facility (ICTF), whose sole operator is the Southern Pacific Railroad, provides a fine example of technology's role in making freight transport more efficient. The ICTF brings together elements of electronic data interchange and computer control of rail yards to expedite the movement of containers and the makeup of stack trains, and nearly every facet of the facility's operations is overseen by computers. Computers in the control tower are linked with those of ocean vessels, so that the yard's computer receives information about each container before it arrives at the Long Beach or Los Angeles Ports. As containers are trucked into the yard from the ports, drivers are directed to the proper areas for container inspection and parking. Yard tractors are equipped with mobile computer units to allow location and status updates for containers and ensure that time-sensitive stack trains are efficiently assembled and dispatched.

[1] Much of the information on the Alameda Corridor Transportation Authority program is derived from "Southern California Consolidated Transportation Corridor" informational document, May 1990.

[2] Leland R. Hill, managing director, Planning & Engineering, Port of Long Beach, personal communication Nov. 16, 1990.

and congestion (especially on highways) is likely to create air quality problems. If the delays worsen and persist, officials look for a way to expand capacity. Building new structures to meet growing demand has been an attractive cost-effective option, in terms of direct costs for land, materials, and labor. However, this is no longer true in many of the country's largest urban areas, where congestion is most severe. For a variety of reasons-large upfront capital expenses, insufficient land where the need is greatest, and community opposition to the expected impacts on the environment and quality of life—States and localities plan to build few new highways, airports, or waterways.

About 20 percent more traffic capacity could be squeezed out of the existing roadways, airports, and waterways[4] by implementing near-term technology developments, discussed later in this chapter. However, traffic demand at many busy airports and highways is expected to outpace the capacity gains possible through technology.

Managing Demand

Better management is another way to increase the capacity of the existing system. Reducing peak-hour trips, minimizing the inefficient mixing of vehicle types; and carrying more passengers or cargo per trip by increasing the average vehicle capacity are all possibilities. These changes could be encouraged by enhancing alternative networks to draw traffic away from busy facilities, by rationing access to overcrowded facilities during peaks, and by charging differential prices to reflect more closely the full costs of congestion and delay.

Shifting demand away from peaks to underused times, locations, or other transport modes is a first step toward reducing delays due to overcrowding; in congested areas, where the network is close to

[4] The Army Corps of Engineers estimates a range of capacity increases of 5 to 10 percent for small-scale improvements to 30 percent or more. See U.S. Army Corps of Engineers, Institute for Water Resources, "The U.S. Waterway System: A Review, " unpublished report, April 1989, p. 26.

Table 3-3-Federal Transportation Trust Fund Summary

Trust fund	Date established	Revenue sources
Highway Trust Fund:		
Highway account	1956	Taxes on gas and diesel fuels and tire sales.
Transit account	1982	A share of the Highway Trust Fund gas tax.
Airport and Airways Trust Fund	1971	Taxes on airline tickets, way bills, aviation fuels, and international departures.
Inland Waterway Trust Fund.	1978	Taxes on marine fuels.
Harbor Maintenance Trust Fund.	1986	Taxes on the value of vessel cargo.

SOURCE: Office of Technology Assessment, 1991.

saturation, small reductions or shifts in demand can prevent many delays. Financial demand management mechanisms, such as quotas or differential pricing, raise costs to users and create issues of social and economic equity that are hard to resolve. These forms of demand management often generate heated protests when they are introduced, because travel patterns are closely coupled to home and work sites, normal working and sleeping hours, and established and familiar costs, such as parking fees.

Providing alternatives to conventional travel is another possible way to change demand. New technology possibilities include a system of tiltrotor aircraft that would not compete for conventional airport infrastructure, and high-speed rail or magnetic levitation rail, which could match airline service at distances up to approximately 500 miles. However, with the exception of high-speed rail, which is now operating successfully in several foreign countries, alternative transportation technologies are still under development. Even if shown to be cost-effective, new technologies will not be ready for public use for at least another decade.

Environmental Issues

The environmental impacts of transportation systems, such as some forms of air pollution and aircraft noise, freely cross political boundaries. Consequently, decisions about financing and managing infrastructure projects, usually made by individual jurisdictions, often do not adequately address environmental concerns. Issues such as alternative fuels for reduced emissions, higher occupancy vehicles, and land-use planning conducive to environmentally sound transportation must be jointly debated and discussed by all the affected jurisdictions.

The financial trade-offs of improvements to transportation systems required for environmental protection are not easy to calculate, yet such understanding is essential for long-term planning. Public transportation officials must soon make decisions about alternative fuels for transit buses, because of the U.S. Environmental Protection Agency (EPA) emission standards for diesel-powered, heavy duty buses. Concerns over the environmental effects of dredging and dredged material disposal already limit channel maintenance and expansion options, especially for harbors and ports in metropolitan areas. Noise is a problem for transport operators across all modes, but is especially serious for airports and airlines. Community groups fighting to curb the noise of airport operations have restricted present operations and blocked growth in some instances, limiting airport development across the country.

System Management and Financing

Transportation networks provide enormous benefits to the national economy. However, Federal fisca1 policies-general fired subsidies, grant matching requirements, trust fund spending restrictions, and other revenue options-are developed and applied by mode and often work against economical system investment and management. Much of the Federal capital spending for transportation infrastructure is managed through trust fired accounts established by Congress for highways, transit, airways, harbors, and inland waterways (see table 3-3). To ensure that federally financed transportation programs are user supported, trust funds are credited with revenues from dedicated user fees and excise taxes, and the balances serve as the basis for Federal spending authority. For example, in 1989 the Highway Trust Fund was credited with $13.6 billion, raised primarily from gas taxes, and $14.3 billion was spent on capital projects. Unlike mandatory entitlement trust funds, such as social security, transportation fired balances cannot be spent without being budgeted and appropriated.[5] Thus the annual transportation spending agendas must compete with other Federal priorities. Over the last decade, the highway, transit, and airways accounts have built up substantial balances, which transportation supporters claim should be appropriated now to address the Nation's large backlog of needs. However, despite recent increases in Federal fuel taxes and other transportation user fees, expenditures from these trust accounts, which are part of the unified Federal budget, will be limited by the domestic spending ceilings imposed in the 1990 deficit reduction package.

Federal program management does little to promote efficient use of transportation systems. In its almost quarter century of existence, DOT has never successfully transcended the autonomy of its separate modal divisions (see figure 3-2) to establish a leadership or coordinating role for multimodal, system-based programs. System-based, State and local investment and management policies and institutions are lacking too. As one example of the types of problems that result, ports both contribute to and suffer from surface traffic congestion, air pollution, and disputes caused by oversize and overweight container shipments. But ports are often independent authorities, and their shipments usually involve interstate commerce, making it hard for State or local governments to affect them. Few examples of successful intergovernmental mechanisms for setting policies or developing and funding programs to address such problems can be found.

Technology and Management Tools

A number of technologies are available for managing infrastructure maintenance and rehabilitation, alleviating traffic congestion and increasing capacity, and prolonging structure life. Many of these technologies are described in chapter 5. Those with the most promise for transportation include computerized inventory management and decision support tools, sensors for condition assessment and transponders for communication and flow control, and a variety of materials for construction and rehabilitation and construction techniques. Despite their availability, however, new technologies are not in widespread use in public works, and technical advances in equipment and software far outstrip the skills and financial resources available to most State and local public works operators.

Surface Transportation Networks: Highways and Bridges

Roads and bridges are key to moving people and goods; indeed every traveler and freight item travels by highway for at least part of almost every trip. Motor vehicles account for roughly 10 times as many person-miles of travel as all other transportation modes combined, and trucking accounts for over 80 percent of all domestic freight revenues and 25 percent of all the ton-miles of domestic freight.[6]

Management and Financing: Who Owns, Pays for, and Operates What

Counties and local jurisdictions own and manage the lion's share of roads and bridges, while States own and administer Interstates, most arterial roads, and one-third of collector roads. The few Federal roads are almost exclusively on Federal property, such as national parks and forests.[7] About one-half of total national spending for roads (about $69 billion in 1988)[8] is provided by States and about one-quarter by local governments. More than three-quarters of the almost 3.9 million miles of public roads that now lace the country had been built by 1920, although less than 15 percent were paved. Even today, 1.7 million miles of road remain unpaved.

All Interstate miles and 97 percent of other arterial route-miles are considered part of the Federal-aid system and are eligible for Federal funding aid for development and maintenance. See figure 3-3 and table 3-4 for further information about funding and road characteristics. Federal-aid funding from the Highway Trust Fund, about $14 billion annually, represents around one-quarter of total road spending. Of the nearly 577,000 bridges in the United States,

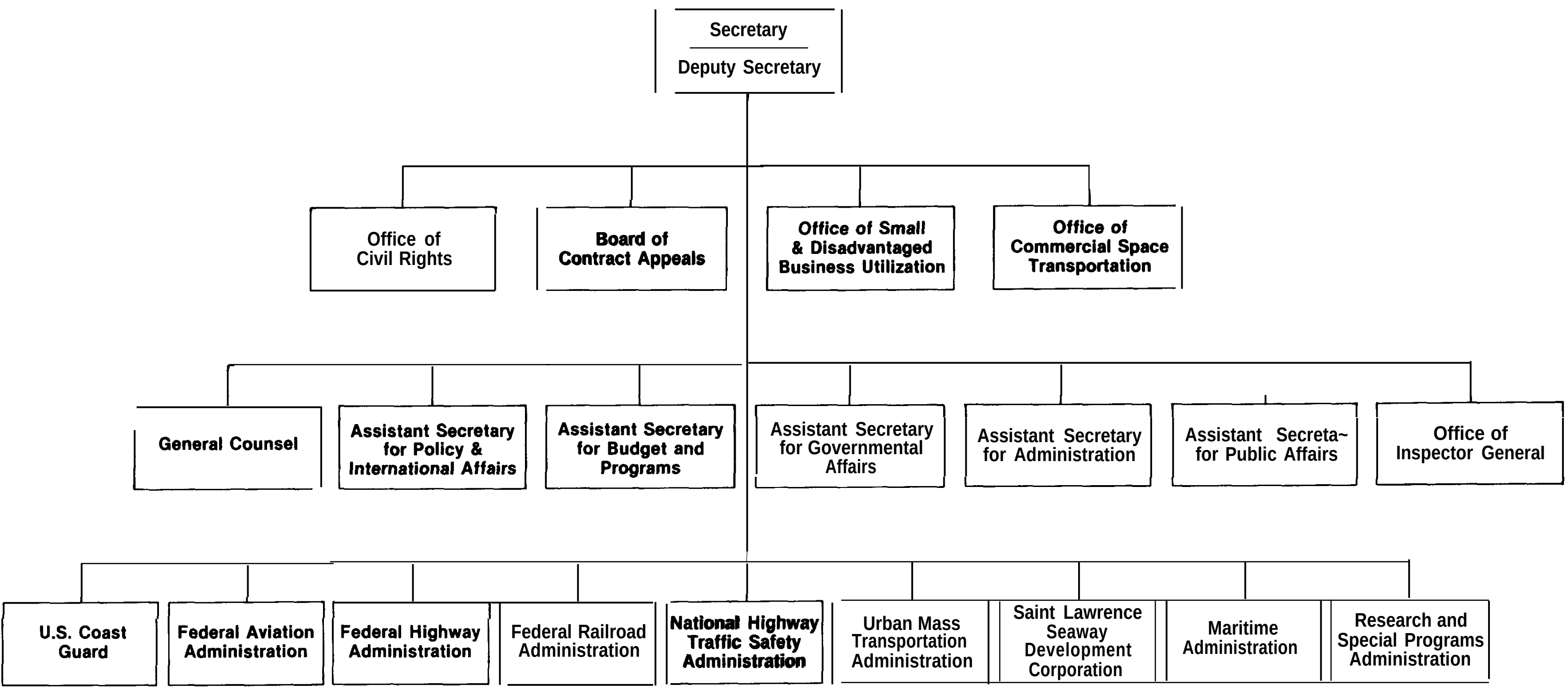
[5] John Hornbeck, *Transportation Trust Funds: Economic and Policy Issues* (Washington, DC: Congressional Research Service, September 1990), p. 2.

[6] National Council On Public Works Improvement, *Highways, Streets, Roads and Bridges* (Washington, DC: May 1987), p. 55.

[7] U.S. Department of Transportation, Federal Highway Administration, *Highway Functional Classification-Concepts, Criteria, and Procedures* (Washington, DC: March 1989).

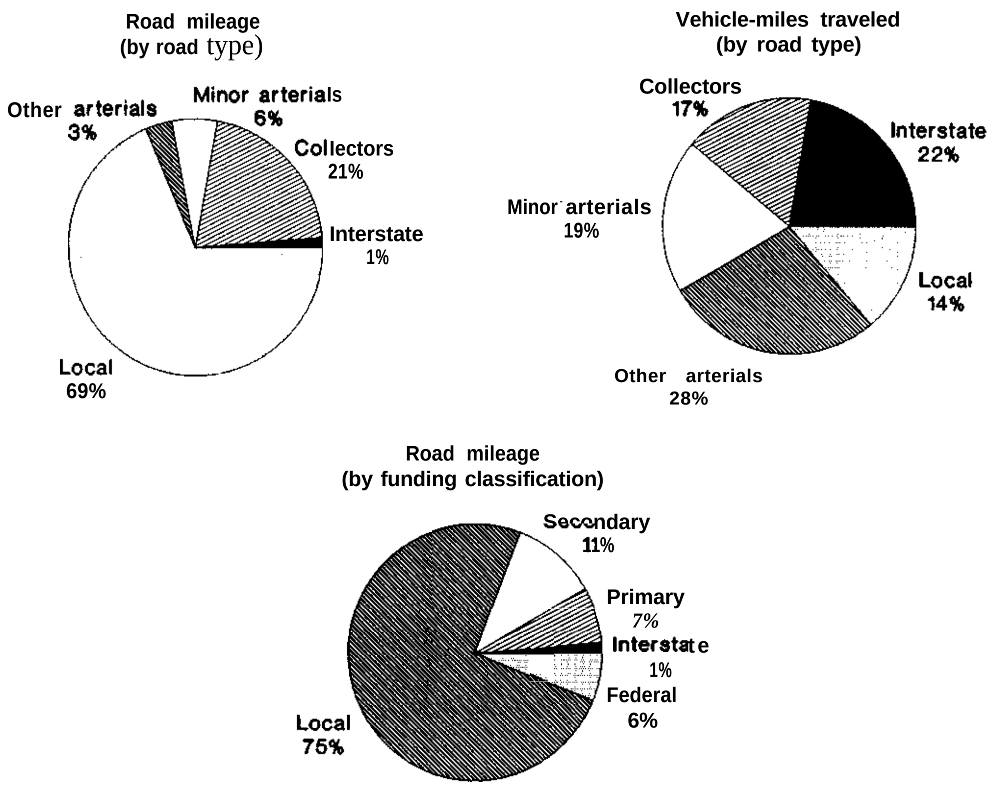
[8] U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1988* (Washington, DC: 1989), p. 38.

Figure 3-2—US. Department of Transportation



SOURCE: U.S. Department of Transportation, 1990.

Figure 3-3-Characteristics of the Nation's Road System



SOURCE: Office of Technology Assessment, 1991, based on information from the U.S. Department of Transportation,

almost 275,000 are on Federal-aid roads, with the remainder on off-system roads.[9]

State highway officials administer a wide variety of State-funded programs and, with the Federal Highway Administration (FHWA), the Federal-Aid Highway Program. States allocate about 60 percent of all highway outlays, construct and maintain about 22 percent of the Nation's highway mileage and 43 percent of the bridges,[10] disperse Federal and State funds to local jurisdictions, and enforce construction standards and grant conditions. All States levy motor fuel taxes; in 1990, the average gas tax was 16 cents per gallon. During the 1980s, 47 States increased their levies—some more than once. Most, but not all, States dedicate this revenue to transportation purposes, and their officials view the large balances in the Federal Highway Trust Fund with anger, believing the Federal Government is withholding these dedicated highway user fees for general budget balancing purposes.

Issues

Local governments design, construct, and maintain the vast majority of the Nation's roads and bridges,[11] and virtually every jurisdiction has a large backlog of road and bridge maintenance and repair needs. These are particularly acute in large, older cities where infrastructure is heavily used and many structures have long since reached the end of their design lives; in New York City, for example, more traffic lanes will be closed for repairs than will be reopening under a rehabilitation program that will

[9] Ibid., p. 134.

[10] National Association of Counties, *Linking America* (Washington, DC: 1989), P. 8.

[11] U.S. Department of Transportation, Federal Highway Administration, *Our Nation's Highways—Selected Facts and Figures* (Washington, DC: 1987), p. 4.

Table 3-4-Highway Mileage and Funding Statistics

Road classification	Miles	Jurisdiction	Capital funding	Maintenance funding
Interstate System[a]	44,000	State	90% Federal 10% State	1OO% State
Federal-Aid Primary System[b] (excluding Interstate)	260,000	State	75% Federal 25% State	1OO% State
Federal-Aid Secondary System[c]	400,000	State	75% Federal 25% State	100?40 State
Federal-Aid Urban System[d]	125,000	State	75% Federal 25940 State	100% State
Local roads[e]	2,751,000	Counties, municipalities, and townships	Not eligible for Federal aid	Local and State
Federal roads[f]	226,000	Federal	100% Federal	100% Federal

a Routes that connect principal metropolitan areas, serve the national defense, or connect with routes of continental importance in Mexico or Canada (subsystem of the Federal-Aid Primary System).
b Interconnecting roads important to interstate, statewide, and regional travel.
c Major rural collectors that assemble traffic and feed to the arterials.
d Urban arterial and collectors routes, excluding the urban extensions of the major primary arterials.
e Residential and local streets.
f Roads in national forests and parks; roads on military and Indian reservations.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, Highway Statistics *1988* (Washington, DC: 1989); and U.S. Department of Transportation, Federal Highway Administration, Our Nation's *Highways: Selected Facts and Figures* (Washington, DC: 1987)

Photo credit: American Society of Civil Engineers

Road and bridge maintenance needs are particularly acute in large, older cities such as New York where infrastructure is heavily used and many structures have passed the end of their design lives.

take 10 years to complete.[12] However, extensive physical rehabilitation is needed on the entire highway system—rural and urban segments alike.

Over 10 percent of the Nation's roads have enough potholes, cracks, ragged shoulders, ruts, and washboard ridges to be classified as deficient; heavy axle weights, such as those of large trucks, and the stresses caused by freezing and thawing of harsh weather are the major causes of pavement damage.[13] Nearly 42 percent of the Nation's bridges are rated as unable to handle traffic demand or structurally deficient (see figure 3-4); costs for repairing and replacing these are estimated at $67.6 billion.[14]

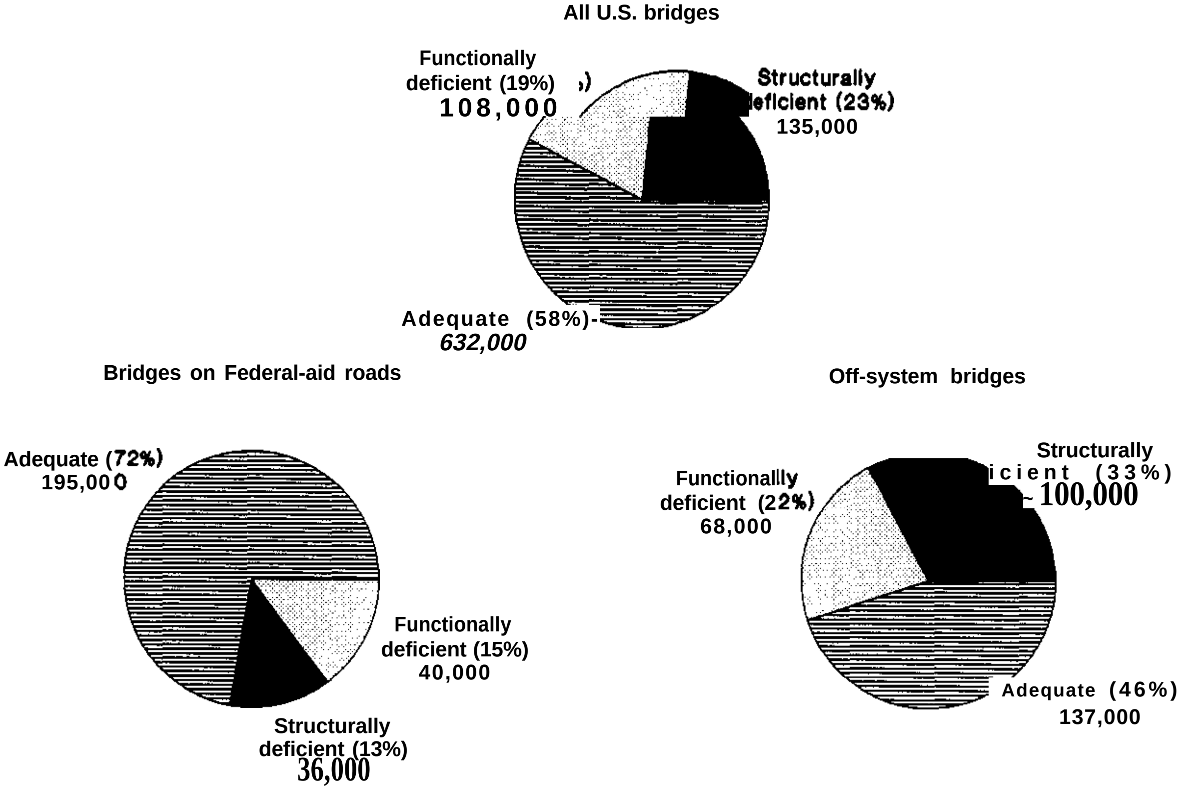
Maintenance is an easy budget item to defer in every jurisdiction when resources are low. However, if maintenance is put off for too long, simple procedures are no longer adequate, and more extensive and costly work becomes necessary. FHWA administers five major highway grant programs (interstate, interstate 4R, primary, and urban and secondary), which can provide up to 75 percent of the funds for construction/reconstruction and rehabilitation of Federal-aid highways. Despite this availability, less than 25 percent of Federal highway obligations have been used for these purposes (see

[12]Yarrow, op. cit., footnote1.

[13]Transportation Research Board, *Truck Weight Limits: Issues and Options, Special* Report 225 (Washington, DC: 1990), p. 27.

[14]U.S. Congress, House Committee on Public Works *and* Transportation, *The Status of the Nation's Highways and Bridges: Conditions and Performance and Bridge Replacement and Rehabilitation Program,* Report of the Secretary of Transportation to the United States Congress (Washington, DC: U.S. Government Printing Office, June 1989), p. 121.

Figure 3-4-Physical Condition of U.S. Bridges



SOURCE: U.S. Department of Transportation, The Status of fhe Nation's Highways *and Bridges* (Washington, DC: June 1989).

figure 3-5) over most of the past decade.[15] In fact, of all the money all levels of government spend on highways annually, only about one-quarter goes to maintenance and repair.[16]

Costs for rehabilitation and maintenance fall most heavily on large, rural States because of their extensive mileage and low populations. They must maintain miles of lightly traveled roads and numerous bridges to standards that accommodate heavy agriculture loads, although such heavy vehicles may use the system only a few weeks a year.

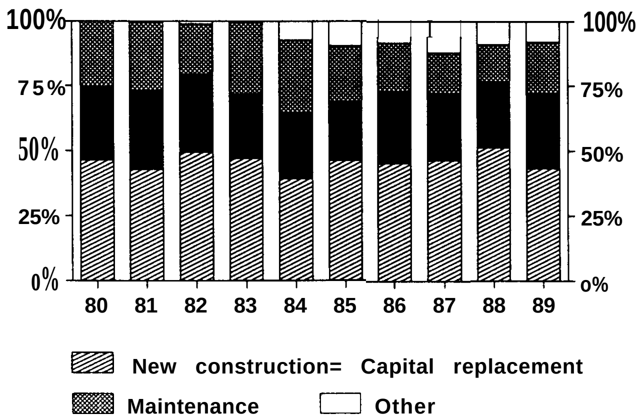
To be eligible for Federal aid, local street and bridge projects must conform to categorical grant requirements. With a few exceptions, Federal funds focus on capital projects, precluding their use to fund preventive maintenance and traffic management improvements, such as upgraded signals, ramp metering, and real-time traffic monitoring, that could reduce congestion. Because Federal funds contribute substantially to State and local highway budgets, it is not unusual for project priorities to be tailored to fit Federal-aid categories or for reconstruction and maintenance to be deferred because money is short or Federal aid is not available.

Hard pressed to finance road improvements, local governments have turned to dedicated portions of State gasoline and sales taxes, seeking greater State and Federal support, and in some cases, private sector partners. Denver's limited access, circumferential highway, E-470, now under construction, provides an example of the potential for non-traditional means of highway financing, such as right-of-way dedication, tolls, and earmarked vehicle registration fees. Such broad-based financing concepts and public-private partnerships are likely to be tried more often in the future, because of the keen competition among government programs for funds.

[15] John Hombeck, *Maintaining Highway and Bridge* Investments: *What Role for Federal Grant Programs?* CRS Report 90-227 *E* (Washington, DC: *Congressional* Research Service, May *31,* 1990), pp. *4-8.*

[16] OTA calculations based on Federal Highway Administration, op. cit., footnote 8, pp. 40, 165-168.

Figure 3-5-Federal Obligations for Interstate, 4R, Primary, Secondary, and Urban Programs, by Improvement Type



SOURCE: Congressional Research Service from Federal Highway Administration. See Congressional Research Service, *Maintaining Highway and Bridge Investments: What Role for Fe&al Grant Programs?* (Washington, DC: 1989.)

Loca1 roads serving regional needs frequently fall victim to differing local, State, or Federal management goals and responsibilities, or their planning and financing become stalled by interjurisdictional squabbles.[17] Furthermore, because Federal and State grants are allocated by mode, communities have little incentive to seek intermodal solutions to areawide transportation problems. Weak land-use planning and development controls further compound congestion problems. While new technology can bring some short-term solutions, changes in land-use management and development patterns, lifestyles, and institutional arrangements are likely to be required for long-term solutions in regions where congestion problems are severe.

Technologies for Highways and Bridges

Technologies can make substantial contributions to addressing congestion and capacity problems and to bringing the physical condition of the highway system to a satisfactory level. If money is available to purchase equipment, and personnel are trained to operate and maintain them, the technologies described below can bring major benefits.

Keeping the System in Good Condition

Keeping pavements and bridges in good condition requires collecting information, careful management, investment in appropriate and durable equipment and materials, and adequately trained personnel. Management and information systems are essential planning and resource allocation tools. Decisions about materials and construction are also key to maintaining a healthy road system.

Pavement and Bridge Management Systems-The essential components of any pavement or bridge management system include data collection and processing, techniques or models for pavement performance prediction, and setting priorities for resource allocation. Most current State pavement management systems resemble that used in North Carolina and its municipalities. This includes visual pavement inspection by trained professional evaluators of the entire paved street system, from a vehicle traveling at about 10 miles per hour. Both State and local evaluators record pavement condition according to the same, well-defined levels of distress.[18] Municipalities use the results to set priorities for engineering investigation, testing, maintenance, and resurfacing. The system helps to set priorities for limited funds and facilitates exchange of technology, information, and training programs.

A somewhat more automated pavement management system, developed by the Army Corps of Engineers, has the capability to store inventory and inspection data, analyze pavement condition, predict future pavement condition, compare costs of maintenance and repair, and plan budgets. It is available for use by public works officials.[19]

Advances in electronic sensors and system management software permit automated data collection and analysis, and these technologies have great potential to speed up and standardize the condition assessment process and help set priorities for repair. Several States have programs utilizing them (see box 3-B). However, when more data are collected, more powerful data management tools and special-

[17] John Gunyou, city finance officer, Minneapolis, MN, personal communication, June 21, IWO.

[18] James B. Martin, "Pavement Management for North Carolina Municipalities," *Transportation Research Record 1200* (Washington DC: National Research Council, 1988).

[19] U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, "Micro Paver Pavement Management System," informational document, May 1989.

Box 3-B—Video Technology and Pavement Management

Since the early 1980s, the Connecticut Department of Transportation has used a pavement survey van equipped with a movie camera to record images at regular distance intervals (100 pictures per mile) on all 7,600 miles of State-maintained road. This process, known as photologging, produces a film of the entire road network which is then developed, producing some 760,000 images, and transferred to videotape. Images from the videotape are then transferred onto 15 double-sided laser videodiscs. Connecticut has developed an image retrieval system that allows any desired stretch of road to be examined on a video monitor to determine pavement distress. When correlated with road geometry and roughness data which is collected simultaneously with the same pavement survey van, this information provides highway engineers with a complete database to use in setting priorities for road maintenance.

Connecticut's surveys are conducted annually and take about 4 months to complete. The State has found that photologging saves gas, makes more efficient use of labor, eliminates much of the need for field inspections, and provides better pavement ratings than its previous method, which consisted of 4'. . . two people riding in a seal@ at 40 miles per hour jotting down general impressions. . ." of pavement quality.[1] Other States pursuing videodisc technology for pavement data acquisition and retrieval include Minnesota, Iowa, Utah, Texas, and Wisconsin. Future efforts will focus on eliminating the need to use movie cameras or video cameras and writing data directly onto disc.

[1] John Hudson, photolog supervisor, and Richard Hanky, transportation senior engineer, Connecticut Department of Transportation, personal communications, Nov. 8, 1990.

ized personnel and expertise become necessary,[20] and these are beyond the resources of many State DOTS.

Bridge Inventories—Investigations into the collapse in 1967 of the Silver Bridge between West Virginia and Ohio, which killed 46 people, revealed a lack of uniform reporting standards for bridges and a need for a national inventory of bridges, improved inspection standards, and inspection training procedures. While a national bridge inventory that includes condition ratings is now in place, recent bridge failures have demonstrated that significant inspection, maintenance, and repair issues must still be addressed (see box 3-C).

Computerized bridge inventory systems can coordinate bridge condition analyses, set priorities, and budget for maintenance and repair. For example, the bridge inventory for Texas is a database that includes 140 different entries for each bridge. The data help the engineers determine a sufficiency rating for every bridge in the State, and those that are classified as deficient are eligible for FHWA funds.[21]

Thermal Mapping—An extension of pavement management for deicing and ice prediction applications, thermal mapping requires mounting infrared thermometers on vehicles to measure pavement temperatures along stretches of road. Thermal mapping can be used to position permanent sensors in the road, to determine how many sensors are needed to provide adequate temperature profiles, and to redesign salting routes. Thermal mapping trials have been carried out in several counties in England.[22]

Paving Materials-Composites, ceramics, plastics, and higher strength cements, are gradually being used more frequently in bridges and highways. They can provide faster curing, weight, and durability advantages over steel and concrete when properly used and in the right conditions. Quick-curing concrete can produce a road ready for vehicle traffic inside of 24 hours, minimizing the need for rerouting traffic, an inconvenience that can last for weeks under traditional paving operations. Though fast-track construction adds $1 to $2 per square yard to the pavement costs, the increase is offset by reductions in traffic rerouting and liability .23 Extensive tests performed on U.S. 71 in Iowa showed promise

[20] Haris Koutsopoulos, "Automated Interpretation of Pavement Distress Data," *Construction*, newsletter of the Center for Construction Research and Education, Massachusetts Institute of Technology, winter 1989, p 10.

[21] Jane Mills Smith, ''Middle Age Crisis, *Windows*, Texas A&M University, summer 1988.

[22] Thermal Mapping International, Ltd., Birmingham, England, informational brochure, n.d.

[23] Marlin Knutson and Randell Riley, ' 'Driving in the Fast Track, ' *Civil Engineering*, vol. 58, No. 9, September 1988, p. 56.

Box 3-C—Bridge Inspections

The 1989 failure of the Hatchie River Bridge in Tennessee highlights some of the inadequacies of present bridge management practices. Four passenger cars and one tractor-semitrailer fell into the river when the bridge collapsed during a flood. The National Transportation Safety Board (NTSB) identified several contributing factors, including migration of the main river channel beneath the bridge and the failure of authorities to evaluate and correct the resulting problems. A lack of redundancy in the bridge design also contributed to the severity of the accident, Channel migration and scour, or wear, exposed the bridge piles to as much as 10 feet of water, reducing their ability to support the bridge. Although a 1987 onsite inspection identified the piles' vulnerability to water, no settlement or leaning was noticed in the supports, and the bridge was given a "poor" rather than "critical" rating, thus not making it a priority for repair. NTSB determined that State officials did not recognize the potential for scour from the inspection report, and that overweight vehicles were frequently permitted to cross the bridge, further weakening the structure.[1]

After its investigation, NTSB issued 19 recommendations for improved inspection and maintenance procedures for the Nation's bridges, stressing the need for dealing with the effects of channel migration and river course changes, overweight traffic loads, and scour on the integrity of the bridge support structures. The recommendations also highlight the need for raising qualification standards for evaluators of bridge inspection reports and for the creation of a system to set priorities for bridge repairs.[2]

[1]National Transportation Safety Board, "Safety Information," informational document, June 5, 1990.

[2]Ibid.

for quick-curing concrete technology. The Strategic Highway Research program (SHRP) has sponsored fast-track. concrete pavement overlay experiments in Missouri on Route 67 with a pavement mixture designed to harden in 12 hours.[24] (See chapter 5 for further discussion of advanced materials.)

Pavement additives for deicing, developed in Europe and tested in the United States, include particles of ground rubber or calcium chloride particles covered with linseed oil. These are mixed into the material used for the road surface. These additives can double or triple paving material costs and are not effective in all climates or under all highway conditions.[25] Salt, currently the cheapest and most available deicer, has been widely used in this country, although it causes extensive corrosion to unprotected pavement. (See chapter 5 for further details.) Laboratory and field tests have shown calcium magnesium acetate to be comparable to rock salt as a deicer, while lacking many of the adverse side effects. However, its price, 15 to 20 times that of rock salt, prevents extensive use.

Design and Construction—*load and resistance factor design* (LRFD) is a promising alternative to standard allowable stress design, which treats all loads and member strengths as if they were known with roughly equal certainty, rarely the case. LRFD recognizes that some loads (the bridge's own weight, for instance) and material strengths can be calculated with a fair amount of certainty, while others (the wind load from a hurricane, for example) can only be guessed. LRFD takes uncertainty into account by multiplying each load by a load factor and each member strength by a resistance factor, with both reflecting the probability that each particular number is wrong. In many structures, LRFD allows the use of smaller members or lower strength steels, reducing the cost of the structure. Load factor design (LFD) was adopted by the American Association of State Highway and Transportation Officials (AASHTO) in 1969 as an alternative method for both steel and concrete bridges. Most States now recognize LFD as an acceptable design method,[26] and by 1992, AASHTO bridge design and construction specifications will be revised in the LRFD format. However, LRFD takes time to learn and requires educating staff and converting or replacing computer programs that use conventional design formulas.

Primarily because they can be constructed quickly, ***segmental bridges*** minimize traffic disrup-

[24]Strategic Highway Research Program, "Focus," newsletter, August 1990, p. 3.

[25]Kevin Stewart, pavement Research Division, Federal Highway Administration, personal communication, Apr 24, 1990.

[26]"Steel Design's Reluctant Revolution," *Engineering News Record*, vol 223, No 19, Nov. 9, 1989, pp. 54-60.

tion, since contractors can place precast or cast-in-place segments from above or below.[27] The behavior of the joints between the precast segments involves complex interactions, however, and great care must be taken to ensure that shear forces are transferred across the joints.

Two promising technologies for strengthening existing bridges are the *reinforcing arch* for truss bridges and the *post-tensioning* system for steel girder bridges. If critical truss bridge members are reinforced with superimposed steel arches, chord supports, and additional floor beams, the carrying capacity and service life of the bridge can be increased at a significant savings compared with the cost of a new bridge. High-strength steel tendons bolted to the ends of the girders and tightened reduce the stress on the bottom of the girders. This process enables the bridge to carry heavier weights, minimizes traffic disruption because work is done above the roadway, and is significantly less costly then replacing single-span steel girder bridges.

Increasing Capacity and Managing Traffic: Smart Cars and Highways

Present strategies for overcoming congestion include building *new* roads, adding lanes to existing highways, creating high-occupancy vehicle (HOV) lanes, and promoting car pooling and public transportation. However, no city, even those using all of these techniques, has achieved more than modest success in solving its congestion problems. Intelligent Vehicle/Highway System (IVHS) technologies can help reduce congestion and improve highway safety, and two of these-advanced traffic management (ATM) and automatic vehicle identification (AVI) and billing-are particularly applicable for public works and are available now for wider use. More advanced IVHS technologies—collision warning and avoidance, driver information and route guidance, and automatic vehicle control-both steering and headway-are under development.[28]

Advanced Traffic Management—ATM systems include urban traffic control systems, incident detection systems, and freeway and corridor control systems. Hardware consists of sensors, traffic signals, ramp meters, changeable message signs, and communication and control devices integrated into a single *system.* Urban traffic control systems coordinate traffic signal operations throughout a given area, based on traffic patterns as measured by detectors in the roadway. Freeway control systems include sensors of all types to monitor congestion and transmit the data to driver-information signs and ramp meters to control access. In the United States, freeway systems are almost always separate from urban traffic control systems. Although several are planned, only a few integrated systems are in place. One of these, Information for Motorists (INFORM), is a traffic monitoring and control system, sponsored by FHWA, along a 35-mile east-west corridor on Long Island.[29]

Because current traffic detectors, usually embedded in the roadway, are susceptible to frequent failure, more reliable methods of measuring traffic are being investigated, including infrared sensors and machine vision systems (video cameras linked to a computer that analyzes the images to generate traffic flow and congestion information).[30]

The Automated Traffic Surveillance and Control system (ATSAC) in Los Angeles (see box 3-D) is one of the most advanced ATM systems presently in use in this country. Pathfinder, an in-vehicle driver information and route guidance demonstration in the Los Angeles area, recently began preliminary testing, and TravTek, an Orlando-based project using similar technology, will begin operation during 1991-93.

Only about 6 percent of urban freeway mileage is covered by ATM systems. While most large, urban areas have arterial traffic signal control systems, many are old and inadequate for current needs, cover too small an area, and do not respond well to

[27] "Controversial Bridges Scrutinized at Conference," *Civil Engineering,* vol. 60, No. *2,* February 1990, p. *20.*

[28] For further details, see U.S. Congress, Office of Technology Assessment, "Advanced Vehicle/Highway Systems and Urban Traffic Problems," staff paper of the Science, Education, and Transportation Program, September 1989.

[29] Lyle Saxton, assistant for advanced technical systems, Federal Highway Administration, personal communication, July 24, 1989.

[30] Panos Michalopoulos, professor, Department of Civil and Mineral Engineering, University of Minnesota, and Robert Behnke, Research Administration and Development, Minnesota Department of Transportation "Testing and Field Implementation of the Minnesota Video Detection System," unpublished document, n.d.

Box 3-13-The Automated Traffic Surveillance and Control (ATSAC) System

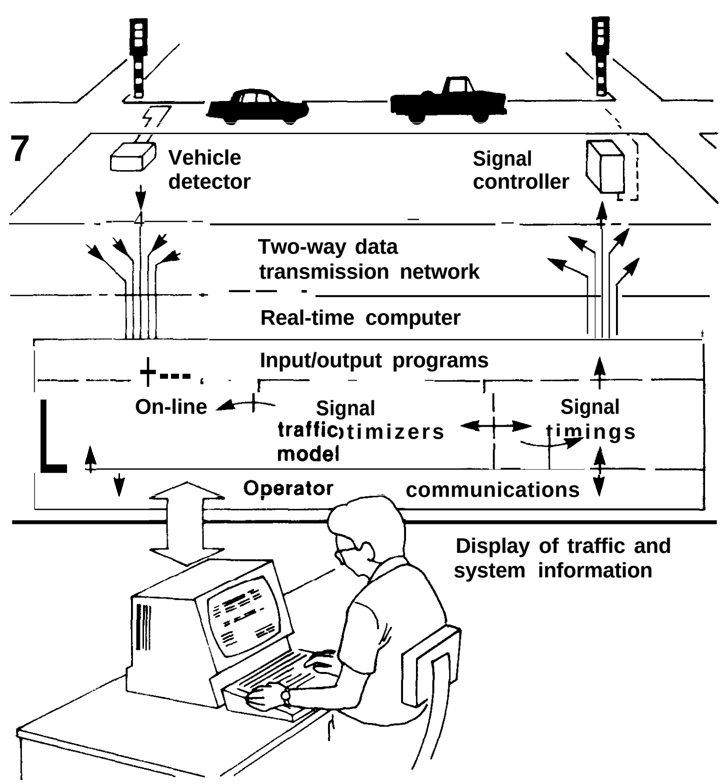
One of the more advanced urban traffic control systems in place in this country is the ATSAC system, a computerized traffic signal control system installed in Los Angeles. It is based on the Urban Traffic Control System (UTCS) software package developed by the Federal Highway Administration (FHWA) and was put into operation several weeks prior to the 1984 Olympic Games. Initial installation included 118 intersections and 3% detectors in a 4-square-mile area centered at the University of Southern California and the Los Angeles Coliseum. It has since expanded to include areas of the San Fernando Valley and central business district for a total of 371 intersections. The airport and Westwood areas are targeted for later implementation, and in 1991, the system is planned to include 1,600 intersections. ATSAC is funded by a combination of FHWA monies, a traffic mitigation fired financed by developer fees, and distributions from the Petroleum Violation Escrow Account fund[1]

From their workstations, ATSAC operators can monitor any portion of the surveillance area at any desired level of resolution, from traffic flow data at intersections to traffic behavior over a region. ATSAC gives the current status of any traffic signal in the network and gives traffic flow data for any loop detector in the network. Since it was first installed, ATSAC has evolved into a signal timing system that automatically selects (and switches) timing plans by matching current traffic patterns against historical data Signal timing can be fine-tuned by manual override or automated control to relieve local congestion. Figure D-1 depicts a typical system.

Closed-circuit television cameras, installed at important intersections assist in incident management and confirm incidents. ATSAC has improved traffic flow and economic benefits: travel time (-13 percent), number of stops (-35 percent), average speed (+15 percent), fuel consumption (–12 percent), and vehicle emissions (–10 percent). Computerized signal control also provides rapid detection of faulty sensors and unusual traffic patterns due to incidents. Estimated cost savings to motorists (business and truck trips only) as a result of lower operating costs and time saved recovered the $5.6-million construction cost of ATSAC after only 9 months of operation. The annual operating costs are recovered within the first week of operation every year.[2]

However, ATSAC relieves street congestion only, not freeway congestion, since freeway traffic falls under the authority of CALTRANS. Recognizing this limitation, the major transportation agencies in the Los Angeles area have begun the Smart Corridor demonstration project, which integrates selected city-operated surface streets and State-operated freeways in a single traffic management system.

Figure D-l—Typical Automated Traffic Management System



SOURCE: Ferranti Computer Systems, GEC Traffic Automation Ltd., and Plessey Controls Ltd., "Dynamic Urban Traffic Control," SCOOT *brochure, 1985.*

[1] Edwin Rowe, general manager, Department of Transportation% City of Los Angeles, personal communications, Aug. 19 and 30, 1989.

[2] Edwin Rowe et al., *ATSAC Evaluation Study* (Los Angeles, CA: City of Los Angeles, Department of Transportation, July 1987).

nonrecurring congestion.[31] Over one-half of all vehicle-hours of delay are caused by nonrecurring congestion or incidents (vehicle accidents and breakdowns that tie up traffic). Incident management programs use a variety of ATM tools to detect incidents, including conventional traffic surveillance, service patrols, closed-circuit television, roadside and mobile telephones, and citizens-band radio.

Automatic Vehicle identification—AVI systems are a promising option for automatic billing on toll roads and bridges.[32] Radio or microwave transponders on a vehicle can be "read' by equipment placed along a route or at a point where information exchange or billing needs to occur, such as toll facilities, weigh stations, and ports of entry. Additional AVI technologies include optical and infrared systems, inductive loop systems, and surface acoustic wave systems.

Because AVI-equipped vehicles need not stop for data transfer, widespread use would substantially reduce delay at these normal congestion points. AVI could also be used to control access to facilities and to provide traffic data for travel flow and congestion monitoring. Such systems are operating at the Coronado Bridge in San Diego, the Mississippi Bridge into New Orleans, the Lincoln and Holland Tunnels in New York City (for buses), the Grosse Ile Bridge in Michigan, and the Dallas North Tollway. The Dallas (see box 3-E) and New Orleans systems are the most heavily used, with 20,000 and 13,000 subscribers, respectively.[33]

AVI also makes possible congestion pricing, or charging automobile drivers for driving in congested areas during peak hours. Congestion pricing provides more funds for system improvements, and may cause some motorists to shift to public transit, make fewer trips, or plan their trips during nonpeak hours, thus reducing delays.

Weigh-in-Motion—WIM systems use road-mounted sensors to determine the weight of moving vehicles by taking into account axle weights, vehicle length, and vehicle speed. By also calculating axle spacing, WIM devices can classify vehicles and determine their compliance with weight standards. Technologies used for WIM include piezo-electric sensors, load cell systems, shallow weighscale systems, bending plate systems, and bridge systems. The most accurate WIM systems currently have accuracies within 10 percent of true vehicle weight, limiting their usefulness for enforcement purposes,[34] although the information they provide about truck weights has proven useful for highway research and pavement design.

Box 3-E—Fast Toll Collection in Dal!as

The Dallas North Tollway is one of the largest automatic vehicle identification (AVI toll roads in the Nation, Since August 1989, all of its toll lanes have been equipped with reading equipment capable of interrogating transponders (toll tags) attached to the inside of the windshields of subscribers' vehicles. The credit card-sized toll tags can be purchased in $40 increments bymail or at a tag store located near the tollway. Tag users pay an extra 5 cents per transaction over the usual toll as well as a $2 service charge for use of the transponder. After a successful transaction, a "valid tag-go" sign is flashed to the driver. If the toll tag credit is used up, a' 'call tag store" sign is fIashed and the driver must pay the toll in cash. Before the system began operation, an average of 350 vehicles per hour passed through a toll plaza lane during rush hour. Now, 800 vehicles per hour pass through lanes for drivers with toll tags or with exact change, and AVI-only lanes, which will be implemented in late 1990, are expected to process 1,200 vehicles per hour, based on a vehicle speed of 10 miles per hour. At present, the tollway has some 30,000 AVI subscribers, accounting for over 1 miIlion AVI transactions monthly.[1]

[1] Ken Tucker, director of toil collection, Dallas North Tollway, personal communication, Nov. 7, 1990.

[31] Gary Euler et al., ''Final Report of the Mobility 2000 Working Group on Advanced Traffic Management Systems (ATMS),' unpublished report, March 1990, p. 2.

[32] Automatic vehicle identification technology is also sometimes referred to as electronic toll and traffic management.

[33] Maureen Gallagher, director of research and member services, International Bridge, Tunnel and Turnpike Association personal communication, May 31, 1990.

[34] Neil Emmott, engineer, Castle Rock Consultants, personal communication Apr 28,1989.

Automatic Vehicle Location—AVL systems currently have their primary application in commercial fleet operations, since they typically identify vehicle location and transmit it to a central facility for monitoring or dispatch purposes. An AVL system consists of equipment to locate the vehicle-usually based on dead reckoning, map matching, proximity to roadside beacons, or radio determination—and mobile communications equipment, which relays this information to the central location. **AVL can** provide real-time information on shipment status and eliminates the need for time-consuming driver-to-control-center communication.

Surface Transportation Networks: Mass Transit

Mass transit refers to regional and municipal passenger transportation systems, such as buses, light rail, commuter rail, trolleys, and subways (see table 3-5). Early mass transit service was provided by private horsecar in the mid-1800s, and cable cars and electric streetcars served numerous urban riders between 1880 and 1920. The versatility brought by buses and automobiles caused rail transit ridership to decline slightly during the 1930s. During the immediate postwar years, transit patronage and revenues fell again, and local governments began to takeover the systems from private operators. The establishment of a Federal grant program for transit in 1964 and substantial increases in Federal support in 1970 (see chapter 2 for further details) brought a large increase in public takeovers of transit agencies.

Transit Management and Financing

Today, most cities and towns with populations over 20,000 have bus systems, usually operated by a municipal transit authority; over one-half (58 percent) of all systems are located in towns with populations of less than 50,000. Local governments manage transit systems as operating departments or through a public transit authority. Transit buses, operating on established routes on set schedules, account for over one-half of all public transit vehicles, passenger trips, and vehicle-miles operated.[35] Seattle, Philadelphia, Boston, Dayton, and San Francisco transit agencies still operate some electric trolleys. Rail transit, rapid rail, light rail, and commuter rail systems are usually owned by municipal transit agencies, although some commuter rail services are run by State governments or operated by Amtrak.

Paratransit operators maybe municipalities, special purpose agencies, or private entities. Services include dial-a-ride, van pools, subsidized taxis, and shared rides in minibuses or vans; paratransit can provide more direct origin-to-destination service, and operates on demand rather than on a fixed schedule. The primary residential users of paratransit are the elderly, handicapped, and children; airport shuttles are heavily used by business people and travelers.

Of total transit revenues in 1988,36 percent came from passenger fares, 53 percent from State and local assistance, and 6 percent from Federal capital and operating assistance, which totaled $3.3 billion (in current dollars) in 1988,[36] down about 40 percent from 1980 (see chapter 2, table 2-2). Quadrupling from about $1 billion in 1980 to almost $4 billion in 1988, State aid to local and regional transit now surpasses Federal aid.[37] At least 40 States provide local mass transit with some funds from general revenues, a dedicated portion of the general sales tax, or motor fuels and vehicle taxes. States support transit because it is one of the few options available for relieving auto congestion and air pollution in urbanized regions, and seven heavily urbanized States contribute 80 percent of total State aid.

Federal capital grants may be used to finance bus and subway car purchases, rail construction, and other capital improvements, but these programs have been criticized for not meeting community needs. Some cities receive more capital funds than they can use, encouraging large construction budgets, which may cause them to shortchange maintenance. Others, often those with older rail ***systems, are*** substantially underfunded[38] and in desperate need of capital equipment and track rehabilitation. About 70 percent of transit operating costs are labor expenses,"[39] these are not eligible for Federal assist-

[35] American Public Transit Association, *1989 Transit Fact Book (W-~* DC: 1989), pp. 10-13.

[36] Ibid., *pp. 24-27,74-75.*

[37] U.S. Department of Transportation op. cit., footnote 2, p. 24.

[38] U.S. Congress, Congressional Budget Office, *New Directions for t& Nation's Public Works* (Washington, DC: November 1989), p. 37.

[39] American Public Transit Association op. cit., footnote 35, P. 33.

Table 3-5-Characteristics of Mass Transit

Type	Right-of-way	Fare collection	Maximum speed	Power source	Places in use	Funding
Bus	City streets and dedicated bus lanes	In vehicle or station	35 mph on city streets, 55 mph on highways	internal combustion engine	Virtually all urban areas	UMTA discretionary grants (sec. 3), formula grants for operating and capital expenses (sec. 9), and operating and capital assistance for rural areas (sec. 18)
Heavy rail	Dedicated underground, surface, or elevated	in station	75 mph	Third rail	New York; Chicago; Boston; Philadelphia; Atlanta; Washington, DC; San Francisco; Los Angeles (under construction)	UMTA formula and discretionary grants (sees. 3 and 9)
Light rail	City streets and/or fully grade-separated tracks	In vehicle or station	55 mph	Overhead catenary	New Orleans; San Francisco; Philadelphia; San Jose; Portland, OR; Boston; Sacramento; Buffalo; Cleveland; San Diego; los Angeles; Long Beach	UMTA formula and discretionary grants (sees. 3 and 9)
Commuter rail	Railroads	In vehicle	100 mph	Diesel/electric locomotive	San Francisco Bay area; New York-New Jersey; Boston; Philadelphia; Chicago; Washington, DC-Baltimore; Miami-West Palm Beach	UMTA formula and discretionary grants (sees. 3 and 9)

SOURCE: Office of Technology Assessment, 1991, based on Urban Mass Transportation Administration (UMTA) information.

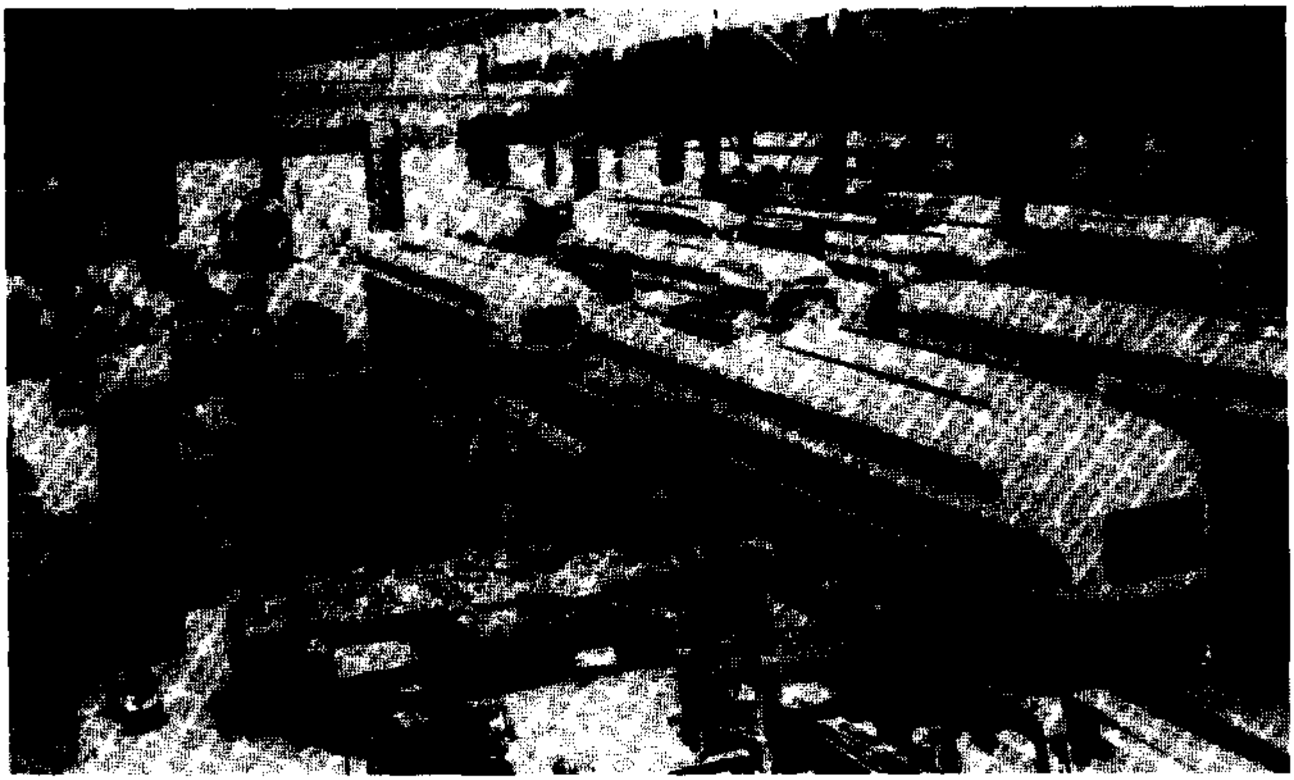


Photo credit: American Consulting Engineers Council

Rail transit systems need to rehabilitate and maintain vital system components. Costs for modernizing these systems are estimated to total $17.9 billion nationwide.

ance. Critical to urban movement, public mass transit is not a profitmaking venture anywhere in the world. In the United States, farebox revenues cover less than 40 percent of operating costs on average, and service is usually subsidized locally from State or local general funds and earmarked taxes. Buses receive substantially higher subsidies than rail transit systems.

Issues

Transit agencies are not typically an integral part of local and regional transportation and land-use decisionmaking which undermines transit's potential role in solving local and regional transportation problems. While transit is subsidized in most communities, its competitive position as a transportation alternative is reduced by municipally subsidized parking and by Federal policies that do not tax employees for parking benefits, but do tax most transit allowances. Furthermore, the costs of alternative capital improvements (a new highway lane, for example) are often underestimated.

Transit systems are important alternatives for increasing surface transportation capacity in congested urban corridors. However, transit must complement strong growth management programs, such as those applied in Oregon (see box 3-F), if transit is to be more effective at alleviating congestion.

Bus transit systems have made major efforts to upgrade their maintenance programs, because vehicles in poor condition break down frequently, making schedules hard to keep. However, many operators of smaller buses, such as those used in small communities or in paratransit, encounter problems with brake wear, corrosion, electrical and air conditioning systems, wheelchair lifts, and vehicle handling.[40] Maintenance costs are thus high for these small operators.

[40] Charles Dickson, director of training, Community Transportation Association of America, personal Communication, May 31, 1990.

Box 3-F-Oregon's Growth Management Program

Oregon is using growth management to control urban sprawl and cut public works costs. All Oregon cities must incorporate urban growth limits and public facilities plans into their State-mandated comprehensive plans and adopt consistent zoning ordinances. State legislation, adopted in 1973 to protect prime agricultural land from haphazard urban development, requires that comprehensive plans show an urban growth boundary, which defines the extent of urban expansion permissible over a 20-year period. The boundary is based on forecasted land-use needs, physical characteristics of the land and local growth policies.[1] Although it took over a decade to achieve, all cities and counties now have State-approved comprehensive plans. State actions, including those of the Highway Department, must be compatible with local plans.

In addition to comprehensive planning requirements and urban growth boundaries, State housing policy is an important growth management tool, because it requires cities to zone for high-density development as a means of stimulating construction of affordable housing. To a greater extent than in most other States, development in Oregon in recent years has followed high-density patterns; in 1989 Portland had the highest percentage increase in multifamily construction in the country and from 1985 to 1989,54 percent of all residential construction in the State was multifamily.[2] Developers generally support the high-density zoning policy because it reduces per-unit construction costs and because the mandated consistency between zoning ordinances and comprehensive plans eliminates lengthy and unpredictable rezoning proceedings. Local officials find compact, highdensity development provides the market needed for mass transit, reduces other municipal service construction and operating costs, and increases affordable housing. Heightened interest in light rail transit, instead of more highways, is another benefit of this policy.[3]

While State officials are optimistic about the long-term effectiveness of growth management to reduce transportation and other facility costs, pockets of existing development outside the urban boundary undercut the effectiveness of growth limits. These low-density unincorporated areas, largely exempt from the strict limits on development in effect elsewhere, continue to grow. In the Portland region, they have absorbed only 5 percent of residential growth, but in other fast growing areas one-quarter to over one-half of residential development occurs in these unregulated places, complicating regional planning and financing for highways and public utilities, Even within urban growth boundaries, new development is not necessarily contiguous to old and gaps occur, which increase public works costs and inefficiency. The Oregon Department of Land Conservation and Development is conducting a major study to evaluate the impact of current growth management programs and how to improve them.[4]

1Land Conservation and Development Commission, *Oregon's Statewide Planning Goals, 1990* (Salem, OR: 1990), p. 14.

2John Kelly, project manager, Oregon Department of Land Conservation and Development Commission, personal communication, Nov. 1, 1990.

3Ibid.

4Ibid.

For r-ail transit systems the components most in need of rehabilitation or replacement are railcars, power substations, overhead power wires, maintemince facility buildings and storage yards, and bridges. All also require high degrees of ongoing maintenance. Facilities and equipment in the poorest condition are usually the oldest, such as those in New York City, Chicago, and Philadelphia, some of which are more than 50 years old. Rehabilitation and modernization costs to bring the Nation's existing rail transit systems to a level ''. . . consistent with current standards of safety, reliability, and aesthetics for new rail systems . . ." have been estimated at $17.9 billion.[41]

Technologies for Transit

Fleet and facility management and regular maintenance are of primary importance in extending the lives of mass transit vehicles, in controlling costs, and minimizing environmental effects.

41Gannett Fleming Transportation Engineers, Inc. et al., *Rail Modernization Study*, Report No. UMTA-PA 06-0099-86-1 (Washington, DC: U.S. Department of Transportation, Urban Mass Transportation Administration, April 1987), p. 2.

Buses

Busways-One traffic management strategy implemented by many cities is the creation of exclusive bus lanes on which only buses and commuter vans may travel. Busways have reduced travel times significantly and cost far less than new rail lines. They can be grade-separated, created from widening existing roads, or by simply dedicating existing lanes to bus traffic.

Automatic Vehicle Monitoring—AVM systems can locate transit buses and communicate information to drivers, dispatchers, central traffic control computers, and passengers. Methods for locating buses include LORAN C, dead reckoning, satellite referencing, and roadside beacons and detectors. (See chapter 5 for further discussion of location technologies.) Radio channels can provide voice communication or data transmission links between the bus and the central control. To speed travel, buses with communication links to the municipal traffic control system (as in some French and Dutch cities) can be given signal priority at intersections. AVM technologies are used by transit authorities for automated bus-to-dispatcher communication, as well as for collection of data on bus travel times, stops, and adherence to schedules, and thus can bean important source of data for planning and management.[42]

Communications technologies, such as cable television, videotex, telephone, video screens, and speaker phones, can provide schedule and status information to passengers on the bus, at bus stops, or at home. Speaker phones and automatic telephone information systems can supply patrons with bus arrival information specific to each bus stop. Cable television enables bus passengers to view map displays of routes and bus locations, while video screens at bus stops give passengers bus schedule and arrival information. Onboard systems display upcoming stops and connections with other modes of transportation.

Electronic Control Systems-Such systems can reduce emissions, smooth shifting, increase acceleration, and quiet operations for engines and transmissions and electronically controlled power and drive trains. The ability to diagnose engine and transmission problems electronically should reduce maintenance costs and allow vehicles to stay in service longer.[43]

Bus systems in cities with serious air pollution problems must comply with new emissions standards by 1994. Emission control equipment and reformulated (''clean' diesel fuel or alternate fuels are among the alternatives, and agencies must weigh the trade-offs between capital costs, fuel costs, maintenance, and relative reduction in emissions in making decisions. Regardless of the ultimate choice, different equipment and/or fuels will bring new maintenance concerns.

Particulate **Traps-These** consist of a metal-clad ceramic falter, which captures particulate from the exhaust stream of a diesel engine. Tests conducted in California demonstrated that particulate traps can remove some 70 percent of smoke and soot emissions from the engine with no sacrifice in performance. However, the reliability and durability of the traps over the life of a bus remains in question. Tests of diesel particulate trap oxidizer systems are in progress or planned in nine North American cities.[44]

Methanol—This is the alternative cleaner burning fuel that has been tested most thoroughly for bus use. It is producible in the United States from natural gas, coal, and biomass. It has one-half the energy content of gasoline, meaning that 1 gallon of M100 (pure methanol) gives about one-half the mileage of 1 gallon of gasoline. However methanol is toxic, corrosive, and highly flammable, so different handling procedures and redesigned fuel and exhaust systems are necessary. Lastly, a distribution system comparable to the existing system for gasoline and diesel fuel will be needed before methanol can be available for nationwide use.

Natural Gas-Used in motor vehicles since World War II, natural gas now fuels primarily light-duty van and truck fleets. The largest current program for buses is in Vienna, Austria, where 400 buses run on liquefied natural gas. Compressed

[42]Canadian Urban Transit Association, *Proceedings: The International Conference on Automatic Vehicle Location in Urban Transit Systems* (Toronto, Ontario, Canada: September 1988).

[43]George Izumi, program manager, Office of Engineering Evaluations, Urban Mass Transportation Administration, personal communication, May 31, 1990; and "NJ Transit Gains Advantage With Electronic Engine and Transmission Control Systems," *Bus Ride, vol. 26, No.* 1, March 1990, pp. *48-49.*

[44]Manufacturers of Emission Controls Association, ''Trap Oxidizer Control Status Report,'' unpublished document, November 1989, pp. 8-10.

natural gas (CNG) is the most common form considered for bus use in this country, however. In contrast to methanol, CNG is not corrosive, causes less engine wear, and gives longer engine durability, although as for methanol, larger onboard fuel tanks and new distribution facilities would be needed. CNG vehicles can require substantially more time to refuel than methanol or diesel fuel vehicles, a particular concern for bus fleets, which can afford little down time.[45]

Rail Transit

Track Inspection Technologies—These include automated track measurement systems, which operate either as dedicated vehicles or measuring devices fitted to passenger cars. The equipment uses electro-optical or electromagnetic methods to give dynamic measurements of track geometry under loaded conditions. It measures and records track location, gage, profile, and alignment in a fraction of the time required by a track walking crew. However, the automated track geometry measurement system does not detect other track characteristics such as rail fatigue, tie fastener problems, or concrete cracks. Newer track geometry cars can be equipped with video or other equipment to record information such as overhead clearance, third rail alignment, foliage clearance, and tie condition. Dedicated rail flaw detection cars are used to test rails ultrasonically for defects, which usually result from fatigue. Track data of all kinds can be stored in computerized data management systems to help in setting priorities for further inspection and maintenance.

New **Rail Propulsion** Technologies—Such technologies as alternating current (AC) traction motors can save substantial energy costs. AC traction motors are operating successfully on rail vehicles in Europe and Japan and have been introduced in New York City and Philadelphia; trolley buses and light rail already use them. AC motors can reduce energy consumed in starting, braking, and heating; reduce maintenance and repair expenditures because they have fewer moving parts; and reduce slipping, skidding, and wheel and rail wear.

Offsetting these benefits is the greater weight of the line filter, which must be added to smooth line current and reduce signal interference. The cost of converting existing cars to run on AC is substantial-about $200 million for one regional agency.[46]

Control Systems—Most modem train control systems now use pulsed currents through the track circuit to communicate allowable speed information and employ cab signaling, rather than wayside signaling, which allows quick response to changing traffic information. While older, wayside signaling conveys information only at block entrances, cab signaling gives signal displays within the cab of the train, and displays are updated continuously in response to the condition of the track ahead. This enables trains to run with a higher level of safety than with wayside signaling (see box 3-D again).

Automated Guideway Transit—AGT typically provides slow-speed continuous service along dedicated, isolated guideways; cars are controlled by microprocessors. They function automatically and do not require onboard operators, but they do require exclusive right-of-way and security systems, such as anti-intrusion devices at stations and on the right-of-way. They can use steel wheels on rails, rubber tires on concrete guideways, or even magnetic levitation. Fare collection takes place in the stations. Examples of AGT include people mover systems in Detroit, Miami, Jacksonville, Tampa, Morgantown (West Virginia), VAL in France, SkyTrain in Vancouver, British Columbia, the M-Bahn in West Germany, and numerous shuttle systems in airports, and amusement parks.

Personal Rapid Transit—Concepts for PRT systems include new configurations of existing technology and feature:

- small, fully automated vehicles (without human operators or attendants), available for exclusive use by an individual or a small group traveling together; and
- vehicles captive **to a** small, dedicated guideway, located above ground, **at or near ground** level, or underground, which provide direct origin to destination service on demand without stops or transfers.

PRT systems face difficult environmental hurdles in the form of objections to above-ground guideways and stations, which duplicate the road network to some extent. Security concerns center on the driver-

[45] L.R. Davis, director, Equipment Maintenance, Southern California Rapid Transit District, personal communication, Mar. 22, 1990.

[46] Officials from the Washington Metropolitan Area Transit Authority, personal communication, Jan. 22, 1990.

less cars and unattended stations, while safety issues include whether many small, closely spaced vehicles can run safely on a single-lane guideway.

Surface Transportation Networks: Railroads

Rail service in the United States is provided by a mix of public and private entities. The quasi-public National Rail Passenger Corporation (Amtrak), created in 1971, is the primary intercity passenger rail company (see figure 3-6). Because of the importance of public sector support to the continuation of passenger service, discussion in this section will emphasize passenger service and the Federal role. However, hundreds of private freight railroads play an equally critical part in the national transportation system, carrying bulk materials, such as coal and agricultural products, and about 50 percent of the market for long-haul transportation of manufactured commodities.[47] Freight railroads compete with barge lines for shipments of large bulk commodities and with tractor-trailer trucks for smaller bulk shipments. To counter the faster, more flexible service trucks can provide, rail companies have concentrated traffic and investment on fewer, high-density lines[48] and introduced double stack and rail-highway vehicle services. The largest, or Class 1, freight railroads, account for over 90 percent of railroad traffic and employ over 90 percent of the rail work force.[49]

Regional railroads are usually defined as those with between 250 and 1,000 miles of track, while those with less than 250 miles of track are classified as *shortline or local railroads.* Most of these 32 regional lines are privately owned. However, 1 of them, and 31 of the over 400 shortline or local lines are owned and operated by State and local governments (although they operate on privately owned track). Since the Staggers Act (see chapter 2), the number of shortline and regional railroads has grown significantly, providing continued service for many localities.[50]

Railroad Management and Financing

The private sector owns and operates most rail infrastructure, including 97 percent of the total track mileage, as well as most bridges, control systems, communications systems, yards, service buildings, vehicles, and support equipment.[51] Amtrak owns much of the track along the Northeast corridor between Washington and Boston (its busiest routes) and some along the Chicago-Detroit corridor, a total of 600 miles. The Corporation contracts with 15 private freight railroads to provide train dispatch and track maintenance services outside these corridors. Its operating fleet includes some 300 locomotives and 1,900 passenger cars, most of which it owns. Of its almost 39 million passengers in 1989, about 44 percent rode on commuter rail systems operated by Amtrak on a contract basis; the rest were intercity passengers.[52] In 1989, Amtrak trains carried more travelers between Washington and New York than any airline.[53]

Each year, Amtrak receives a Federal operating subsidy of about $500 million, which it splits equally between its intercity long-distance routes and its shorter distance Northeast corridor operations. In fiscal year 1989, the Corporation earned $1.27 billion in revenues, enabling it to cover 72 percent of its operating costs from its own sources. About one-half of Amtrak's yearly capital expenses come from internal sources, and the rest come from Federal aid.[54]

States play a relatively minor role in financing, operating, or regulating railroads. Nonetheless, at least 20 States provide assistance to local rail service from earmarked taxes and general appropriations, and most maintain a State Rail Plan that includes an

[47] Informational material prepared for OTA by the Association of American Railroads, Jan. 31, 1990.

[48] Federal Railroad Administration, briefing document prepared for OTA, 1989.

[49] U.S. General Accounting Office, *Information on Regulatory Reform Under the Staggers Rail Act of 1980* (Washington, DC: Aug. 17, 1983), p. 1.

[50] Federal Railroad Administration and Interstate Commerce Commission *A Survey of Shipper Satisfaction With Service and Rates of Shoreline and Regional Railroads,* joint staff study (Washington, DC: August 1989), p. 1; and Association of American Railroads, *Profiles of U.S. Railroads,* supplement No. 1 (Washington, DC: 1990).

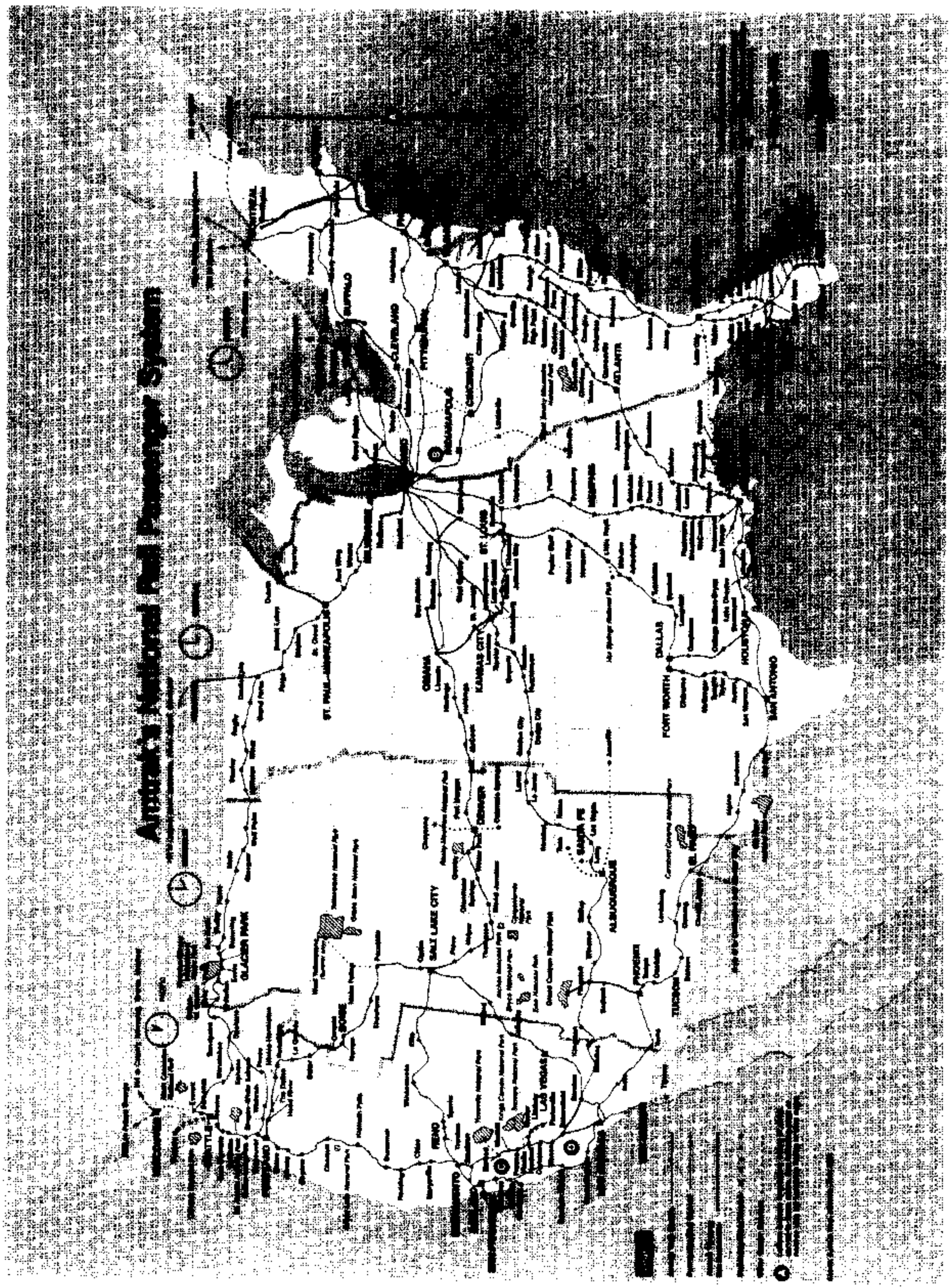
[51] Federal Railroad Administration, op. cit., footnote 48.

[52] Commuter services operated by Amtrak include the Massachusetts Bay Transit Authority (MBTA) and the Maryland Rail Commuter Service (MARC).

[53] National Railroad Passenger Corp., *Annual Report 1989* (Washington, DC: 1990).

[54] National Railroad Passenger Corp., " 1990 Legislative Report," unpublished document, Feb. 15, 1990, pp. 5-9.

Figure 3-6—Amtrak's National Rail Passenger System



SOURCE: Amtrak, 1989.

inventory of facilities and a ranking of proposed projects. A few large, urbanized States, California and Pennsylvania, for example, subsidize or supply intercity passenger train service. Other State aid is distributed as grants or loans to small, shortline freight carriers. Local governments have few direct responsibilities for railroads, although commuter railroads are major highway traffic relievers in congested metropolitan areas.

Rail Issues

Amtrak hopes to achieve full operating self-sufficiency by the year 2000, but needs to replace its aging fleet of cars and upgrade track along several corridors to maintain and expand current levels of service. It could operate far more efficiently with new locomotives and by using double-deck passenger cars on heavily traveled lines. To meet demand on sold-out long-distance routes, Amtrak plans to purchase at least 75 two-level sleeping and food service cars. On several routes, these cars will replace single-level cars, which can be used on other routes to expand capacity.

Although Amtrak must purchase a good deal of new equipment to sustain revenue growth, doing so requires large amounts of capital, which the railroad has few means of accumulating. Yield management, higher fares, and efficient utilization of equipment,[55] its current sources of increased revenue, are unlikely to generate the dollars needed. Improved track, maintenance facilities, locomotives, and passenger cars are expected to cost the Corporation about $300 million annually during the 1990s and require sums far greater than the current Federal capital grants of about $30 million annually.

Rail facilities are strategically located in most cities and offer often underutilized capacity, which, under the right circumstances, could bean economical option for moving people and goods within and between metropolitan areas. However, funding constraints often prevent railroads from making the investments necessary to keep customers. Shortline and regional railroads that have formed from railroad lines where maintenance was deferred and neglected face rehabilitation needs far exceeding their ability to pay. A Federal Railroad Adm'in'stration survey of small railroads found the one-time costs of track and roadbed rehabilitation-replacing ties and ballast and improving track surfaces-to be higher than annual revenues for many lines, about $428 million in total. Modal subsidies, embedded in Federal programs for other types of transportation assistance, provide support for other modes in ways that would benefit railroads.

Labor issues are a final management concern for railroads. Federal regulations requiring a supplemental retirement system for railroad employees, raihoad-funded benefits for employees made jobless by a consolidation, line sale, or abandonment,[56] and railroad workers' compensation statutes are particularly hard on shortline and regional railroads because of their small size and scale of operations.

Rail Technologies

Railroad technology in the United States **is not** characterized by rapid change; for instance, the air brake system is the same conceptually as when it was introduced, and standard track still **consists of steel rails, spikes, and wood ties mounted on ballast** of crushed stone.[57] (For **a potential exception, see box 3-G.)** However, new technologies for railroad operations have developed rapidly in recent years. Electronic data information systems, radio communications, advanced train control systems, and other propulsion innovations have enabled many railroads to operate more efficiently and productively.

Keeping the System in Good Shape

Track condition has benefited **from a new** emphasis on longer wear rail metallurgy, **continuous welded rail, profile grinding to extend rail life, concrete cross ties, new fastening systems for both concrete and wood ties, track geometry measurement systems, track maintenance planning tools, new inspection technologies,** and more mechanized and automated maintenance equipment.[58]

Track Maintenance Management Systems- Such systems function as decision support tools for

[55] W. Graham Claytor, Jr., president and chairman of the board, National Railroad Passenger Corp., testimony at hearings before the House Subcommittee on Transportation and Related Agencies, Committee on Appropriations, Mar. 22, 1989, pp. 2-3.

[56] The Interstate Commerce Commission which has the authority to exempt line sale from labor protection has granted exemptions to most of the newest regional railroads.

[57] Federal Railroad Administration op. cit., footnote 48.

[58] Ibid.

Box 3-G-Magnetic Levitation Research

The High Speed Ground Transportation (HSGT) Act, passed in 1965, established the Office of High speed Ground Transportation in the Department of Commerce whose objectives were to explore advanced intercity ground transportation technologies. Most early work on magnetic levitation (maglev) occured around the time of the act's - at Brookhaven National Laboratory the Massachusetts Institute of Technology (MIT), and a number of private industry research facilities. However, other than feasibility studies and technical assessments, U.S. maglev work essentially ended in 1975, with the expiration of the HSGT Act.

The Department of Energy, Department of Transportation, and the Army Corps of Engineers *have recently begun* anew effort, the National Maglev Initiative, to assess the engineering, economic, and environmental aspects of maglev and determine its feasibility for the transportation system. The budget appropriation for fiscal year 1991 include $10 million for the Federal Railroad Administration and $2 million for the Army Crops of Engineers to begin work. A major program report planned for March 1991 will include technical and economic assessments, plans for developing U.S. capability to surpass existing foreign technologies, and recommendations on whether to pursue further development.

Currently, maglev research is most active in Germany and Japan whose efforts have been underway way since the late 1960s. Research in Germany, sponsored by the Federal Ministy of Research and Technology has focused on electromagnetic suspension designs, while the Japanese are investigating both electromagnetic and electrodynamic designs.

One of the Japanese systems, an electrodynamic"c suspension design was originally developed by the Japanese National Railways (JNR). Work began in 1967, and research and development (R&D) costs through mid-1988 were $416 million. Since the priva tization of JNR in 1987, development of this system has come under the responsibility of the Railway Technical Research Institute (RTRI) one of 12 offshoots of JNR. RTRI receives funds from the Japan Railways Group, a Consortium including six passenger railway companies the Japan Freight Railway Company, and the Japanese govermnent (Ministry of Transportation).[1] The vehicle has a top speed of over 300 miles per hour, but has been tested only over short distances at a test facility in Miyazaki. This system is the only maglev technology that uses superconductivity. This Japanese technology require less sensitive tolerances between track and train than the German system and thus maybe less costly to construct and maintain Although recent advances in developing high-ttemperature superconducting materials are not likely to affect the overall feasibility of this maglev technology, using high-temperaturee superconductors for mshlrb could bring modest gains in energy efficiency cfficiency and reliability.

[1] Richard A. Uher, director, High Speed Ground Transportation Center, Carnegie Mellon Research Institute, testimony at hearings before the Senate Subcommittee on Surface Transportation, Committee on Commerce, Science, and Transportation, Oct. 17, 1989.

railroad engineers, technicians, and planners for identifying physical track assets, inspecting and evaluating track, identifying work needs, and planning and priority setting. Information is collected and stored in large databases and includes installation information; track segment inventory; inspections, traffic levels, maintenance records, and repair costs; and work crew history. These systems can also handle information about operations and store data on planned and completed maintenance and repair work for each track segment.

AC induction Motors-AC motors can be adapted to passenger rail and could extend the mean time between motor failures from 11/2 years to more than 5 years.[59] Amtrak has acquired two AC traction locomotives, which it is now evaluating in revenue service. The motors have fewer parts than DC motors, require less maintenance, and are smaller, lighter, and less noisy. Amtrak has not yet determined whether its future locomotives will use AC or DC traction.[60]

Concrete Cross Ties-Concrete ties provide track with greater stiffness and stability than wood ties and may be more durable, if track and vehicle are well maintained. However, concrete ties are susceptible to cracking or fracture from impact loads, such as those caused by irregularities in track or wheels. Widespread use of concrete ties has therefore been primarily on modem systems that are maintained to high tolerances, such as the TGV in France, and in

[59] K.M. Watkins, director, Motive Power, Amtrak, personal communication, May 25, 1990.

[60] Terry Brunner, general superintendent of Iocomotives, Amtrak, personal communication Nov. 6, 1990.

A *27-mile* test facility is under development in Yamanashi prefecture, and an extensive 4-year test of the system is expected to commence in 1993. About $3 billion will be invested over the next 7 years for construction and testing, and the Yamanashi" test track may become part of a possible revenue line between Tokyo and Osaka.

The other major Japanese system is the High Speed Surface Transportation (HSST) system, an electromagnetic suspension design with a top speed of 180 miles per hour. Development of this system began in 1975 by Japan Airlines, but in 1985, the technology was transferred to the HSST Corporation. Since 1981, the HSST system has received no government funding; this system is still under development with no estimated completion date. HSST maglev has been demonstrated extensively but has never realized its top speed during these demonstrations because test track length has always been less than 1 mile. Because of its relatively low maximum speed in relation to other maglev designs the HSST system will probably not compete with the RTRI system over longer routes. However, the technology is more mature, and applications could begin much sooner.

Modem maglev technology in Germany began in 1969, when the Federal Ministry for Transport commissioned a study on high-speed, track-bound, ground transportation. In 1977, the Ministry of Research and Technology decided to concentrate development work on electromagnetic suspension designs, and between 1970 and 1980, provided funding in support to the Transrapid consortium As of mid-1988, over $800 million had been spent on the Transrapid R&D program. The TRANSRAPID 07 vehicle has achieved a top test speed of 280 miles per hour and accommodates about 200 seated passengers. The Emsland test facility has a 19.5-mile track which has been in operation since 1983; more than 15,000 miles of tests have been accumulated on the system. Although German Transrapid technology is currently the most advanced of the prototype systems many feel its precise tolerance requirements could lead to high maintenance costs. The Transrapid is estimated to cost $20 million per double-track-mile, not including right-of-way acquisition and station costs.[2]

In December of 1989, the German government approved a 33-mile revenue route between the airports of Cologne/Bonn and Dusseldorf, later to be extended to Essen for a total of 51 miles. However, the government has stipulated that the DM 3.6 billion in capital costs must be shared by private industry, the airports and airlines, and the state of Northrine-Westphalia and it is unclear whether this condition can be fulfilled.[3] Recognizing the bleak outlook for maglev in Europe because of the likely dominance of conventional high-speed rail systems-the French TGV and German ICE, for examp--Transrapid is pursuing corridors and feeder routes in foreign markets, such as the USSR, Saudi Arabia, Canada and the United States, to showcase its technology. A 13-mile route from the Orlando, Florida, airport to the Disneyworld vicinity maybe the first high-speed revenue maglev system.

[2] Ibid.

[3] *Spektrum der Wissenschaft*, February 1990, p. 32.

this country, Amtrak's Northeast corridor and heavy-duty "height lines with extensive curvature.[61]

Rail Head Lubrication—This can increase fuel efficiency and reduce track and vehicle wear. Trains traveling over straight sections of lubricated track consume between 3 and 10 percent[62] less fuel than trains traveling over unlubricated sections, and lubrication may save costs for car and locomotive wheel replacements as well.[63]

Passenger Waste Disposal—Criticism for releasing untreated human waste from trains en route led Amtrak in August 1989 to initiate a research program to identify technologies capable of retaining up to 72 hours of waste. Prototype systems have been installed on Amtrak trains, and their durability and the costs associated with providing and operating equipment on existing trains are being assessed.

Increasing Capacity

High-speed train technology alternatives can increase capacity and efficiency without requiring major acquisition of new right-of-way (see box 3-H) in crowded intercity corridors. In the Northeast corridor, electrifying the entire line and utilizing tilt trains could reduce travel time between New York

[61] Ibid.

[62] Douglas B. Tharp, Consolidated Rail Corp., "Examination of Methods to Achieve Rail Lubrication," *Transportation Research Record 1174* (Washington, DC: National Research Council, 1988).

[63] Luther S. Miller, "Rail Greasing: Big New Savings Identified," *Railway Age*, vol. 190, No. 9, September 1989, pp. 49-60.

Box 3-H--High-Speed Rail

With substantial government assistance, high-speed rail has become both successful and efficient in Prance, Japan, and Spain over the past several decades. The TGV France's high-speed rail system, began operations in the early 1980s. Construction on the newest line of the TGV, the Atlantique, began in 1985. The Y-shaped line consists of a main trunk between Paris and Courtalain and two auxiliary branches. The Western Paris-Le Mans branch was completed in 1989, and the southwestern Paris-Tours line was completed in 1990. Total estimated cost is 16 billion francs ($3 billion) for construction of 163 miles of track and rolling stock. The line includes 13 miles of tunnels, 2 miles of viaducts, and seven flyovers to keep trains from crossing existing tracks. Maximum design speed is 300 kilometers per hour (km/hr) (186 miles per hour (mph)), with turnout crossing speed of 160 and 220 km/hr (100 and 136 mph).[1]

Land belonging to the SNCF (the French national railway company), the government, or alongside existing rail or highway right-of-way was used for 60 percent of the Paris-Courtalain stretch. To avoid level crossings, there are more than 310 structures along the line, including 164 road bridges and 139 rail bridges. Continuous welded rail and reinforced concrete crOSS ties are used throughout. The line is electrified and uses five power Substations. A control center at Paris-Montparnasse has telemetry and remote control equipment for the crossovers, spaced at approximately 14-mile intervals, between the two tracks. It also controls electric power feed and can interven via radio Iinks with all trains on the line. Fifteen satellite stations house safety equipment for each crossover site. *The* track-to-locomotive transmission system sends signaling information to the cab, where the driver reads it on the control panel.[2]

The TGV's power and adhesion, and dedicating the high-speed corridor to passenger service with its light loads, made possible a line with gradients of up to 3.5 percent (on the Paris-Sud Est Iine--the maximum grade on the Atlantique line is 2.5 percent), instead of the usual 0.5 to 0.8 percent gradients. As a result, the line could be routed over plateaus where large-radius curves could be easily laid out, and thus avoid valleys, which are often sinuous, densely populated, and furrowed by waterways and roadways--all of which increase construction costs. The TGV lines are compatible with existing track, so that the trains can penetrate city centers and serve all major station on the way.[3]

The Japanese Shinkansen (Bullet Train) long-distance high-speed railways include two groups, the Tokaido and Sanyo Shinkansen, which run Southwest from Tokyo, and the Tohoku and Joetsu Shinkansen, which serve the regions to the northeast. The Tokaido line began service in October 1964, while the Sanyo Shinkansen began

[1] SNCF, Direction de la communication, 'The TC3V Atlantique: Construction of the New Line," June 1986.

[2] Tbid.

[3] SNCF, Direction de la communication, "The Railways of France," brochure, n.d.

and Boston to under 3 hours from the present 41/a hours. Equipment and right-of-way upgrades could lower the time between Washington and New York to under 2 hours 15 minutes. While requiring substantial public investment, these improvements are important in the short term, because they could relieve traffic congestion in air and highway corridors.

Advanced Train Control Systems-ATCS are computer based and give precise data on train position, condition, and speed. Location and speed are determined by coupling locomotive odometers with either in-track transponders or a satellite-based Global Positioning System (GPS). Information is transmitted between the central dispatch computer and the locomotive through a UHF or VHF radio data communications link. Display screens in each locomotive cab show train location and speed, upcoming route profile, speed limits, and other authorities from the dispatch center. The dispatcher can send instructions directly to the locomotive engineer and receive precise information on train location and speed. Efficiency is improved by better coordination of train movements, precise meet and pass planning, and more efficient use of crews and equipment. Sensors mounted on the engine, electrical and air systems, and fuel tanks can collect data and monitor locomotive performance in real time. Transmitted to dispatchers and maintenance facilities, these data can reduce troubleshooting times and maintenance costs. Safety is improved, because if the engineer does not follow speed instructions or operating in March 1972. The Tohoku Shinkansen which runs north from Tokyo, began operation in June 1982; its east-west connecting line, the Joetsu Shinkansen began service in November of the same year. Maximum speed for the line is now 150 mph.

When the Japanese National Railways was privatized in 1987, these lines became the property of the new Shinkansen Holding Corporation, which leases them to three passenger railway companies: the East, Central, and West Japan Railway Companies. A total of 2.7 billion passengers have been carried on the Shinkansen without injury. The Shinkansen's ability to take passengers directly from city center to city center makes it competitive with airline and expressway transportation, and five additional routes are scheduled for future construction.[4]

Shinkansen tracks are equipped with snow-melting facilities to prevent railway switch points from freezing in cold weather. Additional steps, such as covering the lower parts of the cars and using centrifugal snow separators,, which remove snow from the intake air,[5] are taken for the lines that pass through areas with heavy snowfall. Trains operating in areas prone to earthquakes are protected by a combination of earthquake detection and control systems, including seismometers installed every 20 to 80 km along the line. If land cables are damaged by large earthquakes, a communications satellite system will be used to transmit information.[6]

Tilt train technology is based on car bodies capable of tilting when moving through curves to reduce passenger discomfort. Development of one tilting train, the Spanish TALGO, began in the 1940s. The latest TALG0 model is designed for a maximum speed cm straight track of 125 mph and for rounding curves safely at speeds 25 percent faster than conventional trains.[7] The TALGO trainset is made up of a succession of rigid cars articulated so as to permit the train to negotiate curves without vertical or transversal displacement between cars. Acceleration felt by the passenger due to displacement when the train rounds a curve depends on the tilt of the car and is significantly reduced if the car is tilted in toward the center of the curve. The suspension system in TALGO cars is above the center of gravity; the air springs of the main suspension behave elastically, allowing the car to tilt naturally around curves as a result of centrifugal force. The TALGO trains also have an automatic gage changing mechanism to accommodate different track gages.[8] Other tilting train configurations are manufactured by Bombardier of Canada and Asea Brown Boveri, a Swedish-Swiss consortium. These are active tilt systems, which employ powered actuators to cause the desired roll.

[4] East Japan Railway Co., Shinkansen brochure, n.d.

[5] Ibid.

[6] Ibid.

[7] RENFE, "TALGO: An Up-to-Date Train; A Long History," informational document, n.d.

[8] RENFE, "TALGO Pendular," informational brochure, n.d.

conditions along the route require emergency control,[64] speed can be remotely controlled.[65]

Perhaps the most dramatic recent development in increasing the efficiency of rail freight transport has been the introduction of *double* **stack service.** Double stack cars consist of skeleton car spines, each capable of carrying two containers. This reduces weight and aerodynamic drag and cuts by roughly one-half the amount of power needed to move trains at market-competitive speeds; that is, 100 containers on double stack cars require 4 locomotives, the same number needed to haul 50 containers on conventional cars. Double stack has been a major competitive success; long-haul truck traffic in major double stack lanes fell 25 percent between 1985 and 1988, even though long-haul trucking in the rest of the country grew 33 percent during the same period.[66]

Fuel Efficiency Measures-Approaches include automatic devices to prevent or reduce fuel spillage, recovering and recycling spilled fuel for heating and air conditioning railroad sheds and buildings, improved aerodynamic designs of railroad equipment, and calculating the optimal mix of power, weight, and speed for maximum fuel efficiency under various operating conditions. Other technologies under study for increasing fuel efficiency include

[64] Steven R. Ditmeyer, "A Railroad Command, Control, and Communications System for the 21st Century," paper presented at the International Conference on Technology and Technology Exchange, New York, NY, June 30, 1989.

[65] Association of American Railroads, op. cit., foonote 47.

[66] Ibid.

Photo credit: Port of Long Beach

Double stack cars carry almost twice as many containers, but use only slightly more energy than a conventional freight train.

alternative fuels, such as mixtures of diesel fuel distillate with lower grade fuels, and the burning of coal in diesel engines. Rail electrification is another energy alternative, but the high initial cost of converting to electrification might be a barrier, considering the current cost and availability of diesel fuel.[67]

Data Management and Transfer—These are key to efficient operations, and Amtrak has in place a management information system that serves the railroad well. (See chapter 5 for further details on such systems.) Freight railroads have found many benefits in electronic data interchange, the electronic transmission of administrative data, such as tracking materials and supplies, revenue, car accounting records, and freight loss and damage claims. Freight railroads plan to shift to electronic data exchange rather than paper, when cars are interchanged, and some railroads already allow shippers direct access to their information systems.

Federally Managed Infrastructure: Waterways and Airways

In the two transportation areas where the Federal role in operations and maintenance is large-

Photo credit: Port of Long Beach

Many operations at the Intermodal Container Transfer Facility in Long Beach, CA, are computerized for speed and efficiency. Computers in the control tower are linked with those of ocean vessels, and the yard receives information about each container before it reaches port.

waterways and airways-the infrastructure has generally been kept in good physical shape and provides convenient transport except at periods of peak demand. With proper maintenance and rehabilitation, locks and dams can remain operable indefinitely,[68] and safety requirements help ensure the reliability of air traffic facilities. When facilities, such as a major lock or a runway at a busy airport, must be removed from service for rehabilitation, the Federal managers work with all concerned parties to develop ways to minimize delays.

Ports and Waterways

Historically, communities and industries developed near ocean and riverfront ports, which handled raw materials or finished goods primarily for local consumption or from local suppliers. Today, the United States has the world's largest port[69] system, with about 200 major ports, each handling at least 250,000 tons of cargo annually or having channels

[67] Association of American Railroads, "When It Comes to Fuel-Efficiency, Railroads Lead the Transportation Pack," background Paper, September 1988.

[68] U.S. Army Corps of Engineers, Institute for Water Resources, "The U.S. Waterway Transportation System: A Review," unpublished report, April 1989, p. 24.

[69] In this section, "port" means land-baaed facilities as opposed to offshore, midstream, or other nontraditional transfer locations for cargo or passengers. Commercial ports are links in a transportation network serving passengers, freight, and bulk cargo, and do not include facilities used solely for recreation or fishing.

deeper than 20 feet.[70] Critical junctures in the national transportation network, ports often combine truck, rail, pipeline, barge, and ship operations for transferring most of the 2 billion tons of cargo moving into or out of the United States every year. Less than 2 percent is handled directly by offshore facilities and pipelines.

Fifteen percent of total U.S. freight ton-miles are produced by commercial barges and tows carrying bulk commodities, such as petroleum, grain, and coal, on the Nation's shallow draft (less than 14 feet) inland and intracoastal waterway system.[71] The Mississippi River, its tributaries, and connecting waterways are the Nation's major inland water transportation network. (See figure 3-7 for a map of the inland waterway system.) Waterway transport offers the lowest ton-mile costs to shippers.

After a decline during the recession in the early part of the decade, total waterborne commerce in the United States grew at about 3 percent per year during the 1980s. Continued growth at that rate would place heavy demand on certain landside facilities,[72] although adequate port capacity exists to meet U.S. commerce needs.[73] The waterways can also handle more freight shipments, and limited traffic demand makes system expansion unlikely.

Management and Financing

Waterside facilities are constructed, maintained, and operated primarily by the Federal Government, through the U.S. Army Corps of Engineers (the Corps), which supports virtually all U.S. ports of national significance.[74] The U.S. Coast Guard furnishes communication and navigation safety facilities. Until the late 1980s, virtually all navigation infrastructure costs were paid out of the Federal General Fund. Port project location and size were established on a project specific basis, rather than as part of a national system. Thus, the practical effect of many harbor deepening projects has been to maintain competition among ports rather than to meet transportation system needs.

To support economic development, the majority of States with navigable waterways provide grants for construction of landside port facilities and water cargo terminals. Currently these grants, which total about $500 million annually, are administered through State DOTS, economic development agencies, or State port authorities, which coordinate the public works components of major improvement projects. Most States are reluctant to take over responsibility for inland waterways from the Federal Government.

The largest ocean and freshwater port facilities are owned and managed by a municipality or public or quasi-public agencies, such as the Port of Seattle or the Port Authority of New York and New Jersey. These ports consist of bulk facilities, often privately owned, and general cargo facilities, many of which are leased to private operators.[75] Inland waterway terminals are usually privately owned.

Ports raise operating funds locally from user fees and capital from revenue bonds and State appropriations. Since 1986, port operators have been required to share dredging costs with the Corps, through an ad valorem tax paid by shippers into the Harbor Maintenance Trust Fund on all cargo loaded or unloaded at U.S. commercial harbors. Anon-Federal sponsor, often a local government or port authority, must share up to 60 percent of the costs of constructing new or deeper channels. The non-Federal sponsor must finance at least 50 percent of the maintenance dredging costs for new channels deeper than 45 feet.[76] The tax, which finances a portion of harbor maintenance costs, was more than tripled in the 1990 budget agreement, from 4 cents per $100 of cargo to 12-1/2 cents per $100. Since trust fund outlays are limited to 40 percent of the total Federal expenditures attributed to commercial navi-

[70] U.S. Army Corps of Engineers, op. cit., footnote 68, p. 2.

[71] U.S. Army Corns of Engineers, Institute for Water Resources, *The 1988 Inland Waterway Review*, IWR Report *88-R-7* (Ft. Belvoir, VA: November *1988), p. 26.*

[72] U.S. Army Corps of Engineers, Institute for WaterResources, "The U.S. Port and Harbor System: A Review," unpublished report, September 1989, p. 6. Port demand depends largely on cargo volume; deepwater harbor requirements are determined by ship size.

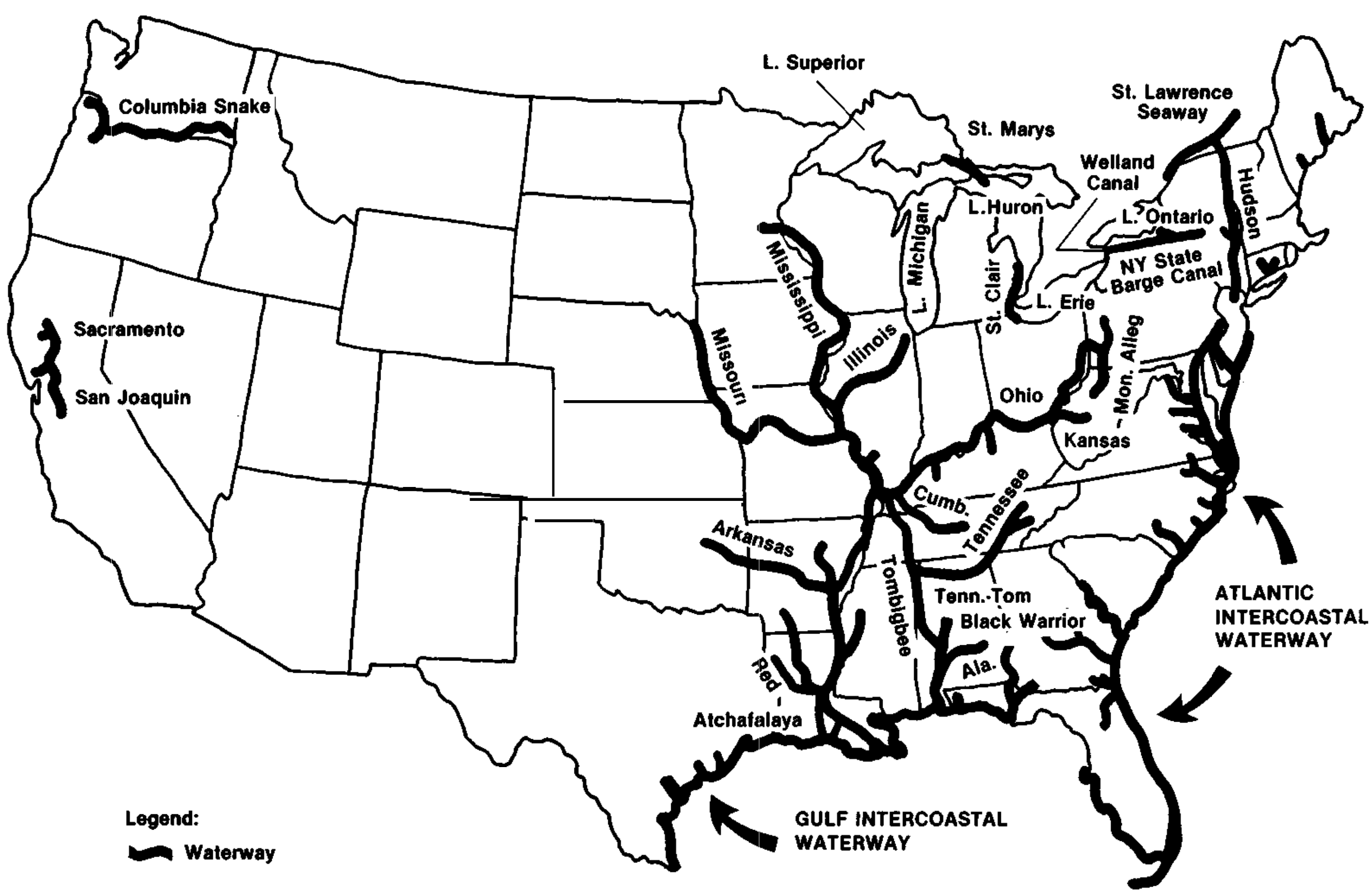
[73] 1bid., p. 13.

[74] Ibid., p. 5.

[75] John M. Pisani, "Port Development in the United States: Status, Issues and Outlook," paper presented at the Sixteenth International Association of Ports and Harbors World Ports Conference, Miami Beach, FL, Apr. 22-28, 1989, p. 13.

[76] The Water Resources Development Act of 1986 (Public Law 99-662).

Figure 3-7—The Navigation Systems of the Continental United States



SOURCE: U.S. Army Corps of Engineers, 88 gation in harbors, annual increases in surplus trust funds are likely.

Because of the tax, users are funding gradually increasing portions of deepwater channel operations, maintenance, and new construction. Requests for expansion projects are fewer and scaled back since the cost-sharing requirements became effective; the Corps estimates that project size has been reduced by two-thirds from the levels initially requested or authorized.[77]

Waterways-The Corps has modified all commercial waterways with locks, dams, bank protection, and dredging to allow passage of 9-foot draft vessels. The number and size of lock chambers determine the maximum through speed for vessels on segments of the waterway. The Corps has standardized lock chamber sizes, and barges have been designed to make the most efficient use of this capacity.

Perhaps because the Federal Government has always supported maintenance for water-related facilities, waterway maintenance costs have not compounded as locks and dams have aged.[78] Site-specific conditions, such as geology, climate, water quality, and usage, affect maintenance and replacement needs more than age. Most locks have been replaced because traffic growth has overtaken their capacity and long backups occur at peak periods, not because they have physically deteriorated.[79]

Barge operators pay a fuel tax that feeds the Inland Waterway Trust Fund (IWTF), which finances 50 percent of construction costs, and applies on the 11,000 or so miles[80] of waterways that account for over 90 percent of inland waterborne commerce. The Inland Waterway Users Board, a federally established body that advises on waterway priorities, has emphasized replacement projects on the Mississippi and Ohio systems and has specifically discouraged spending user fees for new waterways or rehabilitation.[81]

Issues

With limited fiscal resources available to maintain and physically expand the system, Federal investment decisions pose important questions for water transportation. In addition, Federal environmental requirements for protecting wetlands have created difficult and costly construction and dredged-material disposal problems. Thus, fiscal and environmental issues frame the biggest challenges for decisionmakers concerned about ports and waterways.

Fiscal Concerns-Congress has chosen to appropriate more water-related project monies from the General Fund than for any other transportation mode. Presently, 60 percent of harbor maintenance costs and 100 percent of inland waterway operations and maintenance expenses are paid for from the General Fund. In addition, the General Fund pays for roughly 50 percent of all capital costs for both waterways and harbors. In comparison, less than 5 percent of Federal highway expenditures come from the General Fund. In contrast to other public transportation networks in the country, waterway user fees cover no operations or maintenance expenditures.

Projections of future IWTF revenues indicate that they will support approximately five lock and dam replacement projects per decade.[82] Although scheduled increases will raise the industry contribution,[83] the annual fuel tax revenue is now less than 10 percent of the total annual costs (for construction, operations, and maintenance) for the portion of the inland waterway system subject to the tax. Certain segments of the inland and deepwater system generate disproportionate costs relative to the amount of traffic carried (see tables 3-6 and 3-7). Traffic levels on the Tennessee-Tombigbee Waterway, completed in 1985, are far below the projec-

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77 U.S. Army Corps of Engineers, Op. Cit., footnote 72, p. 14.

78 U.S. Army Corps Of Engineers, op. cit., footnote68, p. 24.

79 Ibid., p. 24.

80 Over 25,000 miles of navigable waterways exist in the United States.

81 Inland Waterway Users Board, "The Second Annual Report to the Secretary of the Army and the United States Congress," unpublished report, December 1988.

82 L. George Antle, Institute for Water Resources, U.S. Army Corps of Engineers, remarks at "Managing the Investment Process fOr Deep Draft Channels and Inland Waterways,' the 1990 Transportation Research Board Annual Meeting, Washington DC, Jan. 9, 1990.

83 Congressional Budget Office, op. cit., footnote 38, p. *3.

Table 3-6-Traffic and Operations and Maintenance (O&M) Costs on Inland Waterways, 1986

Waterways	Ton-miles (millions)	O&M costs (millions of dollars)	O&M costs per ton-mile (dollars)
1 Upper Mississippi	12,871.9	53.5	0.0042
2 Middle Mississippi	17,504.7	16.9	0,0010
3 Lower Mississippi	100,058.3	84.2	0.0008
4 Illinois	8,505.9	12.6	0.0015
5 Ohio	61,603.6	87.2	0.0014
6 Gulf Intracoastal Waterway	19,119.6	37.8	0.0020
7 Mobile	5,746.2	23.3	0.0041
8 Atlantic Intracoastal Waterway	367.1	15.8	0.0430
9 Columbia-Snake-Willamette	1,228.2	9.0	0.0073
Total	227,005.6	340.2	0.0015

NOTE: Segments of each waterway have a wider range of operations and maintenance costs per ton-mile.

SOURCE: U.S. Army Corps of Engineers, institute for Water Resources, The 1988 */n/and* Waterway Rewiew, iWR Report 88-R-7 (Ft. Beivoir, VA: November 1988).

Table 3-7-Federal Port Operations and Maintenance Outlays per Ton of Cargo, 1974-84 (In 1985 dollars)

Ports	Average	Minimum	Maximum
All ports	0.22	0.001	270.25”
Large ports (more than 10 million tons per year)	0.17	0.001	0.99
Medium ports (100,000 to 10 million tons per year)	*0.50*	0.001	23.30
Small ports (less than 100,000 tons per year	11.68	0.050	270.25

[a]High operations and maintenance (O&M) costs usually apply to federally maintained harbors with little commercial service. The beneficiaries are often fishing vessels and recreational users, neither of whom pay fees for O&M.

SOURCE: Congressional Budget Office calculations using data from U.S. Army Corps of Engineers.

tions used to justify its construction.[84] These discrepancies raise a number of difficult equity and access issues.

Despite the importance of ports to local economic development, few cities have integrated transportation systems that link ports to pipeline, rail, and truck services. Paradoxically, a port’s success and its contribution to the local economy increasingly depend on its intermodal transfer capabilities rather than solely on the local demand for its waterside services.[85]

Environmental Concerns-Few U.S. channels and harbors have natural depths greater than 20 feet, and ship dimensions set the demand for waterway depth. Bulk carriers and tankers often load to depths of 50 feet, while freighters, including modern containerships, can normally use 40-foot deep channels. However, no minimum standards have been established for ship maneuverability to guide those who must decide how to modify channels. The creation of navigation channels and structures, such as breakwaters and jetties, changes preexisting currents and sedimentation. The design and siting of channels and their protective works are thus crucial factors that determine dredging and maintenance requirements and environmental effects.

In the past, dredged material was often placed within a mile of the dredging site, since transportation to upland or ocean disposal sites added substantially to total costs. However, population growth in coastal areas and wetlands protection requirements now limit land disposal possibilities, and about one-third of dredged material is disposed of in the open ocean.[86] ‘‘The most prevalent single environmental issue facing ports in the U.S. is the proper disposal of dredged material, without which channel improvements would simply come to a halt. ”[87] Although only a fraction of harbor bottom sediments meet the contamination criteria under which disposal in costly containment areas is required,[88] gaining approval for dredging projects from a long list of government and environmental groups can take years. In some cases (Gary, Indiana, harbor, for example), maintenance restrictions have caused waterways to become shallower and narrower, severely limiting the types of vessels they can accommodate.

‘Ibid., p. 87.

85U.S. Army Corps of Engineers, op. cit., footnote 68, p. 16.

86U.S. Congress, Office of Technology Assessment, *Wastes in Marine Environments, OTA-O-334 (’Washington DC:* U.S. Government Printing office, A@ 1987), p. 237,

87Erik Stromberg, president, American Association of Port Authorities, quoted in John M. Pisani, *Port Development in the United States: Status, Issues and Outlook*, prepared for the Sixteenth International Association of Porta and Harbors World Ports Conference, Miami Beach, FL, Apr. 22-28, 1989 (Tokyo, Japan: The Iaph Foundation, 1989), p. 27.

88U.S. Army Corps of Engineers, Op. cit., footnote 72, p. 31.

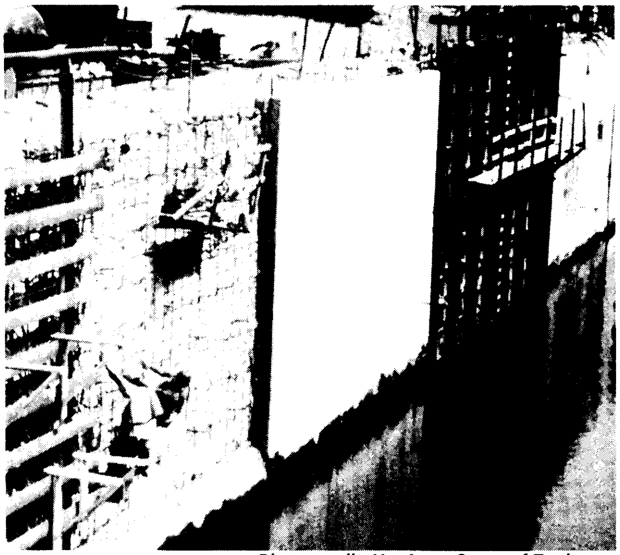

Photo credit: Us. Army Corps of Engineers

Maintenance technologies advanocs developed by the Army Corps of Engineers' laboratories have helped the Corps double the lives of many of the Nation's dams.

The lengthy process from authorization to completion for channel and harbor construction (which averages 22 years, according to the Marine Board) has weakened the effectiveness of port and waterway planning and design. In many cases, fleet demand and market economies change drastically before a channel can open for business, making the design inappropriate for current use.

Technologies

The Corps has research, development, and evaluation projects for maintenance, construction, and rehabilitation technologies and methods ongoing at each of its laboratories and has established an effective technology transfer system through its many offices. Addressing structural problems in locks, dams, jetties, and breakwaters, setting priorities among competing needs, and determiningg when and where modification is economically appropriate are all water system activities that can benefit from recent technology advances. Decisionmaking[90] tools can help industry and government alike to operate more efficiently.

Corps Technology ***Aids-Nondestructive evaluation*** technologies (examination methods used where visual inspection is impractical) can give managers more extensive information about structural conditions and maintenance and repair needs. Although visual inspections followed by core sampling are the most common ways for lock and dam technicians to find structural problems, visible defects are often indicative of a chronic problem that is costly to repair. Sonar is used to find defects on underwater surfaces and electromagnetic sensors and pulse/echo ultrasound devices are used to probe inside solid structures. (See chapter 5 for further details.)

Models and simulations of the physical and economic characteristics are valuable tools throughout the life cycle of a system, and can aid in planning, design, and making investment decisions for infrastructure. For example, techniques for observing and modeling local circulation and sedimentation can help design engineers locate and orient piers, wharves, and other pile-supported structures, so that a structure does not cause accelerated shoaling.[89] The Corps has good modeling capabilities at the Waterways Experimental Station. (For further details see chapter 6.)

Two Corps' programs to coordinate infrastructure-related work at the laboratories and in the private sector are the Repair, Evaluation, Maintenance, and Rehabilitation Research Program and the Construction Productivity Advancement Research Program (see chapter 6). Field-tested projects include *in situ* repair of deteriorated concrete, precast concrete for lock wall rehabilitation, and roller-compacted concrete for dams. (See chapter 5 for details on these technologies.)

Structural **Technologies-During icy winter** conditions or prolonged drought, vessel operators must carry lighter loads, use higher power (which increases operating costs), or find an alternative route. The natural channels of most inland rivers vary with seasonal rainfalls, and controlled releases by the Corps from water reservoirs help maintain suitable river stages throughout the year. However, some dredging is necessary to clear silted and shoaling channels.

Dredging-Dredging's two major components are extracting material and disposing of it. Extract-

[89] National Research Council, *Marine Board, Dredging Coastal Ports: An Assessment of the Issues* (Washington, DC: National Academy Press, 1985), p. 103.

[90] Ibid., p. 101.

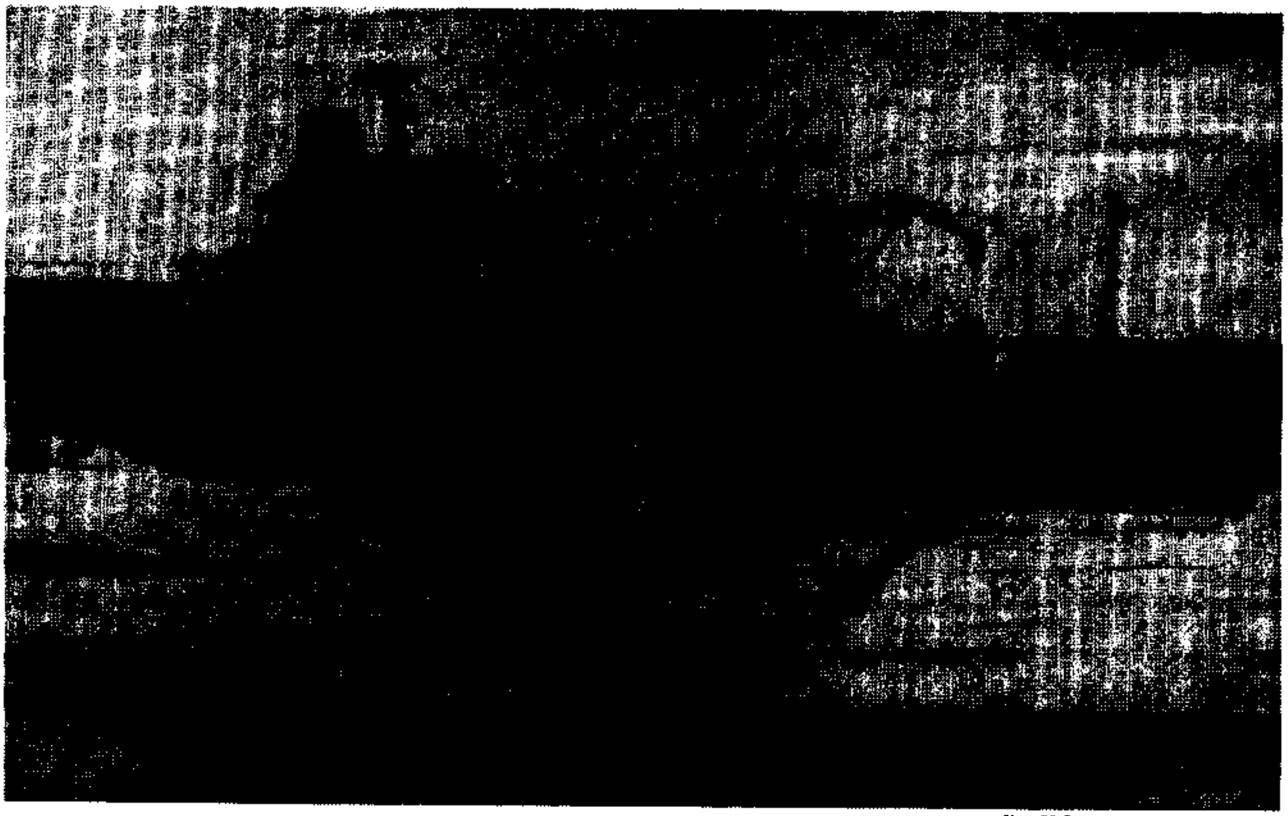

Photo *credit: U.S.* Army Corps of *Engineers*

Although dredges are now more efficient, environmental concerns about the proper disposal of dredged material have slowed channel dredging projects

ing techniques and technologies have benefited from automation, sensing, and positioning advances (see chapter 5). The same dredging equipment is employed generally for both maintenance and construction.[91]

Bank Protection--Articulated concrete slabs and gravel prevent channel migration and permit self dredging channel designs. Dikes and other structures deflect or stabilize currents within a channel.[92]

Lock and Dam-Slackwater systems are used where dredging, river embankments, and flow regulation are insufficient for commercial navigation.[93] Several dams are usually required to make a long waterway navigable. The higher that dams are built, the fewer are necessary, but a dam's cost increases exponentially with height.[94] The number and size of lock chambers, fock filling and emptying rates, and the ***types*** of tows and other vessels determine the traffic flow through a waterway. A typical lock can transfer vessels between pools in a 20- to 30-minute operation. Tows too large for a lock chamber must be split and the two groups of barges passed through separately and then reassembled. Such double lockages take about 11/2 hours.[95]

The capacity of the lock system can be increased by adding locks, rehabilitating structures, or replacing existing locks with larger ones. Since funds for new construction are very limited, smaller, affordable projects with immediate benefits must be considered. Alternative, lower cost, vessel lift technologies

[91]The specific type of dredging equipment used depends on geologic and environmental conditions.

[92]U.S. Army Corps of Engineers, Institute for Water Resources, *National Waterways Study—A Framework for Decision Making: Final Report*, NWS-83-1 (Ft. Belvoir, VA: January 1983), p. B-152.

[93]Open channels are generally less costly to construct and operate and support much greater traffic levels than lock and dam system

[94]U.S. Army Corps of Engineers, op. cit., footnote 92, p. B-153.

[95]Ibid,

and methods have been developed, but are not economically feasible for the locations analyzed by the Corps.[96] Lock-based tow haulage equipment could increase the capacity of some locks by 30 percent by pulling unpowered barge cuts (from double lockages) through the chamber.[97]

Other relatively minor structural improvements include extended guidewalls to permit recombining double lockage tows outside the chamber.[98] New coupling equipment (fixed rigging and permanent winches for tows and barges) to permit faster double lockages and tow work is a cost-effective option for smaller navigation locks.[99] Structural changes that modify river currents, as well as protect locks from tow collision damage, can improve lock approaches and allow tows to position more quickly and safely for lockages.

Traffic Management Options—Although no safety reasons require Federal control of waterway traffic, the low cost and wide availability of communications and surveillance technologies make systemwide traffic management a technical option. Scheduling access to congested facilities would allow better planning by industry and could reduce operating costs, since vessels often operate at inefficient fuel consumption speeds (too fast) given that delay at the next lock is likely. Tow breakage delays could be reduced by a "ready-to-serve" policy; vessel operators would need an extra towboat in each tow, or they could combine resources and station helper boats near each lock. Another traffic management option at locations with single locks is to give commercial traffic priority when traffic is heavy. Recreational vessels could be allowed transit only at scheduled times or on a space-available basis. Safety precautions prohibit mixed lockages of tows and recreational craft.

Locks operate more efficiently when traffic moves in a single direction, because the next tow can be positioned while the lock is cycled. For two-way traffic, the next tow must remain a safe distance away and wait for the departing tow to clear the chamber and approach area. Orderly one-way operation alternates a fixed number of lock cycles (commonly three to five) in each direction, increasing lock flow through by up to 15 percent over a random first come-first served policy[100] and reducing average delays. This method is similar to traffic management on one-lane bridges or during road construction.

While total system capacity will not change with better traffic management and scheduling, industry operating costs will be lower. Industry initiatives, such as new coupling equipment, system scheduling, and better fuel monitoring equipment,[101] can achieve substantial economic benefits.

Technologies for Industry Efficiency-System monitoring and performance data, such as traffic measurement, are essential for decision analysis, leading a number of ports to setup electronic service centers. Shipping documents transmitted by computers route and track cargo, and release import freight. The United Nations has developed EDIFACT (Electronic Data Interchange for Administration, Commerce and Transport) as a standard for the current disparate computer/data management systems.

Other alternatives for economic marine transportation are vessel operating changes, new forms and locations for ports, and vessel design modifications. Short-term alternatives include some of the operating practices already in use today-calling at shallow ports with less than a maximum load, timing movements with tides (or other conditions), and midstream cargo/fuel transfers. These measures are more expensive for carriers than larger vessels operating fully loaded without delays for the tide or lightering.[102]

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[96] Noel Bilbrough, U.S. Army Corps of Engineers, "Middle Columbia River Study: Ship Lift Alternatives," *Transportation Research Circular Number 350: Ports, Waterways, Intermodal Terminals, and International Trade Transportation Issues* (Washington, DC: Transportation Research Board, May 1989), pp. 66-72.

[97] U.S. Army Corps of Engineers, op. cit., footnote 68, p, 26.

[98] Leeper, Cambridge & Campbell, "Upper Mississippi River Transportation Economics Study: FinaReport,'' study sponsored by the U.S. Department of Agriculture et al., April 1989, p. 25.

[99] Ibid., p. 3.

[100] U.S. Army Corps of Engineers, op. cit., footnote 68, p. 26.

[101] Leeper, Cambridge & Campbell, op. cit., footnote 98.

[102] L. George Antle, chief, Navigation Division, Institute for Water Resources, U.S. Army Corps of Engineers, personal communication, July 10,1990.

Loading additional cargo or fuel after the vessel passes restrictive channels is considered the most cost-effective option,[103] and at present coal colliers can load in midchannel below New Orleans, while tankers can load and unload in the Gulf offshore from Louisiana.[104] Alternative vessel designs include a proposed jumbo barge carrier three times the size of the largest ship today. Cargo from the main carrier would be offloaded to barges, which could serve ports that would not need deep-draft channels or large load center facilities.[105]

Building a large "island" offshore in 80 feet of water in the Delaware Bay has been proposed. However, the operational feasibility of such a major offshore terminal would depend on multi-State agreements and substantial new investment in landside infrastructure, and its economic success would depend on diverting much of the traffic from other ports. The potential environmental impacts of construction and operation have already led to strong opposition.[106]

Intermodal Advances—The major recent changes in maritime-related, intermodal operations have occurred in the private sector—in containers and technologies that support fast vessel turnaround, including ship design, cranes, truck chassis, double stack railcars, and electronic information management. The Shipping Act of 1984, which permitted single bills of lading for intermodal cargoes, spurred demand for these technologies. Containers eliminate the handling of individual cargo, improving loading and unloading efficiency and transfer to railcars or truck chassis. New container vessels called "post panamax" ships, because they are too large to pass through the Panama Canal, carry up to one-third more containers than the previous generation. Since these huge vessels have high operating expenses and are designed for transferring cargo efficiently, they must use ports that can provide fast turnarounds if they are to operate economically.

Federal Infrastructure: Aviation

Air transportation is truly a national system in the United States; the effects of a thunderstorm in an air traffic control (ATC) sector near Chicago or a closed runway in Denver ripple across the country in delays, missed connections, and rerouted aircraft. Airlines and the military operate under a uniform set of Federal regulations and fly in a relatively centralized public airspace and ATC system.[107] Each element of the system—pilots, controllers, and other aviation personnel, aircraft, and airports-must meet Federal safety standards and be certified by the Federal Aviation Administration (FAA). Airports and airways are the public works portions of the system.

Management and Financing

Although the routes and airspace or airways linking airports are defined electronically and procedurally, they are nonetheless public works. The federally operated ATC system, established principally for flight safety, coordinates and directs all flights to and from U.S. airports, and comprises one of the most complex transportation operations in the world.

For ATC purposes, the airspace above the United States is partitioned according to airport locations and the amount of traffic into three broad categories: terminal, en route, and oceanic airspace. Terminal airspace surrounds airports, and is characterized by aircraft changing speed, direction, and altitude, as they maneuver after taking off or prior to landing. The airways connecting airports make up the en route airspace, while oceanic airspace begins over international waters, with much of it lying beyond sight of land. Costs for the system, managed and operated by FAA, are paid out of the Federal Airport and Airways Trust Fund and the General Fund.

The National Airspace System (NAS) P!an— First published in 1981, the NAS Plan is FAA's comprehensive program for modernizing air traffic facilities and equipment, and consists of more than 90 separate projects. Relying on advances in automation that are part of the NAS Plan, FAA expects

103National Research Council, op. cit., footnote 89, p. 5.

104Antle, op. cit., footnote 102.

105Lester A. Heel, "Marine and Intermodal Transportation: Issues and Challenges," *TR News, No.* 144, September-October 1989, pp. 15-19.

106Antle, op. cit., footnote 102.

107There are large sectors of uncontrolled airspace across the United States, generally below 12,000 feet, often used by general aviation.

Table 3-8-Passenger Enplanements at 25 U.S. Airports, 1988

Airport	Rank	Total enplanements[a] (in thousands)	Percentage[b]	Cumulative percentage
Chicago O'Hare	1	28,850	5.8	5.8
Atlanta Hartsfield	2	23,573	4.8	10.6
Dallas-Fort Worth	3	23,029	4.7	15.3
Los Angeles International	4	22,179	4.5	19.8
New York JFK	5	19,415	3.9	23.7
Denver Stapleton	6	15,015	3.0	26.7
San Francisco International.	7	14,683	3.0	29.7
Miami	8	14,316	2.9	32.6
Boston Logan	9	11,802	2.4	35.0
New York LaGuardia	10	11,790	2.4	37.4
Newark International..	11	11,580	2.3	39.7
Honolulu International	12	11,081	2.2	41.9
St. Louis International	13	10,139	2.1	44.0
Detroit Metro	14	10,044	2.0	46.0
Phoenix Sky Harbor	15	9,559	1.9	47.9
Pittsburgh International	16	8,971	1.8	49.7
Minneapolis-St. Paul.	17	8,939	1.8	51.5
Houston Intercontinental	18	8,142	1.7	53.2
Orlando	19	8,122	1.6	54.8
Washington National ., ...	20	7,888	1.6	56.4
Philadelphia	21	7,789	1.6	58.0
Seattle-Tacoma	22	7,659	1.6	59.6
Las Vegas	23	7,658	1.6	61.2
Charlotte	24	7,613	1.5	62.7
Baltimore.	25	5,363	1.1	63.8

[a]Includes us. certificated route air carriers, foreign flag carriers, supplemental, air commuter, and air taxis.
[b]Based on 493.8 million passenger enplanements.
[c]Cumulative percentage is a running sum: e.g., the top five airports have 23.7 percent of total U.S. enplanements.

SOURCE: U.S. Department of Transportation, Federal Aviation Administration, *FAA Aviation Forecasts: Fiscal Years 1990-2001*, FAA-AP090-1 (Washington, DC: March 1990).

to address current constraints due to controller workload, computer processing capacity, hazardous weather detection, and communications.

When it was first presented to Congress, costs for the NAS Plan were projected to be $9 billion over 8 years, but adding new projects and changing existing ones may raise total costs to $25 billion by the year 2000.[108] Complexities of implementing technology changes in a large operating system have caused the major projects within the NAS Plan to fall behind their original schedules by 1 to 5 years.[109] FAA also maintains a plan for research, development, and engineering to examine technologies outside the NAS Plan.[110]

Airports—Airports, most of which are not federally owned, provide landing and takeoff areas for aircraft and facilities for transferring passengers and cargo to other transportation modes. The large and small *commercial airports,* which offer cargo and passenger airline service, are owned primarily by municipalities or special authorities and by 13 States. A relative handful of these facilities handle most commercial airline passengers—almost one-quarter of total passengers board flights at just five airports (see table 3-8). Of the over 17,000 airports[111] in the United States, most are public-use *general aviation (GA) airports* owned by municipalities, counties, or private groups and used primarily by personal and business aircraft.

[108]U.S. General Accounting Office, *Continued Improvements Needed in FAA's Management of the NAS Plan,* GAO/RCED-89-7 (Washington, DC: November 1988), p. 3.

[109]Ibid., p. 3.

[110]U.S. Department of Transportation, Federal Aviation Administration, "Federal Aviation Administration Plan for Research, Engineering, and Development,'' vol. I, draft manuscript, September 1989.

[111]U.S. Department of Transportation Federal Aviation Administration, *FAA Statistical Handbook of Aviation for Calendar Year 1987* (Springfield, VA: National Technical Information Service, 1987); included in the "airport" count are heliports and seaplane bases.

The concentration of commercial passengers at major airports permits them to be largely self-supporting from landing fees, airline rents, and revenues from parking and concessions. Management and oversight of groundside facilities differs drastically from airport to airport. Airlines typically lease terminals and gates[112] from the airport operator, obtaining exclusive-use rights, and the major lessors often gain a strong voice in decisions on whether and how to expand ground facilities. Under the 1990 budget agreement, airports are permitted to levy up to $3 per passenger charge, providing anew source of revenue, for use solely on airport improvements.

Medium and small airports rely on Federal or State help in meeting their funding needs. Almost all States have airport aid programs, usually targeted to smaller, nonmetropolitan airports, and most maintain statewide airport development plans. Funds come from State aviation fuel taxes and general appropriations.

Issues

Land-use, financial, and environmental concerns frame many governmental decisions about aviation. System capacity has become a major issue. Because technological advances allow capacity increases without a decline in safety, airspace capacity is limited by Federal investment decisions and technology.[113]

Environmental Concerns—Aircraft noise is a serious problem for airport operators and airlines, leading to measures that permit Federal funds to be used to soundproof homes and schools, and in some cases, purchase real estate in high noise areas. Community groups fighting to restrict airport operations because of noise concerns have limited airport development across the country.

While the intensity of sounds can be measured precisely, determiningg what constitutes objectionable noise is more subjective. Currently, individual aircraft must meet FAA noise standards, based on a 24-hour average of noise energy,[114] commonly referred to as Stage 1, 2, and 3 rules.[115] While differences in local conditions and jurisdictional factors have made establishing a more definitive Federal standard for airport noise difficult, Stage 1 aircraft are already banned, and all Stage 2 aircraft are prohibited after December 31, 2000.[116] Newer aircraft must meet Stage 3 requirements, the strictest ones.

In each successive jetliner generation, new technology has lowered noise levels, but additional reduction through technology may be limited, posing contentious issues. For example, 50 percent of the noise from a Boeing 757 on landing approach is aerodynamically produced, a type of noise that experts believe cannot be reduced much more. Nonetheless, a working group of the International Civil Aviation Organization (ICAO) is studying the feasibility of Stage 4 noise limits.[117]

The 1990 deficit reduction agreement requires that the Secretary of Transportation establish, by July 1, 1991, a national noise policy that considers the economic impact on air carriers and makes recommendations related to aircraft noise to Congress for changes in State and local government authority and other standards, procedures, and programs. No airport will be allowed to restrict Stage 3 aircraft operations without forfeiting all Federal aviation grants or the right to impose passenger facility charges, unless the program was in place before October 1,1990, or the Secretary of Transportation approves the restrictions.

The current level of aviation operations has a small, but significant effect on air quality. In the Los Angeles basin, aircraft exhaust and fueling emissions contribute about 1 percent of the total volatile organic compounds. FAA and EPA are addressing these air quality issues by requiring that new jet engines reduce organic compounds emissions by 60 to 90 percent. EPA is considering regulations

112 Airlines sometimes lease ground space and build their own facilities.

113 Based on current air traffic control separation standards, the usable airspace above the continental United States could accommodate, theoretically, well over 1 million aircraft at once.

114 14 CFR 150, app. A.

115 14 CFR 36.

116 *Congressional* Record, Oct. 16, 1990, p. 12535.

117 Michael Zywokarte, project manager, Engineering, Federal Aviation Administration, personal communication, July 1989.

118 Nicholas P. Krull, Office of Environment and Energy, Federal Aviation Administration, personal communication, July 31, 1990.

Table 3-9-Congested Airport Rankings and Expansion Plans

Airport (1987 rank)	Airport rank by total hours of air carrier delay in 1987	Ranked by total air carrier operations in 1987	Planned construction that will increase IFR capacity
Chicago O'Hare	I[a]	2	
Atlanta Hartsfield.	S[b]	1	X
Dallas-Fort Worth	3[b]	4	X
Los Angeles International. . . .	4[c]	3	
Denver Stapleton		5	x
Newark International.		19	
San Francisco International. .	7[d]	6	
New York LaGuardia	8[d]	21	
New York JFK	9[d]	26	
Boston Logan	10[d]	10	
St. Louis Lambert	11[d]	11	
Miami International.	12[d]	22	
Phoenix Sky Harbor	13[d]	9	
Washington Dunes	14[d]	28	X
Detroit Metro	15[d]	12	X
Philadelphia	16[d]	13	
Washington National , ...	17[d]	25	
Minneapolis-St. Paul	18[d]	18	
Honolulu International	19[d]	16	
Pittsburgh International.	2o[d]	20	
Houston International	2 1[d]	27	X

KEY: IFR = instrument flight rules.

a Total air carrier delay exceeds 100,000 hours.

b Total air carrier delay is between 75,000 and 100,000 hours.

c Total air earner delay is between 50,000 and 75,000 hours.

d Total air carrier delay is between 20,000 and 50,000 hours.

SOURCE: U.S. Department of Transportation, Federal Aviation Administration, Airport *Capacity* Enhancement *Plan*, DOT/FAA/CP189-4 (Washington, DC: May 1989).

requiring vapor recovery systems for aircraft fueling.[118]

Capacity—According to recent estimates, delays cost scheduled air carriers almost $2 billion in extra operating expenses and passengers $3 billion in lost time, excluding commuter and general aviation data, which are not available.[119] About two-thirds of all delays are caused by bad weather-restricted visibility, thunderstorms, or snow or ice on runways—which affects airports less than 10 percent of the time on average. Too much traffic for airports and ATC to handle during normal conditions accounts for roughly 25 percent of delays, while pavement construction and ATC equipment problems each account for less than 5 percent.[120]

Annual airline travel demand depends on the strength of the economy and generally follows trends in the GNP. Current forecasts indicate that increasing numbers of U.S. and foreign airports will have traffic demand exceeding their capacity for longer periods of time each day. Average annual growth of 4.2 percent in passengers enplaned on U.S. airlines and 2.1 percent in total aircraft operations is projected.[121] The annual delay problems that plague 25 commercial airports are shown in table 3-9. If no capacity improvements are made, estimates are that by 1997,[122] 17 airports will be in the same delay category as Chicago O'Hare, Atlanta Hartsfield, and Los Angeles International are today.[123]

119 U.S. Department of Transportation, Federal Aviation Administration, *Airport Capacity Enhancement Plan*, DOT/FAA/CP/88-4 (Washington, DC: April *1988), p.* 1-11.

120 U.S. Department of Transportation, Federal Aviation Administration, *Airport Capacity Enhancement Plan*, DOT/FAA/CP/89-4 (Washington, DC: May *1989), p.* 1-10.

121 U.S. Department of Transportation, Federal Aviation Administration, *FM Aviation Forecasts, Fiscal Years 1990-2001*, FM-APO 90-1 (Washington, DC: March 1990), pp. 5,7.

122 Federal Aviation Administration op. cit., footnote 120, p. 2-1.

123 Ibid., table 2-2, p. 2-4.

Airline hub-and-spoke operations can place as severe a burden on ground capabilities as on the airside, and ground access to and from airports depends entirely on local planning and transportation management. Moreover, no single agency or organization is responsible for research or planning for enhancing the capacity of ground facilities; FAA's authority over landside development and management is limited.[124]

Building more runways and airports, which would provide the greatest increase in aviation system capacity, requires high capital investment, and more important, overcoming community opposition based on land use and noise and air pollution concerns. These are such difficult obstacles that just six of the most congested airports are planning new runways (see table 3-9 again).

Access and Equity Concerns—When traffic demand exceeds runway capacity, as happens regularly during peak periods at busy airports, each single occupant aircraft imposes roughly the same amount of system delay as an airliner with 300 passengers. However, smaller aircraft almost always pay much less in landing fees and Federal taxes for using the system, a policy that embodies difficult and contentious equity and access issues. Major airlines have altered schedules and purchased larger aircraft, so they can carry more passengers and cargo under these circumstances.[125]

Underutilized Airports-Modifying lightly used airports close to busy facilities to make them more attractive to commercial or GA users is generally more feasible than new construction. FAA has sponsored reliever or satellite airport development for GA traffic by earmarking funds especially for developing and upgrading these airports,[126] to reduce delays at nearby, busy, commercial airports by removing the small, slow GA aircraft. However, reliever and other GA airports face some of the same noise and competing land-use problems as commercial airports. Furthermore, any policy to divert traffic also diverts revenue from the major airport.

Restricting Airport Access-Restricting access, at least to certain runways, for small, low-performance aircraft is one way to increase runway availability for large jets. However, unless suitable alternative facilities, such as reliever airports, are found for excluded aircraft, such a policy could be considered discriminatory and a restriction of interstate commerce.[127] Moreover, while quotas and restrictions may be acceptable temporary measures, actions to change basic underlying demand will also be necessary if capacity cannot be increased.

Quota systems for all aircraft are used at several airports where demand exceeds physical or noise-related capacity regularly for much of the day. Four major airports-Chicago O'Hare, La Guardia and JFK in New York, and Washington National-are covered by FAA's high-density rule, established in 1973, which legally caps the number of flights that can be scheduled for these airports. Landing and takeoff slot quotas are established for three user classes: air carriers, commuters, and GA. While GA slots are distributed by call-in reservations, air carrier and commuter slots are allocated by airline scheduling committees, which are granted antitrust immunity to negotiate the assignments. FAA reserves the right to distribute the slots if negotiators fail to reach agreement.[128] During good weather, high-density airports can usually handle aircraft without assigned slots.

Current quota systems favor incumbent airlines, since slots are granted based on prior use, a complaint raised frequently by airlines formed after deregulation and currently by airlines wishing to establish a market at the four airports. Established carriers counter that since they invested in the airport and its market over many years, they should be able to keep their slots, now worth millions of dollars apiece to the holders at several airports.

124 Transportation Research Board, *Measuring Airport Landside Capacity*, Special Report 215 (Washington, DC: National Research Council, 1987), p. 57.

125 After virtually no change since 1983, commercial aircraft seating capacity is projected to grow by three seats per aircraft, on average, in each of the next 12 years. From U.S. Department of Transportation, Federal Aviation Administration, *FAA Aviation Forecasts, Fiscal Years 1990-2001*, FAA-APO 90-1 (Washington, DC: March 1990), p. 53.

126 U.S. Congress, Office of Technology Assessment, *Airport System Development*, OTA-STI-231 (Washington, DC: U.S. Government Printing Office, August 1984), p. 110.

127 Ibid., p. 114.

128 Ibid., p. 114.

Market Concerns-Market pricing of positions at congested airports raises other access and equity issues. Selling (or leasing) airport landing slots through the open market is viewed by many economists as the most effective way to determine the value of airport access and allocate these scarce resources.[129] However, competition among airlines could potentially be limited if slots are hoarded, and small aircraft could be effectively excluded from the airport.

The appropriate use of the proceeds from slot transactions is a contentious issue. Although airlines have been allowed to treat slots as private goods, the slots are created and provided by public agencies, the airport proprietor, and FAA. A strong case can be made that slot payments belong to the agencies providing the services and should be used for public purposes.

Differential/ Pricing-At present, ATC services and public airspace are available at no charge to all properly equipped and operated aircraft. Access to public airports, except where quotas are in effect, is generally open to anyone willing to pay the landing fee, usually less than 2 or 3 percent of the aircraft's operating costs.[130] Landing fees offset the capital, maintenance, and operating costs for runways and other airport facilities. Fees do not generally vary by time of day and are typically based on aircraft weight, which is roughly related to required size of facilities and the amount of wear caused by the aircraft. However, most fees fail to reflect the costs to other users of delay and congestion, and provide no incentive to shift demand to nonpeak periods.

A few airport operators have tried to manage demand by raising landing fees, but small aircraft operators and airlines alike have successfully challenged landing fees in court as unreasonable and discriminatory. In 1986, the Port Authority of New York and New Jersey successfully instituted a surcharge of $100 for GA aircraft landing at its three major airports from 8:00 a.m. to 9:00 p.m., reducing traffic by 30 percent for those times.[131] The Massachusetts Port Authority, reallocated airport costs among all users, charging higher landing fees for GA and lower ones for airlines. However, the fee structure was challenged as discriminatory, and was overturned by DOT (see box 3-I).

Photo credit: Office of ***Technology Assessment***

Taxis and private automobiles carry the vast majority of passengers to and from airports.

Passenger Surcharges-Direct passenger surcharges for flights during peak periods will probably not be passed on to the passengers affected unless fares are regulated in some form, not a likely prospect. Finally, passenger charges alone do little to divert small aircraft or encourage large aircraft use.

Transportation **to Airports-Getting to and** from the airport, which can represent a sizable portion of total trip time, depends on the capabilities of the regional transportation system surrounding the airport and on the convenience of road circulation, the availability of parking, and mass transit access at the busiest airports. Because origins and destinations are so scattered throughout urban areas, road vehicles, especially private automobiles and taxis, carry over 90 percent of the passengers to and from most airports. Airport employees, who account for about one-third of all access trips, usually must also rely on automobiles. Many major airports have significant air pollution problems stemming primarily from automobiles and surface traffic congestion, although aircraft contribute as well.[132] The growth of

[129] U.S. Congress, Office of Technology Assessment, *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment*, OTA-SET-381 (Washington, DC: U.S. Government Printing Office, July 1988), p. 38.

[130] Office of Technology Assessment, op. cit., footnote 126, p. 116.

[131] Jan E. Monroe, "Practical Methods for Shifting General Aviation Traffic From Commerce Service Airports to Reliever Airports," *Transportation Research Record 1218* (Washington, *DC:* Transportation Research Board, 1989), p. 13.

[132] David W. Davis, executive director, Massport, personal communication, May 2, 1990.

Box 3-I—The Massachusetts Port Authority

On July 1, 1988, the Massachusetts Port Authority (Massport) implemented the first phase of its Program for Airport Capacity Efficiency (PACE), a plan to reduce delays at Logan International Airport by basing landing fees more closely on the actual airport costs for accomrnodat.ing each aircraft. Fees rose for small aircraft (the previous minimum of $25 was increased to $91) and fell for the largest airliners. The fee changes caused general aviation flights to drop by one-third and improved Logan's on-time performance ranking, established by the U.S. Department of Transportation (DOT) for the 30 busiest commercial airports, from roughly 21st to 2nd during the last month of the PACE program.[1] However, small aircraft owners[2] filed complaints with the Federal Aviation Administration soon after the PACE plan was announced and on December 22, 1988, DOT ruled that the new fee structure was ". . . unreasonable and contrary to Federal statute. Faced with the loss of millions of dollars in Federal funds for airport improvements, Massport's Board voted to return temporarily to the previous fee schedule and to develop another, more acceptable, pricing method. Logan's on-time performance ranking plummeted to 29th by April 1990.[4]

PACE landing fees had two components: a weight-based portion to cover runway construction, maintenance, and other costs that vary with aircraft size; and a charge to recover costs linked to each flight (such as lighting, emergency services, and snow plowing), which according to Massport, had been previously subsidized by commercial airline passengers. A second phase of PACE, never implemented, proposed peak-hour pricing and slot sales to shift traffic away from high demand periods. DOT accepted the dual-omponent landing fee concept but disagreed with some of the ways Massport divided the costs between the two components of the fee. For example, Massport divided the costs for maintaining crash, fire, and rescue (CFR) services among all landings regardless of aircraft size, since all flights benefit. However, since the requirements for CFR capabilities are based on the size of the aircraft using an airport, DOT ruled that CFR costs should be assigned on a weight-based scale. Moreover, DOT endorsed peak-hour surcharges as an acceptable pricing option for landing fees,[5] Massport remains committed to winning DOT approval of a landing fee schedule that uses peak-hour pricing to improve airport capacity and is developing alternatives.[6]

[1] David W. Davis, executive director, Massport, personnel communication, May 2, 1990.

[2] National Business Aircraft Association, Regional Airline Association, and Aircraft Owners and Pilots Association.

[3] U.S. Department of Tranaportation, Office of the Secrctary, "Investigation Into Massport's Landing Fees,' ' FAA Docket 13-88-2, Dec. 22, 1988.

[4] Davis, op. cit., footnote 1.

[5] U.S. Court of Appeals for the First Circuit, Massachusetts Port Authority v. U.S. Department of Transportation, "Brief of Petitioner-Appellant, Massachusetts Port Authority," No. 88-2227, Dec. 22, 1988.

[6] Tom Champion, special assistant to the administrator, Massport, personal communication, Nov. 8, 1990.

the rental car industry reflects the lack of suitable alternate forms of transportation from many airports. Procedural and management changes, such as parking restrictions combined with strict enforcement and segregating private autos, taxis, limousines, and buses, are inexpensive and effective options.

About 25 percent of airport trips are to or from the city center,[133] so dedicated surface systems such as rail transit and remote terminals are essential to ground access in major metropolitan areas. Water ferries and helicopters, available for a few large, urban airports, transport relatively few passengers, but are an important alternative in cities like New York and Boston, where surface arteries are very congested.

Funding landside investments involves complex, multijurisdictiona1 arrangements that vary widely from airport to airport. The capital improvements sponsored by FAA are limited to on-airport roadways, guideways, and walkways, including bypass lanes, multiple termina1 entry and exit points, curb frontage, remote park and ride facilities, and pedestrian overpasses or underpasses. For projects to improve ground access off the airport property, jurisdictions must seek FHWA and Urban Mass Transportation Administration grants or find State and local funds.

[133] Office of Technology Assessment, op. cit., footnote 126, p. %.

Technologies for Enhancing System Capacity and Performance

Airports can operate close to peak capacity most of the time. Because airport physical expansion possibilities are constrained and runways already operate close to technologically peak efficiency, the critical long-term limit for air travel is likely to be *runway capacity. Gains in* runway performance will require systemwide air traffic management, such as more efficient aircraft routing, spacing, and sequencing within queues. Technology can contribute by reducing distances necessary for safe separation between aircraft, increasing controller productivity, and enabling flights to continue at the maximum rate in all but the most severe weather conditions.

Analytic tools can help air traffic decisionmakers make rational system choices under such circumstances. FAA already has some computer-based models for quantifying the effects of changes in equipment, procedures, airspace configurations, and user demand on system performance. For example, using its NASPAC simulation model, FAA found that the new airport now under construction in Denver should reduce airline delays nationwide by 4 percent on a moderate winter day and 18 percent on a more snowy day.[134] Plans are under way for a dynamic simulation laboratory to further FAA's system analysis capability, and modeling and simulation technologies are being incorporated into the agency's traffic management facilities.

Some of the options for increasing the capacity of existing airports and runways, their current limitations, and the role of technology are listed in table 3-10. While capacity gains from any option can be quantified, they depend on too wide a range of parameters and conditions[135] to detail in this report.[136] Making runway performance under instrument flight rules (IFR) closer to visual flight rules (VFR) capabilities will have the greatest effect on current delays, and requires technology to reduce the safe spacing between aircraft. Increasing VFR capacity requires reducing the time an aircraft occupies a runway, overcoming wake vortex hazards, and managing arriving traffic to eliminate gaps.

Surveillance-One of the most promising near-term technologies for improving IFR capacity at airports upgrades the secondary surveillance system to give faster radar data updates and larger and clearer controller displays.[137] These radar systems, not a part of the NAS Plan, will permit increased operations on parallel and converging runways. Different systems are currently being tested at Memphis and Raleigh-Durham airports.

Civilian surveillance radars require clear lines-of-sight to monitor traffic. Over oceans or remote areas, or at low altitudes where radar coverage is not practical, satellite technologies are available. The most promising satellite surveillance application is dependent surveillance, under which aircraft-based equipment determines position and relays information via satellite to a ground-based ATC facility. Automatic dependent surveillance (ADS) relies on new applications of established communications and navigation technologies and will likely be used first on the busiest ocean routes. Currently, controllers track oceanic flights through position reports from pilots derived from onboard navigation instruments and relayed by high frequency radio. Once established, ADS will allow closer spacing of oceanic flights, but no satellites yet operate in the aeronautical mobile band, which an operational ADS system must use. ICAO technical standards are stall in the process of being developed, and FAA has not yet established an implementation plan or policy for ADS.[138] FAA is investigating advanced satellite technologies that could have applications for ATC, but the potential reliability of ADS makes the cost-effectiveness of the more expensive independent satellite systems questionable.[139]

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[134] The Mitre *Corp.,* "Analysis of National Delays and Throughput Impacts of a New Denver Airport," unpublished document, April 1990.

[135] Airport capacity depends on how operations are split between departures and arrivals and among the mix of aircraft types. Furthermore, IFR capacity is critically dependent on runway configuration. For example, only one runway can be used during IFR at airports with parallel runways that are less than 2,500 feet apart.

[136] A detailed quantitative discussion of ah-field capacity gains resulting from potential operational improvements is presented in John E. Lebron, *Estimates of Potential Increases in Airport Capacity Through ATC System Improvements in the Airport and Terminal Areas,* FAA-DL5-87-1 (Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, October 1987).

[137] Ken Byram, project manager, Parallel and Converging Runway Monitoring, Federal Aviation Administration, personnel communication, Dec. 1, 1989.

[138] Zywokarte, op. cit., footnote 117.

[139] Clyde Miller, Research and Development Service, Federal Aviation Administration, personal communication Sept. 11, 1990.

Table 3-10-Enhancing the Performance of Existing Airports and Airways

Potential enhancement	Goals	Current limitations	Potential technological options
Increase the maximum takeoff and landing rate possible for a runway.	Reduce the time an aircraft occupies a runway.	No more than one aircraft allowed on a runway at a time.	High speed exits from runways.
		Fast, moving, heavy aircraft take more time to slowdown than smaller planes.	Improve aircraft deceleration capabilities.
	Reduce wake vortex hazards, allowing closer in-trail aircraft spacing.	Vortices are intrinsically linked to aerodynamic lift and cannot be eliminated.	Make wake vortices visible to pilots; reduce the strength of the vortices.
		Vortices are usually invisible. Aircraft size difference is a large factor in vortex hazards.	
Increase the maximum takeoff and landing rate possible for airports with multiple runways.	Reduce collision avoidance and wake vortex hazards, allowing closer aircraft spacing.	Ground- and airborne-based surveillance, communication, and human reaction time are presently insufficient to safely separate aircraft at the distances necessary for some parallel runways.	Improve surveillance, guidance, communication, and automation.
Increase the average takeoff and landing rate of a runway or airport.	Reduce runway downtime.	Necessary periodic maintenance.	Longer lasting materials; analytical and management tools (e.g., nondestructive evaluation).
		Snow and ice removal.	Snow and ice sensors; selected pavement additives.
	Reduce enroute airspace-related delays.	Human capability to process and transfer information.	Automation, surveillance.
		Oceanic ATC capability far below domestic level.	Better surveillance, communications, and navigation.
	Reduce collision avoidance and wake vortex hazards, allowing closer aircraft spacing, dose the IFR/VFR capacity gap.	ATC radar and cockpit instruments are not as capable as human vision.	Surveillance, navigation, guidance.
	Reduce time-wasting gaps in arrival stream.	Difficult for controllers to position and sequence aircraft at optimal times for runway approaches, especially if traffic is mixed among aircraft with differing sizes and speeds.	Improved strategic and tactical management technologies for air traffic.
	Reduce delays due to inaccurate/Impredse weather information.	Safety margins must be kept large for dangerous thunderstorms and windshear, resulting in delays.	More accurate weather prediction and detection; better information transfer to controllers and fright crews.

KEY: ATC = air traffic control; IFR = instrument flight rules; VFR = visual flight rules.

SOURCE: Office of Technology Assessment, 1991.

Navigation and Guidance-Long-range radio-navigation systems, LORAN and OMEGA (see chapter 5), permit navigation in remote locations. As part of the NAS Plan, FAA is providing funds to the Coast Guard to install four additional LORAN stations to allow complete coverage across the continental United States.[140] Combined with an ADS link, LORAN or OMEGA could permit enhanced low-altitude and remote-site traffic control.[141]

140 U.S. Department of Transportation, Federal Aviation Administration, *National Airspace System Plan: Facilities, Equipment, Associated Development and Other Capital Needs* (Washington, DC: September 1989), p. IV-58.

141 U.S. Department of Transportation, Federal Aviation Administration, "Federal Aviation Administration Plan for Research, Engineering, and Development" vol. II, draft manuscript, September 1989, p. 258.

Satellite-based systems offer the greatest potential for aviation navigation enhancement. INMARSAT, an international consortium that operates a global satellite system for maritime mobile communications, plans to deploy the first satellite designed to provide civilian aeronautical service. The Department of Defense (DoD) Global Positioning System, which will provide civilian aircraft with location data accurate within 500 feet, is expected to be available for worldwide navigation in late 1993. FAA studied the integration of GPS with LORAN in a single cockpit device and determined that this combination may be suitable as a sole means of navigation, and is currently evaluating avionics.[142]

The NAS Plan includes replacing current instrument landing systems (ILS), which provide course and glideslope guidance for landing aircraft, with microwave landing systems (MLS). MLS allow curved approaches, not possible with ILS, and potential capacity gains in locations where present runway approaches and departures conflict. Although the program has been besieged with controversy and is behind schedule, FAA must comply with ICAO plans to install MLS as the landing aid at international airports by 1998.

Weather Detection and Prediction-Avoiding hazardous weather-windshear,[143] severe turbulence, lightning, inflight icing, or hail-is especially important in terminal areas, where aircraft are close to the ground. Existing radars are able to identify areas of heavy precipitation, often indicative of dangerous flying conditions; however, these radars cannot see clear air turbulence or windshear. Advanced weather radar systems that can measure winds and other automated weather observing systems are being deployed as part of the NAS Plan. Next generation weather radars, funded jointly by DoD, the National Weather Service (NWS), and FAA, will replace existing NWS radars. Because there are no meteorologists at some FAA facilities, the terminal weather radar will employ expert systems to present weather information (such as automatically identifying microbursts) in a usable form directly to controllers.[144]

Communication-Federal aviation communications systems transmit ATC and weather information through voice and digital messages over one-way and two-way radio, landline wire, and fiber optic links. Two communications developments that could support increased airspace capacity are *data link* and *satellite relay* for aircraft. The NAS Plan calls for Mode S digital links to transmit many of the ATC and weather messages sent over voice channels, and to provide new functions such as real-time graphic display of weather and ATC instruction relay and conflation. Digital communications will not replace the current air-ground voice links as the primary system for real-time ATC and weather information until at least late in the decade.

Successful tests using existing satellites for communications have prompted at least five airlines to order airborne systems for their new aircraft.[145] ICAO's Future Air Navigation Systems Committee has stated that". . . satellite-based communications, navigation, and surveillance will be the key to worldwide improvements. ' '[146]

Automation and System Management— Computers are used extensively throughout the ATC system to process flight plans, correlate and display radar returns, and alert controllers to hazardous traffic situations. All traffic control decisions are now made by controllers. However, systems currently being developed will be capable of computing optimal flight paths in real time and relaying instructions directly to cockpits.

ATC Computers-Computers process primary and secondary radar returns, track targets, and provide appropriate data for each aircraft. FAA's Central Flow Control Facility (CFCF) already manages IFR traffic on a national scale. Flight plan information and live radar data from 20 en route centers are relayed to CFCF, where an aircraft situation display presents national traffic data and analyses, updated every 3 minutes, for any portion of

[142] Ibid., p. 256.

[143] Windshear is a change, usually sudden, in wind velocity across anaimraft'spath. The most dangerous form owindshear is the microburst, a rapidly descending column of air that maybe impossible for some aircraft to escape from when flying close to the ground.

[144] Office of Technology Assessment, op. cit., footnote 129, p. 158.

[145] "Tests Demonstrate Potential Benefits of Satellites in Air-Ground Communications," *Aviation Week & Space Technology,* vol. 130, No. 2, July 10, 1989, p. 57.

[146] "ICAO's Turn-of-Century Plan Completed," *Interavia*, August 1988, p. 749.

the continental United States. The system automatically alerts the traffic manager when capacity is insufficient. Under the NAS Plan and R&D programs, FAA is working toward using real-time computer analyses to manage runway and airspace configurations and to issue traffic clearances for optimal traffic flows.

The centerpiece of the NAS Plan is the Advanced Automation System (AAS), a $5 billion project to replace and consolidate computer hardware, software, and workstations at airport tower, terminal, and en route ATC facilities. FAA expects better safety, greater system capacity, and lower operational costs, due in large part to new and expanded automated functions. Among the most important of these new capabilities is automated en route air traffic control (AERA).

AERA, to be implemented in three phases, will predict and resolve traffic conflicts in four dimensions and permit more fuel-efficient and direct flight paths. FAA plans to install the first phase in 1997. The objective for AERA 3, on program completion, is automatic monitoring and control of traffic, and removal of the capacity limitations of the current systems to permit controllers to manage airspace regions much larger than present ATC sectors.[147] Many aviation safety experts view increased use of automation with ambivalence. While automated systems increase efficiency and safety in some areas, they require monitoring and accurate data entry. The role of the human in this increasingly automated environment is a critical issue that needs to be studied extensively to establish bases for setting standards.[148]

Technologies for Enhancing Groundside Capacity—An airport's groundside[149] components—aircraft parking aprons and gates, airport terminals, and surface transportation links-are important factors in total trip time for passengers and cargo. Limitations in groundside capabilities can also restrict air service growth.

The number of passengers and the amount of cargo that pass through an airport are the most common economic indicators applied to measuring airport capacity. However, airport operators also must include employees, visitors, and service and ground access vehicles in their calculations, and analytic techniques and data for measuring groundside capacity are less developed than methods for assessing airside capacity.[150]

Gates and Aprons-Airport gates and aprons are the areas where aircraft receive fuel, maintenance, and other servicing. Although fewer gates would be required if airlines shared them, most gates are controlled by individual airlines. Competition between airlines and widely spread facilities at the busiest airports limit the feasibility of jointly using gates. If airport operators had more control over gates, more efficient use would be possible,[151] allowing faster aircraft turnaround and expanding the parking spaces and terminal access available for aircraft.[152] Apron geometry and level of demand also affect aircraft access to gates, and for the next generation B-777, Boeing plans to use folding wings in the design to avoid gate restrictions.

Security Technology and Procedures—To deter aircraft hijacking and sabotage, FAA requires airlines to screen passengers, carry-on articles, and in some cases, checked baggage, and airport operators to control access to the airfield and aircraft. Technology permits much faster processing than manual searches alone would allow, and relatively few significant delays due to screening occur currently in the United States.

147 Federal Aviation Administration, op. cit., footnote 140, p. III-38; and Federal Aviation Administration, op. cit., footnote 141, pp. 63-64,

148 Office of Technology Assessment, op. cit., footnote 129, p. 125.

149 The boundary between "airside" and "groundside" is somewhat arbitrary. The Federal Aviation Administration includes aircraft gates and parking areas in the airside category, as aircraft in these areas are still subject to air traffic control rules and regulations. In this report, however, airside infrastructure are those components whose performance affects airport and airspace capacity. Each gate and parking space is usually controlled by a single airline, and one airline's gate performance generally does not affect other users of the airport. Exceptions are when airlines share gates or gate backups restrict other taxiing aircraft.

An alternate definition of the groundside is the facilities and procedures involved in the passenger's or cargo shipment's journey from the originating point to the aircraft, aircraft-to-aircraft transfers, and from the aircraft to the final destination. (Note: once on board the aircraft, the passenger or cargo is in the airside).

150 National Research Council, Transportation Research Board, *Measuring Airport Landside Capacity*, Special Report 215 (Washington, DC: 1987), p. v.

151 David W. Davis, executive director, Massport, unpublished remarks, OTA Advisory Panel meeting, Apr. 18, 1990.

152 Refers to passenger or cargo trip-time unless otherwise stated.

Table 3-1 l—Traffic Congestion Increases in 15 Major Cities

Cities	Congestion index[a] (1987)	Percent change (1982-87)	Annual total cost[b] (in billions of dollars)	Annual congestion cost per capita (in dollars)
Los Angeles	1.47	20	7.9	730
San Francisco-Oakland	1.31	29	2.4	670
Washington, DC	1.25	31	2.2	740
Phoenix	1.23	6	0.9	510
Houston	1.19	1	1.5	550
Atlanta	1.16	30	1.1	650
Seattle	1.14	20	0.9	580
New York	1.11	4	6.8	430
Chicago	1.11	11	2.5	340
Detroit	1.10	- 2	1.9	460
San Diego	1.08	38	0.6	280
Philadelphia	1.06	17	2.1	520
Dallas	1.03	22	1.0	530
Minneapolis-St, Paul	0.97	24	0.5	240
Milwaukee	0.94	10	0.2	190

[a]The congestion index is a weighted measure of urban mobility levels, and cities with values greater than 1.0 have congestion problems. Roads carrying more than 13,000 vehicles perfreeway lane per day or 5,000 vehicles perarteriailaneperdayareeonsidered congested.
[b]Congestion cost is the estimated cost of travel delay, excess fuel consumed, and higherinsurance premiums paid by residents of large, congested urban areas.

SOURCE: Office cf TeehnologyAssessment, based on Texas Transportation Institute, "Roadway Congestion in Major Urban Areas, 1982 to 1987,"' Research Report 1131-2, 1989.

The equipment used today consists of x-ray scanners with moving belts and magnetometers, best suited for detecting metal,[153] and their successful use depends on the skill, alertness, and motivation of the people operating them. These methods are most effective at detecting weapons, and are not very successful at uncovering explosives and volatile substances. Passenger background checks and interviews, as are done by Israel's El Al Airlines, are effective screening methods, but are both labor-intensive, time-consuming) and go beyond traditional limits of privacy, limiting their acceptability in the U.S. system.

New technologies for baggage screening include: x-ray tomography devices; electromagnetic and nuclear-based systems that identify atomic elements, such as nitrogen, a key component of most explosives; and vapor detection techniques that recognize and evaluate trace quantities of organic materials often present in explosives. However, further development to improve speed and reliability will be necessary before these technologies are widely deployed. New security systems may require some redesign of airport interiors to accommodate large screening devices.

Conclusions and Policy Options

Although the U.S. transportation networks provide enormous benefits to the national economy, congestion and structural decay are taking their toll on efficiency and productivity, especially in large metropolitan regions, today's centers of economic activities. The quality of service provided by the transportation infrastructure is a product of government investment decisions made over the system's lifetime, about planning, design, construction, operations, maintenance, and rehabilitation. In the United States, shifts in population and transport patterns and vehicle technology occur much faster than governments change the ways they design, manage, and maintain the transportation infrastructure. The result is overburdened infrastructure in the major urban areas, while many rural States must struggle to provide adequate basic services from their shrinking economic bases. Every year, highway congestion in the Nation's largest cities is estimated to cost motorists over $30 billion (see table 3-1 1), while airport delays take a $5 billion toll on airlines and passengers. **OTA concludes that these problems are due more to investment, land-use, and management policies and practices than to inadequate technologies. While new tech-**

[153]X-ray devices introduced recently are able to distinguish among differing materials—organics, plastics, metal-based on density.

nologies can help improve infrastructure condition and smooth traffic flows in congested areas, the Federal Government must change its infrastructure investment policies and address system management issues, if the most pressing transportation problems are to be resolved.

Financing and Investment

Federal fiscal policies-General Fund subsidies, grant matching requirements, trust fund spending targets, and revenue raising options-vary for each transportation mode. These policies do not always lead to economical system investment and management and have created substantially different infrastructure problems for each mode.

Surface Transportation

Aviation and port and waterway infrastructure (where the Federal Government plays major investment and management roles in operations and maintenance, and the rights-of-way—air and water—require structural systems only indirectly) is in quite good physical condition. Although delays occur, most are amenable to management and technical solutions. In contrast, the Federal Government has always been an important, but minority, investment partner only in surface transportation infrastructure-roads, bridges, mass transit, and railroads-leaving management and operations to the State, local, and private owners. Federal surface transportation funding policies have favored capital investments, without a corresponding commitment to operations and maintenance. The result is that State and local government owners of the far-flung road system have cut back and deferred maintenance and rehabilitation. Most simply have not invested in basic operational improvements, such as advanced traffic signal systems. Private owners, primarily railroads, also neglected maintenance, especially on lightly used track sections, abandoning or selling branch lines as soon as they were able.

Changing Federal fiscal policies for surface transportation to allow Federal trust fund monies to be used throughout the infrastructure life cycle and for operations and maintenance is the top priority. Such spending discretion is of critical importance for rural or other economically constrained areas facing unaffordable infrastructure maintenance and rehabilitation needs. In some regions, local transportation grants may best be used for noncapital investments, such as maintenance management systems, employee training, or advanced traffic control equipment.

State matching requirements range from 10 percent for Interstate construction to 25 percent for primary and secondary programs. However, a primary road in poor condition can create a traffic bottleneck that has a major impact on a connecting Interstate, making rehabilitation of the primary artery crucial to smooth interstate travel. Congress could consider equalizing State matching requirements for all highway grants so that decisions about spending priorities reflect regional priorities, rather than projects tailored to fit grant categories. Expanding State and local options for raising revenue, such as tolls, on facilities built with Federal funds is crucial as well, to help leverage and stretch Federal dollars.

Increased flexibility in the use of Federal highway and transit grant funds-the ability to transfer or combine them—would also help transportation system productivity. Examples include railroad improvements (for Amtrak, too, since over 40 percent of Amtrak passengers travel on trains under contract to jurisdictions), park-and-ride facilities, HOV lanes, and preferential treatment for transit or other high-occupancy vehicles. A funding program for surface transportation condition improvement, which would include passenger rail, mass transit, roads, and bridges, might be such a mechanism. Similarly, a program for surface transportation capacity expansion should include new commuter rail and bus systems, new busways, new lanes, including HOV facilities, and expansion to existing systems and facilities.

Market Pricing

Traffic congestion creates additional operating and maintenance expenses for vehicles and infrastructure, and delay costs for users. Since the price paid for using the transportation system is often below real costs, the demand for frequent transport service to many destinations encourages large fleets of small vehicles to clog the infrastructure. The average passenger and cargo capacity of vehicles is a key factor in efficient system flow. Industry uses large vehicles—widebody jets, long, double trailer trucks, double stack trains, jumbo barges, and new containerships-when economics favor them and regulations allow them. User pricing policies (peak-hour tolls) that reflect vehicle costs to the system could favor higher capacity operations,

Table 3-12—Federal Expenditures and User-Fee Revenue for Transportation, 1989

Transport mode	Federal expenditures (in millions of dollars)	Federal user-fee revenues[a] (in millions of dollars)	Dedicated revenue as percent of expenditures
Highway	13,898[b]	14,270	102
Transit	3,595[c]	1 ,357[d]	37
Rail	594[e]	—	—
Aviation	5,748[f]	3,664	63
Ports and waterways	1,436[g]	223[h]	16

a Does not include interest received on trust fund balances.
b Includes funds outlayed for the Federal Highway Administration, the National Highway Transportation Safety Administration, the Forest Service for forest roads and trails, and the Bureau of Indian Affairs for road construction.
c Includes capital and operating grants and limited research and development (R&D) spending.
d Revenue source is 1 cent per gallon from motor fuel tax (1989).
e Amtrak funding and limited Federal R&D spending.
f Does not include expenditures for National Aeronautics and Space Administration, National Transportation Safety Board, or Department of Transportation Office of the Secretary.
9 Army Corps of Engineers outlays for harbors waterways. Doss not include Maritime Administration, Coast Guard, or Panama Canal Company outlays.
h Includes Inland Waterway Trust Fund, Harbor Maintenance Trust Fund, and St. Lawrence Seaway Tolls.

SOURCE: U.S. Department of Transmutation, *Federal Transportation Financial Statistics. Fiscal Years* 1979-1989 (Washington, DC: May 1990).

such as car pooling and mass transit, and possibly lower total energy use and environmental damage. They could also lower life-cycle costs by matching system characteristics and long-term use patterns. For example, a highway policy basing user fees on the pavement wear imposed by commonly used vehicles (truck axle weights, for example) and using the increased revenue to pay for thicker, more durable pavements could lower long-term total highway costs.

Strict market pricing policies raise issues related to ability to pay and discrimination against certain classes of transportation users. OTA concludes that pricing decisions for demand management may require Federal oversight to ensure affordable transportation options to all users. A share of the revenues generated by those willing and able to pay for premium service could fund alternative transportation systems for other users.

General Fund Subsidies

Tying user charges to system expenditures, especially for operations and maintenance, can encourage realistic infrastructure decisions and provide a long-term revenue stream for system management. While social benefits such as defense, environmental protection, and economic development just@ General Fund support for transportation infrastructure, these tax monies currently subsidize each mode to different degrees (see table 3-12). On both the inland waterways and deepwater channels, the General Fund now pays roughly 50 percent of capital costs, a reasonable amount given the multiple purposes these structures serve, and a marked reduction from historic levels. However, water shippers and operators still pay only a minor share of operations and maintenance costs, in sharp contrast to other transportation modes, where users pay most of these costs. OTA concludes that this preferential treatment for port and waterway users is difficult to justify and that it is time for another look at investment and cost allocation **policies for transportation infrastructure. One option is to equalize General Fund subsidies among transportation modes over a 5- to 10-year period. Another is eliminating the subsidies entirely, using trust fund revenues for Federal programs and looking to new revenue sources, such as higher State and local grant matching requirements.**

Whatever the choice, if General Fund subsidies for transportation are reduced, and budget constraints prevent using trust fund balances, user fees and non-Federal funding must make up the difference, or existing public networks will have to scale back. With the exception of the inland waterway operators, most transport sectors would be capable of generating sufficient revenues to remain at present capacity. Congress could consider a long-term, gradual disinvestment of commercially unproductive waterways, unless regional governments and recreational users are willing to meet substantially more of the costs. For example, hydroelectric power, drinking water, and recreational boating opportunities supplied by these navigation projects, if priced at fair market values, could fund significant amounts of system operating and maintenance costs.

Management Framework

Finding ways to increase system capacity and handle increasing demand without constructing new rights-of-way poses enormous challenges. New technologies can marginally increase the capacity of infrastructure, but they are often expensive and eventually reach structural limits. A systems management approach that encourages carrying the same volume of passengers or cargo on fewer vehicles and makes full use of all modes could address air quality, energy use, and congestion problems.

Intermodal Transportation

While individual intermodal operators—airports, marine ports, terminals, and stations-and transportation companies are investing in advanced equipment and electronics to speed cargo and passenger transfers, problems related to intermodal transport increasingly hamper regional surface transportation links. For example, port operations both contribute to and suffer from surface traffic congestion, air pollution, and problems caused by overweight shipments. Many such issues are international and interstate in scope and beyond the capabilities of State and local governments to resolve.

A host of governmental agencies have regulatory and fiscal authority over separate elements of regional transportation, and no effective mechanism for multimodal coordination has emerged. Federal policy has favored capital investment as support for economic development, a policy that has diminishing application in metropolitan areas, where improved system (regional) management will be the key to future economic success. OTA concludes that Federal incentives for addressing regional transportation issues, intermodal links, surface congestion solutions, and environmental impacts are essential.

Institutional Framework

Neither DOT nor Congress has successfully overcome strong, separate modal interests and achieved an appropriate systems approach to solving transportation problems. In Congress, only the appropriations committees have sufficiently comprehensive jurisdiction, but those committees were never intended to set transportation policy. DOT's recently published National Transportation Policy recognized this and encouraged a multimodal approach toward transportation problems. However, this encouragement is not enough; **OTA concludes that unless steps are taken to institutionalize a multimodal approach within DOT, the traditional modally oriented structure will be perpetuated and the agency will not be able to address today's transportation issues effectively.**

If the Federal Government is to regain a leadership role in transportation, changes in institutional management must be made. In the short run, consolidating several of the water management functions and urban modes makes a great deal of sense. Over the longer term, options include restructuring DOT in divisions by broad mode-aviation, and surface and water transportation-or by function, such as metropolitan passenger and intercity freight transportation. Reforming congressional oversight as well, by developing a mechanism to coordinate or concentrate transportation authorization, will be crucial to the success of a restructured DOT.

An immediate option for Congress to consider is to shift civilian water transportation authority from the Army Corps of Engineers to DOT, as was originally envisioned when DOT was created. This would consolidate all transportation policy and trust funds within a single agency with Cabinet-level attention and facilitate multimodal decisionmaking. Because some of the Corps' traditional missions are waning, over the longer term consideration could be given to making the agency into a National Corps of Engineers with the mission of making its engineering and water resources expertise available to support a number of executive agencies on a reimbursable basis. It could remain loosely associated with DoD and maintain its other current responsibilities, or these could be assigned to other departments as appropriate (flood control could be housed in the Department of the Interior, for example).

Transportation Technologies

Advanced technologies, innovative and alternative multimodal delivery systems, more efficient management and methods, and changes to incentives will be necessary to improve the Nation's transportation system. Yet with few exceptions, data collection and research have been insufficient to identify the best choices among the advanced concepts vying for places in the future transport system. Moreover, much in the current institutional and organizational structure acts to prevent adoption of new technologies and management techniques. Officials, particularly at the local level, are often unaware of suitable new technologies, and even when they do know about new tools, they often cannot afford to buy them or to train employees to use them.

Improving Operations

Technological procedures for mitigating congestion and structural limitations are often expensive to implement, but may be cost-effective when other options are unavailable. New traffic management and control technologies could potentially improve traffic flows on congested roadways, airways, and waterways on the order of 10 to 20 percent, although when new capacity is opened in a congested corridor, it is usually fried quickly by latent demand. Many of these options require significant public investments, and in most cases, users would also need to invest in new equipment, raising issues related to ability to pay.

Roadway technologies that speed traffic flows, inform motorists of congested areas, and detect and respond to traffic incidents promptly are being developed and tested. The backbone of all of these systems is an efficient, traffic-responsive signal control system, a basic technology that can offer immediate congestion improvements. Advanced traffic control signal systems are one of the few highway technologies whose effectiveness depends primarily on actions by public agencies, and they represent a vital first step in the development of other Intelligent Vehicle/Highway Systems. In-vehicle guidance and communications systems will be of limited benefit unless they are linked to the public infrastructure. Federal assistance to local jurisdictions for implementing these highway technologies and ensuring coordination between adjacent municipalities to provide smooth inter-city and interstate traffic flow are top priorities.

Managing Demand—Additional reduction in congestion can be attained in urban areas if technology is used in conjunction with full-cost pricing. Longer term Intelligent Vehicle/Highway Systems developments, such as those that control vehicle speed and direction as well as spacing between vehicles, offer greater potential for faster travel and reduced delays, but these technologies are at an early stage of development, and any possible implementation is at least two to three decades away.

The top investment priorities for air are communications, navigation, and surveillance technologies that can improve terminal ATC capabilities and increase effective airport. capacity during inclement weather, the time when most delays occur. Satellite-based systems will be essential for gains in international traffic. However, future gains in ATC capabilities are likely to outpace the ability of airports to handle takeoffs and landings, and some form of demand management is likely to be necessary.

At some congested inland waterway locks, trafffic management and equipment for pulling unpowered tows could increase capacity by over 20 percent. Scheduling access to these facilities would allow better planning by industry and could reduce operating costs. However, the initiative for such system traffic management would best come from the waterway users, since safety issues do not justify precise Federal traffic control on the waterways.

Alternative Modes

Technologies leading to improvement in one transportation mode can benefit the entire system by relieving congestion in other modes. For example, employing high-speed rail in heavily traveled automobile or air corridors, such as those in the Northeast corridor and southern California, could significantly reduce rail travel times and attract passengers away from highways and airports. Improving the attractiveness of bus transit by giving urban buses priority at traffic signals and providing dedicated lanes would similarly help alleviate road traffic in crowded areas. Any gain in roadway performance will likely enhance airport ground access, since most air passengers and cargo depend on road vehicles. See table 3-13 for a summary of the likely effects of various surface transportation measures.

Alternative technologies, such as tiltrotor aircraft or magnetically levitated trains, could play a role in bypassing the parallel problems of limited airport capacity and surface transportation congestion in metropolitan areas. Developing and implementing such radically new technologies will require billions of dollars and is likely to require Federal support. However, since these technologies would serve

Table 3-13-impacts of Surface Transportation Measures

Technology or measure	Impact	Governmental action required
Highways:		
Intelligent Vehicle/Highway Systems	Reduced congestion (10-20%) Improved safety (0-20% fewer accidents) Less driver frustration	Installation of integrated, traffic-responsive signal control systems by local governments ($1 to $20 million/major city) Federal investment in R&D ($10 to $100 million/year)
Timely pavement and bridge construction, maintenance, and rehabilitation .....,. .	Reduced life-cycle cost (50%) Increased life (50%)	Higher annual maintenance expenditures by State and local governments
Rail:		
Timely right-of-way maintenance and rehabilitation	Reduced life-cycle cost (10%) Increased productivity (higher speeds), fewer accidents (50%)	None, private-sector financed
Automatic train control.	Improved service and safety	None, private-sector financed
High-speed passenger rail	Improved service (50-100% quicker travel times than conventional rail) Shift some traffic from airports and highways	Federal support for Amtrak capitalexpenses, Federal support of right-of-way acquisition, construction, and possibly maglev R&D
***Mass* transit:**		
Alternative fuels . . . , ... , ...	Reduced emissions of NOx and particulates (0-20% reduction in ambient air pollution if these fuels are used only on mass transit vehicles)	Increased fuel and equipment expenditures for municipal transit authorities
Automatic vehicle location and passenger information systems	Improved service, increased ridership (10%) leading to congestion relief	Increased equipment expenditures for municipal transit authorities

SOURCE: Office of Technology Assessment, 1991.

overlapping needs, choices may have to be made between them and other technological options, and total *public* costs projected for each system, issues that will need further study. Moreover, Congress will be involved in determining the appropriate sources for funding and how the development program should be managed.

High-speed intercity ground transportation, urgently needed in congested regions such as the Northeast corridor, can ill afford to await the development of maglev or tiltrotor technology. Proven steel-wheel technologies, such as tilt trains and high-speed systems, are available now and can play a key role in speeding passenger travel and relieving congestion from other modes in crowded urban corridors. Tiltrotor aircraft and maglev trains show promise for even faster travel, but require extensive development and are at least a decade away from possible implementation.