chapter eleven

# Mobility and Access in the Information Age

The history of transportation is one of increasing speed, comfort, convenience, safety, and reliability, together with decreasing travel costs. Many people ascribe this historical progress to technological improvements in the two most visible components of the transportation system—vehicles and physical infrastructure. Indeed, the pace of technological advances has quickened in recent times, as successive waves of innovations—the steamship and locomotive, the electric streetcar, the internal combustion engine, the jet engine, containers, and the "megaship"—improved the quality and sharply lowered the costs of transportation. There also have been parallel advances in the physical infrastructure—tunnels, suspension bridges, railroads over all kinds of terrain, the U.S. Interstate Highway System, and modern airports and marine terminals. Although less visible, the institutional infrastructure, which is a third component of the transportation system, has facilitated the coordinated use of vehicles and the physical infrastructure. Institutional infrastructure includes knowledge, technical standards, procedures, and policies that guide the governance of transportation.

Generally, what has not been recognized about this progress is the increasing role played by information technologies in transportation operations and in equipment and infrastructure. These technologies provide vital information, enhancing responsiveness and efficiency, and often make possible other transportation innovations.

Such *knowledge-providing and enabling* technologies have historical antecedents in the sextant and the chronometer, which permitted more precise global navigation in the 18th century, the telegraph, which promoted transcontinental rail operations in the last century, and the radio and radar in this century, which are so critical to navigation. The current efflorescence of new information technologies is transforming transportation industries and their scope of services.

As used here, information technologies (IT) refer to a broad array of devices, functions, and supporting tools used in sensing, generating, processing, transmitting, communicating, and presenting information. The dramatic technological developments in computer hardware and software and telecommunications in recent years can be applied to many transportation operations. For example, IT can be used to coordinate activities across the physically distributed nodes of transportation networks, allowing such innovations as computerized transportation documentation and "quick response" intermodal freight shipments, and are critical to the development of intelligent transportation systems (ITS). Such capabilities can increase personal mobility, lower freight costs, and allow firms to develop customized transportation solutions.

This chapter concludes the *Transportation Statistics Annual Report* section on mobility and access by discussing current and potential advances in IT that offer benefits to travelers and to transportation firms and their customers. These benefits might include new transportation services that are less costly or have other favorable service attributes; the creation of new forms of customer, cost, and competitive relationships; and the substitution of telecommunications for physical movement, which may eventually redefine mobility and access needs that shape *demand* for transportation services. Such new relationships may develop within transportation firms (e.g., use of computerized reservation systems by airlines to achieve multiple objectives such as improved customer service and market positioning) or in enterprises served by transportation (e.g., global sourcing arrangements by manufacturing firms, faster response innovation systems, and networking for firms).

The chapter, after briefly examining the historical context, discusses key elements of IT, and the factors underlying their diffusion in transportation. IT's complementary role as an enabler, rather than a replacement for existing transportation hardware, is notable. This characteristic lowers barriers to the adoption of new technology and promotes rapid and continuously evolving applications of IT in transportation. The chapter then explores IT's implications for passenger and freight transportation services; for example, how are mobility and access affected as the supply of ITS increases? Then, the chapter discusses IT's influence on the demand for transportation mobility and access. The chapter also examines the available evidence on the impact of transportation IT on production enterprises.

## Information Technologies and Transportation Services

### IT in Transportation History

There is interaction and synergy between information and transportation technologies. As noted, enabling technologies such as IT have helped make transportation services more efficient over the years. And, throughout most of history, the capabilities of the transportation system dictated how quickly, easily, and efficiently information could be conveyed across long distances. In the pre-telegraphic era, information (in the form of letters, other written documents, and messengers) traveled only as fast as the available means of transportation would permit. Thus, in

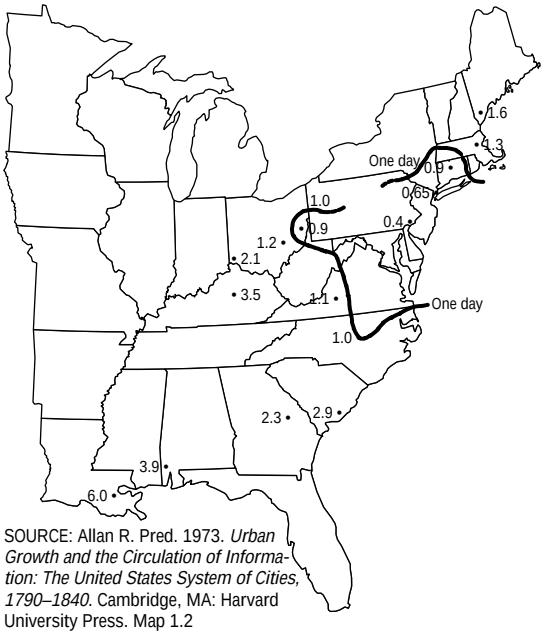
1799, the news of President Washington's death at his home in Mount Vernon, Virginia, took about two weeks to reach southern New England and over three weeks to get to southwest Ohio (see figure 11-1). Three decades later, in 1830, the "express" relay of President Jackson's State of the Union message, given in Washington, DC, took only a day and a half to reach southern New England and over two days to arrive in southwest Ohio (see figure 11-2).

The telegraph, first demonstrated by Samuel Morse in 1844, was a major departure from the historic dependence on transportation to communicate over long distances. The telegraph not only made possible almost instantaneous communications between distant locations but also separated the message from the messenger.

The telegraph had rapid and far-reaching impacts on communications and on the development of transportation in the 19th century. As railroads spread across the continent, an unprecedented volume of goods were shipped at unprecedented speeds on schedules often measured in days and hours, not weeks (see box 11-1).

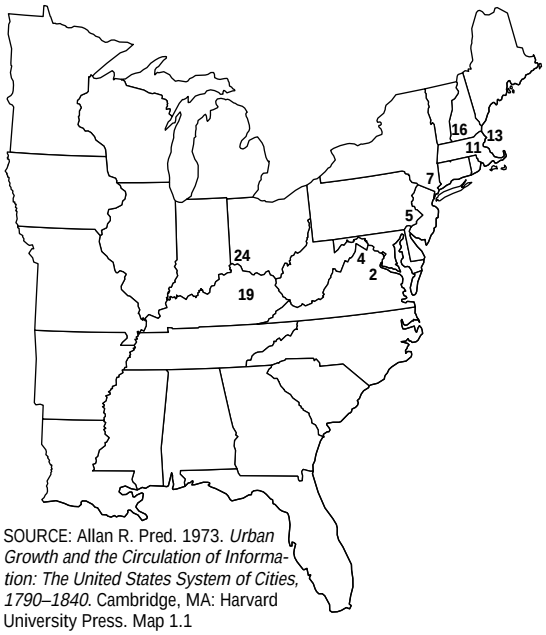
The telegraph, while highly influential, was only one in an impressive procession of information technologies developed in the last century. Figure 11-3 identifies many of the major communications technologies that have appeared since the telegraph. More recently, new information and associated technologies have arrived which, like their earlier counterparts, are improving operation, control, and management of transportation, and transforming many organizational processes involved in the provision of transportation.

Figure 11-2.
**Time Lag in "Express" Relay of President Andrew Jackson's State of the Union Address: 1830**
(Nearest tenth of a day)




SOURCE: Allan R. Pred. 1973. *Urban Growth and the Circulation of Information: The United States System of Cities, 1790–1840.* Cambridge, MA: Harvard University Press. Map 1.2

Figure 11-1.
**Time Lag of Public News of George Washington's Death: Dec. 14, 1799**
(In days)




SOURCE: Allan R. Pred. 1973. *Urban Growth and the Circulation of Information: The United States System of Cities, 1790–1840.* Cambridge, MA: Harvard University Press. Map 1.1

Box 11-1.

**The Telegraph, Railroad, and 19th Century Business Innovations**

The railroad and the telegraph developed together in 19th century America, linking the often widely separated cities of the United States. The telegraph, built along the railroad rights-of-way, provided instantaneous information about train movements. This information was especially important for directing traffic along the single-track lines typical of most early U.S. railroads. Both the railroad and the telegraph expanded rapidly.

Railroads pioneered many managerial innovations to coordinate the flow of shipments and movement of passengers from hundreds of origins to as many destinations across the vast spaces of the United States. These innovations included the line and staff system of administration, new accounting and internal control systems, new financial instruments, and the development of technical standards and organization procedures to facilitate interline flow of goods and people. Some innovations, such as railroad timetables and time zones, had broad social effects, standardizing the way people thought of time.

Innovations by the railroads, where the large modern corporation first appeared, paved the way for the creation of the large modern corporations in other industries. Wholesalers used the new transportation and information technologies to reduce risks, lower inventory costs, and deliver an increasing volume of goods on a more precise schedule. This evolution in the distribution sector continued as new kinds of retailers (e.g., department stores and mail-order houses) arrived later in the 19th century.

SOURCE: A. Chandler. 1973. Decisionmaking and Modern Institutional Change. *Journal of Economic History* 33:1-15. March.

## The New IT: Key Elements

Most transportation uses of IT depend on the often-transparent and inseparable integration of many technologies and capabilities. In some cases, cost and performance improvements in one technical area may make a new range of applications or services available. The potential for IT to affect mobility and access in modern society is rooted in a small set of building blocks:

- telecommunications;
- computer hardware and software;
- navigation and positioning systems;
- surveillance, sensing, and tagging technologies; and
- data exchange and fusion capabilities.

### ► Telecommunications

The ability to make real-time operational information available throughout a transportation system, no matter how geographically dispersed, and to combine this information with data from other sources, carries powerful benefits for operators, managers, and users. The ease and relatively low cost of telecommunications have made this capability a practical reality. Some examples include satellite-based and fiber optic communications channels, cellular telephone systems, and network linkages epitomized by the Internet's "anywhere-to-anywhere" communications.

Not all telecommunications functions involve long-range communications. A very important function is electronic data interchange, which can occur over a very short range: between trucks and wayside inspection stations, highway vehicles and toll collection stations, or cargo containers and port logistic systems.

Telecommunications potentially play another more fundamental role: replacement of the need for some physical transportation. The ability to communicate readily with distant organizations and services permits access that otherwise would depend on physical mobility. Telecommuting, teleshopping, video conferencing, and other "telesubstitutions," although still in relative infancy, may become significant factors shaping mobility and access in the years to come. These approaches are discussed further in this chapter,

Figure 11-3.
**Telecommunications Services Between 1847 and 2000**

| 1847 | 1877 | 1920 | 1930 | 1960 | 1975 | 1984 | 2000 |
|---|---|---|---|---|---|---|---|
| Telegraph | Telegraph | Telegraph | Telegraph | Telegraph | Telegraph | Telegraph | Telegraph |
| | Telephone | Telephone | Telex | Telex | Telex | Telex | Telex |
| | | Sound | Facsimile | Data | Medium-speed data | Packet-switched data | Wide-band data |
| | | | Telephone | Facsimile | Low-speed data | High-speed data | Packet-switched data |
| | | | Sound | Telephone | Facsimile | Switched-circuit data | Switched-circuit data |
| | | | Television | High-fidelity stereo | Telephone | Telemetry | Telemetry |
| | | | | Color television | High-fidelity stereo | Facsimile | Word processor networking |
| | | | | Mobile telephone | Color television | Word processor networking | Text facimile |
| | | | | | Mobile telephone | Videotext | Facsimile |
| | | | | | Personal paging | Telephone | Electronic messaging |
| | | | | | | Video conferencing | Newspaper teleprinting |
| | | | | | | Sound | Videotext |
| | | | | | | High-fidelity stereo | Voice facsimile |
| | | | | | | Color television | Telephone |
| | | | | | | Mobile telephone | High-fidelity telephone |
| | | | | | | Personal paging | Teleconferencing |
| | | | | | | | Video conferencing |
| | | | | | | | Video telephone |
| | | | | | | | High-fidelity stereo |
| | | | | | | | Quadrophony |
| | | | | | | | Color television |
| | | | | | | | Stereophonic television |
| | | | | | | | High-definition television |
| | | | | | | | Mobile video telephone |
| | | | | | | | Mobile telephone |
| | | | | | | | Mobile text |
| | | | | | | | Mobile facsimile |
| | | | | | | | Mobile data |
| | | | | | | | Mobile videotext |
| | | | | | | | Personal paging |

SOURCE: A Jagoda and M. de Villepin. 1993. *Mobile Communications.* Chicester, England: John Wiley & Sons. Figure 3-2.

while the complex relationship between telesubstitution and travel demand was discussed in chapter 6.

## ► Computer Hardware and Software

The price of computer processing power has dropped at approximately 30 percent per year for the last two decades. Such dramatic cost reduction now permits highly sophisticated sensors and computer-based control systems to be built into most transportation vehicles, from automobiles to airplanes. As discussed in box 11-2, many recent advances in automotive safety involve onboard computer-based technologies.

Computer processing power can be used to improve many transportation system functions, such as traffic control and management, and to simulate complex transportation operational systems. Concepts of artificial intelligence and expert systems represent software approaches that can be very effective in particular situations.

Box 11-2.

**Smart Cars**

Digital electronics and computer chips have been used in cars for decades for fuel injection, security systems, and climate control. In recent years, new automated functions have appeared, such as antilock braking systems. Initially, these innovations have been relatively expensive, and thus found primarily in luxury cars. With likely price reductions, most can be expected to permeate the overall fleet in the near future. Examples of features now available or actively pursued in the laboratory follow.

*In-vehicle navigation.* Navigation aids are typically based on Global Positioning System (GPS) location determination, powerful computing capabilities, and CD-ROM digital maps. These aids can provide turn-by-turn navigation instructions, via display or spoken advisories. Some include an electronic directory of restaurants, gas stations, and recreation facilities. While initially an aftermarket option, navigation aids are now offered directly by vehicle manufacturers in some car models. These systems can be coupled to broadcast real-time traffic and weather.

*Emergency services.* At the push of a button, systems now available can communicate via cellular telephone with a response center, imparting information about vehicle location, emergencies, and equipment failure, as well as direct voice communication. Automatic activation in the event of airbag deployment can be included. One variation permits the response center to remotely unlock a car when a motorist has inadvertently been locked out.

*Vehicle suspension and control.* Some systems go beyond the electronic sensing of traction that underlies antilock brakes. Computer-controlled dampers can adjust the ride from soft to firm to match road and operating conditions. Some systems measure the roughness of the road and adjust the operation of the antilock braking system to assure the most effective response.

*Steering enhancement.* Another system compares how the vehicle responds to movements of the steering wheel to the sensed rate that the vehicle is turning. If available traction has been exceeded, as indicated by less turning occurring than was called for, brakes are applied to slow the car to the point at which there is sufficient traction to follow the intended curve.

*Collision warnings.* Devices based on radar or other sensors are being considered to alert drivers to situations in which collision is imminent. Some trucks and school buses are equipped with radar to detect people behind the vehicle (when reversing) or situations in which there is an excessive closing rate with the vehicle ahead. Other sensors can detect vehicles in typical blind spots on both sides of a car. Intelligent cruise control may soon be available—instead of holding a constant speed, the car maintains a constant distance from the vehicle ahead.

*Operator inattention*. Driver fatigue or inattention is a frequent factor in accidents. Methods are being explored to detect drowsiness and other behaviors so that the operator can be alerted.

*Vision enhancement.* The technology of enhancing night vision has long been applied in defense and security settings. Systems are now being explored using radar or thermal imaging to enhance the operator's view, particularly in adverse weather and darkness, and to project an image on or near the windshield.

*Entertainment and communications.* Intel Corporation has announced business partnerships to integrate a standardized computing platform into motor vehicles to perform many computing and communications tasks. These include: wireless telephone, fax, and mail services; Internet access; speech recognition and synthesis for user interaction; linkage to public and private traveler information systems; multimedia entertainment applications for passengers; and user-customized driver information displays. Some products could reach the market as early as 1998.

Enormous databases can be accessed directly using compact disc storage technology.

## ► Navigation and Positioning Systems

Navigation has always been central to long-distance transportation, particularly for the marine and aviation modes. From the invention of the sextant and chronometer to current radio-based systems, improved means of determining position have represented major transportation advances. Navigation is now being transformed by the Global Positioning System (GPS), based on 24 earth-orbiting satellites emitting precisely timed signals. GPS makes possible convenient,

real-time, three-dimensional position information throughout the world with great accuracy and at very low cost.

As technological accuracy improves—dropping from hundreds of meters to a meter or less—and prices fall, new applications become feasible, such as en route navigation for highway vehicles. Many applications involve position determination equipment on the vehicle, with that information communicated (often via satellite link) to a central computer for fleet or traffic management functions. Precise knowledge of location can support functions as disparate as placing and retrieving containers in a port storage area, identifying the whereabouts of a stranded motorist for response vehicles, and assuring safe separation of trains on shared tracks. Tracking techniques are now used by the private sector and the U.S. government to monitor shipments and keep in touch with personnel (see box 11-3).

Just as early navigators needed charts and astronomical almanacs in order to derive their position using a sextant and chronometer, GPS and other modern systems fulfill their potential only in concert with digital maps of high precision, based on a standardized geodetic reference system. More generally, geographic information systems (GIS) have many transportation applications that support operations, maintenance, planning, system analysis, and other functions. A major use of positioning and map technologies is computer-based route guidance, which facilitates navigation in both urban and rural regions. Multiple systems can be used to achieve satisfactory positional precision, reliability and integrity, as when automobile GPS outputs are supplemented by comparison to electronic maps, or an aircraft uses satellite navigation in conjunction with an inertial system.

### ► Surveillance, Sensing, and Tagging Technologies

IT applications are used to identify a vehicle's location, characterize its environment, or permit the exchange of information. Closed-circuit television—monitored by computers—has a growing role in detecting incidents and congestion on freeways. Railroads tag freight cars for wayside identification and aircraft continually exchange identification numbers, altitude, and other information with the air traffic control system. High-performance computer chips and sophisticated pattern recognition software can increasingly carry out complex sensing and surveillance tasks. Tagging of freight-carrying vehicles and of the cargo itself is revolutionizing logistics, as tags become capable of storing situation-specific data (like container contents and destination) and of being read over long distances—via satellite in some cases. A truck with a GPS-enabled tag and cellular or satellite communications capability can be tracked anywhere in the country, reporting vehicle and cargo status wherever it goes. "On-board intelligence" is emerging in the freight system, or in what perhaps should be called the intelligent freight transportation system.

A final aspect of surveillance is the use of vehicle-mounted sensors, such as radar, to detect potential hazards. The sensors are coupled to computers and displays that provide warnings and suggested responses. Collision-avoidance systems of this type have been used in aircraft for many years, and federal and private research programs are currently actively pursuing crash prevention for highway vehicles.

### ► Data Exchange and Fusion Capabilities

Above and beyond the specific transportation functions that various information technologies support, the broad impact of IT on transportation is to produce a much more knowledge-rich

Box 11-3.

**Vehicle Tracking for Safety and Efficiency**

Global Positioning Systems (GPS) and other information technologies that keep track of a vehicle's identity and location have become powerful tools for managing assets and resources, transforming transportation logistics. The U.S. Department of Defense, for example, uses information technologies to achieve "Total Asset Visibility"—timely and accurate information on the location, movement, status, and identity of personnel, equipment, and supplies moving by military or civil transportation services. Real-time tracking and management of these resources was important in deployments to Saudi Arabia and Somalia.

The Defense Transportation Tracking System (DTTS) is used to monitor and expedite routine domestic shipments of arms, ammunition, missiles, and explosives. DTTS uses automated satellite-based information to monitor and expedite 4,000 shipments per month, with 600 vehicles in transit at any time, and to support rapid response to incidents or emergencies. A similar system has been established for the movement of hazardous or toxic fuels. To enforce United Nations sanctions on goods shipments into Serbia and Montenegro, the U.S. Department of Transportation established a tracking and information system for the State Department using satellite communications and a data center in Massachusetts that provided real-time information to teams at border crossings in the former Yugoslavia.

Trucking companies use GPS and satellite and/or cellular telephone communications to monitor the location and status of fleets and to communicate with vehicles and drivers. Communications permit responses to special situations, optimized routings, and help keep customers informed. One firm reports fuel savings of over 10 percent, based on more than halving idling time. One version of the system permits drivers to use Internet electronic mail to communicate with dispatchers and family members. Globally, more than 200,000 trucks are equipped with such systems. Linkage to metropolitan and other traffic management and information services also will soon allow drivers to cope more effectively with congestion and adverse weather, choose optimal routes, and generally improve the reliability and efficiency of pickup and delivery services.

GPS systems also can be used for routing vessels at sea and between and within ports. In 1996, the U.S. Coast Guard brought the differential Global Positioning System (dGPS) online. With reference stations built about every 200 miles along the coast, dGPS enables ships with special receivers to identify their position to an accuracy of 5 to 10 meters compared with 100 meters using other positioning systems. This is a critical advance, especially for large ship navigation, as some channels are less than 100 meters wide. GPS, local and remote radar, management information databases, very-high-frequency radio, and other information technologies can be linked to create comprehensive harbor information systems. The Coast Guard's Ports and Waterways Safety System, now under development, is intended to improve waterway safety (including the avoidance of environmentally damaging spills) and support enhancements of waterways management and efficiency.

Applications are diverse: GPS receivers are being placed in the approximately 1,000 boats that operate on the canals of Venice. Motorboats traveling at excessive speed produce wakes that weaken the foundations of the city's buildings. Satellite-based position reports are automatically radioed from each boat to a central facility every few seconds, providing immediate identification of boats traveling above the 5-mile-per-hour limit. As a fringe benefit, the system will also improve safety, particularly in fog, and will collect engine and operational data enabling more efficient fleet management.

system, in which all participants—users and providers alike—can make decisions and perform tasks on the basis of greatly enhanced understanding of the likely consequences. The combination of often disparate information from diverse sources is central to many IT applications, including real-time operations, inventory and process management, system characterization, and provision of user services. Beyond technical interoperability and establishment of institutional and organizational relationships for effective data exchange, the new discipline of "data fusion" has emerged—the design of computer systems that can facilitate convenient, flexible, and adaptable blending of information from a wide range of independent sources.

Many current and potential transportation applications exist for data fusion, such as evaluation of large databases to identify possible aviation safety problems.

## Factors Underlying Rapid Diffusion of Transportation IT

Two sets of factors underlie the current rapid progress of IT in the transportation sector. From the supply side, IT's enabling role facilitates its application in the transportation sector. From the demand side, numerous market-driven opportunities for IT investment are being created as the American economy undergoes rapid transformation. Such opportunities arise from the dematerialization of the economy (i.e., the proportion of high-value products being transported is rising relative to that of bulky materials), the globalization of production, industrial restructuring, and such institutional changes as deregulation and privatization, which have created an hospitable economic environment for IT investment.

### Enabling and Complementary Role of IT

Unlike some propulsion, vehicle, and infrastructure technologies that supplanted prior generations of technology, IT can be incorporated into transportation operations in an evolutionary fashion. There are four general characteristics of this process.

- *Rapid technical progress.* Driven by markets across all economic sectors, IT is developing very quickly—dropping sharply in cost, while simultaneously increasing in performance. Not only are the basic information technologies advancing, but understanding of how best to use them continues to grow rapidly.
- *Continuous evolution.* IT offers the potential for continuous improvement in the performance of existing transportation equipment and infrastructure, extending its reach, power, and quality of service. As an evolving technology, it does not face as many barriers to use as can be the case when new transportation technologies must supplant older but still functional equipment (e.g., replacement of steam with diesel locomotives).

  The iterative prototyping process of "design a little, build a little" that is common to software can be translated to IT. Major changes based on IT can sometimes be implemented incrementally, as specific technology elements, introduced as a minor tool or convenience, make the transition to critical tool or business necessity. In this manner, the introduction of IT can proceed relatively rapidly compared with the typically very lengthy phase-in of new types of vehicles or structures.
- *Process reengineering.* Full realization of the benefits of IT in transportation may require the redesign of operational processes throughout an enterprise, accompanied by substantial redefinition of work functions. As with other innovations, the pace of IT adoption is determined primarily by the ability of workers and organizations to incorporate the new technology.
- *Ubiquitous applications.* Information technologies applied in the transportation sector are generally those also used across the economy and society for a variety of purposes. The broad appeal of IT markets fosters its high rate of improvement in cost and performance, and facilitates large-scale integration and optimization among transportation suppliers and users.

Further, use of information technologies throughout the economy fosters the development of linkages between business processes. For example, the initial focus of the ubiquitous bar code—the Uniform Product Code—was improved speed and accuracy in accomplishing retail sales transactions. Success in this effort led to linkage of point-of-sale computers (no longer

simple "cash registers") to inventory databases, and supported a shift to greater reliance on just-in-time logistic practices and marketing strategies. With this information infrastructure in place, some supermarkets and other retail stores offer remote computer-based ordering, via Internet or PC-modem connections, coupled to home delivery—a step that, if it becomes widespread, has significant transportation implications.

## Economic Environment for Transportation IT

Broad, ongoing economic changes offer a fertile ground for transportation sector investment in information technologies. These changes in the economy are both transforming transportation activities, and are, in turn, themselves transformed by transportation.

*The increasing role of information and knowledge in the economy.* As incomes rise, knowledge-intensive industries and services have become increasingly important components of the economies of the United States and other highly industrialized countries. While the phenomenon of an information economy has been noted for some time (Machlup 1962; Porat and Rubin 1977), the implications of this shift for transportation have received little attention. Some rapidly growing high value-adding industries move only a small amount of tonnage while accounting for a disproportionately large share of total value of freight carried.

*The globalization of markets and resources.* With the recent expansion of trade (growing three times as fast as gross domestic product (GDP) in the United States) and the development of flexible production systems, economic activity is increasingly geared to serving global markets. Production inputs may be assembled from supply points around the globe. Markets for raw materials, components, capital, labor, and final products are increasingly global and flexible, requiring more responsive and efficient transportation of goods and people. Globalization has been accelerated by jet aircraft, containerized shipping, and satellite and fiber-optic communications.

*The emergence of more market-oriented relationships among economic actors.* Globalization and the intense competitiveness produced by a multiplicity of sources and markets are generating new relationships among all players in the economic system, public and private. These relationships take a variety of forms such as partnerships and networks. The resulting organizational networks are enabled by associated communications and transportation links.

*The beginnings of seamless integration of (intermodal) transportation into the overall production processes.* Competitive pressures on price and service, accompanied by just-in-time manufacturing, outsourcing, and on-demand delivery, have focused attention on how to better integrate transportation functions into the overall production process.

*Long-term lowering of intensity of material and energy use (dematerialization).* Recently, new technologies have led to more efficient and energy-saving production processes. This has lowered the material and energy intensity of the overall U.S. economy. As a consequence, the long-term trend in the United States is a drop in the intensity of use of some industrial materials—as measured by kilograms per dollar of GDP, in constant dollars—such as steel, cement, and paper. Further, the energy use per unit of GDP has also been dropping over time.

The transportation implications of dematerialization are evident in the 1993 Commodity Flow Survey (CFS) conducted by the Bureau of Transportation Statistics and the Census Bureau (see chapter 9 for a detailed discussion). While an enormous quantity (in terms of tons and ton-miles) of natural resources, including energy and

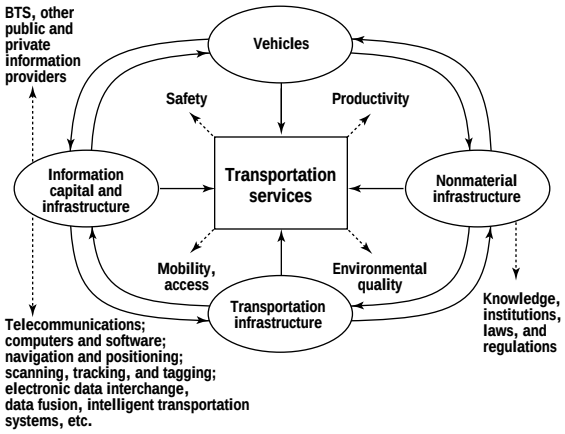
industrial materials, are transported in the growing U.S. economy, the dollar value of such cargo is relatively low. According to the CFS, materials valued at or below $1,000 per ton account for just under 96 percent of the weight, but only 46 percent of the total value of the goods moving over the U.S. transportation network in 1993. The remaining freight (a little over 4 percent of the weight and 54 percent of the value) is made up of eight categories of high-value goods. These include instruments, finished leather and apparel products, machinery, and transportation equipment. Businesses and consumers are willing to pay a premium for fast and reliable service for high-value commodities. Information technologies help provide such services.

## The Transformation of Transportation Services by IT

To better understand the broad impacts of IT on the emerging quality and quantity of transportation services, it may be useful to clarify the systemic nature of transportation services. Societal needs for mobility—and hence transportation—have traditionally been met by a combination of four basic system elements (see figure 11-4):

1. vehicles of all kinds;
2. the physical or material infrastructure (e.g., roads, railroads, and airports) used by the vehicles;
3. the information network infrastructure; and
4. an operational framework or infrastructure: people acting within a framework of processes and knowledge (e.g., policies, rules, regulations, and institutions) who design, build, operate, and maintain the vehicles and infrastructure, and plan and shape the governance and future evolution of the entire enterprise.

Figure 11-4.
**Components of the Transportation System**




The quantity, variety, and quality of transportation services are jointly determined by these four elements, and the interactions among them. Information technologies are being adopted throughout the economy in ways that are fundamentally affecting the nature of society's needs and desires for mobility and access. Today, people around the world can choose among fax, electronic mail, and overnight express for movement of documents, or debate whether an intercity trip might be avoided with a conference call. Options such as these are affecting commercial operations and the daily life of individuals in all spheres of activity. Transportation-related enterprises, like all businesses, are fundamentally affected by IT—at every step from research through manufacturing of goods and operation of services.

Beyond those more visible effects, fundamental changes are occurring in how transportation works and is used. The "bottom line" in transportation applications of IT is determined by the balance between cost and service. IT can affect both strongly. The acquisition and processing of operational, financial, and related data directly support higher system capacity, greater labor and capital productivity, improved efficiency, more effective resource allocation, and better integra-

tion of the many processes and activities that cumulatively produce transportation services.

Detailed understanding of system operations also enables design and implementation of innovative operational concepts and practices. The overnight package delivery service, for example, could hardly exist today without a myriad of computers, digital tags on items, and extensive communications links. It is difficult to imagine operating the nation's commercial aviation system—with well over 1 million airline seats to be filled daily at market-driven prices for several thousand origin-destination pairs—without the technology that underlies and links modern computer reservations systems.

More recently, information technologies are beginning to transform the interface between the service provider and the customer or user. Many ITS applications provide real-time status information about local highways and transit systems, potentially with guidance as to optimal choices for any particular trip. An individual with access to the World Wide Web can find the status of an overnight package in seconds. With a highly controlled and visible transportation system, manufacturers can safely integrate their suppliers into just-in-time production systems and tailor their outputs to short-term customer needs.

Less direct, but potentially of greater impact, are the ways in which information technologies alter the need to travel or the type of transportation consumed. A film can be seen by traveling to a theater, accepting what is available from television broadcasters, traveling to a video film rental store, or staying home but ordering a specific choice for direct cable delivery. A trip for a business meeting may be replaced by a joint telephone call or video conference, and personal purchases may be made by traveling to a store, or by ordering (over telephone or Internet) and relying on a delivery service. Aided by modem-equipped computers, fax machines, and online services, a growing segment of the population finds it feasible—and often preferable—to work from home, either as a telecommuting employee or as an independent business or contractor.

Many of these changes are not of a type that is readily captured in traditional transportation measures and indicators, and are thus particularly difficult to characterize quantitatively in their current infancy; assessment of what is happening is still subjective and largely anecdotal. Speculative literature sometimes presents an exaggerated and possibly misleading picture of a future "cyber-society," but an underlying reality is that the full impacts of this IT evolution on transportation will emerge only slowly in coming decades, and often will not be separable from the effect of other societal changes.

## The Supply of IT-Based New Transportation Services

Information technologies are changing the availability and supply of transportation services, with concomitant changes in the ways that mobility and access needs are satisfied. The most direct and visible impact of IT lies in reduced cost, improved capacity, shorter trip times, expanded availability, better service and convenience, and new functions. These direct user benefits may also be accompanied by minimization of adverse environmental and other social impacts.

### Cross-Modal and Intermodal Transportation

#### ► Urban/Suburban Passenger Transportation

A variety of advanced traffic management and travel information systems are being applied to road and public transit operation in urban and

Box 11-4.

**Advanced Travel Management and Information Systems**

Advanced travel management and information systems include three major components: traffic management, traveler information services, and management of public transportation system operations. Typically, many public sector agencies and commercial service providers collaborate to implement these systems.

*Traffic management systems* are used to manage freeway operations, monitor and control traffic, collect tolls electronically, and respond to conditions that affect traffic. Since 1995, state transportation agencies have deployed more than 20 systems that use a variety of detection, communication, and information technologies (IT) to manage traffic flows. More than 2,000 miles of roadways—primarily high-traffic freeways or arterials—have been equipped with more than 2,100 ramp meters, 600 changeable message signs, 375 closed-circuit TV cameras, and other devices.

For the 1996 Olympic Games in Atlanta, video cameras along freeways, city arterials, and at key intersections helped officials monitor traffic conditions, refine control strategies, and respond rapidly to breakdowns and crashes. Through this surveillance, incidents that might otherwise not be apparent for 5 or 10 minutes could be detected in a minute or less.

The Santa Monica Smart Corridor project in Los Angeles includes an 18-mile stretch of the busiest freeway in the nation and five parallel arterials highways. Automated incident detection is coupled to a decision support system that develops real-time responses for addressing traffic problems. Drivers may be prompted to try alternate routes by variable message signs and broadcasts on highway radio, and changes in ramp metering and traffic signal timing may reduce congestion. When completed in 1998, the project is expected to reduce intersection delay, motorist travel time, and fuel use.

*Traveler information services,* which can be provided by both public and commercial enterprises, enable individuals to make better use of the transportation system, based on real-time and the projected status of the highway network and transit system. Information on what means to use and, possibly, when to travel is provided to en route passengers and individuals making a pre-trip decision. For the Atlanta Olympics, many delivery techniques were used: Internet sites, highway advisory radio, changeable message signs, interactive kiosks, hotel room TV, and electronic bulletin boards. Schedules, route instructions, weather forecasts, and other tourism and special event information proved popular, and enabled people to make optimal travel choices. Other beneficiaries of better information include the customers and providers of delivery vehicles, taxis, and shared-ride services.

In many cities, any individual with Internet access can get virtually real-time data and even images of traffic on critical roadways. Timely and route-specific traffic conditions are available in the Boston area for a free conventional or cellular telephone call; this is a commercial service, funded by public agencies as a means of improving local mobility.

*Management of public transportation services* through IT can improve transit operations, reduce the cost of system maintenance, and generally provide better service and en route information to patrons. Examples include use of IT in the operation of flexible-route and scheduled transit vehicles to give buses priority at traffic signals, to enhance personal security for travelers, and to collect or pay fares electronically.

During the last four years, automatic vehicle location (AVL) systems have come to be widely accepted and sought as key components—along with geographic information systems and wireless communications—for improved operational management of bus fleets. Such information also can be linked with traveler information services to update transit riders about expected arrival times of buses.

AVL systems are now operational in at least 28 transit systems and are being installed or planned in 36 other systems in North America. Most of the newer systems use or plan to use satellite-based location determination. For a $2.3 million investment in AVL technology, Kansas City reduced the number of buses needed and saved $400,000 per year in operations, as well as avoided $1.5 million in new rolling stock. Baltimore and Milwaukee saw 23 percent and 28 percent improvements, respectively, in on-time performance.

Other technologies have proven beneficial even in their early application. Portland, Oregon, found up to an 8 percent reduction in bus travel times using bus priority technology at four intersections. Transportation authorities from New York to California have estimated that benefits of electronic fare collection will be in the millions of dollars annually, based on reduced handling costs, improved security, and less fare evasion.

suburban areas (see box 11-4). In the United States, a partnership between public agencies at all levels and the private technology and transportation industries is stimulating major investments in ITS, ranging from research and development, through operational tests and demonstrations, to real-world deployment. In January 1996, then-U.S. Secretary of Transportation Federico Peña announced Operation Timesaver, an initiative to deploy basic intelligent transportation infrastructure in 75 of the nation's largest metropolitan areas within 10 years.

Box 11-5.

**Intelligent Transportation Systems in Europe and Japan**

The infusion of information technologies into transportation, commonly referred to in the United States as intelligent transportation systems (ITS), is a global phenomenon. In Europe, the term more often used is "transport telematics," the latter word implying the combination of information and telecommunications technologies. Prominent considerations in the development and use of ITS in Europe are the high percentage of passenger travel and freight transportation crossing national borders, and the wide variety of road infrastructure found across the European Union.

Over the last decade, European programs have produced many disparate systems based on a variety of overall system architectures—a result that impedes integration of the various technologies proposed or in use. European governments, however, have been supportive of setting specific technical standards for ITS.

The technologies that comprise transport telematics are viewed by both the public and private sector as important elements in coping with traffic congestion, safety, and transportation-related environmental impacts. The PROMETHEUS program, a 1987 to 1994 private sector initiative, was aimed at developing a uniform European traffic system using telematics. One of the goals of the program was to reduce traffic casualties by 50 percent by the year 2000. Increasingly, traveler's preferences and choices also are being recognized as critical in the evolution of telematics.

Much like Europe and the United States, the public sector in Japan has focused ITS development and use on reducing congestion, improving safety, and protecting the environment. Government funding of several major programs through the mid-1980s led to rapid development of advanced route guidance, hazard and warning displays, and in-vehicle information systems. Since then, private industry also has taken a strong role in advancing these technologies.

Although Japan does not have the problem of transnational interoperability and standardization that is found in Europe, there are many governmental bodies, independent coordinating organizations, and major corporate participants involved in development efforts. As a result, harmonization is highly complex.

Traffic control systems have been in use in 74 major Japanese cities since 1985; changeable-message signs and roadside radio assistance have been operational since the 1970s. In addition, automated toll collection is widely used.

Congestion and complex urban road systems have generated strong demand for in-vehicle guidance systems. This market is served by at least 16 major manufacturers, with sales of 350,000 units in 1994. An estimated 1.5 million vehicle guidance systems are now in operation, with 2.8 million anticipated by 2005. Japanese auto manufacturers are aggressively pursuing "smart car" technologies, particularly navigation for the domestic market, and safety, communications, and antitheft systems, which tend to dominate consumer interest in the United States.

Most existing route guidance systems are "static," that is, they do not incorporate real-time traffic conditions, but always offer the same routings. Dynamic guidance systems that adjust routes to accommodate current circumstances require a parallel comprehensive real-time traffic data infrastructure, necessitating major involvement of the public sector. With the exception of a few American and European cities, only Japan is now beginning to provide this infrastructure, which must be based on national standards for widespread utility. More than 60,000 dynamic route guidance systems are now operational in and around Tokyo, with expansion of the service to other areas anticipated in the near future.

Government ITS research in Japan typically has a long time horizon. Several agencies are conducting research directed toward fully automated driving, including vehicle control, and support of fiber optic and satellite communications infrastructure as early as 2010.

(USDOT 1996) Japan and Europe also have significant activities underway (see box 11-5).

Centralized and coordinated management of highway traffic and transit operations—bus and light, heavy, and commuter rail—is a central ITS element, as are advanced systems for providing convenient and comprehensive information to travelers concerning the current and projected status of all components of the local transportation system. Electronic collection of tolls can greatly reduce peak-hour delays at highway toll booths in urban areas. ITS offers a path to reduced congestion, shorter trip times, lowered urban air pollution, and improved highway safety, with drivers able to make informed travel choices and system managers better positioned to deal with special or unexpected circumstances.

Only limited success has been achieved over the years in bridging the gap between taxicabs (with a high level of service but relatively high cost) and fixed-route buses (inflexible and often infrequent service at low cost). Merely providing reliable and accurate information at bus stops (and by phone or Internet) could make service significantly more attractive. The relative ease of knowing vehicle location (both onboard and at a central dispatching center) may make feasible a variety of intermediate modes, such as buses that can make modest diversions from the standard when pick-up or drop-off is requested.

Demand responsive paratransit services (e.g., dial-a-ride, shared-ride taxi, and vanpooling) have been used across the United States since the 1970s, but the cost-service characteristics have generally restricted them to specialized functions, such as transportation for the elderly and persons with disabilities. Technology advances, however, in position location, navigation, automated dispatching (centralized or onboard), and local communications may yield more efficient and less labor-intensive results that greatly expand the viability of this concept.

► Freight Transportation and Logistics.

Just as information technology has emerged as a critical tool for specific transportation systems, it is also rapidly being applied to the broader management of freight logistics. Combinations of computer and satellite communications technology now make it possible to track the location of a shipment or vehicle virtually anywhere in the world, and for onboard and central computers to exchange any information relevant to the operation. The widespread adoption of just-in-time manufacturing and delivery to wholesalers and retailers necessitates tracking individual shipments and continual adjustments throughout the enterprise to respond to changing circumstances. The net effect is an increasingly tight integration of the entire chain from raw materials and components to manufacturing and delivery to the final customer. Only by providing the ability to track and control shipments precisely can the transportation system achieve the flexibility to respond to the continual changes and quality-of-service demands that characterize the modern global economy.

The attachment of highly informative and easily read digital tags to cargo is an especially valuable mechanism for facilitating intermodal freight movements. Data describing origin, destination, and contents—whether encoded on the tag or contained in a linked database—can substantially improve the speed and reliability of modal transfers while minimizing errors. Even for the large quantity of goods moving without tagging, extensive networks for electronic data interchange permit paperless exchange of invoices, customs documents, bills of lading, and other materials that can significantly reduce delays and costs.

## Air Transportation

For many people, the computer reservation system (CRS) used by airlines is one of the most vis-

ible interactions with transportation information infrastructure. The CRS permits travelers to arrange, often within minutes, airline flights and related services at most of the world's major airports. It tracks price, availability, seat assignments, and meal preference. More than a convenience, this system is now a necessary element in operating the aviation system at its current and anticipated levels. Beyond the basic seat reservation function, the CRS is key to airline yield management techniques, in which pricing is continually adjusted to match airline offerings to market demand for air travel. The net effect of the CRS is intended to be more-profitable flights, improved industry efficiency, and lower ticket prices overall.

Another IT aviation application of special interest to the traveler is the air traffic control (ATC) system—an enormously complicated mix of hardware, software, procedures, and people—that lies at the heart of both safety and air system performance. The dramatic growth of air travel in the 1950s and 1960s led to the creation of an airspace structure—regions in which commercial and other aircraft would fly under controlled conditions including minimum vertical and horizontal separation—based on radar surveillance by ATC centers. The technological and functional evolution of this system can be protracted because it is so critical for safety and because the transition to new facilities and operations must be seamless and as transparent as possible.

The advances, however, have been sufficient to support a quadrupling of domestic passenger-miles flown between 1970 and 1995, with steady improvement in safety and efficiency. (USDOT BTS 1996, table 1-7) By aggregating information on all flights in U.S. airspace, plus weather data, it is possible to move from ATC to air traffic management by holding flights at originating airports to avoid expensive inflight holds (stacking) in the vicinity of congested terminal areas. One sophisticated IT-based advance—now also being examined for highway applications—is onboard collision avoidance technology, providing pilots with alerts of other aircraft potentially on a collision course. As is discussed in chapter 3, onboard Global Positioning Systems (GPS) to avoid impending collisions into terrain are now being installed by U.S. airlines.

Plans and systems are currently being developed for transition to a conceptually new approach—free flight—in which aircraft location is determined onboard by augmented GPS technology, rather than by ground radar facilities, with greatly increased flexibility given to crews in choosing routes. Substantial economic benefits are foreseen. Satellite-based positioning technology is also expected to permit reduced separation standards—hence, higher en route capacity—and improved low-visibility landing capabilities to minimize delays due to bad weather.

Many onboard and air-ground cooperative computer-based systems are used to assist the crew in most flight management functions. Now referred to as a "glass cockpit" (reflecting the adoption of computer-driven displays of information in place of traditional electromechanical gauges), the modern flight deck offers great improvements in the flexibility and type of information conveyed to the crew, and the manner of its display. The glass cockpit is one of the most visible manifestations of the many automated functions that contribute to safety and reduced pilot workload, and have permitted an economic gain through reduction to two- rather than three-person crews in large airliners. Related systems also provide useful real-time inflight information to the operating airline.

The design process for the latest entry into the commercial fleet, the Boeing 777, was greatly facilitated by extensive use of computer-aided-design technology, flight-deck simulators, and

formation of widely separated but digitally linked subsystem engineering teams. The crews for this and other new aircraft receive much of their initial familiarization training on highly sophisticated cockpit simulators.

### Rail Transportation

The current renaissance in freight rail transportation in the United States has been driven by a powerful combination of regulatory reform, innovative operating concepts, and the application of technical advances. Railroad companies must deal with dispersed moving and fixed assets—involving not only the trains a given company operates and its track network, but also the free exchange of rolling stock with other railroads. Railroads have thus been among the leaders in the business world in applying information technologies to their operations. In the 1970s, the railroads implemented optical tags and scanners to identify freight cars as they entered terminals; more recently, railroads have moved to a microwave transponder system. Classification yards, in which several thousand freight cars are received in inbound trains and reassembled into outbound traffic, have long been highly automated in their operation.

The need to coordinate disparate activities over a vast geographic area has meant that railroads have always had a strong interest in communications technology. The telegraph, a key element in creation and operation of 19th century rail empires, has long since given way to extensive and highly sophisticated dedicated fiber optic and microwave digital communications facilities. Traffic management (train dispatching) is now often accomplished from control centers responsible for thousands of miles of rail system, with graphic display of track occupancy and infrastructure status.

Fundamental safety functions—primarily train separation—are still based on the century-old track-circuit concept. As discussed in chapter 3, the Federal Railroad Administration and the industry are now exploring "positive train control" approaches as a safety feature. These approaches are based on the use of locomotive GPS position determination and onboard track geometry data, with digital communications to a control center. These and other concepts using wayside transponder beacons for location appear to offer substantial safety and traffic capacity benefits, although the necessary investment would be quite large. Just as in other modes, GPS also plays an important role in track and other physical plant surveys.

### Intercity Highway Transportation

Many of the most promising highway uses of information technology were noted above in connection with cross-modal urban and suburban applications. Many elements of ITS, however, apply equally to non-urban environments. One example: "mayday" systems—devices that sense an accident, or can be activated by the vehicle operator, and automatically communicate the situation (typically using satellite or cellular systems) to an emergency response agency. When implemented as a commercial service, that agency will also have access to a database containing information about the individual involved. By incorporating a GPS receiver, this system is able to provide precise location information to the responder.

Route navigation systems, typically based on GPS access with a CD-ROM map database, are already popular in Japan, although still relatively costly. They are of greatest value in urban areas, particularly when accompanied by effective routing algorithms, but can also be very useful to the intercity traveler. In addition to navigation functions, such systems can contain information on restaurants, hotels, and services, as well as local traffic problems or—of particu-

lar interest on rural roads—warnings of approaching adverse weather conditions. More localized meteorological information can provide warnings and countermeasures quickly, effectively, and efficiently. Indeed, in some regions of the country, it is estimated that substantial savings of taxpayer dollars could result by reducing the number of snowplow drivers called to duty for severe storms that do not materialize.

To a large degree, onboard computing devices simply represent improved ways to achieve traditional functions, and their presence is relatively invisible to the driver. Innovations now being actively explored offer even more dramatic change. Various night vision technologies, originally developed primarily for defense applications, may be a powerful means of coping generally with the high rate of nighttime accidents, and with the decline in night vision inherent to the aging process. Similarly, appropriately placed radar and other sensors appear capable of providing advance alerts and warnings to drivers for a wide range of potential collision situations.

### Maritime Transportation

A modern cargo ship is an extremely valuable asset of a highly competitive industry. Information technologies are now widely used in assuring maximum operational efficiency and economic yield. Navigation has always been particularly critical in the marine environment for both safety and finances. GPS and steady improvements in oceanic meteorological sensing and forecasting provide the foundation for efficient routing between ports. Continual communication among corporate headquarters, customers, and ships similarly enables economic optimization in routes, schedules, and cargoes. Highly automated port facilities contribute to minimization of the time spent loading and unloading, further improving ship utilization. High-precision augmentations of GPS in harbors and other critical regions (used in concert with digital charts), radar for collision avoidance, and radio communications provide the basic framework for marine safety, which includes avoidance of environmentally damaging spills.

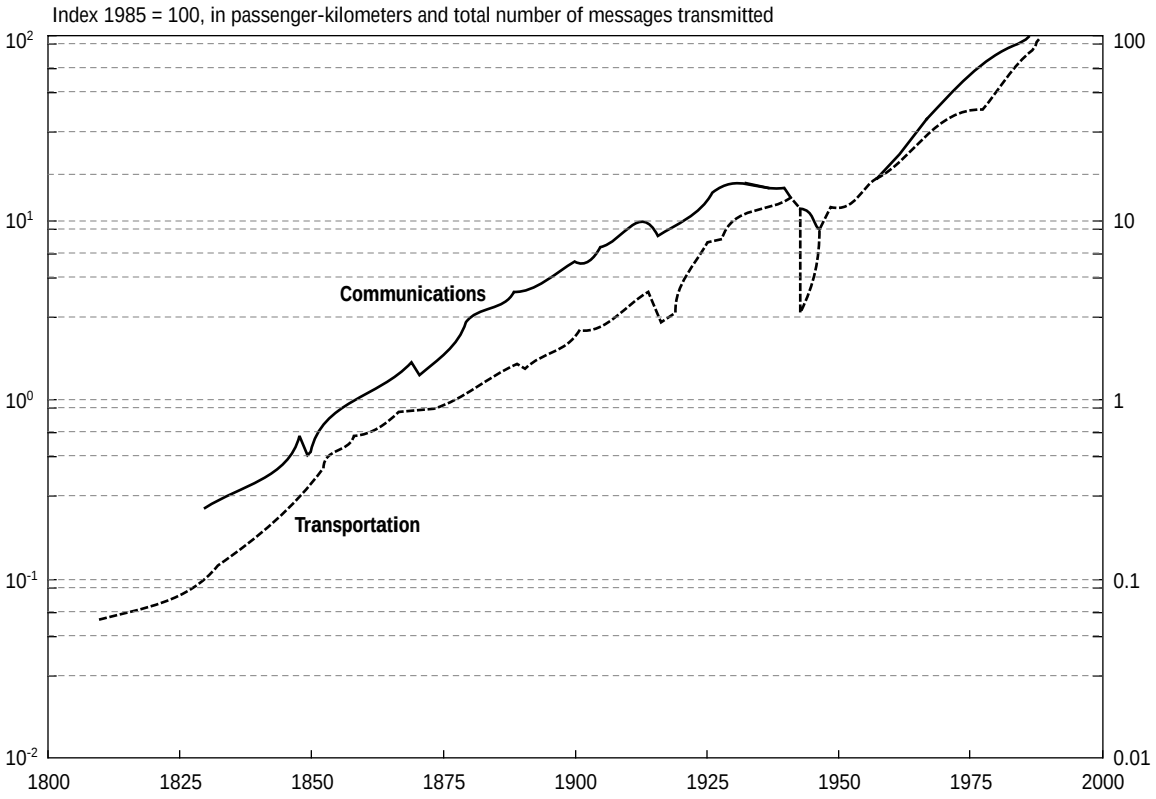
The economics of shipping also benefits from the high degree of automation now applied to ship operations as a result of minimized crew requirements. As is the case for air crews, highly sophisticated simulators play a key role in training bridge officers in the intricacies of handling 100 ton ships.

## IT and the Changing Demand for Transportation

The changes described above suggest the degree to which information technologies can complement and facilitate transportation functions, yielding more attractive cost and service characteristics that often affect, to some degree, the choices made by users and customers. Less obvious, however, but potentially of greater direct impact, is an IT-driven shift in the underlying spectrum of demand for transportation services based on the substitution of telecommunications for physical movement. This is often referred to as “tele-substitution.”

Mobility and access needs and desires can be met in many ways. The place at which products are produced is similarly subject to a wide range of choices. The need for transportation is often discretionary, and, when it is needed, alternative means can be found. One common consequence of the introduction of information technologies is to change the options and the decision criteria applied to them. The brief discussion that follows suggests some of the many ways in which IT substitutes for transportation, stimulates or eliminates the need for it, alters user travel or mode choices (including facilitation of public

Figure 11-5.
**Growth of Passenger Transportation and Communications in France**



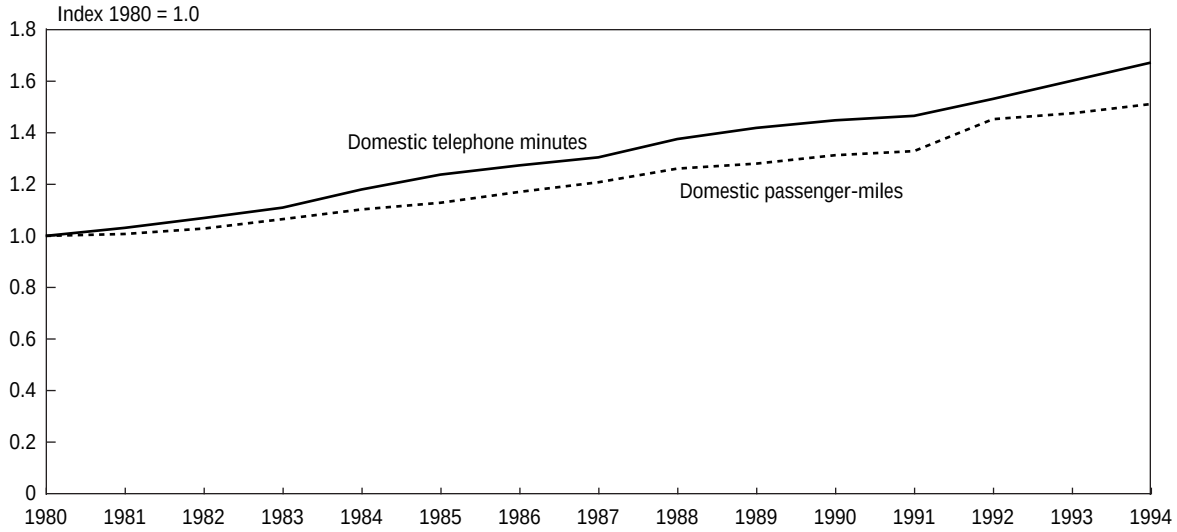

SOURCE: A. Grübler. 1990. *The Rise and Fall of Infrastructure: Dynamics of Evolution and Technological Change in Transport*. Heidelberg, Germany: Physica-Verlag. Figure 4.5.2, p. 256.

sector travel demand management strategies), or substantially changes the nature of the transportation services needed. The extent (if any) of substitution of movement by communications is still speculative. Evidence from the United States and France suggests that both transportation and communications have been growing in parallel—with little support for substitution (see figures 11-5 and 11-6). Since some of these effects are not readily quantifiable, this discussion is necessarily anecdotal and descriptive in nature.

## Local Mobility and Access

For many people, mention of the impact of information technologies on transportation most often conjures up the image of telecommuting—replacing the trip to one's workplace by digital tools and communications links that permit working from home. Some futurists expand on this image, envisioning a "wired world" in which most people spend much of their time at home. Working, shopping, entertainment, social interactions and other activities are to be accomplished largely through digital links. Even if this relatively extreme view is not realized, there is some reality to the expectation of significant

Figure 11-6.
**Growth of Passenger Transportation and Telecommunications in the United States: 1980–94**




SOURCES: Federal Communications Commission. 1996. *Statistics of Communications Common Carriers, 1995/1996 Edition.* Washington, DC.
U.S. Department of Transportation, Bureau of Transportation Statistics. 1996. *National Transportation Statistics 1997*. Washington, DC. December.

potential changes in personal and corporate activities. This evolution will carry with it the likelihood of parallel alterations in the provision of mobility and access, particularly in the urbanized areas, which account for 75 percent of the population and almost two-thirds of national passenger car mileage.

Telecommuting is already a fact of life for many people, but so far with only modest transportation impacts beyond those who practice it. The most common situation is that individuals still travel to the regular workplace two or three days per week. The growth rate for this style of work appears to be rapid, although difficult to measure, and it remains to be seen at what point it may either accelerate or level off. Although it is popular to characterize more than half of the nation's jobs as "knowledge functions" or as employing "information workers," the suitability of many such positions to telecommuting is questionable, as is the desire, ability, or willingness of some individuals to work at home (or at local remote worksites). Transportation effects are limited, since trips to and from work only represent about one-third of urban travel, and often include other errands that would require local travel in any event. Thus, for the foreseeable future, direct impacts of "pure" telecommuting are expected to be modest.

The more general phenomenon of home-based work, however, with telecommuting as a subset, has much broader implications. Establishment of a fully functional home office now requires only a relatively modest investment for capabilities, including fax machine, copier, Internet (with a World Wide Web site) and electronic mail capabilities, voice mail, and multiple telephone lines. These tools, plus a powerful desktop computer running commercial small business software can support a substantial business activity in a fully professional manner, with operating costs far below the level associated with rented quarters. The net effect is to ease entry into the marketplace.

A variety of societal trends are encouraging self-employment: voluntary or forced early retirements, contracting for services formerly performed by employees, need to tailor work to responsibilities to care for family members, aversion to large and impersonal work situations, a need or preference for flexibility in work style and hours, the wish to pursue several types of work simultaneously, or the desire to make one's choice of residence independent of workplace. Information technologies enable and stimulate realization of goals such as these.

Although eliminating trips to an external workplace, home-based workers such as field representatives, salespeople, or service technicians with no formal office may generate trips to customers and suppliers. The home-based worker, however, is more likely to be able to schedule travel in off-peak hours for business as well as other activities, thus increasing personal mobility. Transportation implications include the reduction in work trips, as well as some degree of congestion relief in periods of peak travel. The broader and more speculative impact is the potential to increase urban sprawl and migration to more rural suburban areas as a consequence of improved mobility.

No matter where employed, many people are attracted to the convenience of shopping from home, whether via catalog, television, Internet, or other means. This phenomenon has already contributed significantly to the growth of businesses well attuned to it, including those that can provide the rapid and efficient delivery services on which the entire process depends. This approach is now being introduced by many supermarkets, so that groceries can be ordered without leaving one's home, for next-day delivery. A related development that markedly improves access to many services as well as goods is the relatively low cost to many businesses of providing 24-hour phone service, now being supplemented by posting catalogs and accepting orders via the Internet. The World Wide Web also offers direct access at any time to many documents, forms, tickets and reservations, and general information resources that otherwise might require a significant effort, during business hours, to obtain.

Information technologies also can affect access and mobility in a very different way by providing the means for implementation of demand management and congestion mitigation measures by public authorities. Given the political will and necessity, IT can greatly facilitate the management and control of motor vehicle access to urban areas through road pricing (adjustment of electronically collected tolls) or prohibition of entry for some or all vehicles.

## Long-Distance Mobility and Access

The telephone has provided a partial alternative to some types of business travel, especially in the form of conference calls that involve numerous participants, but is often not a good substitute for face-to-face meetings. Video conferences—with television cameras and monitors at each location providing the visual contact that is so important to human discourse—have been available in some fashion for decades, but problems of cost, availability, and performance have limited their use. Technology advances have now begun to generate interest in "virtual" meetings. The steady decline in equipment and telecommunications costs, accompanied by significant performance and ease-of-use improvements, is producing a growing willingness to consider video conferences as a possible replacement for some single-location meetings.

Several forces in addition to reductions in the cost and functionality advances of IT itself are driving this trend. Most organizations are increasingly cost conscious. The expense of air tickets, plus salaries and incidental expenses can

make the cost of a half-day meeting very high. Interactions between two or several decentralized businesses can involve people from many locations, often in other countries.

Although not a replacement for physical presence, video meetings, if used effectively, have several important strengths beyond their potential for cost savings. They are easier to schedule and can involve more people, often from more places. Systems are now becoming available that, at moderate cost, can enable even a conventional desktop personal computer to operate as a video terminal. Should this capability reach sufficient acceptability in cost and performance to become relatively standard, the accessibility of business colleagues for digital face-to-face meetings would become substantially greater. Personal relationships could become significantly easier to establish and maintain, even while travel budgets shrink. (Realization of this scenario could have significant impact on airlines, dependent on business travel for almost half of their passengers and about two-thirds of their revenue.)

### Access Beyond the Scope of Transportation

The preceding discussion addressed ways in which information technologies can affect the need for physical mobility, substituting for transportation or making it unnecessary. Telesubstitution can also apply to situations in which the distances, travel costs, or other impediments are so great that physical transportation is not practical. Thus, telecommunications and associated technologies can effectively remove distance or locational remoteness as a constraint on access to education, libraries, and some medical care services and consultation. For example, the Internet permits people with common interests in virtually any subject to gather (electronically) for discussions, debate, and exchange of information—no matter how esoteric the subject or geographically dispersed the participants may be. An absence of like-minded individuals in a person's local community need not be an impediment to actively follow a particular interest, whether professional or amateur, intense or casual. As valuable as this type of access is in general, it is of special importance to people who, for whatever reason, may be unable to travel physically and would otherwise be precluded from the activities and services enabled by IT.

Information technologies are also creating opportunities well beyond the realm of simple telecommuting or home-based self-employment. Some types of work—such as telemarketing, invoice processing, and software development—do not require physical presence at a particular location. Businesses requiring these services now can and do seek them anywhere in the world, based primarily on economic considerations. At the same time, individuals and whole communities gain a significant degree of access—that would not exist without IT—to very distant commercial and employment markets in any activity that does not entail substantial physical movement of resources or products.

## Transformation of Production

The growing investment in transportation IT has not only affected the supply of new services and changed demand for transportation, but also affected the type and level of competition and the structure of management in transportation and production firms. The use of IT promoted broad restructuring and strategic changes in these industries, which facilitated the entry of small firms into new markets, creating economic activities such as global sourcing arrangements and business networking. By changing production processes and products, IT also can trigger job redesign, restructure work flows, or alter the

place of work—thereby changing employment patterns.

Because IT has been used to automate and speed up production processes, improve reliability and flexibility, and lower costs, widespread productivity payoffs in the economy are expected. Yet many macroeconomic studies report no substantial gains in productivity. This is referred to as the productivity paradox. One explanation for this paradox is that national statistics on industry productivity do not capture aspects of service quality in terms of how well transportation and logistical companies serve their customers. Further, the benefits of IT use by transportation firms may accrue to and be reflected in the productivity benefits of manufacturing firms and other customers.

An historical example of the productivity paradox draws attention to the long time lag between the advent of the dynamo—a broad technology with pervasive effects like the computer—a century ago and its impacts on the economy, reflecting the time needed for the new technology to penetrate the economy widely. (David 1990)

### Enterprise-Level IT Effects

IT applications focused initially on consolidating operations and lowering the costs of paper-intensive activities, such as purchasing and accounting. Now IT is used to offer flexibility in rapidly evolving business environments, preserving or raising market share, and improving the quality of services and customer interactions. For example, computer reservation systems are used not only for cost reduction and revenue enhancement, but also to offer new customer services. Also, logistical firms use IT to offer management services to production firms on a worldwide basis, which can lower the cost of production, thus blurring boundaries between transportation and production firms.

Increasingly, key assets in transportation and logistical firms are knowledge assets. They include a knowledge base about customers and markets embodied in the firm's IT and supporting systems, and the knowledge and professional skills acquired by workers and management as they develop flexible response capabilities and use IT to improve the firm's internal decision-making.

### Industry-Level IT Effects

Transportation is one of the more frequent users of IT. In the air transportation industry, for example, IT has a major impact on sales, marketing, load management, logistics planning, safety systems, air traffic control, and other activities. The effect on operations is enormous.

It is important to note that in the air transportation and intermodal logistics industries, IT is associated with increasing complexity and customization, as these industries become more transaction-intensive, and increase the scale and variety of their linkages with other enterprises. In this process, transportation IT is altering the existing relationships among end-users, manufacturers, wholesalers, and retailers. Intermediaries are often bypassed, producers may sell products directly to end users, and new businesses may arise.

### Workforce-Level IT Effects

In an environment of intense global competition, there is an organizational need for flexibility, the capacity to respond or change quickly, and the ability to experiment often. Workers need to know how to construct queries, analyze and interpret information, draw inferences, and act. (NRC 1994)

IT comprises tools that affect what workers do and how they do these activities. In this context, IT can help redesign the work process, facil-

itating the separation, the reorganization, and recombination of work activities without regard to space and time. The outcomes of such redesign of the workplace are increased worker knowledge, decentralized decision authority that allows more autonomy and broader tasks at lower organizational levels, and networked organizations. The levels and extent of supervision will also change.

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