DEDICATED TO MAKING A DIFFERENCE

mobility 2001

world mobility at the end of the twentieth century and its sustainability

World Business Council for Sustainable Development

prepared for the Sustainable Mobility Working Group of the World Business Council for Sustainable Development by the Massachusetts Institute of Technology and Charles River Associated Incorporated

one

• introduction

two

• patterns of mobility demand, technology, and energy use

three
• personal mobility in the urbanized developed world

four
• personal mobility in the urbanized developing world

five
• trends in intercity travel

six

• freight mobility

seven
• worldwide mobility and the challenge to its sustainability

introduction

People desire mobility. They desire it both for its own sake and because it enables them to overcome the distance that separates their homes from the places where they work, shop, seek medical attention, go to school, do business, or visit friends and relatives. Businesses also desire mobility because it also helps them overcome distance — the distance that separates them from their sources of raw materials, from their markets, and from their employees. However, mobility is also associated with a variety of negative impacts — congestion, pollution, greenhouse gas emissions, disruption of neighborhoods, noise, accidents, etc. Another concern is that the world's current mobility systems rely almost exclusively on a single source of nonrenewable energy — petroleum. The tension between humankind's desire for mobility and its concerns about the negative impacts associated with mobility raises the question of whether mobility is sustainable. This report was commissioned by the WBCSD on behalf of a group of its members as the first step in addressing that question. It was prepared by a group of researchers from MIT and Charles River Associates, and provides a "snapshot" of worldwide mobility at the beginning of the 21st century. It identifies the major threats to mobility's sustainability. Mobility 2001 covers both the developed and developing worlds, all modes of transportation, and the movement of freight as well as the movement of persons.

Throughout most of human history, "mobility" has meant moving people and goods at the speed a person could walk, a horse could gallop, an ox could draw a cart, or a boat propelled by sails or oars could move through the water. It was not until the nineteenth century that humans harnessed steam energy and used it to move their goods and themselves at a significantly faster pace. The invention of the petroleum-fueled motor vehicle at the end of the nineteenth century and the airplane at the beginning of the twentieth century opened up opportunities for greatly increased speed and greater travel flexibility. Roads could go where railroads could not, and airplanes only needed runways on which to arrive and depart.

As a result of these innovations, the twentieth century was a "golden age" of mobility. The volume of personal travel and the volume of goods moved both grew at unprecedented rates. By the end of the century, individuals who in earlier centuries would have spent their entire lives within a hundred kilometers of their birthplace thought nothing of traveling to distant continents on business or for pleasure. Raw materials, manufactured goods, and food from half a world away became widely available.

All populations and geographic regions did not participate evenly in this twentieth-century expansion of mobility. As the century closed, the average citizen of one of the wealthier nations was able to act as though distance were virtually irrelevant. But average citizens in most of the poorer countries of the world still transported themselves and their goods in much the same way as their ancestors did. Even within individual countries, the access to mobility enjoyed by citizens of different ages, ethnic backgrounds, and incomes varied greatly. Regardless of a country's average income per capita, its wealthy citizens were generally much more mobile than its poor. They were more able to enjoy the benefits that this mobility created — overseas vacations, homes away from crowded city centers. And they also were better able to avoid the negative consequences associated with mobility — congestion, pollution, injuries and deaths from traffic accidents, and so forth.

Although increased mobility yielded great benefits, it also generated major negative consequences. This is not something unique to the growth of mobility in the twentieth century. The desire for increased mobility had led to congestion and pollution problems in densely populated urban areas long before the advent of the automobile, the train, or the airplane. Accidents involving vehicles drawn by horses and oxen or propelled by sails or oars killed and injured people. During the latter half of the twentieth century, however, certain of the negative consequences of enhanced mobility began to become evident on a regional and even a global scale.

Pollution produced by the internal combustion engines that powered hundreds of millions of motor vehicles began to degrade the air quality of more and more cities. The exploration, extraction, transportation, and refining of the fuels to power transportation vehicles began to damage the environment on an increasing scale. Noise from airplanes carrying people and goods to distant places disturbed the peace of tens of millions of people. And by the end of the century, it began to be generally acknowledged that emissions of carbon dioxide from the burning of fossil fuels, a large share of which is transportation-related, was affecting the climate of the planet.

The latter half of the twentieth century also witnessed both urbanization on a scale hitherto unknown in the developing world and the suburbanization of many urban areas in the developed world. Cities in some developing-world countries seemed to leap almost overnight from the age of the horse, the cart, and the bicycle to the age of the automobile and the jet airplane. This greatly increased the number of people exposed to vehicle-related air pollution, congestion, noise, and accidents. It also greatly expanded the world's demand for energy. Suburbanization emptied out the centers of many established cities in the developed world, as people sought to escape the pollution and congestion — only to encounter pollution and congestion in the suburbs to which they had fled.

KINDS OF SUSTAINABILITY

As the century closed, more and more people began to question whether the extraordinary trends in mobility that had characterized the last half of the century were sustainable. Indeed, "sustainability" was a word that began to be heard increasingly in connection with all sorts of transportation issues.

"Sustainable mobility" is a term that can mean different things to different people. The World Business Council for Sustainable Development defines "sustainable mobility" as "the ability to meet the needs of society to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values today or in the future." This definition emphasizes the social aspects of mobility.

But for many people, the term "sustainable mobility" reflects more mundane concerns — concerns relating to whether the transportation systems on which our societies have come to depend can continue to function well enough to meet our future mobility needs.

- Can the number of automobiles and commercial vehicles keep increasing?
- Can our roads accommodate both the increased volume of passenger vehicles and the increased numbers of trucks that seem to be required to transport ever-growing volumes of freight?
- Can existing and planned airports accommodate the increased number of flights that are projected to result from the continued rapid growth of air travel?
- Can the airspace, especially over regions such as Western Europe and eastern North America, accommodate this larger number of airplanes?
- Are the fuels going to be available to power all these cars, trucks, buses, and airplanes?

We will refer to these as issues of operational sustainability.

We will refer to the broader set of concerns reflected in the WBCSD definition as issues of economic, social, and ecological sustainability.

- Even if our transportation systems can be made to handle the increased loads that society is placing on them, can we (or do we want to) live with the results?
- Can urban areas in both the developed and developing worlds cope with growing con-

also improve accessibility by reducing the distance that must be overcome. “Reaching” need not necessarily imply movement to a specific physical location. Someone can “reach” someone else by telephone, and various telecommunications technologies may enhance accessibility. For a given spatial distribution of activities and a given level of telecommunications capabilities, however, increased accessibility generally is associated with increased mobility.

Different modes of transport offer different levels of mobility and accessibility in different circumstances. Consider the automobile and the airplane. In urban settings, the automobile provides the highest level of accessibility. Automobile users do not have to accommodate a schedule. They can depart whenever they wish, and they usually have a choice of routes to their destinations. In contrast, for travel between urban centers separated by more than a few hundred miles, airplanes provide the highest level of accessibility. The greater inherent flexibility of the automobile is overshadowed by the greater speed of the airplane.

But Some Mobility is Desired for its Own Sake

While most mobility is desired because it improves accessibility, some mobility seems to be desired for its own sake. One can engage in philosophical discussions about why people travel more than is required to meet their basic accessibility needs. But it is indisputable that they do. People like to see new places. They like to learn how others live. Sometimes they merely want to “get out of the house.”

Not only do people like to travel, they care about how they travel. They pay more than the minimum price to obtain greater amenities on airplanes, trains, and cruise ships. They spend large sums of money not merely to purchase motor vehicles, but to purchase motor vehicles that have just the characteristics they want. If such vehicles are not available in the marketplace, they will spend money on customization.

So mobility — both the amount of travel and the manner in which travel is undertaken — provides more than mere accessibility. It also is a reflection of people’s individuality and of their status. Why is this? Some blame the motor vehicle industry and the travel industry for “artificially creating demand” through their advertising. But the plain fact is that we really do not have a very good idea why people consume more mobility than they “really need.” This certainly is an issue that could benefit from well-designed, objective research.

Mobility Shapes and Is Shaped by Our Patterns of Settlement

Mobility also shapes our patterns of settlement. For many centuries, transportation was slow and capacity was low, which meant that opportunities were accessible only if people lived near them. Overland travel was slow and dangerous. Only light and compact goods could be transported over great distances — spices, gold, and silks being the classic examples. Ships could carry more goods, and access to ports often determined the location and wealth of cities. But travel by water, especially by sea, was also slow and dangerous. Long-distance interaction was rare, and those who undertook it ran great risks. By and large, people had to live close to one another if they were to interact routinely.

Once technological advances allowed increased travel speeds, the importance of proximity declined somewhat. Individuals and firms became willing and able to sacrifice nearness for other desirable land and building characteristics, such as more space and greater environmental amenities. Many feedback processes combined to make proximity less important. The industrial revolution enabled the development of higher-speed transportation systems. These systems, in turn, facilitated the industrial revolution by opening up tracts of land for larger industrial plants and by providing relatively rapid access to distant sources of raw materials.

Today, two overarching phenomena are shaping the pattern of human settlement. The first of these is urbanization — the tendency for populations to concentrate in cities. The second is decentralization — the tendency of these same urban areas to expand outward, generally at rates faster than overall population growth, producing net declines in the population densities of metropolitan areas. Neither of these phenomena could be occurring without increased mobility.

Mobility systems affect urban growth in an important way because they make areas of a city more or less accessible, altering the land values and an area’s attractiveness for various uses. Transportation investments often open up new areas for development. A common example in both the developed and developing world is the highway on an urban fringe that facilitates suburbanization around the existing urban core.

As population moves to the urban fringes, high-capacity radial urban expressways are often built to facilitate trips by suburban commuters to jobs in the urban core. Other activities follow residents, creating the edge cities seen in both developed and developing countries. Inexpensive land and easy access by private vehicles allow the building of shopping centers, supermarkets, and hypermarchés and malls, which offer a single location for convenient shopping in a wide variety of shops, with free parking and other amenities.

With increasing residential and economic activity in the fringes, the amount of traffic between fringe locations also increases. This encourages the development of circumferential gestion and growing volumes of emissions?

- Can we afford to build and maintain the infrastructure that would be required to relieve congestion, and are we willing to let it be built?

- Has the increased use of private motor vehicles, which offer greater individual mobility for those who can afford and operate them, deprived the poor, the elderly, and others of access to jobs, the ability to visit friends, to purchase the goods they need at competitive prices, and to obtain needed medical attention?

- Can the world bear the economic and environmental costs of locating, extracting, transporting, and processing the petroleum required by a growing number of vehicles?

- Can the planet's oceans and atmosphere continue to absorb the increased pollution generated as a byproduct of the transportation of vastly larger numbers of people and volumes of goods?

Questions relating to operational sustainability largely focus on mobility as it impacts individuals. Can a transportation system enable them to function as they have come to expect? Can I get to work? Can I get to my business appointment in a distant city? Will the package that I am expecting be delivered on time? Questions relating to economic, social, and environmental sustainability, on the other hand, focus more on mobility's impact on the broader society, though often in the context of how this impact might affect the individual. Are emissions from motor vehicle exhaust becoming so great that people in my community (including me) might become ill? Is our society becoming so dependent on the car that older people who cannot drive (including me, when I become old) will not be able to get places and see people? Is the impact

Why Public Transport Loses Market Share — A Primer on the Power of Desirable Mobility Characteristics

In the chapters that follow, we will show that the trend toward privately owned motor vehicles and away from reliance on "conventional" forms of public transport (such as buses and subways) is nearly universal. Various explanations have been advanced to explain this phenomenon. In the United States, some have suggested that the decline in public transport is the result of an organized "conspiracy." Others have charged that the villain is the "unfair subsidization" of lower-density housing.

An understanding of how transportation systems differ in their ability to deliver the various characteristics of mobility leads to a much simpler — and much less sinister — explanation. It also helps to identify the characteristics that "unconventional" forms of public transportation would need in order to compete effectively with the private automobile.

The growth in private motor vehicle fleets derives directly from the mobility benefits and enhancements that these vehicles provide. With their inherent flexibility in schedule and choice of destinations, automobiles offer the maximum potential benefits to be derived from motorized mobility. These benefits — travel time, travel comfort and amenities, and status and prestige — are not entirely related to "functional" mobility.

The automobile is often superior to other modes in terms of travel times and incremental out-of-pocket costs, factors that are frequently thought to be the key drivers of travel choices at the level of the individual trip. In addition, private vehicle travel also offers other service attributes that are important to consumers. For example, while parking capacity constraints may intrude, private vehicles can frequently provide full origin-to-destination service, with minimal walking and waiting times. An automobile trip also offers complete schedule and route flexibility. In particular, it is possible to follow a route that involves one or more intermediate stops so that a single chained trip may serve multiple purposes with minimal disruption. While commuting between home and work, for example, one might drop children off at school, shop, or take care of other personal business. Finally, private vehicles generally provide a superior level of comfort and convenience.

The private motor vehicle's value to the consumer is often more than utilitarian, however. In many if not most societies today, private vehicles not only signify arrival in the middle class, but arguably serve as a tool for "making it" to the middle class, by providing potential access to greater job opportunities as well as a host of other "accouterments" of middle-class life, such as shopping at malls.

The contrast of the private motor vehicle's characteristics with those of traditional fixed-route, fixed-schedule public transport is striking. To begin with, public transport may not even be an option for many trips. When it is, the user needs to find a convenient stop at both the origin and destination, and must wait for a vehicle to arrive. In ideal circumstances, the service is running on time and the user has sufficient schedule flexibility, knowledge, and information to minimize the amount of time spent waiting. But these conditions are not always met, and service unreliability may lead to lengthy waits. At off-peak hours, service may be limited, and there may be no late-night service at all.

For these reasons, conventional public transport systems are best at serving high levels of travel demand concentrated in a relatively limited area or along well-defined corridors; environments where access difficulties are minimized and acceptable levels of service can be offered to many users in efficient and cost-effective operations. Areas that typically meet these criteria include the urban core and the high-density corridors between the core and the suburbs. Indeed, unless a potential service area meets these criteria, investment in public transport facilities with high fixed costs (such as the infrastructure requirements for urban rail) would be unlikely to meet any reasonable economic investment standard. Similarly, fare revenue production by a public transport system in these circumstances would be unlikely to cover any significant portion of the operating costs.

Given public transport's difficulty in fulfilling many mobility-related needs in wealthier societies, it is not surprising to find that its share in providing mobility (and accessibility) declines with increased incomes. As incomes rise to the point where GDP per capita reaches around US$5,000 per year, mobility expands mainly through increased use of public transport, although automobility — accesses to and use of the automobile — starts to assert itself as this figure is approached. Above that income level, increased mobility is largely through greater use of private vehicles, and in many instances, public transport use falls, thereby reinforcing the growth of automobile use. Figure 1-1 shows this trend in a selection of cities in the developed world in the period between 1960 and 1990.

This discussion also illustrates why public transportation's ability to compete for users with the private vehicle is further curtailed by the impact of widespread private vehicle use on urban form. In particular, the sprawling suburbanization engendered by widespread automobile access and use creates a pattern of land use and activity that conventional public transport is particularly ill-equipped to serve: a scattering of demands among many geographically dispersed origins and destinations, with no origin-destination pair or corridor attaining particularly high demand densities.

In metropolitan areas other than those whose land-use patterns (at least in their urban cores) predate the explosion of automobility, public transport systems will need to find ways of more nearly matching the mobility characteristics provided by the automobile in order to capture a significantly larger market share. Understanding what these characteristics are, and how they might be provided by various types of unconventional public transport, is the first step toward eventually permitting communities to reduce their dependence on the private automobile — if that indeed is what they wish to do.

on the world's climate resulting from the emission of greenhouse gases going to harm mankind (including my children and grandchildren)?

Both types of sustainability concerns reflect the vital role that mobility has come to play in our lives as we enter the twenty-first century. We cannot live without mobility. But can we live with its consequences? Will the mobility we need now and expect to need in the future be available to us? Will the economic, environmental, and social costs associated with this mobility be tolerable? For mobility to be truly sustainable, the answer to questions of both types must be "yes."

Mobility 2001 — Taking the Pulse

In 2000, several member firms of the WBCSD decided to "take the pulse" of the world's mobility at the end of the twentieth century. They wanted to know just how mobile people and goods really were in various regions; how this mobility was changing; and the extent to which mobility was threatening to become unsustainable — or indeed, might already have reached that point.

Providing the vehicles and the fuels on which mobility depends is the primary occupation of millions of people worldwide. Millions more service and maintain these vehicles or operate them. Mobility is one of the world's largest businesses, a business based overwhelmingly on energy from a single raw material — petroleum. Virtually all mobility today is dependent on a continuous supply of petroleum, a dependence that is not sustainable indefinitely.

The WBCSD member firms that first assembled in 2000 wanted to understand how companies like theirs might help assure that mobility is sustainable. They had a real stake in the question because they are themselves among the world's largest firms in the mobility business. Their long-run survival depends on mobility being sustainable.

This report, *Mobility 2001*, was commissioned by the WBCSD on behalf of these member firms, which include six of the world's 10 largest companies, and is intended to reflect conditions at a particular moment in time — the end of the twentieth century. The picture we offer is not static, however. Complex phenomena like mobility and the challenges to sustaining it can be understood only if we appreciate the history of the problem, as well as the diversity of that history across the developed and developing world. Because the story involves our largest structures — cities and transportation systems — the deeply rooted issues that we discuss will also persist for decades. If mobility is to be made sustainable by 2030 — the stated goal of the WBCSD member firms supporting this effort — measures that will eventually produce the necessary changes must be undertaken almost immediately.

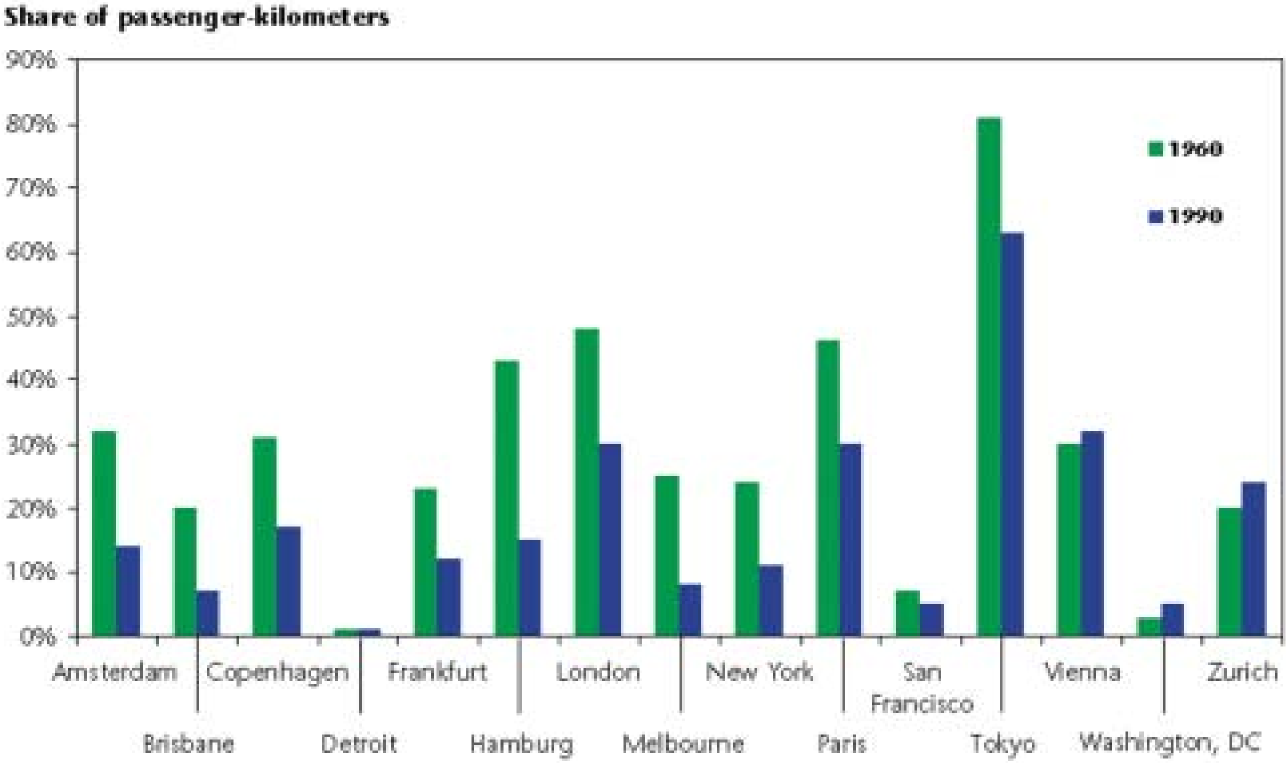
MOBILITY AND ITS IMPORTANCE

Mobility is Principally a Means of Improving Accessibility

By and large, people seek to increase their mobility in order to improve accessibility — "the ease by which desired social and economic activities can be reached from a specific point in space" (US DOT, BTS 1997a; 136.). Distance impedes accessibility. It separates people's homes from the places where they work, shop, seek medical attention, go to school, do business, or visit friends and relatives. It separates firms from their sources of raw materials, from their markets, and from their employees. Mobility enables people to overcome distance.

Mobility is not the only means of improving accessibility. Changing the spatial distribution of activities can

Figure 1-1. Transit share of motorized travel has generally been decreasing



Source: Kenworthy and Laube (1999).
Note: For Washington and Detroit the change is between 1970 and 1990; for Zurich and Vienna, the change is between 1980 and 1990; for other cities, the change is between 1960 and 1990.

roads to facilitate these movements. (These circumferential roads also serve to divert through traffic away from the urban center.) Such roads may be easier and less expensive to construct than urban facilities because land is more available. Again, the provision of road infrastructure can accelerate the outward relocation of households and businesses. Within a few years of being opened, it is not unusual for these roads to carry traffic levels that (on the basis of prior land-use patterns) were not forecast to occur until after 20 or more years of service.

Mobility Enables Economic Development

"The division of labor is limited by the extent of the market," writes Adam Smith, describing how the specialization of production can lower the cost and increase the variety of available goods (Smith, 1776). One of the greatest barriers to the division of labor has always been the cost and difficulty of transportation. Smith observed that the division of labor can only occur in cities. In remote rural areas, each family unit had to be capable of performing virtually all tasks needed to support their survival. No one could afford to specialize because the demand for specialized skills was not sufficient.

But cities could not exist until the reliable, cheap transportation of basic foodstuffs became possible. Only then could people risk not growing their own food, regardless of how unsuited to agriculture their location might be.

Transportation capabilities also determined how large cities could grow. The average city in ancient Greece is said to have had a population of only about 10,000. This was the most that could be supported by the transportation systems that connected these cities and their immediate hinterlands. But the population of ancient Rome managed to grow to approximately 1,000,000 because the Romans were able to transport large quantities of grain from Egypt using high-capacity (for their day) ships. Rome also managed to transport water — by means of aqueducts — and to dispose of waste products — by means of sewers.

Inexpensive, reliable freight transportation also has transformed otherwise worthless substances — such as remotely located deposits of low-grade iron ore — into valuable resources. Indeed, it is not an exaggeration to state that personal and goods mobility has made possible our present globalized economy. While such institutional and political changes as the dismantling of various trade barriers have been necessary to globalization, without the improvements in personal and goods mobility that characterized the last half of the 20th century, such changes would have been meaningless exercises. There would have been no way for trade to increase.

Some contend that, on balance, globalization is not a "good," something that creates net benefits. While there is certainly room for debate about the range and desirability of the consequences of globalization, it is important to recognize that high-quality, efficient freight systems facilitate sustainable development. Indeed, if freight systems were less efficient in enabling people around the world to find markets for their goods and to purchase products from distant lands, then everyone's standard of living would suffer. The poor around the world would be hurt, not helped. There would be more famine and disease, not less. Environmental devastation in developing countries would be increased, not reduced, as people struggle to provide for themselves without the goods they import from the outside world.

Telecommunications and Mobility

As we have already noted, telecommunications systems do indeed facilitate accessibility, but whether they substitute for mobility, enhance mobility, or complement mobility is unclear. Many people consider telecommunications to be a substitute for mobility. According to this line of reasoning, the movement of people (and perhaps also certain goods) will become less and less necessary as telecommunications technologies improve. Electronic mail will replace the physical delivery of letters. The World Wide Web will replace newspapers and magazines. Telecommuting will replace actual commuting. Perhaps. But as one recent advertisement put it, "Ever seen a computer deliver a package?" Achieving high levels of accessibility without mobility may be as difficult as realizing that other promised feature of our information age, the paperless office.

Whether telecommunications technology will ultimately enable the electronic transmission of knowledge, ideas, and information to substitute for the physical transportation of people and goods will depend both on the quality of telecommunications services and the quality of mobility. E-mail is clearly becoming a substitute for conventional postal mail. It provides a readable and reproducible copy instantaneously, yet (once the necessary equipment is in place) it costs a fraction of what standard mail costs. With the development of digital signatures and reliable, secure electronic payment systems, the need for conventional mail is likely to shrink even further. But e-mail may be a special case. Telecommuting is becoming less of a rarity (a recent estimate [Switkes and Roos 2001] suggests that as many as 15 million US workers may be engaging in some form of telecommuting by 2002), but quite often it cannot serve as an acceptable substitute for the actual presence of individuals in the workplace. Videoconferencing is increasingly being used by business. But its quality will have to improve quite a bit before it can replace more than a trivial share of face-to-face business meetings. In short, whether telecommunications technology will turn out to be a net substitute for or a net complement to mobility is still very much an open question.

MOBILITY AND SUSTAINABILITY

For mobility to be sustainable, it must improve accessibility while avoiding disruptions in societal, environmental, and economic well-being that more than offset the benefits of the accessibility improvements. This means that any assessment of mobility's sustainability must include not only a judgment as to its effectiveness in improving accessibility but also a judgment as to the magnitude and consequence of any associated disruptions in social, environmental, or economic well-being.

One way of organizing the information required to make these judgments is to separate indicators into two categories: those measures that society would like to see increased and those that society would like to see reduced. An increase in the former would reflect the success of a system in providing the important values associated with mobility — improving personal accessibility and enabling businesses to provide consumers with affordable products and services. A decrease in the latter measures would reflect the success of a system in mitigating trends that threaten societal, environmental, and economic well-being. These trends include climate change, resource exhaustion, congestion levels that impede productivity and threaten social stability, public health problems created by air pollution, ecosystem collapse, and others. As a general rule of thumb, mobility becomes more sustainable as it increases the measures in the first set and reduces the measures in the second set.

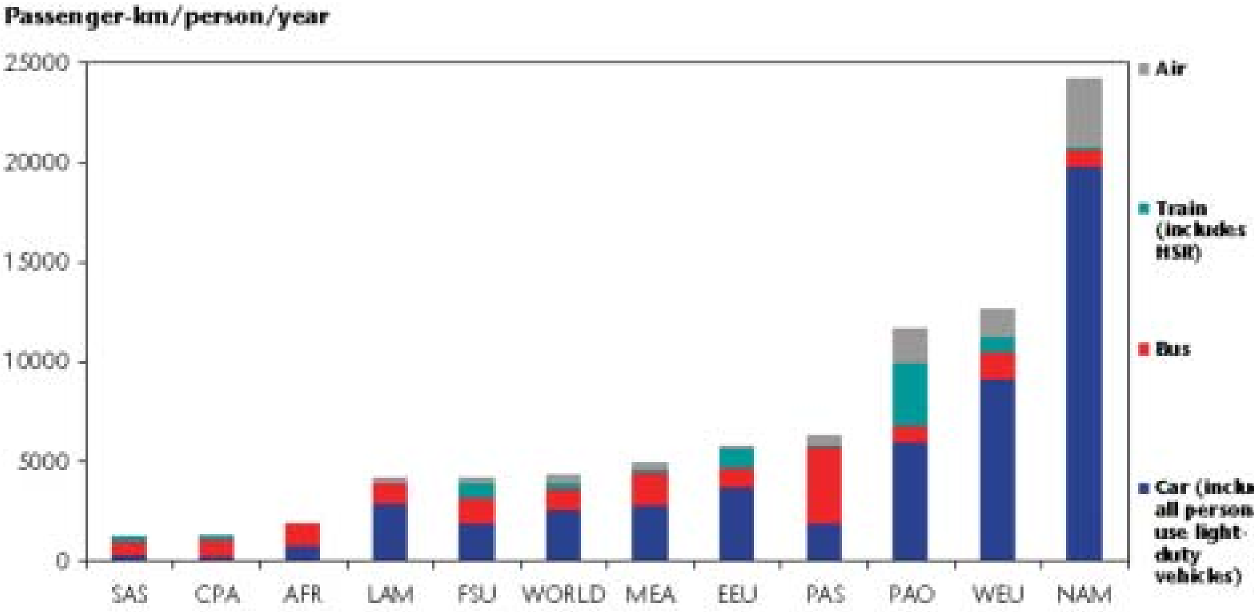
Measures to Be Increased

Access to means of mobility. Distance impedes accessibility, and mobility is the ability to overcome distance. As we have noted above, mobility is not the only way to gain access to goods and services — telecommunications is another — but mobility is surely an important way for people to achieve accessibility.

But mobility itself requires access, and this can be impeded by cost as well as by location. As already noted, privately owned motor vehicles are typically the most flexible means of providing mobility. But in many parts of the world, the cost of purchasing, garaging, maintaining, and operating such vehicles is well beyond the means of much of the population. People must walk, use bicycles or two-wheeled motorized vehicles, or rely on various forms of public transport. Bicycles are limited in their range and in the amount of weight they can carry. Two-wheeled motorized vehicles are less limited in both these regards, but are still expensive. Public transport is generally less expensive in terms of the daily financial outlay required to use it but is often difficult to reach and provides relatively poor and inflexible service.

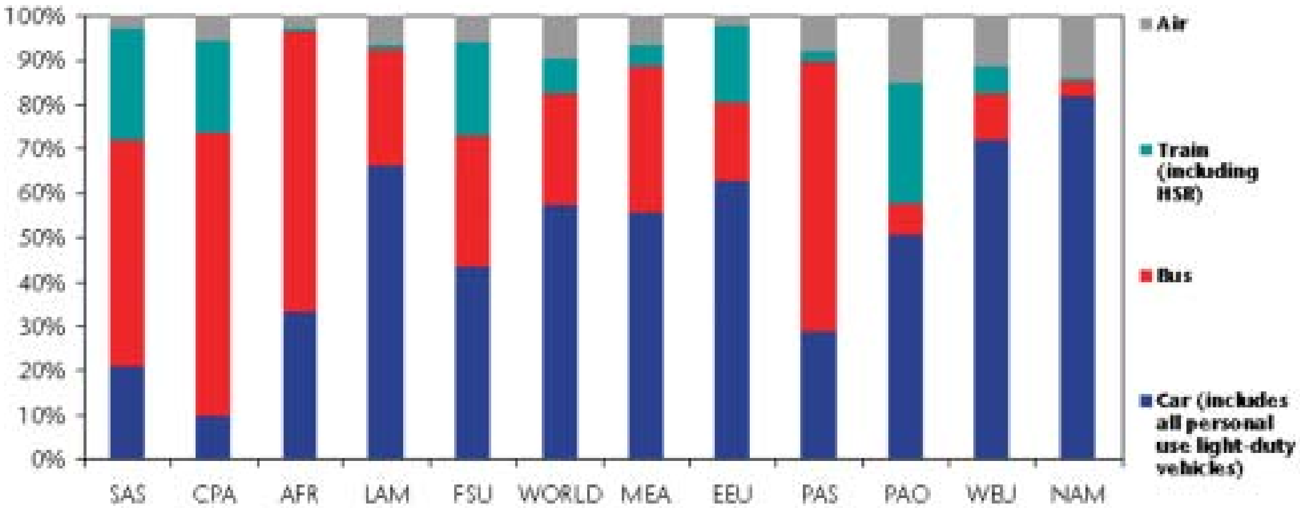
Increasing access to flexible, affordable means of mobility can be

Figure 1-2. Current (1997) levels of mobility in different regions of the world



Source: Updated database based on Schafer (1998).

Figure 1-3. Modal share of passenger-kilometers across the different world regions (1997)



Key:

CPA–China and other centrally planned Asia
SAS–Bangladesh, India, Pakistan
PAS–Pacific Asia
AFR–Kenya, Nigeria, South Africa, Zimbabwe, and other Sub-Saharan Africa
FSU–Former Soviet Union
PAO–Australia, Japan, and New Zealand
MEA–Middle East and North Africa
EEU–Eastern Europe
LAM–Latin America and Central America
WEU–European Community, Norway, Switzerland, and Turkey
NAM–Canada and United States

Source: Updated database based on Schafer (1998).

achieved through improvements in any or all of these various dimensions. Reducing the cost of various types of motorized vehicles is one such avenue of improvement. Improving the flexibility and reach of public transport systems is another. Developing new transportation devices that combine flexibility with low cost is a third.

Figure 1-2 shows annual per capita personal transportation by mode for the world's regions. These data include only travel by bus, rail, auto, and air. Nonmotorized transportation or two- and three-wheeled motorized transport, all of which play major roles in some parts of the world, are not included. These data indicate that per capita use varies by roughly a factor of 24 across these regions, with the United States showing by far the highest. Western Europe and Pacific OECD (principally Japan) show roughly the same per capita levels, at about half the rate of the United States.

Figure 1-3 shows that mode share also varies significantly across regions. Rail use (both intercity and urban) is especially high in Pacific OECD; bus and coach use is high in Europe. The automobile, however, accounts for at least 50% of the distance traveled in each region shown except for four of the first five, Pacific Asia, and the world as a whole. In North America, the automobile accounts for over 80% of total passenger-kilometers.

Equity in access. An increasing reliance on privately owned motor vehicles for transport means that those without access to such a vehicle may find themselves seriously disadvantaged in their ability to get to jobs and services. The limitations of conventional public transport in cities increasingly tailored to the private vehicle only serve to accentuate this risk. Particularly vulnerable are groups such as the elderly, the poor, people with disabilities, and youth.

Worth particular mention in this regard are the needs of the elderly. In the developed countries, the absolute numbers of older people are increasing rapidly, as is their percentage of the population. These people may be healthy and independent for several decades after they retire and may lead active lives requiring considerable mobility. Many will continue to use automobiles, though safety issues must be considered in licensing them. More generally, many older people as they age will increasingly experience physical, financial, and other barriers in using the transport system, in moving around their communities, and in accessing the services and facilities they need. So there are different categories of users among the elderly, but almost all would benefit from a well-developed public transport network as a primary or backup system.

Appropriate mobility infrastructure. Inadequate infrastructure seriously impedes sustainable economic and social development, particularly in the developing world. Extensive passenger rail networks exist only in Asia and Europe, and general roadway provision in the developing countries falls far behind that in the developed world (see Table 1-1).

Lack of capacity is often a serious issue on both urban and interurban links. The basic connectivity of the road network may be deficient, with important population or economic centers poorly linked to the rest of the country. In some cases, specific individual facilities such as bridges are lacking, and less convenient alternatives like ferries serve in their place. The quality of road infrastructure is frequently not good, because of deficiencies in the original design and construction,inadequate control of trucks with excessive axle loads, inclement climatic conditions (extreme heat, heavy rainfall, or severe freeze/thaw cycles), or neglected maintenance.

Inexpensive freight transportation. As urban populations grow, there is greater need to move raw and semifinished materials from where they are found and processed, and to ship finished goods to market. Cities cannot exist without these freight systems, and people in rural areas cannot find markets for their goods without them either. However, the volume of freight and freight-moving vehicles is becoming so great in many areas of the world that they are major competitors for scarce infrastructure capacity and also major sources of air pollution. The growth of e-commerce depends upon an ability to deliver electronically ordered goods quickly and efficiently. Just-in-time manufacturing has similar requirements. Many of the world's existing freight transportation systems were built in different eras to meet requirements that were very different from those of today.

Measures to Be Reduced

Congestion. Personal mobility can be improved on an individual basis and in a rather short period of time. For example, if income is no longer a constraint, people who walked or bicycled can choose to travel using faster modes, such as automobiles and motorized two wheelers. As a result of increased demand for personal mobility, infrastructure demand can increase rapidly. But infrastructure can only be provided collectively at a larger scale, and this takes time. The inertial nature of transportation facility development and urban structure adjustments makes it difficult to keep up with a population's rapid shifts to motor vehicles, and this results in serious system imbalance and enormous congestion.

Travel by private automobile tends to consume more space and infrastructure per unit of travel than does travel by public transport, though the validity of this broad generalization hinges critically on the passenger loadings of the public modes. Full buses make more efficient use of road infrastruc-

Table 1-1. Measures of transportation infrastructure per capita (km/million inhabitants)

	Intercity Rail	Urban Rail	Roads	Motorways
EU 15	415	18	9,330	125
Central and Eastern European countries	635	50+	7,880	24
United States	140*/890	7	23,900	325
Japan	210	6	9,200	51
World	210	4	4,750	35

Source: European Commission (2000).
*Only 38,000 km in passenger service

ture than cars do, and empty buses are less efficient.

Congestion on road networks manifests itself in travel delays and inefficient vehicle operations. Less obviously, perhaps, congestion is the cause of pervasive economic inefficiencies, as individuals, households, and firms adjust their activities to compensate for time lost in traveling and to hedge against the possibility that trips may take longer than expected. Some level of congestion is economically efficient; however, building infrastructure to get rid of all congestion is not a solution. The costs — economic as well as environmental — would far outweigh any possible additional benefits to travelers.

Congestion results from a mismatch between available road capacity and the traffic that attempts to use it at a given time. This mismatch mostly occurs because, as a society, we are not able (or willing) to schedule our activities more uniformly through the day and night. In other words, congestion is often better characterized as a peaking problem, rather than a problem of inadequate capacity.

The relatively simple economic concept of externalities is basic to the congestion issue. The individual traveler who enters the road network during peak travel periods does not pay the full cost that the decision to travel imposes on everyone else. Since price does not equal marginal cost, demand exceeds supply and congestion is the result. Economists have long argued that congestion could be “solved” if only individual motorists could be charged the “full cost” they impose on others by their decision to use roads at peak periods. Until recently, this debate about the theoretical properties of congestion charges was largely academic, since it was impossible to levy such charges without bringing traffic to a halt. However, with the development of technologies capable of levying congestion-based tolls on moving vehicles, the discussion has moved from the academic to the political arena. Apart from cost considerations related to the implementation of a congestion pricing scheme, it has become embroiled in the broader argument over just how great the external costs of driving actually are and whether the level of gas taxes and registration fees already being paid by motorists, especially in places like Europe and Japan, more than cover these costs.

“Conventional” emissions. Transportation vehicles are major sources of local, urban, and regional air pollution. The substances emitted by transport vehicles that contribute to this pollution include sulfur dioxide (SO_2), lead, carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter, and nitrogen oxides (NO_X). These substances are commonly referred to as “conventional” transport emissions to distinguish them from emissions of greenhouse gases, though there is some overlap (see feature box).

Private-vehicle travel tends to generate larger amounts of emissions per unit distance traveled than do public transport modes (Table 1-2), but this is probably too general a statement to be of much value in any specific local circumstances. Clearly, many other factors are involved, including average vehicle occupancy rates, the age and maintenance level of the respective vehicle fleets, and so on.

Technologies to reduce emissions from spark-ignition (i.e., gasoline-powered) engines were first introduced in the United States and Japan in the late 1960s. Europe followed with similar regulations a decade later. Standards for exhaust emissions, and for evaporative emissions of VOCs from vehicle fuel systems, have become progressively more stringent and are scheduled to continue that trend. Emissions from new vehicles in the most strictly controlled regions are 90% to 98% lower than they were prior to control. Other parts of the world are following this step-by-step regulatory approach, though with some lag.

The emissions from vehicles powered by compression-ignition (i.e., diesel) engines (including trucks, off-road construction vehicles, railroad locomotives, and waterborne vessels) were in the past less strictly regulated than emissions from gasoline engine

Table 1-2. Emission rates in London (grams/passenger-km) by mode, 1997

	Private Motor Vehicles				
	4-wheel	2-wheel	Taxis	Buses	Metro
Carbon monoxide	12.9	8.9	1.8	0.3	0.03
Hydrocarbons	1.9	1.1	0.6	0.1	0.0
Oxides of nitrogen	0.8	1.0	1.8	1.2	0.3
Oxides of sulfur	0.05	0.06	0.15	0.02	0.15
Lead	0.02	0.02	—	—	—
Particulate matter	0.04	0.04	0.55	0.02	0.01
Carbon dioxide	197	115	470	89	91

Source: London Transport Buses (1999).

vehicles, in part because exhaust treatment technologies — catalysts for NO_X, traps for particulates — were not sufficiently developed to enable their widespread use. Both technologies are progressing, and plans are in place to reduce NO_X and particulate emissions significantly from current levels (which are about a factor of three below uncontrolled levels).

Emissions from vehicles powered by continuous combustion engines (predominantly aircraft gas turbines) consist principally of NO_X. Aircraft emissions can be a significant local source of NO_X, exacerbating the problem of reducing ambient concentrations of ozone. NO_X emissions from gas turbines have been controlled to some extent by modifying the combustion changes in flat mix chambers of these engines. Further reductions are likely to occur in the future.

Ozone — A Complex Pollution "Cocktail"

Readers may be surprised that we omitted terrestrial (i.e., ground-level) ozone from the list of emissions that cause local, urban, and regional air pollution. This is because ozone is not an emission. It is a complex "cocktail" formed by sunlight acting on emissions of VOCs and NOx. Ozone is controlled by controlling the emissions of these two substances, but which of the two emissions should be controlled to the greater extent differs by region. In some regions, VOCs are the controlling factor. In others, it is NOx. "Overcontrolling" one of these pollutants when the other is the controlling factor can actually increase ozone formation.

The adoption of more effective abatement technologies (generally in response to stricter government-imposed emissions standards) will lead to significant reductions in per-vehicle emissions rates. This will not, however, automatically translate into equivalent reductions in total vehicle-related emissions. Total light-duty passenger vehicle fleet emissions in the United States, for example, are only about 30% to 40% lower for CO and 50% lower for HC than they were before the imposition of controls. Emissions of NO_X have been reduced by even less. This is due to the growth in the number of vehicles and their use, the changes in fleet mix, and high emissions from a small fraction of the fleet due to vehicle age, failure, malfunction, or tampering. (Studies in many parts of the world where strict emissions regulations are in place indicate that about half the total vehicle fleet emissions come from 5% to 10% of the vehicles — the high emitters.) In addition, the turnover time of the vehicle fleet is typically more than a decade, which delays the full impact of stricter new vehicle standards.

In most of the developed world, the rate of decrease in per-vehicle emissions has been large enough to offset the countervailing effects of increases in traffic and the growth in the number of vehicles. As a result, an overall decrease in vehicle-related emissions can reasonably be projected in the intermediate term. In the developing world, however, the reverse is true. The speed of motorization, the lag in adopting more recent vehicle pollution control devices (in part due to the need to upgrade fuel quality and fuel distribution systems), and the slow turnover of vehicle fleets mean that total vehicle-related emissions are growing.

Greenhouse gas emissions. The pollutants discussed above are generally considered a local, urban, or regional problem. Other emissions have a global impact. Carbon dioxide (CO_2) is produced by the combustion of fossil fuels. In the concentrations typically encountered in urban and rural environments it has no known health effects. CO_2 is called a "greenhouse gas" because it is one of the atmospheric chemicals that contribute to the greenhouse effect that warms the planet.

Certain other emissions from transportation — methane, nitrous oxide (N_2O), and vehicle air-conditioning refrigerants — are also greenhouse gases. These gases have a much higher potential effect on climate change per unit concentration than CO_2, although their atmospheric concentrations are much smaller. Vehicles appear to be a modest source of methane and N_2O. Leakage of vehicle air-conditioning fluids (CFCs in the recent past — now banned because of their contributions to the polar ozone "holes") and their replacements are also as significant as greenhouse gases. Use of CFCs is now banned by the Montreal Protocol, though CFCs are probably still being released. The HFCs that replaced CFCs in vehicle air-conditioners are shorter-lived in the atmosphere, though they still have some effect on the earth's thermal balance.

Atmospheric concentrations of carbon dioxide and methane have increased significantly since the start of the industrial age. More recently, the earth has experienced a general warming trend, particularly pronounced in the last decade. Though there has been some dispute about the extent to which increases in these greenhouse gases are responsible for the warming trend, IPCC Working Group 1 recently concluded (IPCC 2001, p. 10): "The warming over the last 50 years due to anthropogenic greenhouse gases can be identified despite uncertainties in forcing due to anthropogenic sulfate aerosol and natural factors (volcanoes and solar irradiance)."

There has been a growing international consensus that prudence requires us to reduce the amount of CO_2 added to the atmosphere through human activities, including transport. It has been estimated that transport activities account for roughly 26% of total worldwide CO_2 production by humans, and this share has been increasing (IEA 2000a).

Production of CO_2 goes hand in hand with the consumption of energy if the source of power is a fossil fuel. Where power is produced from other sources (for example, hydroelectric or nuclear), CO_2 production is minimal. Presently, the only forms of transport that are able to use such clean power on any scale are public transport vehicles in countries such as Switzerland, Norway, and France that produce large amounts of electric power using hydro or nuclear energy. These vehicles (subways, trams, and electric buses) draw their electric power from overhead lines or electrified third rails.

Data from London (Table 1-2) show that private vehicles (and taxis) tend to generate relatively large amounts of CO_2 per passenger-kilometer. The taxi figure is particularly high because taxis usually carry only one or two passengers and may cover considerable distances cruising for new passengers or repositioning themselves. The low figure for London buses reflects the relatively high passenger load factor on buses in the London system. For the United States, where the average passenger load per bus is only about nine, the CO_2 emissions per passenger-kilometer would be somewhat higher.

CO_2 Emissions by Sector

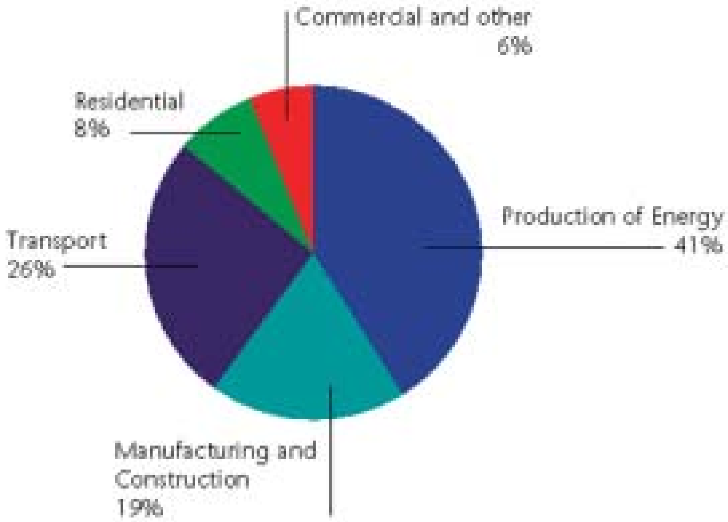
The International Energy Agency (IEA) produces estimates of CO_2 emissions by sector for the world as a whole and by country. Figure 1-4, developed from data included in the IEA's most recent report on CO_2 emissions from fuel consumption, shows emissions by sector. The 26% attributed to the transport sector breaks down into the following subsectors: road transport (both passengers and goods) — 16.9%; other domestic transport (transportation of passengers and goods by rail, air, and inland waterway) — 6.1%; international air transportation — 1.4%; and international water transportation — 1.7%. The sector identified as "energy production" includes the production of electricity and heat (steam) for general use — 32.0%; the production of energy (principally electricity and heat) by firms largely for their own use — 4.3%; and the production of energy by other energy industries — 5.4%. The direct combustion of fuels in manufacturing and construction account for 19.0% of CO_2 emissions; the direct combustion of fuels in residences (largely for space heating) account for 7.6%; and the direct combustion of fuels by commercial and other sectors account for 5.7%. (CO_2 emissions from the production of electricity and heat used in manufacturing, construction, residential, commercial, and other sectors is attributed to the energy-producing sector.)

Source: IEA (2000a).

Transportation noise. Cars and trucks are major sources of noise pollution in most cities. Most developed countries have had vehicle noise emission regulations since the 1970s. Technological progress in engines and exhaust systems has made these vehicles considerably quieter. For example, the EU allowable noise level of a modern truck is approximately equivalent to that of the typical car in 1970. Nonetheless, the noise created by motorized transportation remains a significant impact on urban residents' health and quality of life. Noise is often cited as the main nuisance in urban areas, and traffic noise is the worst offender (a German study suggests that 65% of the population is adversely affected by road traffic noise, with 25% seriously affected). As an indication, residential property values are measurably lower near noise-producing main roads, highways, and railroad tracks.

A typical urban residential neighborhood in the United States has decibel levels between 55 dB and 70 dB. Continued exposure to noise above 85 dB causes hearing loss. A recent study of Austrian schoolchildren found that the low but continuous noise of everyday local traffic can cause stress in children and raise blood pressure, heart rates, and levels of stress hormones. The research, conducted by US and European researchers, was the first major study of the nonauditory health effects of typical ambient community noise.

Figure 1-4. Share of worldwide CO_2 emissions from the combustion of fuel, by sector — 1998



Source: IEA (2000a).

Besides vehicle engines and exhaust pipes, much of the noise produced by vehicles today, especially in highway operations, results from the movement of vehicles through the air, and the contact of tires with the road. The former can be reduced by aerodynamic vehicle body designs (which also have the effect of improving fuel efficiency and reducing emissions). The latter can be reduced through tire tread designs and improvements in pavement surface textures (which also have the effect of draining water more effectively and so reducing the risks of accident). Noise barriers can also minimize the impact of vehicle noise on nearby activities.

Aircraft are another important source of noise. Major airports typically handle hundreds of thousands of aircraft arrivals and departures per year. Most of these aircraft are jet-propelled. In most of the developed world, increasingly stringent aircraft engine noise regulations, coupled in some cases with late-night curfews, have succeeded in reducing the total noise exposure at most large airports. This is much less true, however, for the developing world. In many cases, aircraft that can no longer meet developed-world noise standards are sold to developing-world operators and continue their noisy existence.

Impacts on land, water, and ecosystems. Roads, bridges, airports, harbors, and the vehicles that use them have profound effects on habitats and ecosystem communities of natural species. Transportation infrastructures in developed countries are vast in scale and extent. For example, the road network in the United States consists of tens of thousands of kilometers of lightly traveled roads (paved and unpaved) cutting through agricultural and wilderness areas, dense networks of residential streets and arteries in urban and suburban areas, and heavily traveled highways that can extend uninterrupted for hundreds of kilometers. This extensive system is a source of numerous environmental disturbances. Some of these occur during construction and some during use. Examples are runoff of surface materials, changes in local hydrology, the fragmentation of habitats, and the introduction and proliferation of invasive species.

Once built and in operation, highways and other transportation facilities (such as terminals) have enduring effects on the quality of nearby waters and local hydrology. They are a chronic source of sediments and contaminants as a result of the runoff of materials deposited on the road surface by traffic and road maintenance crews, and by erosion of side slopes and degraded construction materials. Runoff infiltrates watersheds through discharge directly into adjacent ponds and other surface waters, through drainage systems, and through infiltration to groundwater. The migration of road salt into public water supplies and private wells is a significant problem. The physical imprint of the transportation system also has profound effects: streams are rechanneled and wetlands filled, impeding water flows and shifting the location of stream and drainage networks.

These highway system effects are accompanied by those caused by other branches of the transportation system. Water-borne transportation causes several unique disturbances to water systems. Commercial waterways are dredged to widen and deepen channels, upsetting bottom sediments and contaminants. Waterborne transportation has proved to be a vexing conduit for exotic species. The waterborne transportation of hazardous materials can result in release of these shipments, causing water as well as land and air pollution.

The ecological and habitat disturbances caused by roads extend far beyond the land they occupy and the habitats they disturb. The disturbances created by traffic noise, vibrations, and light, for instance, extend for some distance, disrupting essential animal behaviors, such as feeding and reproduction. By subdividing the landscape into small pieces, roads also fragment habitats and interrupt essential wildlife movements. If the patches between roads become too small, the habitat may be incapable of providing resources needed to maintain viable and resilient wildlife populations.

Air pollution also has a major impact on ecosystem behavior. Transportation emissions have cumulative and long-lasting effects on the function and biological composition of ecosystems. Ozone can adversely affect mountain and forest ecosystems over large areas. Emissions of NO_X result in acid rain and nutrient enrichment, suspected causes of biological changes in terrestrial and aquatic ecosystems.

The longer-term ecological effects of these emissions outside urban areas are poorly understood. It is of increasing concern that all emissions from transportation vehicles, and the disruption of habitats and natural processes caused by the extensive transportation infrastructure system and its use, are leading to gradual declines in biological diversity and ecosystem functions on regional and national scales. Climate change is also likely to affect ecosystem diversity and stability.

Disruption of communities. Although more difficult to quantify, the increasing orientation of the urban transport system toward private vehicles can have additional effects on the quality of community life. Urban motorways were sometimes built through the middle of established communities (most frequently through communities with insufficient political power to oppose that alignment successfully), in effect dividing the community and constructing a physical barrier between the two halves.

More generally, there are relatively few opportunities for serendipitous interactions between residents in a community dominated by private-vehicle travel, because when people leave their homes they isolate themselves in cars. This can lead to a loss of sense of community and social cohesion.

"Barrier effects" are not limited to highways. Rail lines can also divide communities, especially when they are elevated to eliminate grade crossings. Communities have objected to actions (such as railway mergers and the construction of new lines) that threaten an increase in the number of freight-carrying trains traveling through them, even though such an increase may mean fewer freight-carrying trucks on the highways.

Transportation-related accidents. The cost in human lives, injuries, and suffering attributable to highway and road crashes is staggering, particularly compared to other, less common risks of harm that invoke much greater publicity with far fewer victims. Toward the end of the 1990s, around 42,000 people were killed each year in road accidents in Western Europe, down from around 56,000 at the beginning of the decade. In the United States, the number of people killed in road accidents per year varied between 40,000 and 45,000. On average in the two regions together, a person dies in a road accident about every six minutes. In some countries, road accidents are the primary cause of death in the 15- to 30-year-old age group. The number of people seriously injured in road accidents is typically more than ten times higher, and the number of people receiving light injuries over 65 times higher, than the number of fatalities. Fatality rates in the cities of the developing world are growing rapidly and are often already at alarmingly high rates, given the low absolute levels of motorization.

Road accident victims are not just motorized vehicle drivers and occupants, but also include pedestrians and bicyclists. In developed countries, these groups account for roughly 10% to 15% of the total number of road fatalities. The plight of pedestrians and bicyclists is worse in developing countries, where they account for a disproportionately large number of road accident fatalities.

Use of nonrenewable, carbon-based energy. Every vehicle requires energy. In order to supply that energy — the energy to transport people and freight worldwide by land, sea, and air — more than one liter of petroleum is consumed each day, on average, for each of the world's six billion inhabitants. In the industrialized countries, transportation consumes more than half the petroleum used for all purposes. In developing countries the share is less than half, but it has been rising and is expected to reach at least half within a decade.

Transportation not only requires a great deal of petroleum, it needs very little energy other than petroleum. Fuels derived from petroleum now account for more than 96% of all the energy used in transportation. There has been no sign of any decrease in that percentage (IEA 2000b). Other sources of transportation energy — coal, natural gas, alcohols, electric power — have been significant in particular places or times but all have been minor fractions of the total.

Therefore, the projected growth in demand for mobility leads to a projected growth in demand for oil for transportation. "Mainstream" projections put consumption levels in 25 to 30 years at twice the level of today (IEA 2000b; EIA/US DOE 2001). This provokes a sustainability debate: for how long will producers of petroleum, a huge but ultimately limited resource, be able to satisfy transportation's ever-increasing demand for oil? And at what price? Linked to availability of supply is the fact that 65% of the world's known reserves of conventional petroleum are located in the Middle East (BP 2000), and there is concern about the rest of the world being so dependent on what has been a politically volatile region.

The more pressing sustainability issue is not the availability of fuel but CO_2 emissions resulting from the production/manufacture and use of fuel, whether the fuel is derived from conventional petroleum, heavy oil, or natural gas. Switching from petroleum-like fuels to other fuels that emit less CO_2 during their manufacture and use could mitigate CO_2 emissions from the use of transportation fuels. That is the principal driving force behind the current interest in fuels such as ethanol or methanol that are derived from biomass, and in fuels such as hydrogen or electric power that can be derived from sources of primary energy that do not emit CO_2. The path to sustainability in transportation energy will have to explore options such as these. Presently, there are many economic, technical, and other barriers to the commercialization of these alternative fuels, but further work can reduce many of those barriers.

Transportation-related solid waste. Vehicles — especially automobiles and light trucks — are major users of materials such as steel, iron, aluminum, glass, and plastics. The extent to which these materials are reused varies significantly by region. In the United States, for example, more than 95% of ferrous material in all deregistered motor vehicles is reprocessed, with at least 75% of the vehicle mass extracted for reuse. This high percentage is driven by the strength of the steel minimill industry and the ready market for its products. In other countries, the percentage is lower. A substantial number of used vehicles is shipped abroad from Europe (to North Africa and Eastern Europe) and from Japan (to Southeast Asia).

MOBILITY 2001 — A ROAD MAP

No single study can hope to provide a truly comprehensive treatment of mobility in all its aspects worldwide, or the challenges to its sustainability. In conducting this study, we have made choices between breadth and depth of coverage that we hope will provide the reader with a sense of the critical issues without overwhelming detail. We have organized the report around a series of six pictures, each a natural part of the mobility story.

Chapter 2 — Patterns of Mobility Demand, Technology, and Energy Use

We discuss the surprising stability in the average amount of time and the average share of income that different populations have been willing to devote to personal transportation over the last 50 years. While the distance traveled per person each day has increased rather steadily, the time spent in accomplishing this travel has varied from about an hour per day to just under an hour and a half per day. With one notable exception — Japan — the share of disposable income spent by the average citizen of a developed country on personal travel has varied between 11% and 16%. The increase in average distance traveled has been made possible by a shift toward faster, more flexible personal transportation modes — especially the automobile and the airplane.

We review the evolution of the basic transportation technologies that have substantially improved the performance and productivity of personal and freight transportation. This review focuses heavily on propulsion systems. With the exception of trains powered by externally supplied electricity, all motorized personal and freight transportation vehicles are powered by some form of combustion engine — spark-ignition, compression-ignition, and continuous ignition (turbine). Improvements in materials have also contributed to these improvements in transportation. We describe these materials and efforts to increase their recyclability. Finally, we describe the characteristics of the petroleum-based fuels currently used to power essentially all vehicles and review the effectiveness, to date, of the relatively limited efforts being made to enable us to make the transition from our near-complete dependence on these fuels.

Transportation technologies — both propulsion systems and vehicles — continue to improve. Several trends, such as the increased market share of the more efficient diesel engine in passenger cars and light trucks and the limited production and marketing of hybrid electric vehicles, offer the promise of significant improvements in light-duty vehicle energy efficiency. These, as well as other efforts by the automotive and aircraft industries and their suppliers to explore and develop better performing and more efficient vehicle technologies, indicate that even more improvements are likely in the future.

Chapter 3 — Personal Mobility in the Urbanized Developed World

The developed world is generally characterized by high incomes, high levels of urbanization, high mobility, and by populations that are both aging and stable. (By “developed world” we mean the countries of the OECD excluding Mexico and Korea.) It also is characterized by very high rates of ownership and use of automobiles and other light-duty vehicles. Indeed, with very few exceptions (Tokyo being the most notable), large developed-world cities are overwhelmingly dependent on automobiles for motorized personal mobility.

This very high degree of automobility has made possible a reduction in the population density of most urban areas. The reduction in population density, in turn, has undercut the competitiveness of traditional public transport, reinforcing the use of the private automobile and disadvantaging those who, for one reason or another, do not have access to a car. The dependence on the automobile has meant that emissions from these vehicles, as well as from trucks that deliver freight to the same urban areas, account for much of the air pollution that plagues many cities throughout the developed world. Emissions of carbon dioxide from developed-world motor vehicles presently account for the majority of transportation-related greenhouse gas emissions, though this is changing as motorization in the developing world grows rapidly. This vast number of vehicles congests the roads and is responsible for large numbers of injuries and deaths, not only of the occupants, but also of pedestrians and others.

We describe efforts that are under way to deal with these challenges to sustainability. Improvements in engine technologies and fuels have helped to reduce per-vehicle emissions of many pollutants, though increases in the number and use of vehicles have served to offset these reductions to a considerable degree. Vehicle-related accident rates have fallen in many countries, and the "survivability" of occupants has improved due to structural improvements and the use of seat belts and the like. These are positive developments. On the negative side, congestion seems to be getting worse in the urbanized areas of most developed countries. Efforts to construct new transportation infrastructure have been overwhelmed by demand generated in response to construction of more road capacity, and by community resistance to the location of many urban infrastructure projects. The congestion-reduction promise of "intelligent highways" remains to be fulfilled. Motor vehicle–related greenhouse gas emissions continue to rise, as technological improvements are overwhelmed by growth in vehicle use, though the rate of increase has been slowed in some countries. Also, efforts to roll back the tide of private automobiles in a major way by luring drivers to conventional public transport have largely failed. Public transport ridership has been increasing in many cities, but public transport's share of total urban personal transportation has not. In sum, many challenges exist to making personal mobility sustainable in the urbanized areas of the developed world.

Chapter 4 — Personal Mobility in the Developing World

The developing portion of the world is characterized by low but generally rising incomes and by rapidly growing and relatively young populations. The most important developing-world phenomenon is the extremely rapid rate of urbanization in many countries. "Megacities" — large urban agglomerations sometimes containing tens of millions of people — are springing up throughout the developing world, especially in Asia and Latin America. These tens of millions of people have to get to work, get to school, and shop. The goods they produce and consume have to be transported from their factories and to their stores. The waste they generate must be collected and disposed. All this requires transportation.

The number of vehicles — from bicycles to motorized two-wheelers to cars to trucks and buses — is growing even more rapidly than the populations of many of these urban areas. A large share of the trips in such locations, however, is still made on foot, and the intermingling of pedestrian traffic with self-propelled and motorized vehicular traffic generates massive congestion and very high accident rates. Traffic-related deaths and injuries in developing-world cities are very numerous, especially among the poor. The motorized vehicles spew out pollutants that can make air in these cities virtually unbreathable. Many of these vehicles have no emissions controls, and those that do are often poorly maintained. In contrast to the urbanized areas of the developed world, vehicle-related air pollution in the developing world is clearly getting worse. The same is true of transport-related emissions of greenhouse gases. If present trends continue, transportation-related developing-world greenhouse gas emissions will pass those of the developed world within the next 25 years.

Given this situation, it should not be surprising that we conclude that personal mobility in the developing world is poor in many regions and is deteriorating in many areas where it had been improving in the past.

Chapter 5 — Trends in Intercity Travel

There is much more intercity and intercontinental passenger travel in the developed world than in the developing world. But even in the developed world, intercity and intercontinental passenger travel accounts for a very small share of total trips (though a somewhat larger share of passenger-kilometers traveled). In the developed world, the principal modes of intercity travel are the private automobile, rail (increasingly, high-speed rail), and commercial aircraft. In the developing world, the travel that does occur is by bus, by conventional rail, and to a small but rapidly growing extent, by air. We concentrate most of our attention on rail and air.

Rail passenger traffic is important in several countries, especially Japan, China, India, the countries of the EU, and Russia. Many passenger rail systems, such as India, China, and Russia, are poorly maintained and have antiquated rolling stock. As these countries continue to develop, intercity passenger rail is likely to face increasing challenges from other modes. Other passenger rail systems — Japan, much of the EU, and, to a small extent, North America — are being upgraded to enable them to compete not so much with road vehicles but with airlines. These high-speed rail systems are meeting with some success, especially when distances are relatively short and the quality of air service relatively low.

Indeed, considering the problems we find facing air transportation, it may be that rail's competitiveness will grow substantially in the years ahead. Air transportation has been growing extremely rapidly and is generally forecast to continue to do so for the next several decades. But it faces major sustainability challenges. One of the most important but least appreciated is the significance of its greenhouse gas emissions. At present, air transportation is responsible for between 8–12% of transport-related carbon emissions. It is becoming understood, however, that these emissions are responsible for a much greater share in terms of global warming potential, because of where they occur — not at the earth's surface, but high in the atmosphere. This is believed to lead to an approximate doubling of their impact. Moreover, given the rate that air travel is projected to increase, aircraft-related greenhouse gas emissions will take on an even greater importance in the years ahead.

Another important sustainability issue facing air transportation is the rapid growth of airport and airway congestion. In spite of significant advances in the reduction of aircraft noise, airports are still noisy facilities. They also are major sources of conventional pollution, both from the aircraft that use them and from the vehicles that service these aircraft and that transport passengers to and from them. Expanding existing airports or finding sites for new airports is very difficult.

Chapter 6 — Freight Mobility

Freight mobility is absolutely essential to the modern world. The ability to transport large volumes of goods long distances at very low costs enables cities to exist, farmers to find markets for their crops, firms to reap the advantages of specialized production, and consumers to have access to a vast variety of goods at affordable prices. The importance of freight mobility is not confined to the long-distance movement of goods. The efficient movement of freight within an urban area, or over regional distances (100–500 kilometers) is a key to competitiveness.

There are several important sustainability concerns with respect to freight. One of these is the amount of energy used. Although much freight transportation is relatively energy-efficient, the sheer volume of freight moved means that the total energy requirement of the world's freight transportation systems is quite large. Freight transportation uses an estimated 43% of all transportation energy at present. Vehicles transporting freight also contribute in an important way to emissions of conventional pollutants as well as greenhouse gases. Freight vehicles also contribute to traffic congestion, noise, and accidents. Freight handling facilities are major users of land, especially in and near cities. As in the case of personal motor vehicles in the developed world, improvements are being made in the emissions characteristics of freight-hauling vehicles, especially trucks. However, the continuing shift in freight traffic from less-polluting rail to more-polluting trucks is serving to offset these improvements. This trend toward increasing volumes of truck freight traffic is also offsetting improvements in truck energy efficiency. The growing use of air freight to move small packages is a trend that is increasing the energy used (and the greenhouse gas emissions) of the air transportation system.

Chapter 7 — Worldwide Mobility and the Challenges to Its Sustainability

In this final chapter we bring together the pictures presented in the previous six chapters to summarize what we have learned about the state of worldwide mobility and the major challenges to its sustainability as we enter the twenty-first century. We present a summary picture of the state of mobility in the developed and developing world. We then identify the major cross-cutting challenges to the sustainability of mobility and indicate where things stand both as to the level and the rate of change of these challenges. Finally, we translate these findings into their implications for various transportation modes.

With regard to the automobile and other personal-use light vehicles, we find that the major developed-world challenge is to preserve (and, if possible, enhance) the desirable mobility characteristics of automobile-based mobility systems while reducing (or, preferably, eliminating) the nonsustainable characteristics of these mobility systems. The nonsustainable aspects include: the adverse consequences on certain groups in society (especially the poor and the elderly) that the growth of automobility has had on their ability to obtain access to aspects of life now considered commonplace in most developed countries; the light-duty vehicle's contribution to various environmental and ecological problems; the automobile's significant contribution to death and injury due to occupants and accidents; and the automobile's contribution to congestion.

The major challenge in the developing world is to avoid being choked — literally and figuratively — by the rapid growth in the number of privately owned motorized personal-transportation vehicles. This growth is causing the same environmental, safety, and congestion problems as exist in the developed world, but in much of the developing world, they are worse, and becoming more so.

With regard to air travel, the major challenge is to avoid the disadvantages of success. Some way needs to be found to increase the ability of the world's airports and airway systems to handle the projected growth in air traffic in a manner that the public will find acceptable. And looming on the horizon is the formidable challenge of dealing with the energy requirements and greenhouse gas emissions of this transport mode.

With regard to passenger rail systems, the challenge is to find ways of attracting the number of passengers needed to realize their favorable emissions and energy-use characteristics. Siting problems will also loom large if many countries do indeed undertake major programs to upgrade their passenger rail systems. The sustainability challenges facing motorized freight have much in common with those facing the automobile — emissions, congestion, and safety.

There is one additional major sustainability task facing all modes in all parts of the world — the job of developing sufficient institutional capacity to enable the other challenges to be met. Technology offers hope in solving (or at least mitigating) many of the challenges to achieving sustainable mobility. But technology cannot do this on its own. Transportation systems are very complex, very long-lived, and affect large numbers of people in many different ways. Building consensus about what needs to be done to make mobility sustainable, and then implementing what this consensus implies, will be a tremendous challenge, especially in democratic countries where everyone with a stake in something can demand to be heard. This may be the greatest challenge of all to achieving sustainable mobility — and one in which business will have an important role to play.

two

patterns of mobility, demand, technology, and energy use

This chapter reviews several trends that influence the demand for and supply of mobility around the world. The first is the growth of population, especially the urban population, in both the developed and developing world. In the developed world especially, this growth in urbanization is being accompanied by a decline in average population density — a phenomenon we refer to as "suburbanization." The second is the surprising stability over at least the past 50 years in the average amount of time that individuals spend traveling each day and the average share of their disposable income that they spend on transportation. Increases in average distances traveled have resulted from the use of faster and more flexible modes, not increased travel time. The third is the developments in vehicle and propulsion technologies that have improved the productivity and performance of transportation systems. The fourth is the transportation sector's almost total reliance on a single, nonrenewable fuel — petroleum. This final trend also means that the transportation sector is inevitably a focus of attention in the debate over global climate change, since the combustion of petroleum produces carbon dioxide.

Mobility in the twenty-first century has many faces: the Boston businessman commuting to his "streetcar suburb" in a light-rail vehicle (i.e., trolley); the Dublin mother driving her children through new suburbs west of the city; the Kenyan village woman walking several kilometers to fetch water each day; the Bangkok manufacturer ferrying her goods to market in a three-wheeled, motorized cart; and the Yokohama longshoreman discharging Saudi Arabian oil from Norwegian tankers. Despite the vast differences of means and motive for travel around the world, past patterns of mobility share certain characteristics that are likely to persist into the foreseeable future: people travel daily, to obtain food, to find work, to play and relax. As people's incomes rise, they travel farther and faster, and they purchase more and more goods — an appetite that the increasingly cheap and efficient system of global freight works to satisfy. More and more people live in cities, or in the suburbs that spread inexorably around them, and the majority prefer automobiles above all other means of transport — a choice that has wide and profound consequences for their neighbors and their environments. Perhaps the most important result of more motorized travel is the world's increasing dependence on one source of energy, petroleum-based fuels. These trends pose challenges to both the operational sustainability of mobility, as well as to its economic, social, and environmental sustainability, and must be accounted for in planning for a healthy and prosperous future.

Notes are gathered at the end of each chapter.

The most obvious commonality is that all people travel. Even people at the very bottom of the world's economic ladder must travel for survival — for food or water or work — perhaps using the most basic means of travel, walking or bicycling or animal transport. Therefore, when world populations grow, total travel grows. And population is growing, more than doubling in the last 50 years and increasing by about 75 million people per year. More than 95% of this growth is in developing countries, whose networks of roads, trains, and airports are barely able to accommodate the present demand for mobility. The lack of finances to invest in additional infrastructure further inhibits future potential for growth.

Many of the urban areas in which these growing populations are increasingly concentrated are now megacities, which pose special problems of congestion, pollution, and land use while still needing to provide opportunities for growing passenger and freight mobility.[1]

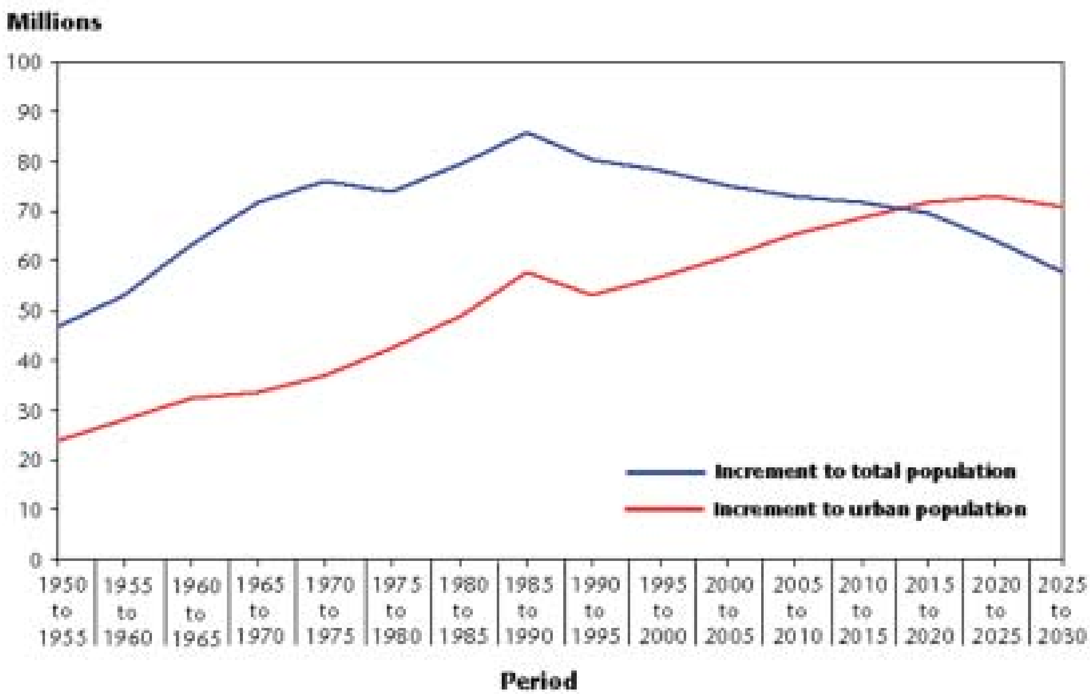
Compounding the mobility demands of an increasingly large and more urban population is the travel demand created by rising income. Data from all regions of the world over the last 50 years demonstrate that travel (the average number of kilometers traveled per person, per day) increases as income increases — and income, however unevenly distributed, is increasing around the world. As income rises, people increasingly take trips for reasons other than survival. For example, in the industrialized world, only about 20% to 25% of all travel is now work-related.

Another noteworthy historical observation is that people travel farther as their incomes rise, but they do not travel for longer periods of time. On average, they spend roughly an hour a day traveling, regardless of distance. That means, of course, that people shift to faster means of transportation, from walking to bus, train or two- and three-wheeled vehicles, then to cars, and ultimately to high-speed trains and airplanes. This move to faster vehicles is not only more expensive but consumes more energy per passenger-kilometer traveled.

Almost all of the motorized vehicles (except for electrified trains) share one crucial characteristic: they are driven by a combustion engine. No other transportation power plant can match the compactness, cost, flexibility, and reliability of the two widely used versions of this engine — the gasoline spark-ignition and the diesel compression-ignition engine. During the past century, technical advances in these combustion engines, and the vehicles they power, have yielded steady improvement in the performance, convenience, and safety of all motorized vehicles. Current trends suggest these engines will continue to improve, forming a powerful competitive barrier for new technological entrants to the marketplace.

A similar situation holds for large aircraft: they are propelled by gas-turbine-based jet engines. This propulsion technology provides superior performance at lowest cost, and it too has developed substantially over

Figure 2-1. Annual increments of the world population and of the urban population, 1950–2030



Source: UN (2001).

Medians Don't Tell the Whole Story

It helps to understand the past and likely near future of mobility by looking at broad aggregate trends such as median travel growth, times, distances, or expenditures in an entire region. But those aggregations disregard the facts that travel behavior of individuals is widely dispersed around the medians, many higher and many lower. Some data from passenger travel in the United States during 1995 vividly illustrate how wide this dispersion is for time spent traveling, money spent on travel, number of trips per day, and average distance of a trip.

Here are a few numbers from the data: Median travel time is about 45 minutes a day, but 20% of people travel more than 100 minutes a day; median household expenditures on travel are about 12% of disposable income, but 20% of households spend more than 25%; the median person makes about 2 ½ trips a day, but 20% of people make more than five trips a day; and the average trip length is about four kilometers, but 20% of trips are at least 15 kilometers. At the other end of the spectrum are the people that travel much less than the medians — the old, the infirm, and the poorest.

the past several decades and continues to improve.

The fuels these engines use form another crucial characteristic of transport technology: 96% of all the energy used for transportation, for both passengers and freight worldwide, comes from a single raw material — petroleum. Fuels derived from petroleum have attractive technical characteristics and historically have been available in adequate supply at a reasonable price, despite steady increases in demand. Even though world demand for transportation energy is projected to double in the next 25 years, an adequate supply of conventional petroleum or other fossil fuels, at a competitive price, is likely to be available for decades. However, market disturbances are possible, since most known reserves of conventional petroleum are located in the Middle East, currently a politically unstable region.

A key issue of sustainable transportation is that fuels derived from fossil resources, petroleum or alternatives, result in large CO_2 emissions during fuel manufacture and consumption. As policies emerge to constrain CO_2 and other greenhouse gas emissions from the transportation sector, more fuel-efficient vehicles can make an important contribution to sustainable mobility. However, ultimately it may be necessary to harness cleaner, alternative sources of energy, such as biofuels or the carbon-free production of hydrogen and electricity.

TRENDS IN POPULATION AND URBANIZATION

The most significant factors driving demand for mobility in the twentieth century are the rapid growth in the number of people in the world, their steady migration into cities, and the decline in the population density (inhabitants per square kilometer) of these cities. At the beginning of industrialization in the mid-nineteenth century, world population was around 1.2 billion. Between 1900 and 1950, it grew from 1.7 to 2.5 billion. Between 1950 and the end of the century, it more than doubled, reaching 6.1 billion in 1998. In the early twenty-first century, world population is expected to continue to grow, but at a declining rate. Most projections foresee a combination of low fertility and low mortality leading to a peak of about 10 billion people in the middle of this century. Although this level is still below the higher range of recent estimates of the earth's carrying capacity of 12 billion people (Cohen 1995), such growth in population imposes increasing pressure on the earth's resources.

Urbanization and its Concentration in the Developing World

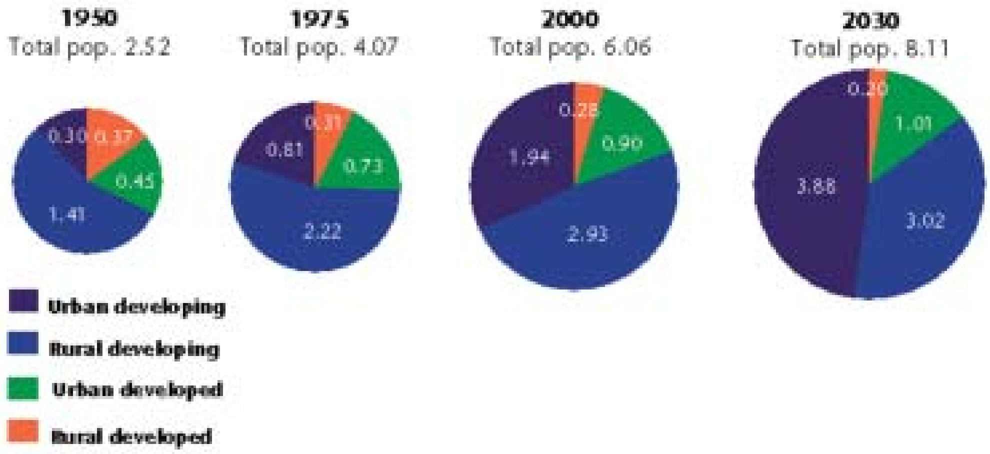
Two trends that have dominated population patterns in the last half-century — urbanization and the concentration of population growth in the developing world — are expected to extend into the coming decades.

Though the extent of urbanization varies widely across the globe — only 37% of Asians live in cities, as opposed to 77% of North Americans — the trend across the globe has been, and continues to be, toward increased urbanization.[2] Figure 2-1 shows that last century's trend of population growth in urban regions is expected to continue through 2030. Indeed, it is expected that after 2015, growth in the world's urban population will exceed total growth, implying a net decline in the world's rural population.

The industrialized world is already largely urbanized: About 75% of its population is currently concentrated in urban areas, and this share is projected to increase to nearly 85% by 2030. By contrast, only 40% of the population in the countries of the developing regions lives in urban areas, though there are regions that are highly urbanized — e.g., Latin America, where 75% of the population is urbanized (UN 2001). By 2030, urban areas in the developing world are expected to house about 56% of the entire population of those regions. Globally, 60% of the world population is projected to reside in urban areas in 2030, up from approximately 47% in 2000.

The other trend dominating population trends is the gradual stabilization of population growth in the developed world, and a consequent concentration of growth in the developing world. As Figure 2- 2 shows, in the period between 1950 and 2000, the population of the developed world grew by 46%, from 810 million to 1.19 billion. In contrast, the population of the developing world increased by nearly 200%, from 1.7

Figure 2-2. World population growth, 1950–2030 (billions of people)



Source: UN (2001).

billion to 4.9 billion. These trends are expected to continue, and most of the population growth in the coming decades will be in the developing world. As noted above, it is estimated that the population of the world will increase by about 2 billion people to 8.1 billion by 2030. The developing world — particularly the urban regions — is expected to be responsible for virtually all of this growth. Already today, developing countries host 80% of the world population, and this share is projected to rise to 85% by 2030.

The consequence of these two trends — the process of urbanization, and its increasing concentration in the developing world —is most strikingly illustrated by the increase in the number of megacities. As Table 2-1 shows, in 1950 New York City was the world's only megacity, with a population of 12.3 million. By 2000, 19 cities worldwide had grown to that size — only four of them were in the industrialized world. According to projections by the United Nations Population division, the number of megacities will increase to 23 by 2015, and 18 of them will be in developing countries. The sheer number and size of these cities impose significant challenges, ranging from efficient energy and transportation systems to health and social concerns, including sanitation, safety, and housing.

Suburbanization

The population "explosion" in the world's cities has been accompanied by a contemporaneous process of suburbanization: an expansion of the urban region and a trend toward a lower density of activity than evident before the middle of the twentieth century. Though suburbanization has progressed at different rates across the world, and has taken on different characteristics in different places, there has been a near-universal trend toward redistributing the urban population across a greater geographic area.

Transportation has played an important role in facilitating this trend. Starting in the mid-nineteenth century, urban residents have taken advantage of the introduction of ever-faster and more flexible means of transportation to move farther away from the city center. The electric trolleys of the late-nineteenth century made the first waves of European and North American suburbs accessible to daily commuters. Compared to walking and horse carriages, the trolley offered a fourfold increase in speed. This allowed people to double the distance between their suburban residence and their city-center office, and still make the same number of trips in the same amount of time. The widespread use of automobiles after 1950 increased the range that can be covered per unit time by almost one order of magnitude, and allowed suburbs to expand dramatically.

Although proliferating in size and number across the globe, suburbs are especially popular in the United States. American suburbs grew for several reasons, including the expansion of interstate and ring-road highways to facilitate automobile travel; the flat-rate fare scheme of many metro and train systems (allowing people living farther out to pay the same fare that other commuters paid for a shorter trip); abundant and cheap land; low interest rate financing schemes for home buyers (in the past often offered by the trolley companies); and the quickly erected (often self-assembled) balloon-frame house (Jackson 1985). As a result, urban areas grew much faster than their populations. Between 1970 and 1990 alone, population in the New York City metropolitan area grew by only 8%, while the urban area itself increased by as much as 65% (Doyle 2001).

Urban expansion in the developing world is also accelerating, often in ways similar to the expansion taking place in the industrialized world. And, as in the developed world, the real estate market has a large role in facilitating urban outgrowth in developing countries. For example, in Prague, large real estate companies have in

Table 2-1. Population of cities with 10 million inhabitants or more — 1950, 1975, 2000, and 2015 (in millions)

1950		1975		2000		2015	
City	Pop.	City	Pop.	City	Pop.	City	Pop.
1. New York	12.3	1. Tokyo	19.8	1. Tokyo	26.4	1. Tokyo	26.4
		2. New York	15.9	2. Mexico City	18.1	2. Mumbai (Bombay)	26.1
		3. Shanghai	11.4	3. Mumbai (Bombay)	18.1	3. Lagos	23.2
		4. Mexico City	11.2	4. São Paulo	17.8	4. Dhaka	21.1
		5. São Paulo	10.0	5. New York	16.6	5. São Paulo	20.4
				6. Lagos	13.4	6. Karachi	19.2
				7. Los Angeles	13.1	7. Mexico City	19.2
				8. Kolkata (Calcutta)	12.9	8. New York	17.4
				9. Shanghai	12.9	9. Jakarta	17.3
				10. Buenos Aires	12.6	10. Kolkata (Calcutta)	17.3
				11. Dhaka	12.3	11. Delhi	16.8
				12. Karachi	11.8	12. Metro Manila	14.8
				13. Delhi	11.7	13. Shanghai	14.6
				14. Jakarta	11.0	14. Los Angeles	14.1
				15. Osaka	11.0	15. Buenos Aires	14.1
				16. Metro Manila	10.9	16. Cairo	13.8
				17. Bejiing	10.8	17. Istanbul	12.5
				18. Rio de Janiero	10.6	18. Bejiing	12.3
				19. Cairo	10.6	19. Rio de Janiero	11.9
						20. Osaka	11.0
						21. Tianjin	10.7
						22. Hyderabad	10.5
						23. Bangkok	10.1

Source: UN (2001).

recent years been purchasing large tracts of peripheral lands for residential and commercial megaprojects.

Another feature distinguishing suburbanization in the developing world has been the preponderance of the urban poor on the periphery. In cities ranging from New Delhi to the Colombian cities of Bogotá and Cali, the urban poor forced out of the city center either by high rents, or occasionally by diktat, inhabit large tracts of the periphery. Facilitating the mobility of this segment of the population is a particularly significant and important challenge to the sustainability of the developing world city.

PATTERNS OF TRAVEL BEHAVIOR AND DEMAND

The Effect of Income on Travel Behavior

Rising incomes are driving travel demand across the globe. As people earn more, they can afford faster, mechanized travel, and travel farther in a shorter period of time. The first humans roved through forests, grasslands, and waters, searching for food. After settling down, they cultivated land and herded animals, using farm animals if they were wealthy enough to buy them. Still, their movements were determined by mainly one purpose: survival. Not much changed until the beginning of industrialization, when real incomes began rising in many parts of the world, more people could afford to make trips beyond those necessary for survival, and motorized transport made those trips feasible. Even today, low-income residents in the cities of the developing world typically take only one or two trips per day. One trip is dedicated to a combination of work (short-term survival) and education (longer-term well-being), and sometimes another is taken for personal business (usually shopping at local markets). With rising income, people continue to dedicate one trip to the combination of work and education, but then take additional trips associated with personal business (e.g., shopping for a variety of goods, health care, and religious services) and leisure (including holidays).

People also tend to increase the distances they travel roughly in proportion to increases in their incomes, particularly as they start to access faster modes. That pattern has been remarkably constant in all areas of the world over the last 50 years, ranging from regions with an average annual gross domestic product (GDP) as low as $500 per capita up to regions with a GDP as high as $20,000 per capita (Figure 2-3). Other factors can come into play. For example, the higher population density (shorter distances to travel between places) and greater transport prices in Europe (compared to North America) decrease demand, so Europeans travel about a third less distance than North Americans at the same GDP per person. Still, income remains the dominant factor in setting overall travel demand for the very large populations of people described in this report.

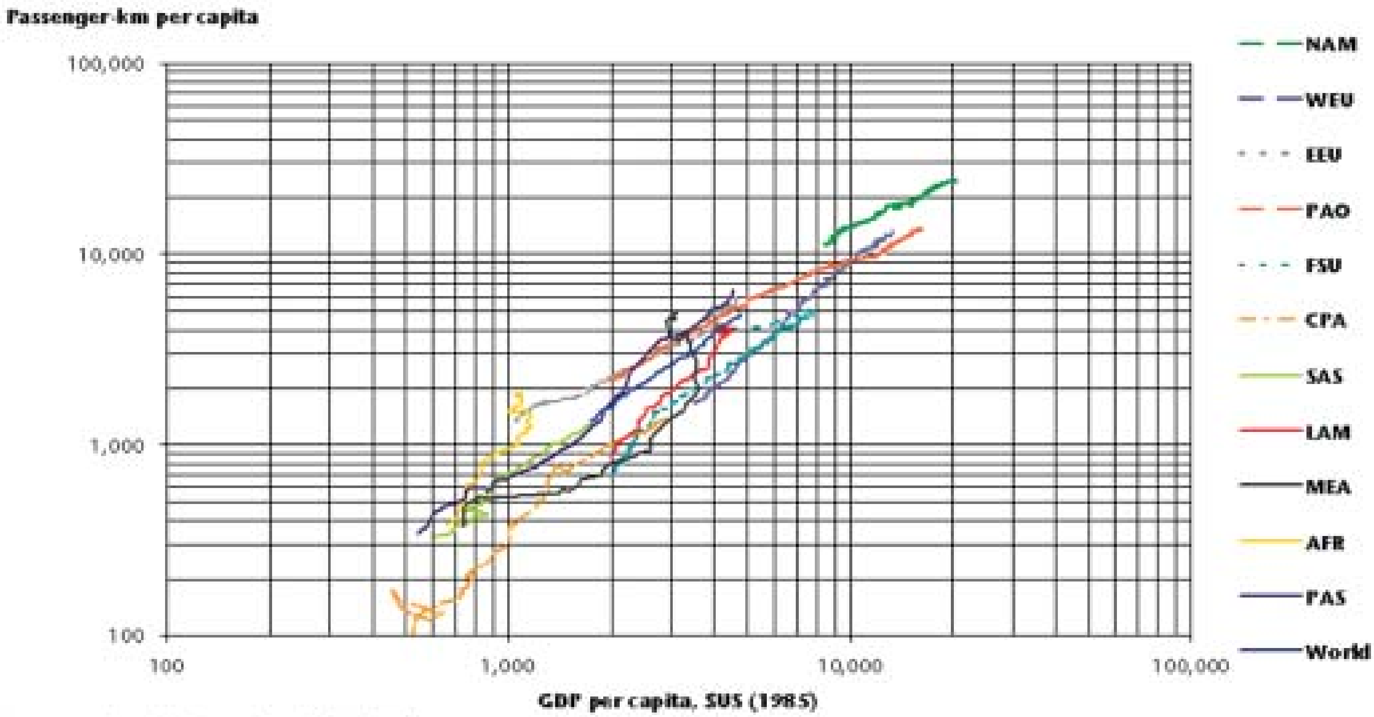
In the richer industrialized world in the last 50 years, higher expenditures on travel increased the total daily trip rate to more than three trips per person, and the average trip distance rose by a factor of 2-3. Meanwhile, work-related travel declined to only 20% to 25% of all travel, and some travel became an end in itself, often just for the sake of experiencing the freedom provided by driving an automobile. Traveling to survive no longer dominates the demand for mobility.

Although the total distances traveled increased over the last 25 years, it is somewhat surprising to note that the time spent traveling remained roughly constant in many different countries over many different time periods. For example, Americans and Dutch who traveled 40 to 60 kilometers per person per day spent about the same time traveling, a little over an hour a day, as Tanzanians and Ghanians, who traveled only about 5 kilometers per day (Figure 2-4). As expected, within the overall average for any particular region, there can be large differences among groups; for example, in the UK people over 70 years of age spent only about half as much time traveling as people in their 30s and 40s.

Another pattern is that people in industrialized regions spend roughly 11% to 16% of their disposable income on travel, regardless of the average daily distance traveled — whether they are Americans who travel over 60 kilometers a day or Britons who travel about 30 kilometers a day (Figure 2-4). Densely populated, with fewer cars and more developed commuter trains, Japan is an exception at 7% to 8%. People in nondeveloped regions spent a smaller share of their income on travel, but that is likely to rise as industrialization progresses.

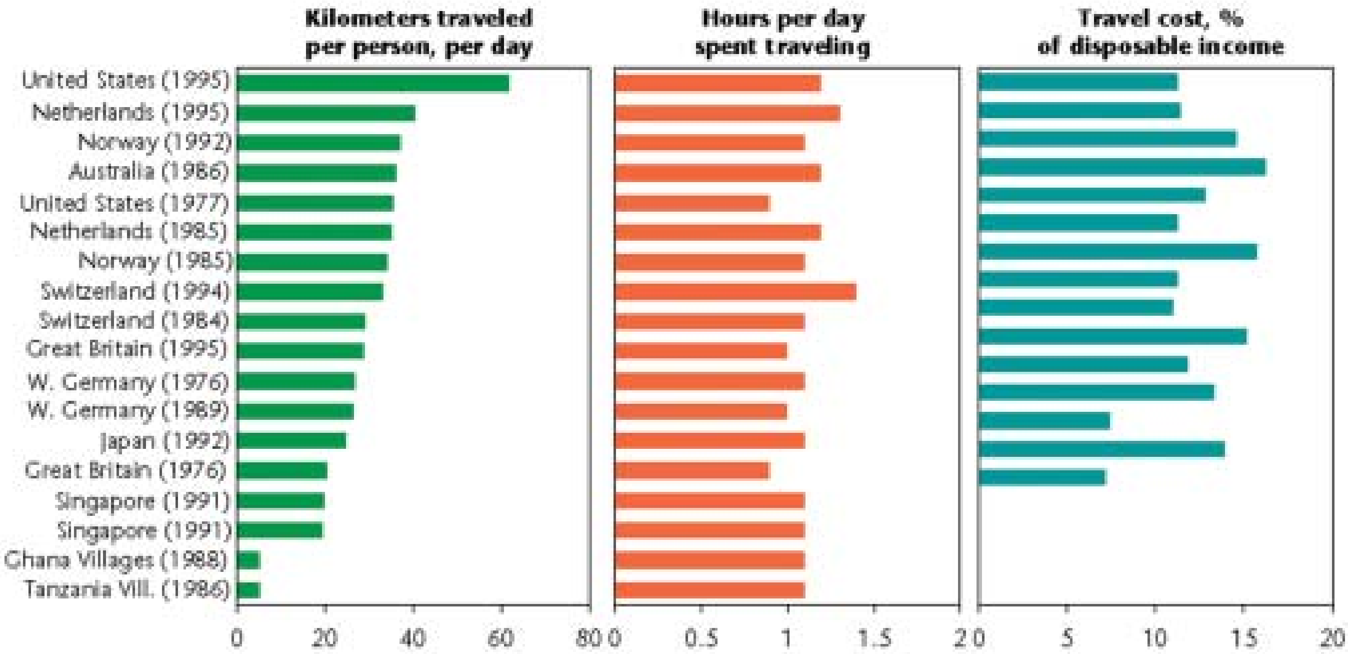
Considering the wide range of places and circumstances around the world, it is remarkable that people's travel time is so consistent. There is no wholly satisfactory explanation of the results. One could argue that only about an hour or so for travel is left after typical time expenditures of

Figure 2-3. More money, more travel, everywhere



Source: Updated data based on Schafer (1998).

Figure 2-4. Distances change, time does not



Source: Database updated based on Schafer (2000).

eight hours for sleeping, nine hours for work and free time, four hours for domestic obligations and child care, and two hours for eating and personal care. But all those "typical" time allocations can be higher or lower, leaving less or more time for travel.

The fixed amount of time that people budget for travel means that any increase in daily travel distance must be satisfied by a faster means of transportation. Rising income and transportation expenditures enable the use of ever-faster means of travel, and these in turn expand the distance that can be covered within a fixed travel time. As income and daily travel distances rise, the percentage of trips made by automobile also tends to rise. While it is now below 10% in the developing world, it has risen to roughly 50% in Western Europe, and to nearly 90% in the United States.

Travel Growth: From Walking to Cars to Planes

The broad patterns of travel behavior — increasing trip frequency, trip distance, and travel expenditure as incomes rise — become evident in the statistics of passenger transportation around the world. Between 1950 and 1997, the total number of kilometers traveled each year by each person then on earth went up more than threefold. The total transportation system, accommodating both that per capita increase and population increase, provided over eightfold more passenger-kilometers in 1997 than in 1950.

The average world growth rate of kilometers traveled annually has been rising at an impressive rate of 4.6% per year. The growth rate in some poor regions is even larger. China is the premier example, growing at 9.4% per year, although from an admittedly low base. Table 2-2 lists some statistics of growth, in both absolute and percentage terms, by all means of transportation over the 1950-1997 period. Total passenger travel in industrialized regions of the world is now roughly equal to total travel in all other regions; it was almost four times as large in 1950. Nondeveloped countries closed the total-travel gap and will move ahead, perhaps far ahead, in the future. Although there is equality in total passenger miles traveled, annual per capita travel is still about six times as high in industrialized countries as elsewhere.

In addition to overall growth measured by total distance traveled, there have been major shifts among means of transport. As people earn more and travel more, they use faster or more convenient (and less energy-efficient per passenger-kilometer) vehicles, automobiles in particular. The greatest loser is therefore travel by rail, worldwide. In fact, since 1950, rail travel has decreased dramatically as a share of the total travel, especially in nondeveloped regions where it was the dominant form of motorized travel (see Figure 2-5).

In industrialized regions over the last 50 years, automobiles accounted for a roughly stable 70% to 75% of the passenger-kilometers traveled, with higher percentages in North America offsetting lower percentages elsewhere. By contrast, in nondeveloped regions, automobile travel rose from less than 20% of the total in 1950 to about 40% now, and that share is continuing to rise.

Bus travel in industrialized regions declined steadily to a share well under 10%, while it has risen elsewhere to about 45% — providing the preferred method of public transportation as railway use declines.

Table 2-2. Growth in passenger-kilometers traveled

	1950		1997		AAGR*, %/yr	
	Per Capita	Total (billions)	Per Capita	Total (billions)	Per Capita	Total (billions)
Industrialized Regions	4,479	2,628	16,645	14,951	2.8	3.8
Other Regions	373	717	2,627	12,998	4.2	6.4
World	1,334	3,345	4,781	27,949	2.8	4.6
Specific Segments						
United States	11,205	1,706	24,373	6,530	1.7	2.9
Western Europe	1,668	542	12,631	5,658	4.4	5.1
Former Soviet Union	705	127	4,152	1,250	3.8	5.0
China	NA	NA	1,313	1,634	NA	NA
India	348	125	1,457	1,392	3.1	5.3

Source: Updated database based on Schafer (1998).
*Average Annual Growth Rate, 1950 to 1997.
NA–Data not available.

Figure 2-5. Percentage shares of total passenger-kilometers traveled

Source: Database updated based on Schafer (1998).

The share of travel by air or high-speed rail has grown rapidly in industrialized regions. Air travel is expected to grow faster, measured as an annual percentage growth rate, than any other travel mode in all regions during the next 20 years.

Focusing on motorized transport makes it easy to forget how much of the world's population travels on foot or by bicycle. Walking or bicycling accounts for more than half of all trips made in a number of Indian cities, and 60% to 90% of all trips in many Chinese cities. In poorer rural areas, the dominance of nonmotorized transport is even stronger. Although roughly one-third of all "trips" are made on foot in OECD countries, the short trip lengths (generally well below one kilometer) result in an almost negligible traffic volume. Travel surveys suggest that walking accounts for less than 5% of total passenger-kilometers in Western European countries and merely 1/2% in the United States.

Implications for the Future

In the earliest years of industrial development, bus and bicycle travel increased to supplement walking and animal transport. With further development, automobiles began making inroads to the extent that money and traffic would bear. At the highest levels of industrialization, the share of automobile travel peaks and may decline as higher-speed, higher-cost options are used more often.

Changes in travel demand during the last 50 years in developed countries give us a clue about likely future trends in other developing countries. Since 1950, the Western European transportation system has been completely transformed. While buses and railways accounted for 70% of total traffic volume in 1950, their share was only 15% in 1997, a decline caused primarily by competition from the automobile, with its flexibility of schedule, comfort and convenience, and higher door-to-door speed. Between 1950 and the early 1980s, the automobile increased its share in traffic volume from 30% to 74%. Since then, it has begun to decline slightly because of the more rapidly increasing traffic volume of aircraft and high-speed rail. Experience in the Pacific OECD region, mainly Japan, was similar. The share of conventional railway traffic dropped from 80% in 1950 to some 30% in 1990.

Some centrally planned economies checked the growth of automobiles by making it difficult or expensive to acquire private vehicles, yet even in those countries growth persisted, driven by the almost universal desire to have full control over personal mobility.

If the patterns of the developed world repeat themselves in developing nations, concerns about environmental sustainability will increase. Large new capital investments in infrastructure will be needed, both CO_2 and other emissions will rise rapidly, and the urban congestion that is nearly ubiquitous will challenge the very operability of the road system. In the highly dense cities of China, India, and elsewhere that depend heavily on pedestrian and bicycle travel, substantial land-use changes would be necessary to relocate urban residents to less dense neighborhoods and suburbs, with required road and public transport links.

One particular outcome of growing mobility in the developing world will be an increase in the use of energy for transportation, and consequent CO_2 emissions, in a proportion greater than the increase in total passenger-kilometers traveled. In the aggregate, developed countries now use about twice as much energy as developing countries per average passenger-kilometer traveled. With the decline of railroads, the option of using electricity for transportation energy has also declined, thus increasing the almost-exclusive reliance on liquid fuels.

These trends raise concerns about the prospective growth of automobile travel in developing regions. Between 1950 and 1997, the world automobile fleet increased from 50 to 580 million vehicles — a fivefold increase in vehicles per capita. But the nondeveloped regions, despite having about 85% of the world's population, now have only about 25% of those vehicles. Developing countries with low motorization rates (less than about one vehicle per 10 inhabitants) but rapid economic growth may add vehicles to their fleets at very high rates — as high as 10% to 30% per year, compared to typical rates below 5% for fully developed countries. Rates of increase that rapid would make especially heavy demands for new infrastructure and result in sharply higher emissions and congestion.

TRANSPORTATION TECHNOLOGY

Some Vehicle Fundamentals

It takes energy to move mass — people and goods. In all vehicles, energy is consumed to produce mechanical power in the engine. That power drives the wheels of land vehicles, the propeller for a ship, or provides thrust for a jet aircraft. This driving power overcomes the resistances to vehicle motion: the air (or water) resistance or drag, the rolling resistance of the tires on the roadway, the vehicle's inertia as it accelerates, the incline of a hill, and the high altitude to which a plane must ascend. Generally, the power required to accelerate vehicles at rates that match drivers' needs and wants is much larger than the power required to drive at steady speed on a level road. Air resistance is proportional to vehicle frontal area; the other resistances are proportional to vehicle mass. Thus vehicle size and weight are critical parameters in determining vehicle energy use.

In wheeled vehicles, the efficiency with which the engine and drive train convert fuel to power at the wheels obviously also affects energy use. Efficiencies vary between the different engine and transmission technologies used in wheeled vehicles, and with the type of driving practiced. In urban settings with frequent low-speed driving and significant time spent idling, these efficiencies are lower. Under higher-speed highway driving conditions, these efficiencies are higher. Table 2-3 illustrates these energy conversion efficiencies for typical engines and drive trains. Reducing the energy consumption of a vehicle thus requires some combination of reduced vehicle weight, size, or drag, or improved engine or transmission efficiency.

Historical Perspective

Today's transportation technologies originated in the discovery of petroleum in 1859, the invention of the four-stroke spark-ignition engine by Nicolaus Otto in 1876, the compression-ignition or diesel engine by Rudolf Diesel in 1892, and the jet engine by Frank Whittle in the 1930s. The high power per unit weight and size of these engines, their compatibility with high energy density fuels derived from petroleum, and the low cost of both engines and fuels, have been the key requirements for large-scale use of motorized transportation vehicles.

The most ubiquitous transportation vehicle is the automobile. In 1950, there were about 50 million cars on the world's roads, 76% of them in the United States. The global automobile fleet (including all four-wheel personal vehicles) is now about 600 million. On average the fleet grew by more than 10 million vehicles per year over this period. Simultaneously, the truck and bus fleet grew by about 3.6 million vehicles per year. Although the growth rate has slowed in the highly industrialized countries, population growth and increased urbanization and industrialization are accelerating the use of motor vehicles elsewhere. Outside the United States, the growth in automobiles is especially high, more than 8% per year. There are also approximately 100 million powered two-wheelers (two-wheeled motorized vehicles) around the world, and they have increased by about four million vehicles per year over the past decade.

In parallel with this growth in the total market, vehicles have evolved, as well. The engine, transmission, and body technologies are making steady strides in sophistication and performance. The key vehicle attributes — performance, efficiency, ease of starting, driveability, range, reliability and durability, convenience and comfort, emissions, safety — have all improved significantly. At the same time, the diversity of models available to the public — vehicle size, configuration, style, purpose — has increased substantially, too. This diversity is fueled by increasing affluence in the developed world, and by the increased flexibility of modern production processes.

The oil crises in 1973 and 1979 provided a strong impetus for vehicle efficiency improvements. In the following decade, the fuel economy of new US passenger cars doubled. Since then, established technologies, such as gasoline spark-ignition and diesel engines and transmissions, continue to improve steadily through incremental changes and the introduction of new technologies and materials (e.g., engine power and torque per unit of displaced cylinder volume have been and are increasing about 1% per year).

New materials with better performance and lighter weight, or lower cost, continue to be introduced (e.g., aluminum and plastic replacing steel in selected body panels, plastic intake manifolds replacing aluminum, and rubber bumpers replacing chromed steel). Manufacturers are also continuously introducing and refining new technologies. Exhaust catalyst systems for emissions control, introduced in the 1990s are now extremely effective at reducing emissions. Computers, sensors, and controls improve the functionality of engines and transmissions, and provide new opportunities, such as anti-lock braking systems and traction control, and such new convenience features as automatic vehicle interior environment control and navigation systems. Improving vehicle features through the use of new and improved technology is an important marketing tool in an increasingly competitive industry.

Major improvements have also been seen in heavy-duty trucks and aircraft. The former have been equipped with more fuel-efficient engines and more streamlined tractor units. The latter have seen higher-bypass jet engines, the greater use of lighter materials, and the development of energy-saving technologies such as winglets. Aircraft technology is discussed more fully in Chapter 5.

Current Technology Status

This historical evolution of vehicles and technologies continues. As far as light-duty personal vehicles are concerned, the trend is for more choice for customers along all dimensions, and improved performance and functionality, often at reduced cost. Although there is increasing diversity

Table 2-3. Typical engine and transmission efficiencies

Technology	Urban Driving	Highway Driving
Gasoline engine	10%–15%	25%
Diesel engine	15%–22%	35%
Automatic transmission	70%–80%	85%
Manual transmission	85%–90%	90%–95%

Source: Weiss (2000).
Note: These efficiencies are energy flow out/energy flow in. For engines, energy flow out is the power, energy flow in is the fuel.

in vehicle types, the technologies used in these different types of vehicles are remarkably uniform. Smaller land vehicles (motorcycles, cars, light trucks) mostly use the cheaper gasoline engine. Larger vehicles (buses, heavier trucks, rail) use the more efficient but heavier and more expensive diesel. In countries where fuel costs are high and taxes on diesel fuel are lower than taxes on gasoline, diesel engines are increasingly the buyer's choice in light-duty vehicles (e.g., in France and Germany between 33 and 50% of new cars are powered by diesels). Both types of engine are steadily improving in terms of performance, efficiency, emissions, weight, smoothness, and reliability. Several manufacturers recently put into production the direct-injection engine, a new, more efficient type of gasoline engine. Diesel engines are similarly improving, especially by increasing their power with more efficient turbochargers, and decreasing their emission of pollutants. In light-duty vehicles, diesels now provide performance that is as good as that with gasoline engines.

Due to current pressures to reduce fuel consumption, air pollution, and CO_2 emissions, substantial development efforts directed toward these objectives are under way within the automotive and allied industries. Efforts to improve engine efficiency by variable valve timing, cylinder deactivation to reduce engine displacement during normal driving, reductions in engine friction and accessory loads, and more sophisticated engine management, all show promising potential. Some of these approaches, in their simpler form, are already in production. Improved efficiency transmissions are being developed with more gears, and new concepts, such as continuously variable transmissions and clutched automatically shifted manual transmissions are being introduced. Vehicle weight reduction, through material substitution and improved design, continues, as does the reduction of drag through more streamlined body design and improved tires.

New propulsion system concepts are also emerging. Most auto manufacturers are planning a transition to 42-volt electrical systems to improve the efficiency of many on-board, electrically powered components. Significant improvements in fuel consumption can be achieved by switching the engine off during idle. Integrated starter/generator systems that provide rapid engine restart appear promising. Various types of hybrid electric propulsion systems — an internal combustion engine coupled with a battery and motor/generator — are the focus of intensive industry efforts. Toyota and Honda have recently introduced hybrid systems into the passenger car market in limited but significant numbers. Other automotive manufacturers have announced plans to start introducing hybrids in cars, light trucks, and SUVs in the next couple of years. In low-speed, stop-and-go urban driving (e.g., in Japan), these hybrids offer large improvements in fuel efficiency, albeit at a significant increase in initial vehicle cost. The fuel efficiency benefits are still substantial but less under higher-speed driving conditions such as in the United States. One benefit of these more sophisticated hybrid systems is the recovery of some of the vehicle's kinetic energy normally dissipated in braking.

Another class of road vehicles widely used in developing countries and in parts of Europe where the climate is favorable comprises the relatively inexpensive motor scooters, small motor bicycles, and "three-wheelers." These provide significantly greater mobility (and goods-moving capacity) than walking or bicycling, at costs far below those of cars and light trucks in industrialized countries. Since these vehicles largely (but not exclusively) use inexpensive two-stroke gasoline engines, they have high emissions of air pollutants (especially VOCs) and noise. Their numbers are substantial, some few hundred million, and they are an important low-cost component of transportation systems in developing countries. They are, however, much less safe in an accident than standard cars, and are a significant contributor to the relatively high levels of traffic-accident-related fatalities in the parts of the developing world where they are prevalent.

There have been parallel but more modest technological developments in public transportation. Initiatives include a new generation of light-rail vehicles (the Boeing Vertol LRT) in the United States, rubber-tired guided systems built in Japan and France, and several monorails, constructed mainly in Japan. By and large these innovations have had limited success; new systems and wholesale replacement technologies have thus far largely failed to supplant traditional regimes. Where public transport shares automobile technologies, it has benefited from manufacturers' improved fuel efficiency, reduced emissions, the increased use of more durable and lighter materials, and electronics in vehicles for communications and control.

Buses have also benefited from technological innovations, but rarely are these given the public attention focused on modern light rail, the newly arrived aristocrat of urban transportation. The most important innovations have to do with the infrastructure used by buses. There are many instances, especially in Latin American cities and most Brazilian cities, of buses being provided with exclusive rights of way. Automatic bus priority at intersections — widespread in Europe — is also a significant advance. Electronically guided buses have recently been developed but have yet to be proven in extended passenger service.

The main change in passenger railway technology since the 1970s is the spread of electrification and the introduction of high-speed rail. Automatic vehicle operations and "moving block" signaling have been introduced, but have not yet produced much improvement over the best conventional technology. Despite the application of advanced technology in Western Europe, Japan, and North America, the traditional Moscow Metro still sets the world standard with its 40 trains per track per hour and 99% reliability while carrying more passengers than all the urban rail systems in the United States put together.

Technological innovation in public transport has been limited, partly because of issues of scale compared with that of the automobile, and because the technology is fragmented among countries, regions, and manufacturers. A few global groups emerged in the bus and, especially, rail industries, where the economies from consolidation are greater. If healthy competition is maintained, this should allow both enhanced technological innovation and lower equipment purchase and maintenance costs. This trend is propelled by the privatization of public transport operations. Private operators have had to take a more commercial approach to purchasing, with less of the customization and "buy local" policies that contributed to this fragmentation in the past.

Sustainability Challenges Posed by the Technologies of Motorization

Chapter 1 highlighted several disruptive impacts of motorization, such as injuries and fatalities from traffic accidents, local air pollution, global warming, noise, access for the non-motorized, and long-lasting effects on ecosystems through habitat interruption and destruction. A subset of these sustainability challenges are related directly to the technologies used to manufacture and operate motor vehicles. The operation of combustion engines produces effluents and CO_2 emissions that increase the concentration of greenhouse gases in the atmosphere; consume oil, which is a nonrenewable resource; and generate noise pollution. The manufacture of vehicles requires the use of large volumes of materials ranging from iron, steel, and aluminum, to lead, platinum, and palladium.

Air quality impact of automotive technology. As has been noted in Chapter 1, motor vehicles account for a large share of the air pollution in our cities and surrounding metropolitan regions. Gasoline and diesel-fueled engines are the major source of hydrocarbon (HC), oxides of nitrogen (NO_X, reacting in the atmosphere to form ozone, which is damaging to human health, materials, and vegetation), carbon monoxide (CO), particulate matter, and (in many urban regions outside the OECD) lead.

Significant technological strides have been made in automotive technology, with emissions from new vehicles in the most strictly controlled regions 90% to 98% lower than they were prior to control. Expectations are that emissions of air pollutants from vehicles will continue to decrease as stricter regulations are imposed, primarily through the development of more effective exhaust catalyst systems. Important issues to be addressed in reducing emissions are the durability of these systems (solving the high emitter problem), their increasing cost, and noble metal requirements. Also of concern are the constraints emissions requirements impose on developing more efficient gasoline engine technologies (exhaust after-treatment technologies typically reduce a vehicle's fuel efficiency). For diesel-engine vehicles, the development of effective exhaust treatment technologies for particulates and NO_X is a very high priority. Implementation of such technologies, however, require simultaneous reduction in the sulphur content of the diesel fuel. Expectations are that such technologies are likely to be developed and implemented over the next decade. However, it will take time for them to become robust enough for extensive use in the market.

Global climate change impact of automotive technology. In addition to the consumption of petroleum, a nonrenewable resource, the combustion of petroleum-based fuels produces CO_2, which is thought to contribute to global climate change. Indeed, transportation's impact on the global climate goes beyond the impact of vehicle emissions. Producing and distributing automotive fuel, and producing, distributing, maintaining, and recycling vehicles in themselves can produce significant greenhouse gas emissions. Analysis of such a "wells-to-wheels" impact of petroleum-based gasoline and diesel fuels suggests that the combined energy production and distribution efficiency is about 83% and 88%, respectively (Weiss et al. 2000). For some other fuels, the energy losses and hence CO_2 emissions are significantly larger. In addition, the energy required in the vehicle manufacturing process is equal to about 10% of the total energy that will be used by the vehicle over its lifetime.

Aside from a dramatic change in fuel — such as replacing petroleum fuels with biomass-derived fuels — reducing CO_2 emissions from transportation requires a reduction in the amount of fuel consumed. Better technology helps accomplish that reduction by reducing vehicle resistance to motion, and by converting fuel energy more efficiently to mechanical energy at the wheels.

Vehicle resistances (mass or inertia, aerodynamic drag, tire-rolling resistance) have decreased and engine and transmission efficiencies have increased over the past two decades, following the oil crisis of the 1970s. However, in the developed world the benefits of these changes have been partly offset by increases in vehicle size and performance. New types of vans and sport utility vehicles, which enjoy wide popularity in North America and more recently in Europe, exacerbate the trend to increased vehicle size, weight, and fuel consumption.

In the near future, it is anticipated that vehicle fuel consumption could potentially be reduced significantly through evolutionary improvements in engines, transmissions, and vehicle materials and design. Technology improvements such as material substitution and other weight reduction measures, development of increasingly higher power and more efficient engines, and changes that improve transmission efficiency and use more efficient engine operating regimes, are all continuing. In turn, vehicles will steadily become more efficient over the next decade and beyond as these technologies are refined.

There are, however, some trade-offs between fuel consumption improvements that can be achieved and the mandated emissions reduction requirements. In the United States, at least, it has been claimed that the continued tightening of NO_X standards will make it impossible to use diesels in passenger cars, even with improved NOx exhaust treatment. Very strict emissions standards in California are set for the next decade to continue to achieve reductions in total fleet emissions. Future standards for the United States nationwide, Japan, and Europe also tighten substantially. The use of the more efficient diesel engine in light-duty vehicles could well be restricted by some of these requirements, until effective exhaust emissions treatment technology for diesels is developed.

Beyond these anticipated evolutionary improvements in vehicle fuel consumption (reduction by about one-third in 20 years, at constant vehicle performance), incorporating new technology (e.g., lighter materials such as aluminum and hybrid propulsion systems) can provide additional fuel consumption reductions (a further reduction of up to one-third below the anticipated evolutionary improvements).

Challenges posed by vehicle manufacturing processes. The manufacture of motor vehicles raises sustainability questions related to energy use in the manufacturing process, CO_2 emitted in the production and fabrication of these materials, and, in some isolated cases, to the availability or cost of sufficient natural resources. Iron and steel remain the primary structural materials, but increasing amounts of plastic, aluminum, and fiber composites are used. Vehicle manufacturers regularly change the materials they use as part of ongoing efforts to reduce cost, reduce weight, and to accommodate regulatory requirements. Advanced higher-strength steels are permitting a reduction in the weight of steel used for the same strength.

A critical consideration is the ability to recycle the materials in vehicles at the end of their lifetimes. Producing virgin material usually consumes more energy than using recycled materials. A conspicuous example is aluminum. About 220 Megajoules (MJ) of energy are needed to produce one kilogram of virgin aluminum; about 40 MJ are needed for recycled aluminum. This particular example is important, as well as being conspicuous, since more aluminum is likely to be used in future vehicles in order to reduce weight and fuel consumption.

At present, a considerable percentage of all ferrous metals are recycled in the automotive industry (about 95% in the United States), although not all of it is reused in vehicles (about 25% to 30% in the United States); much goes to less demanding applications. Smaller fractions of other materials are recycled. As mandatory recycling becomes more common around the world to conserve energy, resources, and landfill space, vehicle manufacturers are expected to respond with materials and recycling technologies that increase the levels and efficiency of recycling. For instance, it is likely that uses will have to be found for the less recycled plastics and shredder residue materials where currently recycling economics are unfavorable.

Although availability of traditional materials is not a major issue, availability of new materials could be. If fuel cell propulsion systems become common, the platinum-group metals used for catalysts in fuel cell systems will have to be almost entirely recovered and recycled; known natural resources are insufficient for complete virgin supply.

The Rise and (Partial) Fall of Lead in Gasoline

Awareness of the environmental and health woes stemming from exposure to lead has resulted in its phaseout from gasoline in most of the industrialized world and in increasing parts of the developing world. Compounds of lead were first added to gasoline in the 1920s in order to increase octane number and thus allow engines to operate at higher compression ratios and higher efficiencies. However, the lead was discharged into the atmosphere with exhaust gases from the engine. Because of increasing awareness of lead's toxicity, especially to children, steps to reduce lead discharges were taken, first in the Soviet Union in 1967, when the sale of leaded gasoline was banned in some large cities. In the United States, significant phase-out of lead in gasoline began in 1974, when fuel suppliers were required to offer at least one grade of unleaded gasoline. The motive was not only to reduce human exposure to lead, but to make possible the use of catalytic converters on vehicles to reduce other pollutants in exhaust gases. Lead in gasoline poisoned the catalysts in the converters, making the converters ineffective, as well as poisoning people. The phaseout of lead continued, and was completed in the United States in 1996, when all use of leaded gasoline in highway vehicles was banned. Similar phaseouts have occurred, usually more slowly, in other industrialized countries. However, lead is still widely used in many developing countries because it is a cheaper and more efficient way of increasing gasoline octane number than the alternatives available.

Vehicle Emissions Reduction — A Qualified Success

Emission standards for cars were first introduced in the United States and Japan around 1970, followed shortly thereafter in Europe. These requirements have been steadily made more stringent every few years. The state of California, with its severe smog problems in Los Angeles, has forced the pace with the strictest standards for emissions of non-methane hydrocarbons or organic gases (NMOG) and oxides of nitrogen (NOx), the critical ingredients in forming photochemical smog. Today's California emissions standards for these pollutants are about 1% and 6%, for NMOG and NO_X, respectively, of the precontrol grams-per-mile vehicle emission rates. These large reductions have been achieved in part by reducing the emissions from the conventional gasoline-fueled internal combustion engine but primarily by developing catalysts, sensors, and control systems, that get rid of all but a few percent of the emissions leaving the engine. This per-vehicle emissions reduction is an impressive success story. However, its impact on urban air quality is partly offset because it takes some 15 years for the older, higher-emitting cars to be retired from the in-use vehicle fleet because of steady growth in vehicle miles traveled, and due failures in the emission control technology in a small fraction of vehicles. On-the-road surveillance indicates that 5%–10% of the cars in use are responsible for half the total fleet emissions. Future regulations — both stricter emissions standards (five times stricter than today's) and the requirement for extensive on-board diagnostics to identify failures — are intended to offset growth and deal with the "high-emitter" problem.

A final sustainability issue in recycling is preventing escape of harmful materials into the environment. For example, lead is a toxic material whose use in gasoline is being eliminated around the world, but whose use in batteries cannot realistically be eliminated in the near future. Likewise for refrigerants in vehicle air conditioning systems; the CFCs (or HFCs) have potent greenhouse effects if allowed to escape into the atmosphere rather than being safely recovered.

ENERGY FOR TRANSPORTATION

That petroleum-based fuels are far and away the leading source of energy for transportation is the central fact that dominates all discussion of energy and transportation. Every vehicle requires energy to move. In order to supply that energy, more than one liter of petroleum is consumed each day, on average, for each of the six billion humans on earth. In the industrialized countries, transportation consumes more than half of all petroleum used for all purposes. In developing countries the share is less than half, but it is rising and is expected to be at least half within a decade.

Not only does transportation need a great deal of oil, it needs very little energy except oil. Fuels derived from petroleum (crude oil) now account for more than 96% of all the energy used in transportation, a trend that is not expected to decrease (IEA 2000b). Other sources of transportation energy — coal, natural gas, alcohols, electric power — have been significant in particular places or times, but all have been minor fractions of the total. For many years, mobility has relied almost entirely on the availability of petroleum fuels — gasoline, diesel fuel, jet fuel, and bunker (ship) fuel. There is little likelihood of greatly reducing that dependence for many years to come even though consumption of these fuels indefinitely at the expected levels of demand is unsustainable.

Petroleum Supply, Price, and Trends

The birth of the oil industry dates from the discovery of oil by "Colonel" Drake while drilling a well in Pennsylvania in 1859, but it wasn't until the expansion of road infrastructure and vehicles in the first half of the twentieth century that petroleum production expanded dramatically. Production during the second half of the century increased even more rapidly as a result of economic development around the world and the discovery of large new low-cost sources of petroleum in the Middle East (Table 2-4).

The price of crude oil, traditionally expressed around the world in US dollars per barrel, has not followed production in a continuous upward path. Average prices experienced large and sometimes rapid fluctuations during the past quarter century. Since 1973, the price of crude oil (expressed in constant 1998 dollars) has ranged from a low of $12 to a high of $63 (EIA/US DOE 2000). Prices fluctuate within that range over short time intervals. For example, they tripled between December 1998 and August 2000 — provoking public demonstrations in Western Europe and the United States. Price instability is likely to continue, since the prices buyers are willing to pay for crude oil are highly sensitive to their expectations about imbalances between supply and demand — both of which are sensitive to changing economic and political forces. Therefore, predictions about future oil prices are uncertain at best; there has been little "trend" for guidance about the future.

About 41% of all current oil production originates in the 11 member countries — Venezuela, Nigeria, and Indonesia, plus eight countries in the Middle East and North Africa — of the Organization of Petroleum Exporting Countries (OPEC). OPEC countries also hold 77% of the world's reserves of crude oil (BP 2000). OPEC members meet periodically to agree on the total amount of oil they will produce in an attempt to keep market price in some target range that responds to the expected balance of supply and demand. The price at which large producers sell their crude oil may have little to do with the cost of production. In the spring of 2001, Saudi Arabia, the world's largest crude oil producer, sold oil for about $25 per barrel; it costs about $1 to $3 per barrel to find, develop, and lift that oil to the terminal (IEA 2000c).

Assuming a crude oil price of $25 per barrel, countries that import crude oil (most countries in the world) transfer about $350 billion a year to the countries that export crude oil — about 30 countries with significant exports — for the 38 million barrels a day they buy. In addition, consuming countries import and pay for about 16 million barrels a day of refined products. That total transfer of funds can be a burden on poorer countries and motivates the effort to use indigenous fuels, if possible. Even the United States, the world's second largest crude oil producer, currently spends about 1% of its GDP on imported petroleum and products.

The cost of fuel to consumers is made up of four elements: the cost of crude oil to the refiner; the cost of refining the crude oil to final product fuels; the cost of distributing that fuel from the refinery to the vehicle tank; and the taxes (or subsidies) imposed by governments on the fuel. For example, assuming crude oil prices of $22 per barrel, Table 2-5 shows the composition of the ex-tax cost of the fuel in the United States.

Although the ex-tax cost is 23 to 26 cents per liter in the United States, taxes may increase the consumer cost to as much as $1.00 per liter, as in the UK. Consumer cost may be even less than 23 cents in those developing countries where fuel costs to consumers are subsidized by the government; in Nigeria the recent pump price of gasoline was 18 cents per liter (Economist 2001a). Fuel taxes or subsidies are instruments of public policy that may have multiple objectives, such as raising revenue or encouraging one fuel versus another through lower taxes; for example, France and Germany tax diesel fuel at only about half the rate of gasoline.

Many analysts expect that the dominance of petroleum fuels for transportation will have to begin declining at some time in the future, but the real debate is about when. That expectation is driven by two main considerations of sustainability: climate change through greenhouse warming and resource availability.

In addition to the CO_2 emissions from burning petroleum fuels in the vehicle, there are additional sources of energy consumption and CO_2 that can be attributed to transportation fuels. One source is the energy used, and accompanying CO_2 emitted, in producing petroleum, refining it, and delivering finished fuels to the vehicle tank. As already noted, that energy is equal to about 10% to 15% of the energy of the delivered fuel. Another source is the release or flaring of natural gas that is unavoidably produced along with petroleum in some oil fields, gas that cannot be used at the site. Natural gas is largely methane, a gas with about 21 times the potency of CO_2 as a greenhouse gas, and therefore its release unburned can be a significant contributor to global warming.

Resource availability is a concern, as there is a continuously rising demand for crude oil that cannot be satisfied indefinitely and economically by exploiting the currently estimated resources of petroleum in the earth. Some other sources of transportation energy are believed to be necessary eventually, with a serious transition beginning in the next 20 to 50 years (e.g., Economist 2001b; US DOE 2001). Linked to "availability" is the fact that 65% of the world's known reserves of conventional petroleum are located in the Middle East (BP 2000), and there is concern about the rest of the world being so dependent on such a politically volatile region. Natural resources other than conven-

Table 2-4. World production of crude oil

Year	Production (million tonnes/year)
1875	1
1900	21
1925	149
1950	525
1975	2,635
2000	~3,700
2020	~5,600

Sources: BP (1977), EIA/ US DOE (2001).

Table 2-5. Ex-tax consumer cost of fuels in the United States

	Gasoline	Diesel Fuel
	(cents per liter)	
Crude Oil	14	14
Refining	8	5
Distribution	4	4
Total	26	23

Source: Weiss (2000).

tional petroleum can also be used to make transportation fuels (see feature boxes), and that somewhat eases concerns about "running out" of oil.

The possibilities of moving away from petroleum-like fuels based on any fossil raw materials are widely debated and analysts are not likely to reach a broad consensus in the near future. In the meantime, oil use grows apace. Both the International Energy Agency (IEA 2000b) and the US Department of Energy (EIA/DOE 2001) project that world demand for transportation fuels (almost entirely petroleum) will grow at 2.5% and 2.8% per year respectively for the next 20 years (see Table 2-6). Those growth rates result in a doubling of demand in 25 to 28 years. Future world oil prices are seen somewhat differently by the two agencies, at $27 per barrel and $22 per barrel respectively. It is no criticism of these agencies to note that historically, most predictions of long-term prices have been less than accurate.

IEA's most recent World Energy Outlook (IEA 2000b) expresses concern about the CO_2 impacts resulting from the increase in transportation energy demand in the "business-as-usual" reference case reflected in Table 2-6. In an alternative scenario, IEA concludes that a combination of taxes, regulations, better technology, and demand restraint could stabilize CO_2 emissions after 2010 — but with unspecified effects on mobility.

Refining and Quality of Petroleum Transportation Fuels

Before crude oil can be used for transportation, it must be refined into products suited for particular types of engines, such as gasoline spark-ignition engines or diesel compression-ignition engines. Most refineries are located in oil-consuming countries, and crude oil is carried to those countries from oil-producing countries in pipelines or large oil tankers.

Crude oil is a natural mixture of a vast number of individual chemical compounds; most of them are hydrocarbons (compounds containing only carbon and hydrogen), but other compounds contain additional atoms such as sulfur, oxygen, and nitrogen. It is the objective of refining technology to sort out and modify the natural petroleum compounds into groups that function best in their end uses as fuel and other products. Refineries produce many products, including the main transportation fuels. The nature and volumes of those products depend on the type of crude oil refined, the refinery equipment available, and the demand from customers. Over the years, refiners have had to accommodate not only overall growth in demand but differences in growth rates among fuels and among countries. Large changes in demand are not easy to accommodate rapidly. Refineries are complex and capital-intensive, so lead time is required for both design and construction of new equipment.

Table 2-7 shows that, paralleling recent trends, there will be increasing demand for highway fuels (gasoline and diesel fuel) during the next 20 years or so, and that the rates of increase will be more than twice as fast in developing countries (4.7% to 4.8% per year) as in industrialized countries (1.3 % to 1.7% per year). Furthermore, there is an especially rapid rise in the demand for air mobility, which should cause world jet-fuel consumption to rise by 4% per year compared to 2.4% and 3.2% per year for gasoline and diesel fuel respectively. All of these changes will require not only additional crude oil production but also new refining capacity.

Highway fuels — gasoline for spark-ignition engines and diesel fuel for compression-ignition engines — will remain dominant, with a total demand three to four times the total demand for non-highway fuels. Gasoline is more volatile than diesel fuel. It has a median boiling point of about 70°C to 125°C compared to about 240°C to 300°C for diesel; the ranges reflect the fact that optimum boiling points depend on climate, with lower boiling points preferred in colder climates. The two fuels also differ in average chemical composition, which largely controls the ignition characteristics of the fuel. Better gasolines have higher octane numbers that permit combustion to occur smoothly and in a controlled way in the engine. Better diesel fuels have higher cetane numbers that permit the fuel to ignite

Table 2-6. World oil demand and price, 2020

	Units	IEA (OECD, Paris)	EIA (US DOE, Washington)
Oil price	1999 US$	27.04	22.41
Total oil demand	MB/day	114.7	119.6
Total growth, 1998–2020	%/year	1.9	2.3
Transport oil demand	MB/day	57.8	~63*
Transport oil growth, 1998–2020	%/year	2.5	2.8

Source: EIA/ US DOE (2001).
*Assumes 96% of EIA transportation energy is oil.

Table 2-7. Recent and projected world transportation fuel demand (million barrels/ per day)

Fuel	Industrialized Countries				Other Countries			
	1990	1999	2020*	Growth*	1990	1999	2020*	Growth*
Gasoline	11.2	13.1	17.3	1.3%	3.8	4.9	12.5	4.7%
Diesel fuel	5.2	6.6	9.5	1.7%	3.0	4.5	12.0	4.8%
Jet fuel	2.5	3.0	5.6	2.9%	1.1	1.2	4.3	6.1%
Bunker fuel	1.2	1.2	1.3	0.5%	1.0	1.2	1.6	1.6%

Source: EIA/US DOE (2001).
Notes: "Industrialized Countries" include North America, Western Europe, Japan, and Australasia.
Growth = % per year from 1999 to 2020.
* Indicates estimate.

as quickly as possible after injection into the engine. In general, the types of molecules that have high octane numbers also have low cetane numbers, and vice versa.

Over the years, the quality of many transportation fuels has changed, sometimes because of new requirements for operating improved engines, but often because of new environmental requirements to reduce emissions resulting from the use of those fuels.

A current example is the required reduction of sulfur in both gasoline and diesel fuel over the next ten years, with the objective of reducing emissions from vehicle exhaust, primarily by reducing the deterioration of catalysts. New regulations in the United States will reduce sulfur in gasoline to 30 parts per million (0.003%) and in diesel fuel to 15 parts per million (0.0015%). In the European Union, the limit for both fuels will be 10 parts per million (0.001%). Similar changes are expected in most other industrialized countries.

It is possible that more changes in the quality of petroleum fuels will be required in the future to satisfy new environmental regulations. These may require new refinery investments. It is also likely that quality will eventually be upgraded in the developing countries, where requirements are currently less demanding than in the industrialized countries. The case of removing lead from gasoline, cited earlier, is an example.

Nonpetroleum Transportation Energy

The overall role of nonpetroleum fuels in supplying energy for transportation can be illustrated by International Energy Agency data for 1998 (see Table 2-8). The table shows world consumption of gas, electricity, and coal — the three major nonpetroleum fuels — as a percentage of world consumption of petroleum for transportation.

Table 2-8. World transportation energy use, 1998

Energy Source	Consumption as % of Petroleum
Natural Gas	2.4
Electricity	1.2
Coal	0.4

Source: IEA (2000b).

Although petroleum dominates worldwide, other transportation fuels can be significant locally. Examples are ethanol from sugar cane in Brazil, and ethanol from maize in the United States. Fuels derived from natural gas, such as hydrogen or methanol or dimethyl ether, have also been proposed (e.g. IEA 1999) and tested. None has yet commanded a commercially significant market, but hydrogen is clearly a leading contender for the "ultimate" fuel from an environmental point of view, if technical and economic barriers can be reduced sufficiently.

Past and existing uses of non-petroleum fuels are often motivated by particular national circumstances that cannot be applied to many other countries. For example, cheap indigenous coal is used to power railroads in countries in mainland Asia where there are limited supplies of indigenous oil, and where spending foreign exchange on oil imports is avoided if practicable. Another example is using ethanol from sugar cane in gasoline blends in Brazil in order to reduce imports of oil and to provide employment in a massive sugar-cane growing and conversion industry.

Natural gas (NG) is used more extensively for transportation. Most of this natural gas is used to power compressors on pipelines rather than in vehicles. A recent status review (EIA/DOE 2001) states that there are now more than a million NG vehicles on the road worldwide, with the largest fleets in Argentina (600,000) and Italy (345,000). Natural gas is also used to fuel buses where local authorities believe it will improve air pollution. Vehicles built to use natural-gas fuel cost more than gasoline vehicles, have shorter driving ranges, and are less convenient for customers during refueling; as a result, government-subsidized programs around the world have had mixed success.[3] Despite these cost issues, programs to reduce air pollution in congested urban areas have encouraged the use of CNG-fueled vehicles in recent years.

CNG is not an option for vehicles such as heavy trucks, railroad locomotives, towboats, and ocean-going ships, which require engines that are larger than those capable of using 100% natural gas. Natural gas cannot self-ignite; used alone, it can be used only in a spark-ignition engine. However, the thermodynamic properties of spark-ignition engines put an upper limit on their power output. Most larger and heavier vehicles must therefore use some type of compression-ignition engine. Progress has been made in developing "dual-fuel" compression-ignition engines, which have virtually the same power characteristics as "conventional" diesels, and use a relatively small amount of diesel fuel as an igniter, but obtain most of their energy from either CNG or liquefied natural gas (LNG).

As noted above, alternatives to petroleum fuels are often proposed in order to achieve superior environmental performance. Whether or not that objective will be achieved requires a life-cycle assessment of the total system, i.e., consideration of not only how the fuel behaves in the vehicle — how much energy is used and how large the emissions are — but also how much energy is consumed and how much pollution results from producing the fuel and delivering it to the vehicle.

The type and quality of fuel also affect the composition of exhaust gases (other than greenhouse gases) from vehicle operation, gases that contain pollutants such as NOx and particulates. Technologies for new vehicles and fuels should be able to reduce those pollutants to sustainable levels. However, emissions of pollutants from operating existing vehicles can be high and can have significant effects, especially in congested urban areas around the world. Changes in quality of the petroleum fuel alone can have only modest effects on emissions from the existing fleet.

Developments in Fuel-Cell Technology

Major efforts are underway to develop fuel-cell propulsion systems for land transportation vehicles. With hydrogen as fuel, this technology has the potential for increasing propulsion system efficiency with very low levels of air pollutant emissions. Most of the major auto manufacturers, joined by companies in the supplier industry and major petroleum companies, are working to develop fuel-cell technology for light-duty vehicles and buses. Fuel-cell systems and concept vehicles (cars and buses) are being aggressively developed and tested with steadily improving performance. Although limited numbers of fleet vehicles may be available within the next five years, these efforts are largely focused on the longer term, where the very low emissions and high efficiency of direct-hydrogen-fueled fuel cells may become important. Many technology issues involving cost, size and weight, practicality, and hydrogen storage must still be resolved. An overriding issue is the feasibility of introducing a hydrogen fuel production and distribution infrastructure. A critical unanswered question is whether hydrogen can be efficiently enough produced, distributed, and stored on the vehicle, without producing significant CO_2 emissions.

Hydrogen, like electricity, is an energy carrier and not a primary energy source. Electricity has been hampered as an automotive energy source because of poor battery technology and high cost. Hydrogen is of interest because it may be easier to store onboard a vehicle than electricity; today, much frontier research is focused on improved hydrogen storage technologies. Long term, electricity may be generated without fossil energy use (or with sequestration of carbon emissions), and hydrogen may be generated from fossil sources with sequestration of emissions or from electrolysis of water. In the latter case, conversion of electricity to hydrogen for transportation use will depend on issues like cost and the competitive advantage of hydrogen storage over battery storage.

Petroleum-Like Fuels without Petroleum

Traditional liquid transportation fuels, such as gasoline, diesel, or jet fuel, are usually produced by refining the natural fossil resource of petroleum (crude oil). From time to time, as crude oil prices have increased or as questions have arisen about the adequacy of crude oil supply in the long term, other fossil resources have been considered for making fuels. Among those resources have been tars and natural gas, both with the potential to provide large additions to fuels available from conventional petroleum. For example, Canada's National Energy Board states that more than 300 billion barrels of recoverable tar exist in Alberta. Suncor Energy, a company now producing oil from that tar, claims it can be produced for less than $10 per barrel (NY Times 2001a). That amount of Alberta tar exceeds Saudi Arabia's reserves of 264 billion barrels (BP 2000), which constitute 25% of the world's conventional petroleum reserves. As another example, Shell is planning to construct a plant in Egypt to convert natural gas to diesel fuel at a cost that would be competitive with crude oil priced at $15 per barrel (World Fuels Today 2000). World reserves of natural gas are about equal in energy content to world reserves of conventional petroleum, so the potential supply is very large. The prospective use of alternative fossil resources like tar or natural gas may help reassure us about long-term fuel supply. However, CO_2 emissions from manufacture and use of fuels from those alternatives will be no lower and are likely to be higher than from crude oil.

Beyond environmental considerations, an alternative fuel must be competitive in cost and have no characteristics that would cause it to be rejected by customers and other stakeholders in the automotive system: fuel and vehicle producers and distributors, and governments at all levels. For example, there can be real or perceived problems with fuel safety or toxicity, and time and convenience of refueling. Most experts agree that there will be large barriers to the widespread use of alternatives to fuels derived from petroleum or other fossil resources. Nonetheless, those barriers will have to be overcome eventually in order to have a sustainable transportation system. Therefore, work on such alternatives as biomass-derived fuels and carbon-free production of hydrogen and electricity deserves high priority.

CONCLUSIONS

If past is prologue, the patterns of mobility demand, technology, and energy use that emerged in the twentieth century are bound to repeat themselves in the twenty-first. The global population is rising, especially in the developing world, and people are migrating to cities and their suburbs at a steady pace. Incomes are rising, fueling more demand for faster travel. The overwhelmingly most popular means of transport is the automobile, which indicates that its unfortunate side effects — accidents, congestion, air and noise pollution, environmental damage, and increasing reliance on finite reserves of petroleum — will proliferate on a global scale. Evidence from China and other rapidly motorizing regions strongly suggests that this will be the case, with adverse consequences for the operational, social, economic, and environmental sustainability of their citizens' mobility.

Yet it is not certain or preordained that all of these glum predictions will come to pass, and that the new century must repeat all of the errors of its predecessor. The industrialized cities of Europe and North America offer lessons on the costs and benefits of motorization, and how to avoid the most deleterious costs. Whether the developing nations can learn from those lessons depends on a delicate balance of technological advances and political will power. Corporations are racing to produce more efficient engines that will be powered by cleaner, renewable fuels. Yet it is unclear that commercially viable alternatives to petroleum-powered internal combustion engines can be mass-produced in the near future. Until they are, the urban leaders, especially those of the rapidly growing megacities like Shanghai, Bangkok, Mexico City, and Johannesburg, need to plan and build neighborhoods and commercial districts that will not be totally dependent on the automobile.

NOTES

1. There is no agreed-upon definition of “megacity.” Some sources define it as a city with a population of 5 million. The World Resources Institute uses a cutoff point of 8 million. This report will adopt the definition used by the United Nations, i.e., any city with a population of over 10 million.

2. Some of the variation in urbanization levels across countries stems from differences in the definition across countries of what constitutes “urban.” We have used data developed by the UN Population Division (UN 2001).

3. One barrel, the traditional unit of measure in the oil industry, is equal to 42 US gallons. There are 7 to 8 barrels per ton for major crude oils. Crude oils produced from different locations can differ greatly in quality, and prices per barrel reflect those differences in quality; prices cited here are averages.

3. Experiences vary, but a report published by the US General Accounting Office in December 1999 compared the relative purchase, maintenance, and operating costs of diesel- to natural-gas-powered buses in the United States. The GAO determined that public transport systems that operate full-sized CNG (compressed natural gas) buses pay approximately 15% to 25% more for them, on average, than for similar diesel buses, though some of this difference may be due to the lower volume of CNG buses. Maintenance costs for many (but not all) CNG bus operators exceeded those for diesel buses (GAO 1999).

three

mobility in the urbanized regions of the developed world

In virtually all urban areas of the developed world, the automobile plays the dominant role in providing urban mobility. Public transport is still very important, especially in Europe and Japan. But its share of total developed-world passenger miles has been falling almost everywhere. Auto ownership and use has grown substantially over the last 50 years throughout the developed world. This, in turn, has enabled urban areas to decline in average population density, further damaging public transport's competitiveness. Technology has enabled some reduction in the total transportation-related emissions of carbon monoxide, sulfur dioxide, and volatile organic compounds; however, slow fleet turnover, lack of proper maintenance, changes in the mix of light-duty vehicles, and increased driving has kept the reduction in total emissions well below the reduction in new vehicle emissions. Transport-related emissions of carbon dioxide have not declined. Improvements in fuel efficiency of new vehicles have been more than offset by increases in the total number of vehicles, changes in vehicle mix, and increases in vehicle utilization. Accident rates have decreased as vehicles and roads have improved. Congestion appears to be increasing, though truly comparable cross-national data on congestion are difficult to find. A range of strategies is being tried in different urban areas to offset the adverse impacts of motor vehicles. These include restrictions on central city auto use, traffic "calming," the promotion of car-pooling, and various approaches to promoting the increased use of public transportation. Technology is showing how to increase the capacity of existing highway infrastructure, and interest in the use of congestion charges and pollution charges seems to be growing.

For the purposes of the discussion in this chapter and the next, we have distinguished between the "developed" and the "developing" world. By the former, we mean primarily the 25 countries that constituted the Organization for Economic Co-operation and Development prior to 1994: North America (except for Mexico), Western Europe with Scandinavia and Turkey, Japan, and Australasia (except for New Guinea).

Of course, the broadly similar indicia of economic development that distinguish these countries from the rest of the world do not necessarily imply a comparable degree of homogeneity in their urban development patterns or their transportation characteristics. The urbanized regions of these countries encompass a wide spectrum of cities, ranging from such megalopolises as Tokyo, New York, Osaka, Los Angeles, London, Istanbul, and Paris, down to much smaller, less dense, and much more disparate metropolitan areas. Even that short list of major urban agglomerations spans quite a diversity of physical and economic development patterns. In many ways, no two cities in the same country are alike, let alone two cities across the world from each other. Can one validly speak of Ankara, Barcelona, Cork, New York, San Francisco, Venice, Wellington, and York in the same breath?

Nonetheless, despite our inevitably oversimplistic division of the world into two domains, there are a number of major, relevant consistencies across the developed world — in consumer aspirations and behaviors, in passenger transportation trends, and in the structure of the problems with which transportation planners and policymakers must grapple. As we shall see, not all of these similarities are qualitatively different from the situation in the developing world, but there do tend to be sharp differences of scale, social and political constraints, and financial resources that justify speaking separately about the two domains.

With respect to mobility, the most characteristic feature of countries in the developed world is the high level of ownership and use of private motor vehicles for personal travel, a phenomenon we will characterize as "automobility." These countries are further characterized by extensive suburban development and the generally declining role of public transport. These shared mobility trends have produced shared concerns about whether comparable levels of mobility can be sustained in the future. Although the details of these concerns may vary somewhat across the different countries of the developed world, the scope of the problem, the history of its evolution, the options that have been considered, and the current state of play are broadly similar across these nations.

In this chapter, we will highlight the important mobility trends, the related sustainability issues, and comment on the approaches that have been suggested and tried. A major focus of our effort is to develop some understanding of the important commonalities across the developed world, as well as the significant differences relating to mobility and sustainability. Developing such an understanding is key to determining how useful and applicable different approaches may be.

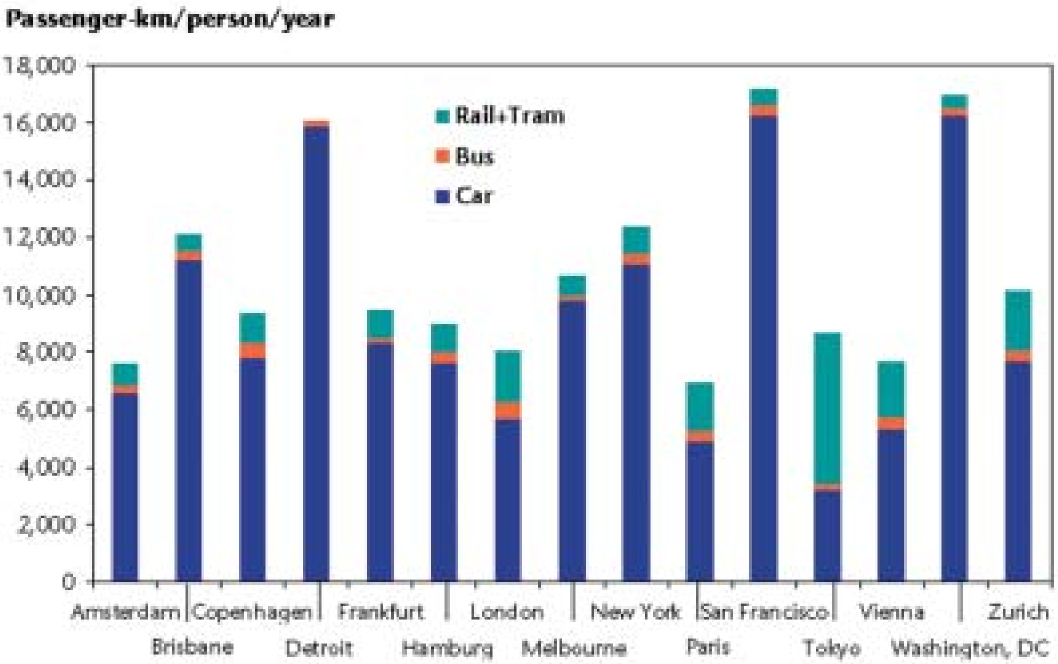
TRENDS IN URBAN MOBILITY IN THE DEVELOPED WORLD

Figure 3-1, which provides an overview of the contribution of the major modes of transport to mobility in a selection of cities across the developed world, clearly indicates the dominant role of the automobile in providing urban mobility. In the developed world, the private vehicle has become the most common form of motorized transportation, accounting for about 40% of passenger-kilometers traveled in Tokyo and over 95% of passenger-kilometers traveled in the cities of the United States. Public transport has a smaller role, albeit a very significant and important one, especially in Western Europe and Japan.

Urban Decentralization and Automobility: Two Mutually Reinforcing Trends

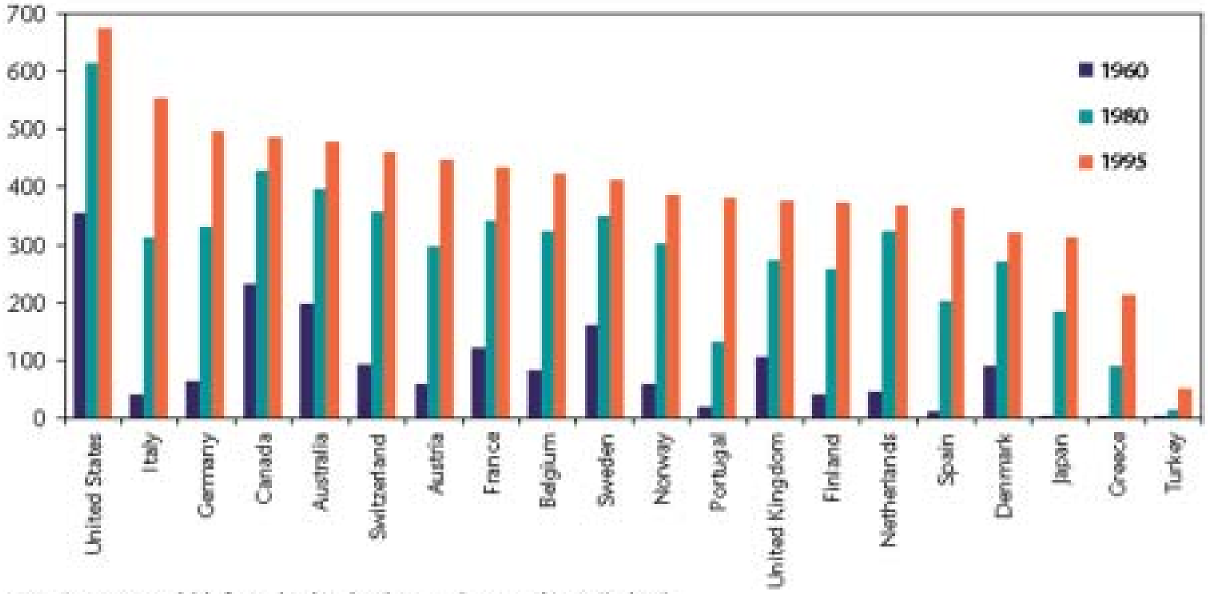
Two interrelated urban trends are observed almost universally in the developed world. First, the populations and economic activities of the cities have tended to disperse to outlying areas and, consequently, metropolitan areas have spread out, with lower-density development at the fringes. Second, ownership and use of automobiles within and around urban areas have increased. At the individual level, these trends have been driven by a strong aspira-

Figure 3-1. Indicators of transport use, 1990



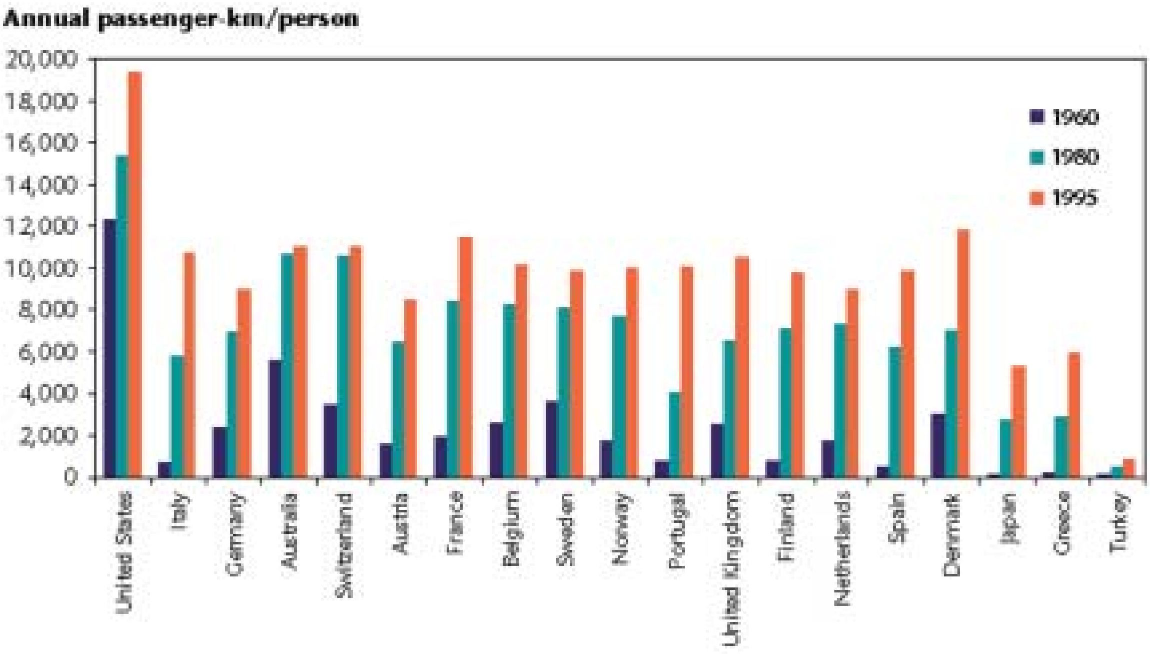
Source: Kenworthy and Laube (1999).

Figure 3-2. Ownership of passenger cars in OECD countries, 1960–1995



Note: Data not available for Iceland, Ireland, Luxemburg, and New Zealand.
Source: Updated database, based on Schafer (1998).

Figure 3-3. Use of passenger cars in OECD countries, 1960–1995



Note: Data not available for Canada, Iceland, Ireland, Luxemburg, and New Zealand.
Source: Updated database, based on Schafer (1998).

tion of city dwellers toward both lower-density living and increased personal travel as their incomes increase in real terms, and their trip-making opportunities expand through the construction of new roads.

Rising auto ownership and use. Combining complete route and schedule flexibility with comfort, privacy, and speed, automobiles symbolize to their users a very high level of mobility, significantly superior to that offered by any competing means of travel. In the decades following World War II, rising incomes and the widespread availability of affordable automobiles produced sharp increases in the number of automobile owners in the cities of the developed world. The United States is the most extreme case of this trend, with a registered motor vehicle for nearly every licensed driver. As Figure 3-2 shows, however, automobile ownership levels are high all across the developed world, and have been rising steadily in the last four decades. Further, as Figure 3-3 shows, automobile use, as defined by annual passenger-kilometers traveled per person, is also high and has been increasing across the entire developed world.

A drive toward the suburbs. The rise in automobile ownership and use parallels, and is deeply intertwined with, the growth of suburbs around the cities of the developed world after World War II. Table 3-1 details the population shifts in a number of cities as residential suburbs blossomed and inner-city neighborhoods wilted. A few cities have enjoyed some population increases, due to the redevelopment of their urban cores, but these renewals have almost never been enough to offset the overall decreases in population and density.

Urban residents seeking more space and privacy began to move to the suburbs as soon as urban train systems and affordable housing made that possible. Beginning in London in the 1850s and spreading across Europe, people followed the new train systems out of the urban core. By the early twentieth century, "streetcar suburbs" were widespread as people sought to leave the crowded, noisy, malodorous, and frequently unhealthful housing conditions of the inner city for cheaper housing in more peaceful surroundings.

In the early 1900s, the fixed patterns and limited capacities of the street railways limited the expansion of suburbs, but the growth of automobile ownership, and the suburban road networks built to accommodate it, accelerated the growth of suburbs dramatically.

The suburban migration was reinforced in some countries by national policies encouraging home ownership. As people moved to the suburbs, their employers and retail merchants followed. Cheap land was also a factor in drawing many businesses to the suburbs, where they could easily offer ample and free parking. In an environment characterized by widespread auto ownership, public transport accessibility is no longer a significant factor in the location decisions of these firms.

The dispersal of residences and jobs affected the geographic pattern of travel demands. Instead of the very

Table 3-1. The growth of selected metropolitan areas, 1960–1990

Metropolitan Area	Data for 1990			Annual Rate of Change, 1960–1990		
	Population (thousands)	Area (km^2)	Density (persons/km^2)	Population	Area	Density
Tokyo	31,797	4,480	7,097	+2.4%	+3.1%	-0.6%
New York	16,044	7,690	2,086	+0.4%	+1.5%	-1.1%
Paris	10,662	2,311	4,614	+0.8%	+2.1%	-1.3%
London	6,680	1,578	4,232	-0.6%	+0.9%	-1.4%
Detroit	3,697	2,900	1,275	0.0%	+1.4%	-1.4%
San Francisco	3,630	2,265	1,602	+1.3%	+1.4%	-0.1%
Washington, DC	3,363	2,449	1,373	+2.1%	+3.5%	-1.3%
Melbourne	3,023	2,027	1,491	+1.4%	+2.5%	-1.0%
Hamburg	1,652	415	3,982	-0.3%	+1.5%	-1.8%
Vienna	1,540	225	6,830	-0.2%	+0.8%	-1.0%
Brisbane	1,334	1,363	978	+2.6%	+5.2%	-2.5%
Copenhagen	1,153	333	3,467	-0.5%	+0.7%	-1.2%
Amsterdam	805	144	5,591	-0.3%	+1.6%	-1.9%
Zurich	788	167	4,708	+0.4%	+1.2%	-0.8%
Frankfurt	634	136	4,661	-0.2%	+1.9%	-2.1%

Source: Demographia (2001).

high-density commuting flows between a limited number of areas (a "few-to-few" pattern of trips from the suburbs to downtown) that characterized urban areas in the early twentieth century, there are increasingly scattered trips between many geographically dispersed origins and destinations, with no origin-destination pair or corridor attaining particularly dominant traffic flows (a "many-to-many" pattern). And this is the case for all trips, not just the journey to work. Nonwork travel (shopping, personal or family business, recreation, etc.) is also likely to involve destinations that are geographically dispersed in the urban fringes and the core, and so require either individual trips to scattered locations or complex trip chains that accomplish multiple purposes with one trip. Conventional public transport is not efficient in serving these kinds of trips and travel patterns.

Table 3-2. Motorways and road network in developed countries, 1970–1997

	Motorways (km)		All Roads (thousand km)	
	1970	1997	1970	1997
Australia	1,027	1,388	885	931
Austria	488	1,613	94	129
Canada	4,789	17,119	755	908
Belgium	488	1,679	94	146
Czech Republic	—	485	56	56
Denmark	198	929	63	71
Finland	108	444	72	78
France	1,553	9,900	793	893
Germany	4,100	11,309	464	656
Greece	65	529	35	41
Hungary	171	438	98	211
Iceland	—	—	11	13
Ireland	0	94	87	96
Italy	3,913	6,505	284	308
Japan	638	6,117	1,015	1,153
Luxembourg	7	118	5	5
Netherlands	975	2,225	98	126
New Zealand	100	144	92	92
Norway	41	100	72	91
Poland	139	264	295	377
Portugal	66	797	42	69
Spain	203	9,063	139	163
Sweden	403	1,324	125	139
Switzerland	651	1,613	60	71
Turkey	—	1,560	59	62
United Kingdom	1,057	3,362	322	399
United States	53,701	88,962	6,003	6,315

Source: OECD (1999a), tables 10.1B, 10.1A.

Provision of highway infrastructure. All across the developed world, the trends described above in land and automobile use have been facilitated in large part by the concomitant development of high-quality, extensive highway infrastructure. They include the United States' 41,000-mile Interstate Highway System, the 10,300-kilometer network of French autoroutes, the 8,900-kilometer system of Italian autostrada, the 11,400-kilometer network of German autobahn, and the 6,100-kilometer network of motorways in Japan (IRF 1999). From 1975 to 1995, the European motorway network as a whole grew 116%, from 23,600 kilometers to 51,100 kilometers, while the entire road system grew by 586,000 kilometers to a total of 3.69 million kilometers (Table 3-2). Integral to achieving this expansion of inter-city and urban highway networks was the establishment of effective construction funding and financing mechanisms, such as the gas-tax-funded dedicated Highway Trust Fund in the United States.

Although some of the motorways constructed in these network expansion programs served freight and passenger movements between cities, many were designed to serve urban traffic in and around cities. As people moved to the suburbs, high-capacity radial urban expressways were built to facilitate travel between the suburbs and the urban core. Similarly, as the amount of traffic between suburban locations increased, many cities developed circumferential roads to facilitate such movements. Often, the provision of road infrastructure seemed to accelerate the outward relocation of households and businesses. It was not unusual to find such roads, within a few years of being opened, carrying traffic levels that (on the basis of prior land-use patterns) had not been forecast to occur until 20 or more years of service.

At the turn of this century, there are indications that new road construction in the urban areas of the developed world is likely to be more limited than in the last five decades. For a variety of reasons, building new roads is not as easy as it used to be. Some metropolitan areas are simply running out of land, necessitating costly underground construction, as in the case of the Paris periphèrique exterieure (A-86). Even when sufficient land is available, the high cost of right-of-way acquisition serves as a powerful impediment to urban road construction. But primarily, increased environmental and social sustainability concerns relating to roads (discussed in detail in coming sections) have greatly slowed down new highway construction projects in the urban areas of the developed world.

Extent of and prospects for these trends. Many of these trends first became evident in North America and only later in other parts of the developed world. There were several reasons for this: the fact that the United States and Canada survived World War II with their infrastructure and productive capacity intact; the aggressive highway construction programs begun in the 1950s; the relatively high personal income levels that led to near-universal auto ownership; fiscal policies that subsidized home ownership; cheap gasoline; and a relative lack (compared with other developed countries) of strong land-use controls at the metropolitan and regional level.

However, the forces of urban decentralization are at work in Europe as well. Between 1970 and 1990, the share of metropolitan population living in the central city has declined in virtually every European city. It went down from 32% to 23% in Paris; from 41% to 38% in London; from 38% to 30% in Zurich; and from 80% to 67% in Amsterdam. Such declines occurred despite the fact that local governments in Europe have more control over land use, that public transport service is far more extensive, and suburban home ownership is not subsidized by the tax code. A striking example of an exodus to the suburbs is the former East Germany, where people are moving out of central cities in droves, as incomes and auto ownership rise. In Leipzig, a city of 500,0000, about 20% of city apartments are vacant, their owners having chosen to move to the suburbs — an option that was denied to them during the communist regime. Europe's middle class has moved to the suburbs — where they shop in malls, live in low-density subdivisions, and drive on traffic-clogged highways. The city as a compact urban area with clearly delineated boundaries is a thing of the past in Europe, no less than in North America. These developments are summarized in Table 3-1.

In the absence of major economic upheavals, the trends described above — those of urban decentralization and increased automobility — are likely to continue in the foreseeable future. In the developed nations, where the market is mature and car ownership levels are already high, growth in demand for cars has leveled off and consists primarily of replacement vehicles and additions of second and third household cars. However, there appears to be no similar leveling-off in the growth of travel demand. Because of declining urban densities and a dispersal of travel origins and destinations, cars are being used more intensively, i.e. for more trips and over greater distances. Between 1970 and 2000, urban automobile travel per capita increased by 30% to 35% per decade in Europe, and by about 45% per decade in the United States (see Figure 3-3 on page 3). With rising incomes, automobile use is expected to continue to increase, as our society becomes ever more mobile. Future growth in per capita automobile travel is expected to be especially pronounced in metropolitan areas, whose outward boundaries continue to expand, and whose declining population densities and increasingly dispersed travel patterns preclude an extensive use of alternative means of transportation. According to OECD forecasts, vehicle-kilometers of travel (VKT) in OECD countries are expected to grow over the next two decades (2000–2020) at 2% per year (OECD 1995a, chap. 3).

The Role of Public Transport

Public transport is an important means of mobility in the developed world, particularly in the larger and denser urban settlements. Public transport accounts for a significant share of all trips in most large cities in Japan and Western Europe and many of the cities of the United States. However, the role of public transport has been decreasing in most cities of the developed world, in large measure as a result of the trends toward automobility and suburbanization discussed above.

The extent of public transport in the developed world. Table 3-3 shows that the different regions of the developed world provide different levels of public transport. Though the regions listed do not include the entire "developed world," they give a good indication of the range of situations found. As always, at this high level of aggregation, the reliability and comparability of statistics are questionable, and the figures for the world are very broad estimates

Table 3-3. Some indicators of public transport system capacity

Region	Urban Rail (thousand km)	Buses and Coaches* (thousands)
European Union	6.8	500
United States	1.8	30†
Japan	0.8	257

Source: European Commission (2000).
*Includes local and intercity travel.
†Another 570,000 buses are dedicated to conveying students.

intended only to provide a means of gauging scale.

All three regions have urban rail systems in their major cities, although the EU heavy urban rail networks are by far the most extensive. Buses are the most important means of local public transport in Europe and the United States, but in Japan, they are less important than the railways.

In all developed countries, there are extensive taxi systems. It is difficult to obtain reliable statistics on the levels of provision because of the different types of licensing systems (or the absence of licensing). However, if all types of private-hire passenger vehicles are included, it is not uncommon to find provision levels reaching as high as one vehicle per one hundred population.

Trends in the use of public transport in the developed world. Table 3-4 shows the differences in the use of different modes of public transport across different parts of the developed world. As the data in Figure 3-1 illustrated, public transport in the United States makes, in aggregate, only a minimal contribution to mobility, while in Japan and Western Europe, public transport is a very important contributor to mobility. There are some significant differences in transit use, even between Japan and Western Europe: Europeans use rail almost ten times as much as Americans, but only a quarter as much as the Japanese. In the United States, most urban rail use in the United States is concentrated in the largest cities, and New York City alone accounts for over a third of the urban public transport ridership in the United States. Rail is heavily used for commuting in the large Japanese metropolitan areas. It is noteworthy that the number of daily rail journeys in the Tokyo/Yokohama region exceeds that in all of the Americas (that is, the area stretching from Patagonia to Alaska).

In most countries of the developed world, the role of public transport is diminishing even though absolute levels of use continue to rise slowly. For instance, in the European Union, public transport use has grown by 40% since 1970, though the population it serves grew by only 10%. Western Europeans therefore use more public transport today than in 1970, with buses leading the way, followed by rail, then urban rail. Private vehicle use has grown even more markedly, however, and consequently, public transport’s share of total trips has fallen from 22% to 14%. In the United States, public transport has also grown (albeit very slightly) since 1970, following a dramatic two-thirds reduction in ridership between the end of World War II and 1970. However, with automobile traffic growing by almost 90% over this period, public transport's market share has declined substantially. Of major metropolitan areas, New York has the largest share of person trips by public transport (7.7%), followed by Philadelphia (5.5%) and Chicago (4.2%). These shares decrease to 0.7% in Houston. Nationwide, public transport serves 1.8% of person trips and 2.1% of person-kilometers (US DOT FHWA 1990, 1995).

Over the period since 1970, bus use in Japan has stayed more or less constant, but railway use has grown by 40% despite the very rapid growth in automobile ownership from fewer than 100 automobiles per 1,000 population to almost 400. However, automobile use in Japan is low, being barely two-thirds of that in the European Union countries and very much lower than that in the United States.

Public transport operations. Across most of the developed world, local public transport is managed by public institutions. Sometimes the government provides a public transport system on its own initiative, and other times the public sector takes over financially troubled private operators. The latter was particularly common in the United States, where public transport services (initially dominated by streetcar operations) were provided by private enterprise. In France, local public transport services (outside of Paris, Marseilles, and a few other cities) have long been provided by private operators franchised by local government agencies. In recent years the rest of Europe has begun to emulate the French example, and the privatization of public transport is expanding rapidly.

The degree of privatization, and whether it extends to both train and bus systems, varies widely among different countries. In the United Kingdom, outside London, bus services are fully deregulated, with the public sector's role confined to ensuring the provision of services deemed socially necessary. But the more general model for bus operations is for a public-sector client to specify the service requirement and then procure this competitively from private operators. Securing private competition for

Table 3-4. Some indicators of public transport mobility (km/capita/year)

Region	Urban Rail	Bus and Coach*
European Union	110	1,100
United States	75	250/845†
Japan	254	755

Source: European Commission (2000); US DOT, BTS (1999).
*Includes local and intercity travel.
†The higher figure includes dedicated school bus services.

rail transport is more difficult, but it has been achieved in Sweden and the United Kingdom. The evidence regarding the success of privatization efforts thus far is mixed. In most instances, costs to the public purse have been reduced. In some instances service levels have also improved, but there are conspicuous examples of the opposite having occurred. Certainly the effects have not been uniform, and concerns relating to safety and long-term economic viability remain. In the United States,
conditions on the use of federal grants have made the introduction of competition more difficult. Most local public transport operations (other than school buses) remain in the hands of public operators, although the contracting out of public transport management functions is quite common in medium-sized and small metropolitan areas.

Nonmotorized Transport (NMT)

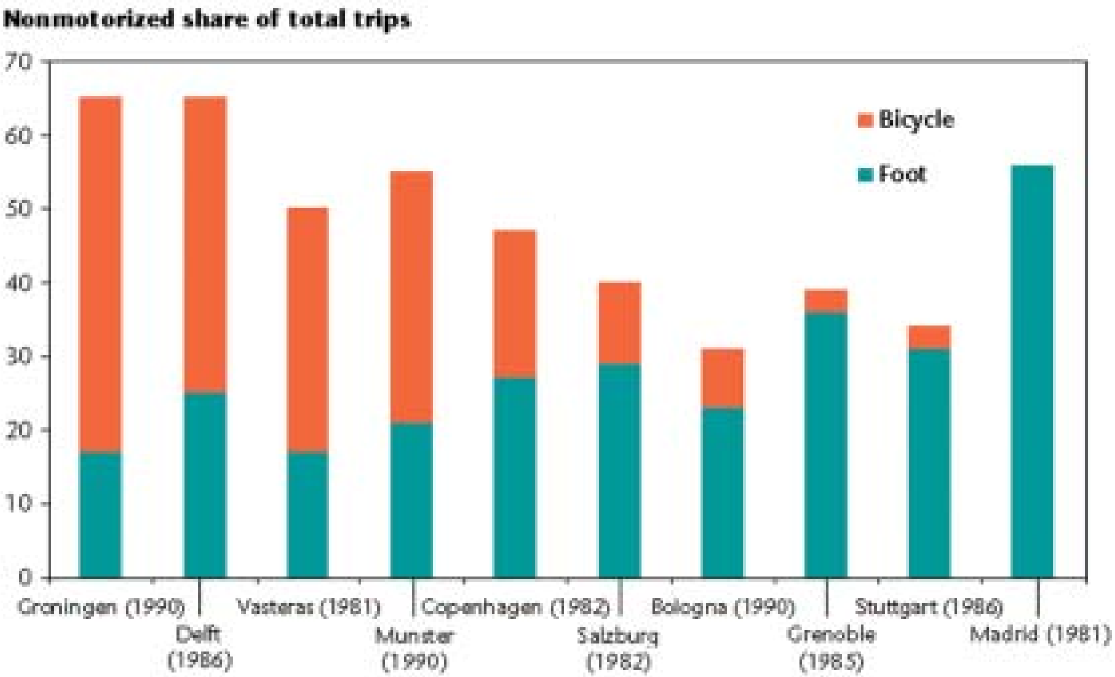
In almost all cities, walking is the most prevalent mode of transport for trips less than 1 kilometer or so in length. In gentle terrain, bicycling is generally agreed in principle to be a competitive mode for trips up to 5 kilometers or more; however, bicycle usage varies considerably from city to city. Figure 3-4 shows data for a number of European cities that suggest that walking and bicycling together account for a significant share of total trips in a number of cities. Available data suggest nonmotorized transport is less important in the United States, accounting for about 6.5% of trips and 0.5% of trip-kilometers for local trips — i.e., trips shorter than 100 miles — in the country as a whole (US DOT BTS 1999).

There are many reasons for the varied popularity of walking and bicycling. Some of the differences can be attributed to local topography and climate, but tradition and culture play a role, as do transport and land-use policy.

SUSTAINABILITY CONCERNS

Though the widespread ownership and use of private automobiles produce widespread benefits at many levels — increased personal mobility, regional development, and greater access to social and economic opportunities — they are also responsible for a number of negative developments that raise serious sustainability concerns. An automobile-dominated transport system leaves some members of the society behind because they are too poor to own a car, physically incapable of driving, or too old to handle a car safely. Urban motorways, built to accommodate increased traffic, divide and disrupt urban neighborhoods. The rising use of motor vehicles and rising travel demand can lead to deteriorating air quality and greater emissions of greenhouse gases, accelerated depletion of fossil-fuel reserves, higher accident rates, and mounting traffic congestion. Public opinion everywhere views traffic congestion as the consequence of motorization that most seriously affects the environment and the quality of life. Congestion and delay not only waste time and are a major irritant to individual travelers; they also burden businesses and the economy with higher costs. Indeed, the vitality of national economies is

Figure 3-4. Role of nonmotorized transport in selected European cities



Source: Krag (1993).
Note: Bicycle information not available for Madrid.

intimately linked to a smoothly functioning transportation system.
We now summarize the nature of those concerns at the beginning of the twenty-first century. We will first review those aspects most closely tied to vehicle technology (accidents, emissions, noise, etc.), then look to wider social impacts, including increased levels of traffic congestion.

Road Safety

The cost in human lives, injuries, and suffering attributable to highway and road crashes is enormous. Toward the end of the 1990s, around 42,000 people were killed each year in road accidents in Western Europe, and between 40,000 and 45,000 in the United States. In some countries, road accidents are the primary cause of death in the 15- to 30-year-old age group. The number of people seriously injured in road accidents is typically more than ten times higher. Road accident victims are not just motorized vehicle drivers and occupants, but also include pedestrians and bicyclists. In developed countries, these groups account for roughly 10% to 15% of the total number of road fatalities. Between half and three-quarters of the highway fatalities in developed countries occur outside of urban areas; however, even one-quarter of these totals attributable to motor vehicle accidents in urban areas is a large amount.

There are various ways of estimating the monetary costs to society of road accidents; the different methods vary in the way they account for pain and suffering and economic losses. Estimates of accident costs in most developed countries are typically in the range of 1% to 3% of GDP.

During the last decade, all industrialized countries have made important strides in reducing highway fatalities — down 25% in Western Europe and 30% in the United States — a trend attributable to a combination of safer vehicles (dual air bags, mandatory safety belts, antilock brakes, etc.), safer highway designs, faster incident response, and better post-accident care. All of these trends are expected to continue into the foreseeable future.

Integrating Sustainability Concerns into the Transportation Planning Process: The US Experience

In the United States, as in other developed countries, the battlegrounds on which the initial skirmishes over highway development were fought in the 1960s and 1970s were proposals to build high-speed, limited-access highways through already-developed metropolitan area corridors. Often, the planned routes would require taking over land already used for residential or commercial purposes. Critics pointed to the likely displacement of established homeowners and neighborhoods, to increased local noise and noxious emissions, to greater congestion and decreased pedestrian safety on nearby local streets, and to the sometimes adverse social and aesthetic consequences of new urban highways. And in the highly charged racial climate of the times, the debate took on racial overtones, too, sometimes characterized as “building white folks’ roads through black folks’ bedrooms.”

A legal avenue through which the opposition to further urban highway construction could be channeled was provided by the 1969 National Environmental Protection Act (NEPA), which required “environmental impact statements” to be prepared for all proposed “major federal actions significantly affecting the quality of the human environment.” The courts’ interpretations of NEPA provided an effective weapon in the opposition to the urban highway plans: Many of the proposed links were abandoned within metropolitan areas, while others were restricted or rerouted in some way.

With the battle joined primarily over limited access highway construction plans, it was inflamed by two other issues or developments: automotive emissions (for which the legal catalyst in the United States was the 1970 Clean Air Act amendments) and the OPEC-driven oil shortages of the early 1970s. Public policy focused on cleaning up the exhausts of private vehicles and making them more fuel-efficient. While the Clean Air Act amendments did pay some attention to modifying vehicle usage patterns (calling for “transportation control policies” in major metropolitan areas), by far the most attention was placed on encouraging technological adaptations of the internal combustion engine to reduce noxious emissions and improve fuel economy. The US federal government has found it considerably less risky to promote a policy of salvation through technology — by placing pressure on the automotive manufacturing and fuel production industries to adapt their products — than to pressure drivers into changing their behaviors through sharply increased prices or driving restrictions.

Nonrenewable Resource Consumption

Current vehicle propulsion technologies are based on the combustion of petroleum-based fossil fuels. Transport is not only the major, but also the most rapidly growing sector of oil consumption in OECD countries. Between 1973 and 1988, transport’s share of total oil consumption in OECD countries grew from 43% to 60%. Light- and heavy-duty road vehicles —passenger cars, light trucks, motorcycles, and heavy trucks — use approximately 75% of all transport fuel. Through the effects of stricter government standards, higher fuel prices, and voluntary efforts by vehicle manufacturers, there have been notable improvements in vehicle fuel consumption and carbon dioxide emission rates over the past several decades. Much of the initial impetus for these efforts was provided by the oil crisis in the 1970s. The greatest initial reductions in fuel consumption predictably occurred in the countries with the most fuel-inefficient fleets, i.e., the United States, Canada, and Australia. In the United States, the fuel consumption of new light-duty vehicles (automobiles and light trucks) declined by an average of 3% per year between 1978 and 1987.

Table 3-5. Changes in emissions of atmospheric pollutants

	European Union 15, 1990–1996		United States, 1990–1997		
	Total Change	Highway Transportation	Total Change	Highway Transportation	Current Status
Carbon monoxide	-20%	-26%	-4%	-11%	Primarily an infrastructure design issue in the construction of tunnels, etc.
Oxides of nitrogen	-10%	-14%	+3%	+11%	Concerns abated to some degree with development of advanced technologies.
Sulfur dioxide	-43%	-21%	-17%	-41%	Expected to decrease to marginal levels.
Volatile organic compounds	-13%	-25%	-10%	-16%	Role in ozone production a serious concern.
Lead	n.a.	n.a.	-21%	-95%	Phased out of use in most of the developed world.

Sources: European Commission (2000); US EPA (2000a).

In the United States, average new light-duty vehicle fuel consumption reached its low point of 9 l/100 kilometers in 1987. Since then, it has been increasing, in large part because of growing sales of light trucks, minivans, and sport utility vehicles (SUVs). While engine efficiency is continuously being improved, consumers often prefer to exchange some or all of the potential fuel efficiency gains for increased performance characteristics, such as increased power and torque. Moreover, changes in safety regulations sometimes lead to increased vehicle weight, resulting in higher levels of fuel consumption. By 1999, the average fleet new vehicle fuel economy had risen to 9.6 l/100 kilometers (US DOT, NHTSA 1999a).

Due to the slow rate of fleet turnover, the fuel consumption of the on-road fleet is higher than that of the new vehicle fleet whenever the latter is falling. In 1995 it is estimated that the fuel consumption of the on-road light-duty vehicle fleet was 9.5 l/100 kilometers in OECD Europe, 11.4 l/100 kilometers in OECD North America (the United States and Canada), and 10.0 l/100 kilometers in OECD Pacific (Australia, New Zealand, and Japan). Including the other road vehicle types (motorcycles and heavy trucks) raises these figures to 10.1 l/100 kilometers for OECD Europe, 13.5 l/100 kilometers for OECD North America, and 13.3 l/100 kilometers for OECD Pacific (OECD 1995a, Annex).

Carbon Dioxide Emissions

In the developed world, transport is one of the few industrial sectors for which CO_2 emissions are growing. It has been estimated that transport activities account for roughly 28% of total worldwide CO_2 production by humans. The share of transport in total CO_2 production is slightly higher in North America (roughly 33%) and slightly lower in Western Europe (roughly 24%). The United States alone accounts for roughly 24% of total global CO_2 emissions,[1] so the US transport sector emits roughly 8% of the total world output of CO_2.

In 1998, the auto industry in Europe signed a Voluntary Agreement with the European Union to reduce corporate CO_2 emissions of the new car fleet from an average of 186 g/km in 1995 to 140 g/km in 2008 (DEFRA 2000). It is likely that manufacturers will rely heavily on sales of diesel engines and smaller cars to reach the target. However, total transport-related CO_2 emissions are closely connected to the total amount of fuel consumed. This depends, in turn, upon the number of transport vehicles, and the intensity of use of these vehicles in addition to the in-use efficiency of the average transport vehicle. Transport-related CO_2 emissions are expected to rise in all OECD countries at least through 2015. Average vehicle fuel consumption is expected to decline, but this decline is projected to be overwhelmed by increases in the number of vehicles and in the intensity of their use (OECD 1995a, chap. 2).

Noxious Emissions

Concern about local air pollution caused by automobiles was one of the original sustainability concerns related to automobile use in most of the developed world. During the last 30 years, most industrialized countries have adopted vehicle emission control measures in an effort to control and abate deteriorating air quality in urbanized areas. Preventive measures include exhaust emission standards, evaporative emission controls, fuel quality requirements, inspection and maintenance programs, and refueling controls. These control measures have resulted in substantial reductions in vehicle emissions (see Table 3-5), and in an overall improvement in air quality as measured by the declining number of

Table 3-6. Farebox recovery ratios for selected cities in developed countries

City	Agency	Type of Organization	Operating Costs Covered by Fares
London	LT	Transport authority	90%
Tokyo	Toei	Transport authority	86%
New York	NYC Transit	Transport authority	63%
Tokyo	TRTA	Rapid Transit authority	75%
Munich	MVV	Transport authority	51%
Paris	RATP	Transport authority	43%
Milan	ATM	Municipal authority	37%
New York	PATH	Transport authority	48%
Berlin	BVG	Municipal authority	33%

Source: London Transport (1998); US figures updated using US DOT FTA (1999).

days that pollutants in the air exceed recommended levels.

According to OECD estimates, HC and NO_X emissions in OECD countries will fall substantially during the period 2005–2010 (OECD 1995a). Beyond that point, however, the OECD forecasts suggest if present trends continue, emissions of HC and NO_X will start increasing as vehicle-kilometers traveled increase, and will be above their 2000 levels by 2030. For CO, if present trends continue, levels will fall until 2010, level off, and then start increasing again.

Vehicular Noise

Most developed countries have had vehicle noise emission regulations since the 1970s. Technological progress in engines and exhaust systems has made new vehicles considerably quieter. For example, the EU allowable noise level of a modern truck is approximately equivalent to that of the typical car in 1970 (European Commission 2000). Nonetheless, according to a statement issued in June 1999 by European Health, Environment and Transport ministers, transport — and in particular road traffic — remains the main cause of human exposure to ambient noise. The proportion of the population in the European Region exposed to “high” noise levels (equivalent to 65 dBLAeq over 24 hours) increased from 15% to 26% between 1980 and 1990. And about 65% of the European population is estimated (WHO 1999) to be exposed to noise levels leading to serious annoyance, speech interference, and sleep disturbance (55–65 dBLAeq over 24 hours).

Besides vehicle engines and exhausts, much of the noise produced by vehicles today, particularly in highway operations, results from the movement of vehicles through the air, and the contact of tires with the road. The former can be reduced by aerodynamic vehicle body designs (which also have the effect of improving fuel efficiency and reducing emissions). The latter can be reduced through tire tread designs and improvements in pavement surface textures (which also have the effect of draining water more effectively and so reducing accident risks). Noise barriers can also minimize the impact of vehicle-generated noise on nearby activities.

Economic Viability of Public Transport

The inability of local public transport across most of the developed world to recover costs raises a concern about its economic sustainability. Most local scheduled surface public transport operations in developed countries are unable to meet their operating costs from commercial revenues. Table 3-6 gives an indication of the extent to which public transport operating costs are covered by fares in a number of large cities.

Differences in accounting practices make direct comparisons difficult. The London costs, for example, include depreciation, renewals, and private financing charges as well as direct operating costs. Not all of these charges are necessarily included in the cost totals used to calculate the farebox ratios for other national agencies. However, the necessity of substantial external funding for urban public transport operations is quite clear. In the United States, passenger fares cover just less than 40% of operating costs; in Europe, this ratio is closer to 50%, and in Japan the figure is probably somewhat higher than this. In addition to operating costs, capital expenditure is frequently aided by public grants, although many agencies also use loans and bond issues to finance capital projects, and these have to be funded from their revenue accounts.

The total sums involved can be considerable. The United Kingdom, with perhaps one of the least subsidized public transport systems in the developed world, receives about US$3.5 billion per year in external funding,[2] which is equivalent to US$0.50 per journey or US$0.04 per passenger-kilometer. Elsewhere, subsidy rates are usually significantly higher than this. In the United States, for example, governmental funding for public transport exceeds US$8 billion per year, giving support rates in excess of US$1.00 per journey and US$0.13 per passenger-kilometer.

In effect, public transport needs significant public subsidies to operate. There are certainly many reasons to provide public transport with public support, and there is little risk that the inability to recover operating costs would force the suspension of public transport service in any major metropolitan region in the developed world. However, subsidies and the resulting levels of service are often vulnerable to the vicissitudes of public opinion and varying levels of political support for public transport. Consider, for instance, the example of GO Transit, the public transport system serving the Toronto metropolitan area. Long heralded as a leading example of an effectively governed, well-managed system with high ridership in North America, GO (despite fairly high, mandated farebox recovery ratios) has been so starved of capital expenditures in recent years that it now faces serious service and maintenance problems (IBI 1999).

Ambivalent Public Attitudes to the Social Impacts of Private Vehicle Use

As a result of the debate and attention to these matters over the last third of the twentieth century, there is now a widespread public awareness in the industrialized countries that private vehicle use contributes significantly to air quality problems, global warming, petroleum depletion, accidental deaths, and so on. Surveys frequently express significant public concerns about these matters, and concerns about the social costs of private vehicle use have led to a quite remarkable shift in governmental transport investment policies over this time period.

Yet for the great majority of the population, expressed concerns rarely translate into modifications of personal behavior. The same public continues to use private vehicles profligately, and shows very few signs of adjusting the values by which personal transportation decisions are made. In particular, consider the use of public transport over the automobile. A study analyzing the effect of zero fares on public transport ridership in selected cities in the United States found that even free public transport had only a modest impact on ridership (Domencich and Kraft, 1970, p. 85). To attract a significant number of riders away from the automobile, the study concluded that travelers would need to be paid not to use their cars and instead use public transport. In other words, the provision of public-transport capacity at a highly subsidized price does not guarantee its use, even when roads are congested and it is shielded from such congestion. There is little relationship between improved service and lower fares on public transport, and private use of automobiles. People like driving their cars, and there is little that democratic governments can do to lure them to public transport. Restrictions on parking availability and high charges for auto use may be required for people to switch from driving to taking public transport. What is sometimes characterized as the public's "love affair" with the automobile might be described more accurately as a "love-hate relationship." Altschuler (1975) has convincingly rationalized this paradox in a US context:

> The consumer does not want government to interfere with his life. He is receptive to having government provide improved service — e.g., public transport — but he will oppose having government disrupt his neighborhood, harm his environment, or make it difficult for him to drive. The status quo is the thing. Citizens oppose new highways because they disrupt existing neighborhoods, social patterns, and natural ecologies. They oppose programs to reduce auto travel because such programs would disrupt established life styles and travel habits. They can adjust to inconvenience if they have to, but they are angry if they feel that their elected representatives could have averted the need — or, even worse, deliberately created it.

Creation of Transport-Disadvantaged Social Groups

Because of the great reliance on private vehicles for transport in developed societies, people who cannot afford to buy or lease a vehicle, as well as those who, because of physical or mental handicaps, cannot operate one, may find themselves seriously disadvantaged in their ability to get to jobs or services, or to take care of other needs. Children and teenagers as well as elderly adults may also suffer from the automobile-orientation of the transport and land-use systems.

This effect is particularly perverse in the case of people kept by poverty from owning a private vehicle. The system limits their access to the very job opportunities that could provide the means of improving their economic situation and rising out of poverty.

Although many public transport systems are adapting vehicles and stations to accommodate the needs of riders with disabilities, the origins and destinations of these riders may not be conveniently served by the public transport system. Problems of access to, and egress from, the system are even more dissuasive for these riders than for the general public. Special-purpose, often door-to-door demand-responsive systems can meet some of their needs but generally require significant advance booking and do not provide tight schedule guarantees, so they may be less convenient in some ways than conventional public transport.

Increasing suburbanization and the living patterns of older adults suggest that the automobile will be of growing importance to the next generation of retirees. However, many older people have special transport needs that may not be well met by an automobile-dependent system. Countries in the European Union as well as

Japan and the United States will experience significant population growth, both in real numbers and in the proportion of older people. The number of people in Europe over 60 is expected to grow by 66% to 116 million in 2025, from a 1996 base of 77 million. In Germany, France, and the United Kingdom, between 15% and 17% of the population is over 60, with trends indicating rapid aging over the next two decades. Italy has the distinction of being the oldest nation within Europe — defined as the proportion of people over 60 coupled with the lowest fertility rate. Italy now has more people over age 60 than people 20 and younger. Similarly, Japan's population leads most of the world in the number of older adults. The number of Japanese over age 60 is expected to grow by 65% over the next 25 years, from 26 million to 40 million. The US baby-boom population totals nearly 80 million people. As this group ages, the number of people over 60 will nearly double in 25 years. There are more than 44 million people over age 60 today in the United States; their number is projected to increase to well over 80 million in 25 years.

As the population grows, cars driven by the elderly will constitute an increasing proportion of traffic, especially in the suburbs and in rural areas, where many elderly people tend to reside. Addressing the issue of millions of drivers in their late 70s and beyond involves a tough trade-off between safety and mobility, between the risk to life and the risk to quality of life. Overall, older drivers spend far less time on the road than younger drivers and have fewer accidents. On the basis of accidents per miles driven, however, they have a higher rate of crashes. The rate rises after age 75 and increases significantly after 85. The driver fatality rate shows that drivers over 75 years of age are more vulnerable than any other age group except teenagers. Factors like vision and hearing impairment, disorientation, memory disorders, and side effects from medicines are largely responsible.

Understandably, most elderly people want to hold onto their cars and driver's licenses as long as possible. A valid driver's license is as much a certificate of continued vitality and independence as it is a mobility necessity. To have to give up driving is viewed as a step toward dependency and isolation. While some countries have adopted stringent procedures aimed at identifying unsafe elderly drivers and getting them off the roads, public attitudes toward the treatment of elderly drivers are shifting, as the younger generation confronts the reality of sustaining the mobility of their own elderly parents. There is a growing sentiment that it is both unreasonable and unfair to expect elderly people to give up their cars, since doing so would be tantamount to sentencing them to a life of imprisonment in their homes. Instead, one increasingly hears demands that society must find ways to make it safe for older people to continue driving. To a significant extent, that is why the focus of debate has shifted in the last few years. While there still are calls to get unsafe older drivers off the road, far more attention is being paid to help elderly persons stay on the road.

Community Disruption

Although more difficult to quantify, the increasing orientation of the urban transport system toward private vehicles can have additional effects on the quality of community life. As we have seen, the more flagrant cases of this provided the initial rallying call for the “freeway revolt” against urban highway expansion in the United States. Urban motorways were sometimes built through the middle of established communities (most frequently those with insufficient political power to oppose that alignment), in effect dividing the community and constructing a physical barrier between the two halves.

More generally, in a community dominated by private-vehicle travel, there are relatively few opportunities for serendipitous interactions between residents, because when people leave their homes they isolate themselves in cars. This can lead to a loss of sense of community and social cohesion. To attribute such developments entirely to automobility would be a gross distortion, yet there is a palpable, if inchoate sense that the increased use of cars over longer commutes has led to a more harried, less friendly society.

Traffic Congestion

The general public views traffic congestion as one of the most vexing drawbacks of a widely automotive society. Moreover, though highway traffic congestion is a subject that is sometimes sensationalized, there is growing evidence that congestion is increasing in intensity, duration, and geographic coverage across the developed world. According to the *2001 Urban Mobility Study* published by the Texas Transportation Institute (TTI 2001), the average annual delay per person in the United States has climbed from 11 hours in 1982 to 36 hours in 1999.[3] An OECD study that uses average daily vehicle-kilometers per road-kilometer as a proxy measure of congestion concludes that congestion is also increasing in Europe (OECD 1999b).

Further, there is evidence that congestion has gone from being essentially a localized peaking problem — stemming from too many drivers trying to use a limited number of critical road links at critical times; i.e. “rush hours” — affecting a few drivers, to becoming a more widespread phenomenon that affects most drivers. For instance, a 1992 study of US congestion found that the percentage of peak-hour urban interstate travel that occurred in congested conditions increased from 40% in 1975 to close to 70% by 1990 (TRB 1994). Changing urban travel patterns, particularly the increasing role of suburb-suburb trips, are responsible for many of these trends. Congestion resulting from suburb-suburb trips has a different pattern from the localized severe “rush-hour” congestion on radial links to central business districts; it tends to spread in time and space.

The consequence of these trends, as the Texas Transportation Institute (2001) and OECD (1999b) studies demonstrate, is that urban residents are spending double and triple the amount of time in congested traffic that they did only 20 years ago. Wasting hours each week in congested traffic is a deeply frustrating and fruitless use of time for adult urban residents. The economic, social, and environmental costs to society of thousands of drivers driving slowly on congested highways and major thoroughfares are considerable; the drivers are unable to perform productive economic endeavors, or to engage in beneficial recreational activities with family and friends, while their automobiles produce substantial amounts of airborne pollutants. Unfortunately, because of the growth of suburbs and the inability of public transport to serve them, the staunch opposition to new highway construction, and individuals' visceral attachment to driving in their own cars, an equitable, politically palatable solution to urban congestion remains elusive.

MITIGATING STRATEGIES

Every industrialized nation has worked to develop policies to mitigate the adverse effects of motorization without impairing the continued growth of mobility. In this section we describe the most common of these strategies, highlighting best practices and particularly successful applications. The mitigating strategies can be classified under six broad categories: (1) reducing the demand for automobile use; (2) improvements — both physical and operational — in the provision of highway and public transport infrastructure; (3) improving the transport options available for travelers; (4) using innovative land-use and urban-design strategies to reduce travel demand; (5) integrated approaches that combine multiple strategies; and (6) "civilizing" the motor vehicle by modifying its design to increase safety and crashworthiness and reduce emissions and fuel consumption. The discussion that follows will address all but the last strategy, which is covered at length in Chapter 2.

Each of these broad categories includes multiple strategies. For instance, the demand for automobile use can be reduced in a number of ways: automobiles can be priced to reduce demand; more environmentally sound paradigms of vehicle ownership and use can be encouraged; and automobile use can be restricted. Similarly, supply-side improvements could include building new infrastructure, as well as operating and managing existing infrastructure more efficiently.

Reducing the Demand for Auto Use

Over the last three decades, the negative effects of the auto have spurred the creation of several strategies to ameliorate these effects by reducing the demand for automobile travel. They include direct restrictions on auto use as well as a number of innovative ideas that are more nuanced in their approach.

Transportation Demand Management. Transportation Demand Management (TDM) is a set of techniques that aim to reduce or redistribute travel demand, curtail solo driving, and decrease auto dependency. Typical TDM techniques include promotion of carpooling, flexible working arrangements, telecommuting, road pricing, and time-saving high-occupancy vehicle (HOV) lanes. In recent years, metropolitan regions in several developed countries have adopted TDM as part of their transportation plans. In the early 1970s, several US corporations initiated voluntary carpool programs in response to appeals to conserve fuel during the energy crisis. More recently, corporations have offered flexible working hours, telecommuting, and other actions aimed at reducing or redistributing commuter travel demand. California and certain metropolitan areas of the United States mandated ridesharing programs during the 1980s, but later

"Foregone Travel" Due to Telecommuting or Home-Based Work

Telecommuting is often promoted for its potential to reduce demand for automobile travel. This has been especially so in the last decade, as the use of such communication technology as mobile telephones, email, and the Internet has proliferated. Working full time at home and telecommuting have become practical options for many workers. Workers now regularly go online to access information, transfer work documents, communicate with other project staff, and make electronic purchases of business supplies and services from in-home offices.

However, this technology revolution has thus far not been accompanied by any noticeable decrease in travel. Some analysts suggest that non-technology-related constraints limit the potential of telecommuting to reduce travel demand. The choice of whether to telecommute depends on both external constraints such as lack of job suitability, management willingness, or appropriate technology, and internal constraints such as desire for workplace interaction, insufficient self-motivation to work alone at home, and concern about visibility for advancements.

Further, data from the US Nationwide Personal Transportation Survey as reported by Eash indicate that home-based workers tend to travel roughly the same amount as traditional commuters, but differ in how their travel is distributed among trip purposes. Telecommuters generally reduce their travel by approximately 30% on days when they do not commute to a work location. However, shifts in trip purposes and departure times are the more likely travel impacts of information technology than reductions in vehicle-kilometers traveled.

Source: Eash (2001).

terminated them in the face of widespread public opposition. Modest TDM programs also have been implemented in Australia, Canada, and the Netherlands.

Evidence over the past two decades reveals that demand management has a limited influence on travel behavior; not unusual are the results of an evaluation of efforts in the San Francisco Bay Area which estimated that "conventional" TDM (excluding road pricing options) had the potential to reduce total fuel use and emissions by about 7% to 8% (Harvey and Deakin 1991).

City center automobile restrictions. Automobile restrictions have won acceptance as a legitimate technique of congestion management and as an instrument of achieving sustainable mobility in crowded city centers. They are employed in more than 100 cities of Europe, North and South America, and Asia as documented by OECD surveys (OECD 1984). Center-city restrictions vary in duration, scope, and severity, ranging from temporary traffic prohibitions in commercial districts during shopping hours to permanent closure to vehicular traffic in entire historic town centers ("car-free zones"), as in Vienna, Austria; Munich and Bremen, Germany; and Bologna and Turin, Italy.

More drastic restrictions, involving outright bans on automobile use in center cities, have been instituted when pollution reaches unhealthful levels. In Athens, Mexico City, and during a September 1998 pollution inversion incident in Paris (cool air trapped by warm air above it, which keeps pollution from dispersing), authorities banned cars from entering the city center on alternate days, according to whether license plates ended with an odd or even number.

Traffic calming. In residential areas, there are a variety of regulatory and physical "traffic-calming" measures used to slow down and discourage through-traffic. The roots of the movement to reduce or "calm" vehicular traffic can be traced to Western Europe, where concern about traffic and the political will to act upon it surfaced in the early 1970s. The Netherlands pioneered the concept of the *Woonerf* — protected residential areas in which pedestrians had absolute priority over vehicular traffic; and German cities introduced the concept of *Verkehrsberuhigung* (the origin and literal translation of the term "traffic calming") — a policy of limiting the use of autos in residential areas using an array of techniques, such as diverting through-traffic, limiting parking to designated areas, installing physical speed restraints and declaring certain areas off-limits to the automobile. In the last decade, many regions in the United States have adopted physical design measures to dissuade motorists from cutting through residential areas en route to and from work.

Traffic Calming — A US Example

In Montgomery County, Maryland, a prosperous suburb adjacent to Washington, DC, that has experienced rapid growth in the last two decades, county authorities responded to complaints from residents and neighborhood groups about growing commuter cut-through traffic by installing "speed humps." These are raised mounds in the pavement that force drivers to slow down to 15–25 mph, depending on design. Other techniques used by Montgomery County include "chokers" and small traffic circles (also known by the British term, "mini-roundabouts"). The former create an illusion of a narrower street and act as a psychological deterrent to excessive speed; the latter oblige motorists to slow down at each intersection as they negotiate the tight turns of the traffic circle. In the last three years the Montgomery Transportation Department has installed about 1,000 speed humps and a few dozen intersection mini-circles in residential neighborhoods throughout the county.

The rebirth of the city car. The launching of Renault's Twingo, Fiat's Cinquecento, Volkswagen's Lupo, and DaimlerChrysler's A-class and Smart models in the late 1990s marked a rebirth of the ultra-compact "city car" compatible with the crowded urban environment. Unlike their 1970s precursors that were spartan in appearance and aimed at young, budget-conscious drivers, the current generation of "minis" are designed to appeal to more affluent customers. Sales figures over the past several years, and the interest stimulated by the launching of DaimlerChrysler's Smart, suggest that the city car has found a market niche among European car buyers who want a small, maneuverable, and fuel-efficient car but also desire style, fun, and a good driving experience. This favorable market reception is being reinforced by government/industry-sponsored field tests of small electric and hybrid city cars such as Renault's Praxitèle at Saint Quentin-en-Yvelines near Paris, Fiat's Elettra Park in Turin; and Honda's City Pal in Motegi, Japan.

Car sharing: Separating ownership from use. Leasing cars on a short-term basis, otherwise known as "car sharing," is another strategy aimed at reducing the impact of cars in cities. Car sharing gives urban residents access to cars without requiring them to own one. The concept works because members of car-sharing organizations do not depend on cars for everyday use. The typical member of an auto cooperative is a young, single, city dweller who needs personal transportation only occasionally. Car-sharing projects can generally be divided into three types: single-port systems (where users return the vehicle to the place where it came from), dual-port systems (to commute between two stations), and multiport systems (where the user can leave it at any other port). Most existing car-sharing cooperatives are single-port

Japanese Experiments with Shared-Use Cars

In October 1997, Honda Motor Company launched the Intelligent Community Vehicle System (ICVS) at their Motegi site. The ICVS provides several lots from which users (Honda employees) can select four different types of electric vehicles for short-term rental. Smart cards unlock and start the car. User fees are calculated automatically and deducted from the users' stored value cards. The lots and vehicles are outfitted with AVI technology, which allows the ICVS management center to monitor vehicle location in real time. Vehicles are equipped with an auto-charging system that instructs the vehicles to dock at a charging terminal when batteries are low.

systems. Multiport systems remain technically challenging to implement because of the difficulty associated with keeping the vehicle offer in balance over the various ports given differing levels of demand across time and location.

Auto cooperatives have been multiplying rapidly in Switzerland, Germany, Austria, and the Netherlands. While early auto cooperatives appealed primarily to environmentalists and community activists wishing to declare their independence from the automobile, the current clientele is motivated more by personal convenience and cost savings than by ideological convictions. Car-sharing efforts in North America are still in their infancy, though fledgling car-sharing initiatives have sprung up in several cities in the United States, including Portland, the San Francisco Bay Area, Seattle, and Cambridge, and in Quebec City, Montreal, Toronto, and Victoria in Canada.

Though car sharing is an interesting and innovative experiment, it is not currently expected to make a large reduction in the demand for personal automobiles in the industrialized countries. A study commissioned by the Swiss energy office estimates a market potential for car sharing of not more than 1.5% of the driving population (Hormandinger 1997).

Fuel taxes: Pricing automobile use appropriately. Appropriate pricing of the automobile as a tool toward achieving sustainability is a long-cherished goal of many economists. They argue that sustainability concerns arise because auto users capture all of the benefits of their trips, but pay only a fraction of the costs. In particular, drivers don't pay for the pollution, noise, and CO_2 they produce, the congestion delays they impose on other travelers, or the risks of accidents associated with their driving. Economists theorize that if drivers were asked to pay these costs through appropriate ownership and use charges, they would be more discerning in their travel choices. Lower and more sustainable levels of auto use in the aggregate would follow as a consequence.

Economists promote fuel taxes as a good (though not perfect) proxy for a "use" charge on gasoline use and consequently, for various pollutant emissions. The theory is that higher gas taxes influence consumer behavior in a myriad of complex ways. In the short term, consumers react by curtailing automobile use. The empirical evidence suggests that short-term effect is relatively minor — a 10% increase in fuel price translates to a 2% to 3% reduction in total automobile travel (Graham and Glaister 2001).

However, such automobile use differences understate the total impact of fuel taxes on sustainability. As the cost of gasoline consumption increases, consumers buy lighter, more fuel-efficient cars, thus reducing their gasoline consumption per kilometer traveled (though doing so causes somewhat of a rebound effect, as the impact of a higher fuel charge is reduced on a per-kilometer-traveled basis), and organize their lives (including where they live) in order to drive less. In turn, smaller and lighter cars make less of an impact if they are involved in accidents (though conversely their ability to protect passengers from other heavy vehicles is also reduced), and organizing housing decisions to drive less produces more compact suburbs and cities.

Indeed, empirical analyses of the effects of price on gasoline consumption in the OECD countries indicate that price increases have a very significant effect on gasoline consumption (and thus CO_2 emissions). Though the range of estimates varies significantly across studies and across different countries, the evidence suggests that a 10% increase in gasoline price has the effect of reducing total gasoline consumption by 6% to 8%, with much of the reduction a consequence of consumers choosing to use relatively fuel-efficient automobiles (Graham and Glaister 2001). Indeed, an analysis of the impacts of gasoline price changes between 1960 and 1985 suggests that among the OECD countries and in the United States, Canada, Ireland, and Finland, a 10% increase in gasoline prices would be accompanied by at least a similar reduction in total gasoline consumption (Sterner and Dahl 1992).

Wide variations in fuel taxes across the industrialized countries facilitate some understanding of the aggregate effects of fuel taxes on gasoline consumption. Gasoline prices in Western Europe are between two to three times the price of gasoline in the United States, and prices in Japan, Australia, and Canada are about 65% higher than in the United States (OECD 1999a). Further, analysis of 1995 data suggests that average fuel use per kilometer in the United States is about 50% to 80% higher than in Western Europe, and about 10% to 20% higher than in Japan, Australia, and Canada. Fuel use per capita in the United States is more than twice the per capita use in Western Europe and Japan, and about 70% higher than in Canada and Australia (Schipper and Marie-Lilliu 1999).

In other words, there is some evidence that where they have been implemented, high fuel taxes play a role in reducing gasoline consumption. However, increasing fuel taxes is a political challenge; such taxes are wildly unpopular with voters and have a regressive effect on poor and elderly drivers who live on fixed incomes. In most European countries, fuel taxes are already very high, and increasing them even more would be highly unpopular. This is also true in the United States, where fuel taxes are relatively low.

Congestion pricing. Congestion pricing, or peak-period pricing, is a specific pricing scheme that charges auto users a premium for using road capacity when it is scarce, i.e., at peak periods. Singapore's "area licensing scheme," which has been in continuous operation since 1975, is often cited as an example of the potential effectiveness of congestion pricing as a tool to relieve congestion. Under this scheme, fees imposed on cars entering the city center during rush hours have resulted in roughly a 40% decrease in peak-hour traffic. Variable tolls implemented on several French autoroutes on approaches to Paris and in three cities in Norway (Bergen, Trondheim, and Oslo) have likewise had a significant impact, by spreading travel demand to "shoulder" periods. However, efforts to introduce congestion pricing more widely have, thus far, met with only limited success. Until recently technology was a hurdle: The technologies needed to implement efficient tolling on high-speed, high-capacity roadways have become available only in the last decade. Furthermore, for a number of reasons, citizens and their politicians in most places have resisted the use of pricing to restrict peak-period driving. In the United States, attempts by the federal government to promote congestion pricing in the 1970s and again in the 1990s were rebuffed. Under a Congressionally authorized "Congestion Pricing Pilot Program" enacted in 1991 and reauthorized in 1996, a number of communities carried out "pre-implementation" studies, only to conclude that there is not enough political support to proceed with implementation (Orski 1992). Congestion-pricing initiatives in Sweden and the Netherlands have likewise met with opposition. An attempt to implement a congestion-pricing scheme in London has also met with significant opposition (see feature box).

Nonetheless, there are some indications that the future of congestion pricing is likely to be brighter than its past. First, technology is no longer a hurdle; the development and widespread experience with advanced electronic fare collection mechanisms renders the actual implementation of a congestion-pricing program relatively straightforward. Second, there are some recent experiences where congestion-pricing schemes have been successfully introduced without significant opposition. Politically, the best prospects for wider adoption of this strategy appear to be in connection with the introduction of new roadway facilities where the tolled facility offers a

London Considers Congestion Charges — For Four Decades

London has long considered charging drivers for the use of congested roads in its central and inner areas. As early as 1964, The Smeed Committee reported on the Economic and Technical Possibilities of Road Pricing, concluding that it was the most efficient form of congestion control and was within technical reach (UK Ministry of Transport 1964). No action was taken on the findings of this study. In 1974, the Greater London Council initiated public consultation on a Supplementary Licensing Scheme for central/inner London (GLC 1974). This scheme was not implemented because of concerns about administrative complexity and problems of enforcement.

In 1979, a simplified scheme was devised which applied only to car drivers and was aimed principally at keeping out through-traffic (GLC 1979). Again, concerns about enforcement and the adequacy of the peripheral routes led to a quiet end for congestion pricing in London. In 2000, London began a new form of administration, headed by an executive mayor whose platform included the introduction of congestion charging in the Capital. After a thorough study, the British government enacted legislation to permit direct charging for road use, creating the Greater London Authority (ROCOL Working Group 2000). This plan is now being prepared with the aim of implementation by the end of 2002 (Greater London Authority 2001).

The current plan will cover the ten-square-mile Central Business District, and charges will be levied between 7:00 a.m. and 7:00 p.m. on weekdays. The daily charge of £5 will apply to both cars and commercial vehicles. Public transport, some other public service vehicles, motorcycles, vehicles of people with disabilities, and electrically propelled cars will not be charged. License plates will be checked against a list of vehicle numbers with a valid warrant to travel (automatically entered into a computer database on payment of the charge), and a number of traffic-management and public-transport improvements are to be introduced concurrently. The scheme is predicted to reduce traffic in central London by 10% to 15% and reduce congestion by 20% to 30%, and should generate net revenue of £190m a year, which must by law be spent on improving transport in London.

Prime Minister Tony Blair joined with the Conservative Party in opposing the London congestion-charging scheme. Together, they pledged to block the proposal in London's governing body, the Greater London Assembly. It will be interesting to see whether Mayor Livingstone, who made the congestion-charging scheme one of his central electoral pledges, will succeed in making the 40-year-old dream of British transport economists come true.

high level of service alternative to older, unpriced, competing facilities. In Southern California in the 1990s, implementations of this sort included the opening of a privately funded and operated SR91 Express Lanes system, allowing drivers of single-occupant vehicles to pay a fee to access a time-saving lane previously restricted to high-occupancy vehicles.[4] Drivers still have the option of staying on the old, slower, but unpriced facility.

Enhancing the Capacity and Efficiency of the Existing Road and Public Transport Infrastructure

Enhancements in the capacity or efficiency of infrastructure can address the economic sustainability of public transport and the operational sustainability of the road system.

Expanding the physical capacity of the highway system. One way to relieve road congestion is to expand the capacity of the highway system by building new motorways, widening and improving existing arterial highways, and eliminating bottlenecks caused by inadequate roadway design. Building new roads is the traditional approach to relieving congestion (or keeping congestion within tolerable limits).

However, it is clear that building new roads is not a foolproof "solution" for congestion. Building new roads is not always possible; it is almost always expensive; and the new capacity is regularly swamped by traffic growth induced in part by the anticipated easier travel conditions and changes in land use.[5] Although it is difficult to measure "induced demand" — trips that would not have been taken but for the construction of the new roads — analysts agree that new roads induce some new traffic. Estimates of induced traffic's share of total traffic range widely, with estimates ranging from 10% to 100% of all traffic (e.g., SACTRA 1994, Hansen and Huang 1997, Fulton et al. forthcoming).

Building new roads is not as easy as it used to be. There is little reason to believe that opposition to new highways will lessen in the future. Although new roads will be built, concerns about environmental and social sustainability will slow the pace of expansion of new infrastructure and widen the gap between travel demand and highway capacity to meet that demand. Hence, by itself, expanding road infrastructure does not seem to offer a valid strategy to achieve an operationally sustainable transport system.

Moreover, even discounting for new roads that will not be built because of community opposition, the demand for highways often exceeds the financial resources available. Thus new and innovative sources of financing are often key to successful infrastructure projects. The most prominent and popular of these new financing methods are new twists on an old idea — toll roads. Many new roads and highways in Europe, and some in the United States, are being built as toll facilities and are financed by the revenue from their tolls.

Innovation to increase the operational and economic efficiency of public transport. There are a number of initiatives afoot that promise to increase the operational and economic efficiency of public transport systems. Some are based on technological developments, such as the use of smart cards as a fare medium; the development of real-time passenger information systems that immediately inform passengers of delays in the system's extensive use of Global Positioning Satellites (GPS)-based automatic bus location systems; and dynamic scheduling and routing of paratransit to meet excess demand or make up for delays. Still other innovative operational initiatives include door-to-door public transportation service.

Other initiatives involve more vigorous and imaginative management by public authorities and institutions.

Underground Metroroutes

With surface rights-of-way through densely populated areas virtually exhausted, the Paris regional transportation authorities are planning to build underground routes as the most efficient — and often the only — way to relieve surface traffic congestion. The Paris regional plan for 2015 envisions a 100-kilometer network of high-capacity underground highways or metroroutes. The plan calls for a low-clearance, two-level roadway, each three lanes wide.

The first application of the metroroute concept is a 10-kilometer segment of the A86-West autoroute, which would complete a missing link of an outer beltway in the Versailles area, west of Paris. Engineers estimate that about 90% of traffic in the Paris region would qualify for the low-clearance doubledeck tunnels. By excluding heavy vehicles, the design can accommodate steeper entrance/exit ramps and tighter curves. Estimated cost of the project, which is currently under construction with a projected opening date of 2003, is $2 billion, or $320 million/mile.

These include an increase in track sharing, i.e., joint use of mainline rail lines by intercity, regional, and municipal public transport systemwide; regional integration of public transport schedules and fares; the development of regional transportation associations; and the widespread outsourcing of public transport service operations to save money and improve service.

Among the most important global trends in public transport management are efforts to improve the economic viability and efficiency of public transport by turning the operation of public transportation systems over to the private sector. Known in its various forms as deregulation, privatization, outsourcing, contracting, franchising or competitive tendering, the aim is always the same: to improve the service quality and performance of public transport by injecting competition and entrepreneurial approaches into service delivery.

Deregulation and outsourcing are particularly popular with governments trying to improve public transport service. No longer associated with any particular political ideology, deregulation and outsourcing do not necessarily imply complete privatization. In many cases, the government retains policy-making functions (decisions about routes, fares, schedules and service standards) and contracts with private providers for service operation. Service contracts are awarded competitively to the lowest responsible bidder. In some cases, employees of a public transport agency may themselves compete for contract awards.

Operational highway improvements using intelligent transportation systems technology.

New and innovative management techniques and technology are helping improve the operations and efficiency of existing highways. Operational improvements are particularly effective in reducing unpredictable disturbances in the traffic flow caused by collisions, vehicle breakdowns, special events, and road repair. These improvements are made possible by recent advances in a set of communication and information technologies known collectively as Intelligent Transportation Systems (ITS) technology. The most significant technologies that have emerged after a decade of research and experimentation include:

- *Sensing and communication technologies*. Three kinds of technologies are proving to be particularly important. The first are technologies that provide a means to detect disturbances in traffic flow quickly, enabling highway operators to clear accident scenes and restore normal operating conditions more rapidly. The second are vehicle-based emergency response systems using Global Positioning Systems (GPS) satellite technology, which can pinpoint a car's location even if the driver is injured or cannot accurately describe his or her whereabouts. A third application also uses GPS technology along with automatic vehicle identification techniques to monitor and control the movement and regularity of vehicles.

- *Advanced traveler information systems*. Traveler information systems enable shippers, fleet operators, and individual travelers to make more informed transportation decisions based on real-time information about traffic conditions. For instance, real-time traveler information systems alert motorists to incidents and special events and advise drivers about alternative routings. Real-time parking information systems guide motorists to parking facilities that still have vacant spaces. Sophisticated roadway weather monitoring systems alert motorists to unfavorable road conditions and road hazards ahead.

- *Advanced payment mechanisms*. Electronic toll collection (ETC) reduces bottlenecks at toll plazas, and makes possible the use of congestion-sensitive highway tolls that can increase charges during rush hours. Smart cards enable more efficient fare collection from transport riders.

- *Advanced traffic management technologies*. Computer-controlled, traffic-responsive signal systems are used to smooth out traffic flow. Improved equipment and techniques shorten the time required for routine road repairs and reduce disruptions caused by work zones.

Real-time Passenger Information Systems

Signs that tell riders precisely when the next train will arrive are a common sight in the rail public transport systems of Germany, Switzerland, Austria, and Japan. Radio receivers installed in the signs receive up-to-the-minute information from the train control center and computers on board the trains, and post the information almost instantly on bright electronic displays in subway stations and at light-rail stops. Such real-time passenger information systems are used widely by public bus systems throughout Europe and Asia. They are now increasingly being used in the United States as well.

It remains to be seen whether intelligent transportation systems will have an impact on traffic congestion. So far, there is only limited anecdotal evidence of a positive impact of ITS on congestion as measured by improved traffic flow and reduced trip time.

ITS programs in the United States, Western Europe, and Japan have benefited from sustained government support. As these technologies demonstrate success and prove their worth, the need for continued government developmental support is being questioned. In the United States, there is an emphasis on transferring primary responsibility for implementing ITS systems to state and local governments. In Europe and Japan, national governments are expected to continue playing a central role in deploying ITS infrastructure.

Improving the Available Transport Options

Planners suggest two strategies to facilitate sustainable mobility in this category. First, reduce auto dependency by increasing non-auto transport options. Second, provide mobility and accessibility options for those who do not have access to autos.

Provision of public transport. In the last three decades, the cities of the developed world have significantly enhanced their public transport. In the EU, the bus and coach fleet has steadily grown and is now 50% larger than in 1970. The total number of buses in the United States has grown by over 80%, although most of this growth is in the number of school buses. In Japan, the bus fleet grew by about a quarter during this period. There has also been an expansion in urban rail in the last quarter century, with new systems constructed in a number of US and European cities. In some cities (for example, Atlanta, Miami, Naples, Bilbao, and Kyoto), this has taken the form of metros, while in other, generally smaller cities (such as Portland, San Jose, Nantes, Rouen, and Manchester), it has taken the form of light rail. Most of the established metro systems outside the United States have been extended over the last two decades, and higher degrees of automation are being introduced. However, though these enhancements in the provision of public transport have been accompanied in most cases by increases in absolute levels of patronage, public transport's share of total trips and total kilometers traveled has actually declined almost universally across the developed world in this period.

Transport Deregulation Around the Developed World

In the United Kingdom, public bus service in London was deregulated in 1984. A public authority, London Transport, determines routes, timetables, and fare structures, and sets service and vehicle specifications. In the mid-1990s, 40 companies provided service under competitively awarded contracts.

In 1986, public transportation in the rest of the UK was deregulated, giving private carriers complete freedom to determine fares and schedules. At present, more than 75% of public bus services are operated commercially. An assessment ten years after the deregulation of bus services in Britain found that bus lines in London had gained ridership, while those in other parts of the country had registered a marked decline. Operating costs declined by 23.5% in London and 30% outside London during the period 1986 to 1995. For the same period, total subsidies decreased by 48.3% in London and 28.8% outside London.

Beginning in 1989, a wave of legislation transformed Scandinavian public transport, with 16 of Sweden's 24 counties now awarding contracts competitively. In Stockholm, private operators provide approximately 80% of metropolitan bus and rail services. Similarly, under 1989 Danish legislation, Copenhagen Transport was required to convert its bus service to competitive contracting. And Helsinki, Finland, completed conversion of all bus services to competitive contracting in 1995.

Although Switzerland's Postbus Service is owned by the Swiss government, 80% of its bus services are now contracted. The 20% that are operated directly by Postbus are subject to the same competitive bidding requirements as the contract carriers. Switzerland's new Railway Act aims to bring competition to regional public transport.

In Tokyo and Osaka, Japan, private subway lines have been operating for many years on a fully integrated basis with municipally owned systems. Most major cities throughout Australia — Adelaide, Melbourne, Sydney, and Perth — have converted or intend to convert to competitive bidding. This includes bus as well as rail services. In New Zealand, a 1990 act of Parliament required that all public transport services be provided commercially or under a “competitive pricing procedure,” and the reforms were completed in 1996.

In the United States, private provision of public transport service is rare, although examples exist. Las Vegas has converted its entire public transport system to competitive contracting. Indianapolis runs about 70% of its bus service under private contracts, and Denver, Houston, Los Angeles, and San Diego also contract significant portions of their bus services.

Improving nonmotorized transport. Among the OECD countries, Denmark and the Netherlands are the leaders in promoting NMT. The second Dutch Traffic and Transport Structure Scheme (SVV2), covering the period 1990–2001, identifies the bicycle as the ideal mode for trips of up to 5–10 kilometers (in fact 40% of all automobile trips in the Netherlands are less than 5 kilometers in length). At the same time, the SVV2 recognizes a number of issues associated with bicycle use, including the need to provide direct, safe, and attractive bicycle routes between residences and trip destinations; the need to provide bicycle parking facilities; and the problems of safety and bicycle theft. Within the framework of the SVV2, the government developed a national Bike Master Plan (BMP), covering the period 1990–1997, to promote and improve bicycle use. Roughly 575 million guilders (US$230 million) was spent by central, provincial or local government on bicycle projects. Despite this substantial public investment, BMP research concluded that bicycle policy alone was not sufficient to increase bicycle use and restrain growth in car use (ECMT 2001).

Denmark has some of the most aggressive pro-NMT policies in the world. Copenhagen has roughly 300 kilometers of separated bicycle trails, roughly half the total length of the city's road network. Bicycles sharing the roadway with cars are given priority over turning vehicles at intersections, and a public education program inculcates a “culture of respect” by drivers for pedestrians and bicyclists. Such initiatives have resulted (EU 2001) in Copenhagen's having one of the lowest rates of transportation-related fatalities per person in the world (1.3 deaths or serious injuries per year per thousand residents). Copenhagen also runs a City Bike program, which in 1997 provided roughly 2,500 free bikes at key locations

Advanced Traffic Information Systems in Tokyo, Japan

In the Tokyo metropolitan area, motorists can access one of two traveler information systems. The first system, launched in February 1994, is operated by the for-profit ATIS Corporation, a partnership of the Tokyo Municipal Government and several private companies. The company's traveler information center receives traffic data from various sources, merges it and sends updates to the subscribers' terminals (personal computers, in-vehicle devices, etc.) every five minutes. The second service, VICS (Vehicle Information and Communication System), established as a cooperative venture between Japan's Ministry of Post and Telecommunications, the National Police Agency, and private industry, began operation in the Tokyo metropolitan area in April 1996. VICS provides drivers with real-time information on traffic conditions, travel time, highway incidents, lane closure, construction updates, and parking availability using an FM multiplex broadcasting system and roadside microwave and infrared beacons to communicate with motorists. The beacons can superimpose traffic data on digital road maps displayed on the car's video screen and provide more detailed information in the form of text messages. As of 1998, about 3,600 microwave beacons and 18,000 infrared beacons installed along the expressway network served nearly three million equipped autos throughout Japan. The chief source of revenue for VICS operation is a fee imposed on manufacturers of VICS in-vehicle devices.

Traffic and Incident Management, Melbourne, Australia

Since 1989, Melbourne's freeways have been equipped with an electronic congestion and incident detection system (ACIDS) using detection loops at approximately 500-meter intervals. The loops send signals every 20 seconds to a traffic control center indicating speed, volume, and lane occupancy data. Should the rate of change be significant over several consecutive intervals, an alarm is sounded in the traffic control center. Once the central computer raises an incident alarm, operators view the area by video surveillance and take appropriate action to inform motorists of the congestion ahead and dispatch an incident-clearing team.

Drive Time, an extension of the incident detection system, uses the same detection loops to calculate travel time for each 500-meter section of the road. Times in adjacent segments are totaled and converted to times between freeway exits. The information is presented on electronic variable message boards, showing estimated travel times from the sign location to various freeway exits. A color-coded strip shows traffic conditions on segments between each major exit. Other variable message signs at freeway entry ramps alert drivers of traffic conditions on the freeway, giving them an opportunity not to enter (or exit) the freeway if conditions ahead are "red." Information about travel times between specific freeway exits and about incidents is also available over the telephone.

around the city. The bikes are paid for by advertising, and are maintained by the Municipality, using prison inmates. There are plans to increase the number of bikes in the program. Copenhagen has also taken measures to make the use of cars undesirable; for example, it has reduced the availability of parking and converted streets to pedestrian zones. The city has also pursued a public transport-oriented urban development plan (the so-called finger plan, based on radial rail corridors). At the national level, automobile ownership in Denmark is discouraged through very high vehicle registration fees (105% to 180% of the vehicle purchase price), although the gasoline tax is in the middle of the range of European rates. Roughly one-third of the city's home-to-work trips are made by bicycle (Newman and Kenworthy 1999).

Providing transport options for those without autos. There are many programs and policies to provide mobility for those without access to autos. Effective solutions frequently focus on particular groups, such as the poor, those with disabilities, or the elderly. Policymakers typically focus on three kinds of strategies:

- *Ensuring that mainline public transport services are sensitive to the needs of those without access to autos*. Often agencies provide minimum levels of off-peak public transport service to ensure that service is available for so-called captive riders, even when such service would not be justified on strict economic grounds. Also, there has been a concerted effort across the developed world to ensure that public transport service is accessible to those with special needs. For instance, in the United States, the 1990 Americans with Disabilities Act laid out a minimum set of physical design standards for public transport vehicles and stations that public transport services must meet to serve those with special needs.

- *Paratransit services*. In several regions, there are trips that conventional public transport is unable to serve. In many cases, local authorities provide dedicated demand-responsive paratransit services to help people with special needs complete those trips. Such programs are often targeted at the disabled and the elderly. (Examples include "The Ride," offered by the Massachusetts Bay Transportation Authority in the Boston metropolitan region.) These services have both advantages and disadvantages relative to conventional public transport. Being demand-responsive and door-to-door, they often offer a high level of service, and as a result there is disagreement about what constitutes fair and efficient pricing for the service. On the other hand, these services usually require significant advance planning. Also, many citizens with disabilities argue that as a matter of dignity they deserve to be integrated with mainstream society as much as possible, and being able to use public transport is an important element of this effort. Many citizens with disabilities and their advocates decry targeted paratransit services — even those offering higher levels of service than conventional public transport — as humiliating.

- *Direct user-side subsidies* to help those without autos either get them (in the case of the poor) or buy alternative transport services (such as taxi service) directly.

Portland, Oregon's Urban Growth Boundary — The Rigors of Land-Use Planning

The experience of Portland, Oregon, has been widely cited as an example of using land-use policy to guide new development into public transport-friendly high-density growth. Though Portland has indeed achieved much by way of compact, public transport-friendly development, a closer look at the city's experience reveals the tensions and controversies associated with such land-use planning, and identifies some of the costs that accompany the sustainability benefits.

The current planning regime owes its origins to legislation passed in the 1970s, which required every city to delineate an urban growth boundary. The initial goal was to identify enough vacant land to accommodate projected long-range urban population growth. New development outside of the growth boundaries was regulated to protect existing farms and other rural uses from leapfrog development. More than one-third of the land included in the original growth boundary for the Portland metropolitan area was vacant, and only around 10% of the vacant land was unfit for development. Almost all of the original vacant land available for development has now been filled in. Metro, Portland's directly elected regional government, which is statutorily responsible for verifying the availability of adequate land for 20 years of future growth every five years, resisted pressures to expand the boundary during its first 20 years. It instead preferred to accommodate growth by encouraging local governments to adopt higher density zoning standards, with limited success.[6] Although more than 30 boundary adjustments were made during this period, each involved less than 20 acres. However, pressures on Metro have mounted, bolstered by significant increases in housing prices.[7] In 1998, Metro authorized an expansion of around 3,500 acres, creating enough room for approximately 23,000 housing units and 14,000 jobs.

There remains considerable disagreement in Portland about the effectiveness and benefits of the urban growth boundary; supporters argue that it has controlled sprawl and encouraged public transport use, while detractors argue that it has provoked land and housing price increases by creating artificial scarcity. Neither of these claims appears to be entirely accurate. On the one hand, development in the vacant areas frequently exhibits the typical characteristics of sprawl; it is probably true, however, that the boundary limited the spatial extent of the sprawl. On the other hand, land and housing prices in Portland are still not particularly high compared to similar areas in the region. Some argue that price increases in the 1990s can be entirely explained by traditional market forces. In summary, Portland's apparent "success" in managing land use is constantly being put to the test. Though the current regional government seems to be committed to a sprawl control policy, it needs to remain responsive to its local constituents and is also required by statute to ensure that land shortages do not persist.

Sources: Newman and Kenworthy 1999, Knaap 2000, Portland Metro 2000, Patterson n.d.

Land-Use and Urban Design Strategies

In the last three decades, some urban regions in the developed world have successfully employed land-use policy to facilitate a pattern of development in which public transport can play a significant mobility role, and limit sprawl.
Before discussing alternative policy regimes, it is important to note that land-use policy works best in rapidly growing residential and commercial developments where existing structures can be easily reused over time. In established regions, the durability of existing housing stock limits the effectiveness of land-use measures. In the United States and the United Kingdom, for example, annual construction of new housing represents only around 1% of the existing stock.

Public transport-oriented development. This policy encourages residential, employment, and recreation buildings to cluster around rail public transport stations. The goal is to build compact, pedestrian-friendly communities where many trips can be made on foot or by bicycle, and longer commutes are made by train.

This approach has been followed widely — and successfully — in Europe, Canada, and Japan. Examples include Stockholm's satellite towns along commuter rail lines radiating from the city; the French villes nouvelles on the outskirts of Paris; Toronto's high-rise developments along the Yonge Street subway; Japan's public transport communities at the termini of private rail lines; and Germany's transit-oriented suburban communities such as Munich's Perlach and Frankfurt's Neustadt. In the United States, on the other hand, only a few examples of public transport villages exist. In a great many suburban locations, community opposition to high-density development makes public transport-oriented development difficult to implement.
Spatial location policies: The Dutch ABC policy. The Netherlands, one of the smallest developed nations in Europe, has a comprehensive approach to land-use planning: the ABC policy. Dutch planning focuses not only on curbing traffic growth and urban sprawl, but also on developing compact cities and protecting open areas. ABC explicitly seeks to reduce automobility through

The Public Transport Metropolis

A study of 12 metropolitan areas where public transport successfully retained a prominent mobility role found three common trends across the cities. First, a vibrant city center, such as in Zurich and Melbourne, where public transport is an important means of circulation. Second, an ability to adapt settlement patterns to be conducive to public transport — such as in Stockholm, Copenhagen, Tokyo, and Singapore — by concentrating offices, homes, and shops around rail stations in attractive, well-designed, pedestrian-friendly communities. Third, an ability to adapt public transport technologies to serve spread-out, low-density patterns of growth, efficiently using a combination of institutional (such as an innovative track-sharing agreement between the municipal rail system and the regional railways in Karlsruhe, Germany) and technological (such as the track-guided buses that provide transfer-free feeder and line-haul functions in a single vehicle in Adelaide, Australia) innovations. Key additional lessons include:

Å*The need to lay out a well-articulated vision of land use* to direct transport planning for the future. Examples include Ottawa's 1974 master plan that defined an east-west axis for channeling growth, which led to North America's largest and most successful busway network.

Å*An effective champion to articulate the vision,* win others over to their vision, and translate the vision into reality. Many successful public transport metropolises have benefited from inspired leadership, such as Sven Markelius' stewardship of the Stockholm regional plan, or mayor Jaime Lerner's 20-year governance of Curitiba, Brazil.

Å*Efficient institutions and governance* that promote close coordination of transportation and land use. One exemplary model is the Verkehrsverbund found in Germany, Austria, and Switzerland, which ensures that problems commonly plaguing regional public transport services — such as a multitude of different fares, uncoordinated timetables, and excessive transfers — are eliminated.

Å*Competition and an entrepreneurial ethos* to contain costs, reward efficiency, and spur service innovations. For instance, in Munich, Karlsruhe, Curitiba, and Adelaide, the public sector retains control over how service is provided (level, quality, frequency, routing) and lets market forces and competition determine at what price the service is provided.

Å*Giving public transport priority and discouraging car use.* Ottawa, Copenhagen, and Zurich give priority to public transport vehicles. These measures are supplemented with restraints on automobile use by a combination of pricing and physical design.

Å*Designing the city for pedestrians.* An overarching design philosophy of most public transport metropolises is that cities are for people, not cars. For example, in Copenhagen, Munich, and Curitiba, large parts of the historical core are given over to pedestrians. In other cities, trams and light-rail vehicles blend nicely with auto-free zones. In addition, through conscious design, public transport is made part of the community's physical and symbolic core.

Source: Cervero 1998.

programs such as the one encapsulated in its slogan for business location: "the right business in the right place."

The ABC policy classifies businesses into three categories based on the importance of their need for public access and road transport. Business development sites are similarly classified in terms of their public transport and road accessibility. The policy attempts to encourage businesses with a high number of employees and visitors to locate on sites with good public transport accessibility, such as near centrally located public transport or rail stations ("A" sites) or near major public transport nodes in less central locations ("B" sites). "C" sites, with good road access, are primarily intended for businesses that depend on road transport for their operations. Associated with each type of site are restrictions on the number of parking spaces that can be provided there: "A" sites are limited to 10 to 20 parking spaces per 100 employees and "B" sites to 20 to 40 parking spaces per 100 employees. These rules are sufficiently restrictive that businesses have a strong incentive to locate in accordance with the intentions of the policy.

Overall, the Dutch accept the ABC policy, though objections to the highly restrictive parking limits, along with economic pressures at the local or provincial levels, have led to a relaxation of the parking rules in some areas of the country.

Integrated Approaches

The most successful examples of cities controlling automobility and improving the sustainability of their transport system use combinations of the policy options above. Isolated policy responses are unlikely to have a significant impact.

Copenhagen, for example, combined public transport-oriented land-use planning, high automobile ownership charges, priority treatment of bicycles, and numerous improvements to center-city social life. Portland applied spatial growth controls, development of a light-rail public transport system and, again, many enhancements to improve the quality of center-city life.

As another example, Zurich upgraded its tramways into a modern, high-quality, and reliable public transport system operating on separate rights-of-way obtained by removing traffic lanes from general use. A computer-based signaling system ensures that trams do not have to stop at traffic intersections. Seasonal "Rainbow" passes reduce riders' cost per trip to very low levels. Intensive marketing and information campaigns promote the use of the tram system, and special maps show people how to get to particular destinations such as restaurants and cultural attractions via the public transport system. These public transport system improvements were accompanied by complementary land-use and urban improvement policies. Large shopping centers were developed around major stations. Urban public transport villages were developed around the public transport lines, including Tiergarten, a public transport village built in an abandoned quarry in central Zurich. As a result of these and related measures, the automobile mode share for the journey to work fell by 9% between 1980 and 1990.

In the mid-1990s, in a major study of urban travel and sustainable development, the OECD concluded that successful treatment of the problems of sustainable mobility will require integrated approaches that combine mutually reinforcing measures (OECD 1995b). It recommended approaches that were classified into three integrated "strands":

- Best practice — the wider use of known successful methods in land-use and transport planning, traffic management, and public transport provision.
- Policy innovations — application of research into land-use planning and traffic management. Innovative land-use planning policies would widen travel choices by influencing the location of homes and jobs, while traffic management measures would include congestion pricing, telecommuting, and investments to improve public transport performance.
- Sustainable development — recommendation of a progressively increasing fuel tax designed over time to make a significant reduction in the amount of automobile travel. The study recommended a 7% annual increase in the real price of fuel, applied continually over the next 20 years.

Several years after issuing its recommendations, the OECD (2001) stated that "the practical application of even one, let alone all three strands of this policy package, faces formidable implementation barriers. Coherent integration of environmental, transport, and land-use policy has proven to be extremely difficult." While the OECD was perhaps overly optimistic with regard to the timetable of implementing their recommended measures, the example stands as a warning of the dangers of extrapolating measures (or even coordinated groups of measures) that have worked in particular cities to a national or supranational level.

CONCLUSIONS: A STRATEGY FOR SUSTAINABLE MOBILITY

This assessment of existing issues and trends associated with the search for sustainable mobility suggests the following general conclusions:

- The need for mobility will increase in the future. The challenge is to develop strategies that accommodate future mobility needs while controlling and mitigating potential harmful side effects, i.e., to create "sustainable mobility."
- Automobile-based transportation will continue to be the preferred means of personal mobility in the urbanized regions of the developed world. To preserve the automobile as a sustainable means of transportation, policies governing its use will have to undergo significant modification. Automobile management techniques such as travel-demand management, the use of variable pricing, and car sharing have shown a potential for somewhat reducing our reliance on automobiles. While individually the impact of auto management measures may be small, collectively they can be a useful element in an overall strategy for sustainable mobility.
- Innovative policies and technologies have shown promise in alleviating many of the harmful side effects of motorization. In particular, the technology of Intelligent Transportation Systems (ITS) may increase the efficiency and productivity of the transportation system without requiring politically untenable new highway construction.
- The influence of public transport as an instrument of sustainable mobility is expected to decline if cities spread out and their populations continue to disperse. However, public transport will remain essential for the future mobility and economic viability of large metropolitan regions in the industrialized world.
- Private financing may offer alternate sources of capital for highway infrastructure.
- Environmental concerns will seriously constrain future highway construction in urban and environmentally sensitive areas of the developed countries.
- Case studies of exemplary metropolitan mobility systems suggest that several factors foster a favorable sustainable mobility environment:
- Enlightened political leadership — a commitment to achieving sustainable mobility at the highest levels of local political leadership.

- Supportive policy environment — an explicit policy to support public transportation. This policy may be accompanied by limiting the use of automobiles in the city center and traffic-calming measures in residential areas.

- Stable fiscal environment — a dedicated source of funding to support operation of the transportation system, and adequate capital to ensure a steady program of improvements and expansion of transportation infrastructure.

- Supportive land-use policies — a deliberate effort to concentrate development in transportation corridors and control the rate of development outside designated urban boundaries.

- Receptivity to innovation — a willingness to introduce new technology and experiment with new service-enhancing innovations.

- Interagency cooperation — close coordination among various administrative units in charge of transportation and physical interconnections between light rail, metros, and buses.

NOTES

1. The 15 EU countries account for roughly 13% percent of world CO_2 emissions, China for another 13%, and Japan for roughly 5% of the total.

2. These numbers exclude compensation for concessionary fares, which is treated as a user rather than an operator subsidy.

3. The change in levels of delay are probably more useful than absolute levels themselves, since traffic studies usually measure delay relative to the time required to make a trip in free-flow conditions. In reality, building infrastructure with sufficient capacity to allow free-flow conditions under all levels of traffic would never be economically justified.

4. The location is remarkable. Prior to the SR91 lane, there were no toll highways at all throughout California, and Southern California is widely regarded as the worldwide epitome of automobility. In the 1970s, attempts to dedicate an existing freeway lane in the Los Angeles region to high-occupancy use had to be withdrawn in the face of strong driver opposition.

5. London's orbital motorway (the M25), completed in 1986, is often cited as the most compelling example of this phenomenon.

6. The average lot size of new detached housing decreased from 13,200 to 8,700 square feet, and the percentage of attached housing (row- and townhouses) in the stock increased from around 3% to around 12% during the period. Such changes take a long time to produce their full effects and, of course, some of these changes may be attributable to factors unrelated to the growth boundary. Residential densities generally remained lower than originally planned.

7. Median home sales price increased by 91% between 1990 and 1997, compared to 21% for the nation as a whole.

four

personal mobility in the urbanized regions of the developing world

The developing world is urbanizing and motorizing at a very rapid rate. Cities in the developing world are growing and motorizing so rapidly that they have not had the time or the money to build new infrastructure or to adapt to new technologies. The growth in the geographic spread of urban areas in the developing world is undermining the ability of public transport systems to provide the services on which most urban dwellers rely for the bulk of their mobility needs. In short, mobility, already poor for most developing-world urban dwellers, is declining.

Pollution, much of it transport-related, is at extremely high levels and is growing worse. Developing-world, transport-related carbon dioxide emissions are growing rapidly and will surpass transportation-related carbon dioxide emissions in the developed world in little more than a decade if present trends continue. Deaths and injuries from transport-related accidents occur at substantially higher rates than in the developed world.

Some developing-world urban areas are achieving some measure of success in dealing with these problems. But, even more than in the developed world, replicating these successes is proving extremely difficult.

The mobility picture in cities of the developing world is much more variable than in the developed world. Great variations in mobility result from levels and distributions of incomes in the cities, their histories of economic and administrative development, and many variables that defy easy categories. Yet many cities of the developing world share similar patterns in their mobility. Rising incomes, increasing motorization, congestion, and the growth of cities outward into suburbs — trends that are ingrained in the developed world — are clearly emerging in developing cities. Motorization is occurring so quickly in developing cities that not only is it overwhelming the operational sustainability of those cities' infrastructure systems; it is also causing social, economic, and environmental imbalances and inequities.

Most of the citizens of the developing world are suffering from poor or deteriorating mobility conditions. In many cities, average vehicle speeds have declined to 10 kilometers per hour, and commute times of over an hour or more, with corresponding losses of productivity, are common. Cities suffer the most severe environmental impacts from motorization because of the added congestion and because the motor vehicles tend to be in poorer condition than those in developed countries. Governments are loath to impose regulations that would raise the cost of auto purchase and use. There is a tendency to keep already aging vehicles on the road much longer, and environmental regulations governing emissions are poorly implemented. Developing cities also suffer such high rates of serious traffic accidents, principally inflicted on pedestrians and bicyclists by untrained or reckless drivers, that accidents are a serious public health issue.

At the root of these problems is the fact that cities of the developing world are growing and motorizing so rapidly they have not had the time or the money to build new infrastructure or to adapt to new technologies. The cities house and transport too many people, on insufficient numbers of poorly maintained roads and rails, and lack the money and institutional vigor to fix the problems.

To put the problem in perspective, note that in 1950, less than 30% of the world's population comprised urban dwellers. By 2005, that number will be 50%. Indeed, "megacities" of more than 10 million people are now a defining characteristic of the developing world. In 2000, 15 of the 19 megacities were in developing nations. By 2015, 18 of the 23 megacities will be in the developing world.

The cities have large proportions of their populations below the poverty line, people who in many cases cannot afford even the fares of transit vehicles. Survey research at Ouagadougou (Burkina Faso) found that people in the lowest-income quintile spend over 20% of their income for transportation, and the average over the entire urban population is more than 15%. Typically the poorest, most recent arrivals in a city are isolated on its fringes, living in very modest dwellings and lacking many of the most basic services, such as sewerage and trash removal. Many of the "street people" of south Asia and Africa indeed have homes; it is just that they are unable to reach them — because of the cost and/or time involved — between work days.

Many thoughtful critics seek to reverse this trend toward urbanization, and cite Western capital, global trade, consumer marketing — all the disparate forces of "globalization" — for despoiling formerly rural societies and drawing people into cities. Although the global economy has certainly accelerated urban growth, it is not the root cause. The natural human desire to escape the drudgery and labor of subsistence farming, and seek greater income, mobility, and comfort is irresistible. Even China's rigid controls on internal migration are unable to prevent the rapid growth of "undocumented" citizens in Beijing and Shanghai.

This seemingly inexorable trend toward urbanization has serious implications for the developing nations themselves, and for the global community at large. If developing nations are able to raise their incomes, to improve their education and health care, and build socially just, economically strong societies, then such advancements will originate in their cities. It is in cities that financial capital, economic expertise, and ambitious labor accumulate, in cities that politicians, bureaucrats, and media debate, universities teach, hospitals heal, and where students, artists, and citizens of energy and vision congregate, clash, and create. It is in the cities, as sprawling, congested, and unruly as many developing cities currently are, that the new social and economic fibers of their nations will grow and flourish.

But the rapidly deteriorating mobility conditions of developing cities hinder their progress on several fronts. For instance, Bangkok includes only 10% of the population of Thailand, but accounts for 86% of the country's GNP in banking, insurance, and real estate, and 74% of its GNP in manufacturing. The World Bank estimates that Bangkok loses up to 6% of its economic production due to congestion (Willoughby 2000a). Indeed, Bangkok suffers far more burdensome congestion than any US city, despite motorization levels of about 200 autos per thousand population in 1990, compared to the US average of about 675 autos per thousand at that same time.

Most developing cities are simply too dense to handle motorization. Chinese cities average 200 to 250 persons per hectare, compared to 50 persons per hectare in Western European cities. This incredible density creates great pressure for developing cities to grow, to sprawl outward, a trend that automobile ownership encourages and accelerates. As congestion gets worse there is, in fact, an increased advantage to using a private car. In the absence of transit with exclusive rights-of-way, congestion is likely to be the worst on the main arteries, which are used for public transit routes. Auto users can avoid this in some measure by choosing routes or destinations that avoid the main arteries.

Although automobiles improve the mobility of their few, wealthy owners, they increase congestion and delays for the many who cannot afford them. Automobiles are a particularly heavy burden on those whose travel is limited to slow-moving public transport vehicles, which cannot escape the congestion of major thoroughfares. That is not the auto's only contribution to social inequity. On a larger scale, the outward growth of cities widens the gaps between those able to afford cars and those that cannot by moving economic and social opportunities beyond the reach of non-auto owners.

To examine the mobility of developing cities in one chapter is a daunting task. Conditions in such a broad group, and the data available to study them, vary widely. Nevertheless, mobility in developing cities is a crucial topic for the WBCSD and its readers to examine. For it is in its cities that the future health and vigor of the developing world rest.

URBAN MOBILITY AND MOTORIZATION: A GROWING CHALLENGE

Rising incomes have led to a surge in the use of automobiles in the major cities of the developing world. This trend is increasing the short-term mobility of individuals with the income to afford cars. Yet few cities in the developing world have the roads and highways to sustain widespread use of automobiles. The result is increasing congestion, air pollution, and rapid, yet haphazard land development. As more offices and jobs shift to locations accessible only by car, the income differentials and social inequities between automobile owners and the rest of their societies are exacerbated. Public transport and nonmotorized transport (NMT), principally walking and bicycles, remain the principal means of mobility for most citizens of the developing world. The challenge for policy-makers is to integrate automobiles, public transport vehicles that range from small minivans to large buses, and NMT, in a manner that decreases congestion and increases mobility while minimizing other costs to the external environment.

Fundamentally, much of the rise in motorization is driven by rising incomes for a section of the population in the cities of the developing world. Rising incomes lead to increased levels of trip-making, motorization, and shifts from public transportation to private

Table 4-1. Greater Santiago — evolution in motorization, auto mode share, trips

	1977	1991	Change	Annual Growth
Autos/thousand persons	60	90	50%	2.9%
Auto mode share	9.8%	15.8%	61%	3.4%
Trips/capita	1.14	2.12	86%	4.4%
Motorized trips/capita	0.95	1.7	79%	4.2%

Source: SECTRA (1991).

automobiles.[1] In places as diverse as Santiago, Chile, and Jakarta, Indonesia, higher-income residents make 30% more trips than lower-income residents. In São Paulo, the households from the highest-income sextile have more than double the trip rate of households from the lowest (Companhia do Metropolitano de São Paulo 1999, table 17). Also, as was observed in Chapter 2, wealthier people tend to travel using faster and more expensive modes. Figure 4-1 illustrates the effect of income on mode choice in Santiago and São Paulo — as people seem to move from foot to public transport and then to auto.

Table 4-1 illustrates that auto ownership, and the rising incomes accompanying it, often result in a disproportionate increase in the use of autos. The table shows that a 50% increase in auto ownership in the period 1977 to 1991 led to a 61% increase in the use of automobiles in the same period in Santiago.

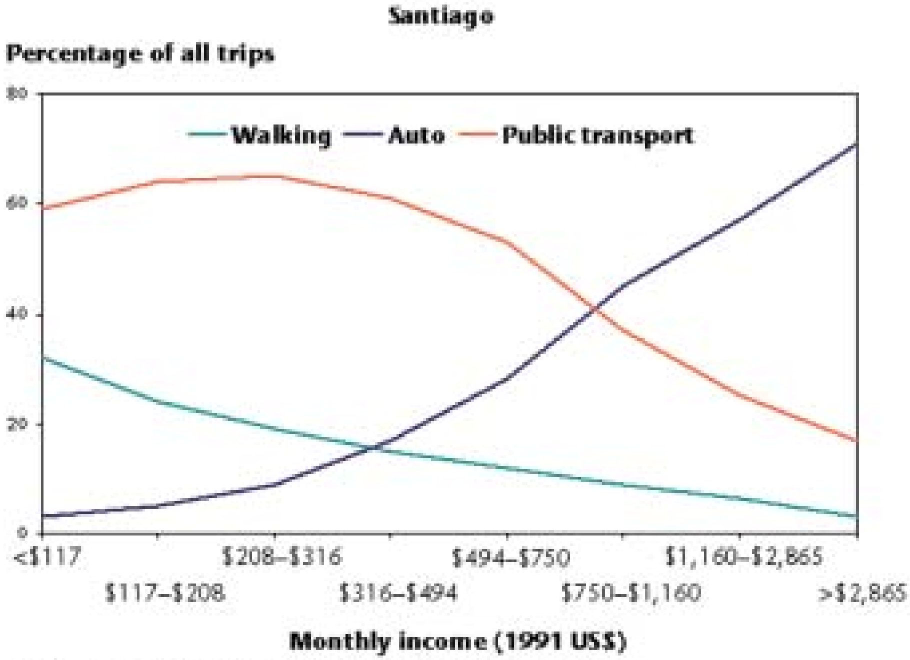
Despite this growth in motorization, the auto remains only a bit player as a facilitator of mobility for most people of the developing world. A detailed look at mode shares across the cities in the developing world (see Figure 4-2 and Appendix Table A-1) shows that public transportation still dominates trip-making in almost all cities. Indeed, the principal exceptions to this rule are some cities in Asia and Africa — such as Tianjin and Marrekech — that still have a heavy share of walking and/or nonmotorized vehicle trips.

The Rapid Growth of Motorization

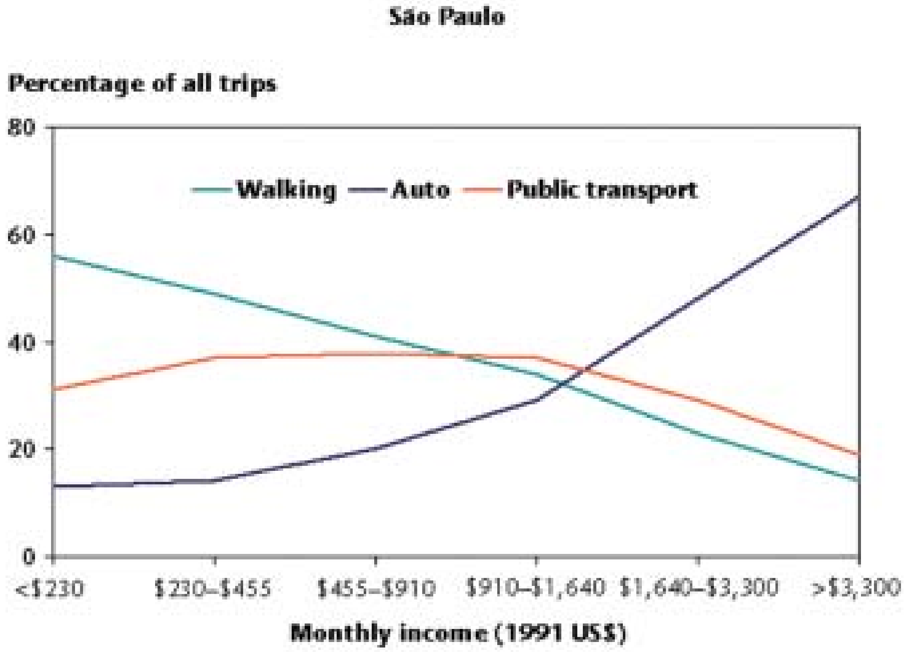
Motorization — the growth in motor vehicle fleets — is the major force affecting mobility in almost all areas of the developing world. More cars, motorcycles, buses, trains, and trucks mean that more people and goods can potentially travel more places more rapidly. This is especially true when motor vehicle fleets increase more rapidly than population. The motorization rate — which measures the number of motor vehicles per person — provides a gross indicator of vehicle ownership levels, suggesting, for example, what percentage of the population has access to some form of motorized transportation. The term motorization typically refers to road vehicles, although rail-based forms of transport are also motorized.

In the short run, motorization provides improved individual mobility, but the rapid pace often overwhelms infrastructure, urban structures, and institutions. Building infrastructure is a lengthy and expensive process, one that can rarely keep pace with rapid motorization, so short-term system imbalances and high congestion levels often result. Perhaps equally important, institutional structures may be even less suited to deal with rapid motorization, as regulatory structures and standards, public finance systems, and cultures change much more slowly than the growth rate in motor vehicles. This often further exacerbates congestion as well as motorization's other negative impacts, like accidents and air pollution. In the short run, the rate of change in motorization poses the greatest challenge, while in the

Figure 4-1. The relationship between income and mode share in Santiago and São Paulo



Note: Santiago does not add to 100%; not all modal shares included.

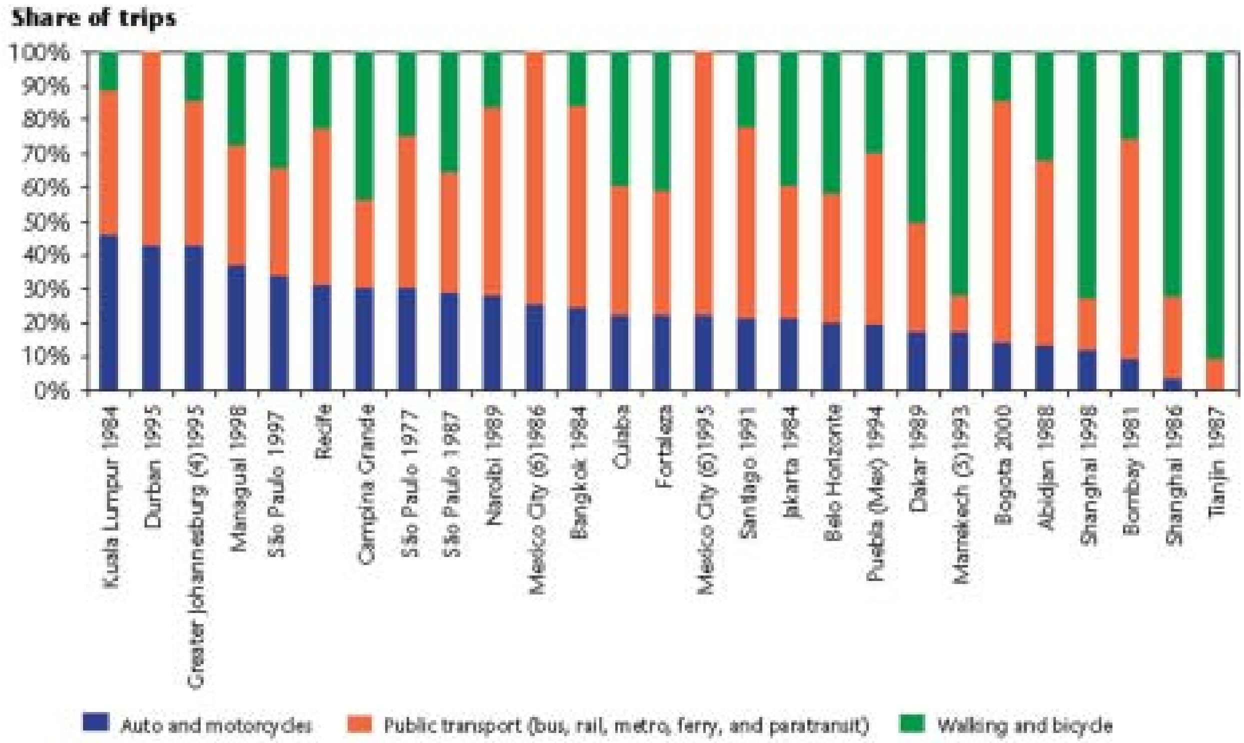


Source: SECTRA (1991); Companhia do Metropolitano de São Paulo (1999).

long run the challenge comes from the total overall number of motor vehicles.

Empirical analysis suggests that motor vehicle ownership increases roughly in step with income growth (see, for example, Ingram and Liu 1999); across countries, per capita income explains 70% to 80% of a nation's motorization rate (IIEC 1996). Not surprisingly, high motorization has usually accompanied high rates of economic growth, as in certain Asian countries in the recent past. In China, the vehicle fleet is increasing at 15% a year, automobiles by 25% a year. In countries such as Philippines, Thailand, and Cambodia, the average annual rate of motor vehicle fleet growth from 1991 to 1996 was higher than 20%. As a result of continuous growth in the last 30 years —

Figure 4-2. Mode shares in selected cities of the developing world



Source: Various sources, see Appendix Table A-1.
Note: Data not available for volume of nonmotorized trips in Durban and Mexico City.

including an annual growth rate of 23.7% in the period between 1985 and 1992 — in 1996 South Korea had motor vehicle ownership of over 200 per thousand people.

Further, motorization is overwhelmingly concentrated in the urban areas of the developing world (see Appendix Table A-2 for detailed motorization rates), for several reasons. First, national wealth concentrates largely in the urban areas of these countries. As a result, the majority of people with incomes over the threshold of auto ownership live in cities. Second, technology import (e.g., through joint ventures), foreign direct investments, infrastructure improvement, and individual life-style changes mostly occur first in urban areas.

In India, for example, the four metropolitan areas of Delhi, Mumbai, Calcutta, and Bangalore account for about 5% of the nation's population but 30% of the total registered vehicles (TERI 2001, World Bank 2000). In Iran, South Korea, Kenya, Mexico, Thailand, and Chile about 50% of the country's automobiles are in the capital city (WRI 1996). Similarly, the motorization rate in Bogotá — over 100 cars per thousand people — is two times higher than the national level (DAMA 2001a). In 1998, Harare reportedly concentrated 45% of Zimbabwe's vehicles, a share that had climbed from 37% in 1994.

Beyond the low motorization rates and generally rapid growth in motor vehicle fleets, there are some important differences between motorization in the developing world and that in the developed world. First, there is the astonishingly rapid speed with which motorization is occurring — a speed, as we will discuss later, too fast for infrastructure provision to keep up with. Second, although enough to overwhelm the

There is Significant Variation in the Motorization Rates Across the Developing World

By 1996, the average motorization rate in the developing countries was about 30 vehicles per thousand people, with the majority having less than 50 vehicles per thousand people (compared with 400 or more per thousand people in the developed world).

Over a dozen wealthier developing countries, such as Malaysia, Argentina, South Africa, Mexico, Costa Rica, Chile, Panama, Uruguay, Thailand, and Belarus, had exceeded the motorization rate of 100 vehicles per thousand people. Lower-income countries, on the other hand, have one-tenth the per capita fleet levels, leading to the possible characterization of "two tiers" of developing countries. Over the spectrum of the motorization rates in the developing countries, the Latin American countries are largely at the higher end, the African countries are at the lower end, and the Asian countries fall in between — average motorization rates in 1996 were around 80, 20, and 40 vehicles per thousand people, respectively (see Table 4-2).

Motorization is Not All Autos — The Role of Two-Wheelers

Although the data in Table 4-2 refers only to automobiles, two-wheelers are an important element of motorization in parts of Asia and Africa. Including two-wheelers, most Indian cities have private motor vehicle ownership rates similar to the wealthier cities of Latin America (which are nearly all due to four-wheeled vehicles), while doing the same for Kuala Lumpur and Bangkok pushes those cities' motorization levels close to those of western European countries. Reasons cited for the motorcycle motorization phenomenon in many countries include: lower capital and operating costs than automobiles, coupled with lower levels of real purchasing power; superiority in time and door-to-door convenience relative to autos in congestion; superiority to an often deteriorating public transport system. All lead to widespread acceptance of the motorcycle among the middle class (Akinyemi and Medani 2000).

Despite their prevalence, until recently motorcycles have been ignored both in planning and infrastructure implementation (including traffic counts) as well as in pollution control efforts. This is changing. The motorcycle may well be serving as a stepping-stone for private vehicle users, who will move from bicycles to motorcycles and perhaps eventually to automobiles. For example, in Hanoi the number of bicycles per thousand people increased from 143 in 1955 to nearly 500 by the end of the 1980s. Since 1985, however, motorcycles have increased sharply, growing from just 7.5% of the two-wheeled fleet to 33% by 1992. Bicyclists have, reportedly, registered a concomitant decline — an estimated 10% annually (Hai 1995).

existing road infrastructure, motorization in developing countries is still low in absolute levels compared to the developed world. Perhaps most important, however, are the staggering differences in vehicle ownership across income groups. In other words, though growth in auto ownership has done much to improve the mobility of the few in the developing world who have directly benefited from it, it has not necessarily enhanced the mobility levels of the vast majority, who continue to rely on nonmotorized travel and motorized public transport. Indeed, our discussion will illustrate that this rapid motorization may in many ways actually decrease the mobility of those who do not have access to automobiles.

The overall motorization growth in the developing countries simply means that more people are on the move. The demand for mobility may be even larger in developing countries than in developed countries, given that the magnitudes of both the total urban population and its growth in the developing world are nearly ten times larger than those in the developed world during the past decade. Inequality of mobility in the developing city is worse when sizable portions of the urban population are in both motorized and nonmotorized categories. When employment opportunities migrate to areas that are accessible only by auto, the dilemma is that people without access to automobiles become excluded from new economic growth. Thus while motorization is in relatively early stages but increasing rapidly, inequality also increases rapidly.

Nonmotorized Transport (NMT): Still a Dominant Means of Travel

NMT is the dominant means of transport in the developing world because the majority of citizens cannot afford access to motorized transport. Across Africa, Asia, and Latin America, studies show walking to be the major transport mode among the poorest city residents (see, for example, Barrett 1991, Heierli 1992, Hathway 1996, and Figure 4-1 in this report). Even in relatively motorized Latin America and Central and Eastern Europe, walking still accounts for 20% to 40% of all trips in many cities. In Warsaw, for example, walking accounted for 30% of all trips in 1993 (Malasek 1995, p. 177).

The widespread use of walking by the poor, explains, in part, the long average travel times seen in developing country cities. Although walking can

Table 4-2. Motorization rates in developing nations, 1998

Upper Middle Income	Motorization (vehicles/ thousand inhabitants)	Lower Income	Motorization (vehicles/ thousand inhabitants)
Argentina	176	Egypt	30
Brazil	77	Honduras	37
Hungary	268	India	7
Libya	209	Indonesia	22
Malaysia	172	Kenya	14
Mexico	144	Mozambique	1
Averages	174		18.5

Source: World Bank (2000).

be burdensome and unsafe in the presence of dangerous traffic conditions, it also has some benefits: no cost, flexibility of schedule, and no risk of vehicle damage. The main problems with walking are the poor provision of adequate infrastructure (i.e., sidewalks, crosswalks, etc.), which contributes to the high incidence of pedestrians being hit by motor vehicles; barriers posed by major road projects and inconvenient pedestrian overpasses; and the long distances many poor residents must travel for daily trips. The poor typically live far from quality employment, and educational, shopping, and recreational opportunities. Their dependence on walking clearly hampers their accessibility.

While walking may predominate among the poor, it is not exclusive to the poor. Even the highest income groups in São Paulo, for example, take over 10% of all their trips on foot. In addition, it must be remembered that most public transport trips also start with a walk trip — in Santiago, for example, between 70% and 80% of Metro trips start or end with walking (Metro 2000).

For the poor in the developing world, private vehicle ownership is typically confined to nonmotorized vehicles — such as bicycles, animal carts, or cycle rickshaws. In the poorest regions, ownership of such vehicles already indicates some level of economic achievement. Indeed, in some places such as China and Vietnam, owning a bicycle is considered middle-class, although motorization is quickly changing that reality. Generally, in most countries where bicycle use is highly prevalent, it is not exclusively a mode for the poor, but rather is more widely spread across the population at large, suggesting the presence of a bicycle "culture." For example, a recent study of bicycle use in five developing-country cities in India, China, Central and South America, and Africa found that the Chinese city Guangzhou, despite having the highest per capita income, also had by far the highest bicycle ownership rates (500 per thousand population). This is more than double the rate in the next highest city, Delhi, and represents the highest bicycle usage rates in the sample (Tiwari and Saraf 1997). Guangzhou also had an even split between male and female cyclists, while in the rest of the cities men comprised by far the larger share (90% and higher).

In some cities, primarily in Asia, nonmotorized cycle rickshaws offer a form of paratransit (see the following section), providing important mobility services to the poor and lower middle class. Many cities in India, Bangladesh, Indonesia, the Philippines, Vietnam, and China use cycle rickshaws extensively. These vehicles offer employment opportunities to the drivers, eliminate the risk of vehicle theft for the user, and also eliminate the up-front capital costs that an individual would otherwise face to make a bicycle purchase.

In general, bicycle and other nonmotorized vehicle use is highest in Asian cities and parts of Africa; in Latin America (with the exception of Cuba) and Central Eastern Europe it is normally less prevalent. Nonetheless, even in the traditional bike cities of China, usage seems to be on the decline due to rapid motorization, unsafe travel conditions, and an increasing negative public perception of bicycling as a way to travel.

Public and Paratransit Systems: The Crux of Developing-City Mobility

Road-based public transport still carries the brunt of passenger transport duties in the cities of most developing countries. The structure and level of provision of road-based public transport varies considerably across the developing world. A common trend across the globe is that formal public-sector bus transit is increasingly overwhelmed by nimbler, informal "paratransit" competition, which is loosely regulated by the public sector. Private paratransit operators range from large minibus companies with several vehicles in their fleets, to individual taxi and rickshaw operators.

While the bus may be the traditional "workhorse" of developing cities' transportation systems, most cities offer a rich menu of vehicle types providing some form of public or paratransit transportation service. Paratransit's share in urban transport varies from a low of about 5% of motorized trips in Dakar, Taipei, and Tel Aviv, to some 40% in Caracas and Bogotá, and as high as 65% in Manila and several other Southeast Asian cities (Cervero 1997).

There are many different types of paratransit and public transport vehicles in the cities of developing countries, ranging from nonmotorized three-wheelers (becaks) plying the narrow streets of Surabaya to the 250-passenger, bi-articulated buses on the high-capacity segregated busways of Curitiba, with almost every two-, three-, and four-wheel vehicle imaginable in between. By one estimate there were 16 modes of public transport on the city streets of India (Darbera and Nicot 1986).

Latin America. In Latin America, private-sector operators prevail under various forms of public "management," ranging from competitively tendered route franchises in, for example, Santiago and Buenos Aires, to the loosely regulated situation in Lima. The operating "companies" also run the gamut, from a handful of private operators in Brasilia to literally hundreds, if not thousands, of owner-operators in places like Mexico City. In some places the public sector still plays a service provision role, while in others some form of subsidy to private operators is provided.

"Informal" operators have become an important force in much of the region, grabbing market share from unwieldy larger operators, while also becoming political powers strongly shaping policy and a government's ability to implement that policy. For example:

> In Mexico City, colectivos evolved from government-tolerated shared sedan taxis, serving 5% of trip demand in the early 1980s, to a massive fleet of minibuses today, effectively supplanting bus service in the city and likely also cutting into the city's Metro ridership.
>
> In cities such as Recife (Brazil) and San José (Costa Rica), informal van services and minibuses are successfully competing with formal bus services for trips in outlying areas of the city (de Aragão et al. 2000).

Africa. In Africa, formal bus service is provided using different combinations of public and private operation. For instance, in Egypt, South Africa, and Tunisia, bus service is predominantly provided by the public sector, while in Nairobi it is privatized. However, as in Latin America, the effectiveness of such formal systems is increasingly being undermined by competition from the informal sector. In Nairobi, the fully private, unsubsidized system has witnessed a drastic decline in the mode share of large buses since the legalization of minibuses (*matutus*) in the mid-1970s. Some 6,500 12- and 25-seater *matutus* currently capture 70% (700,000 passengers per day) of the public transport market; their dominance reportedly led to the withdrawal of the British company, Stagecoach, from its partnership in operating Kenya Bus (Koster and Hop 2000). According to an analysis of several bus and matutu routes, the *matutus* completely dominate bus system operations in every respect, providing passengers service with nearly half the waiting and total trip time, at two-thirds the price (see Table 4-3).

Similar cases of paratransit dominance appear in Harare, Zimbabwe (see Mbara 2000), and in South African cities, where minibuses (*kombis*) dominate. In metropolitan Johannesburg, for example, 35,000 *kombis* — nearly 60% of which operate illegally — account for over 50% of all public transport trips, causing a decline in the bus services provided by government and private operators (Vorster et al. 2000).

Eastern and Central Europe. Eastern and Central Europe and countries of the former Soviet Union still display residual characteristics of the former state-owned systems, although central government's divestment of financial and vehicle responsibility to local governments threw many systems into rapid deterioration. At the same time, declines in real income combined with higher unemployment reduced passenger demand, so many systems experienced important declines in revenues (Gwilliam 2000a). Not all systems faced massive declines, however. From 1988 to 1992, public transport ridership in Hungary went down by 33% and in Poland by 13%, while in the Czech Republic the decline was a modest 2% (Pucher 1999). Currently, several forms of private participation are being pursued, such as the so-called joint stock company and, increasingly, sub-contracting and franchising of services.

Informal operators are also on the rise, but not universally. For example, in Riga, the capital of Latvia, public companies still dominate, despite poor operating performance; the private sector is apparently not growing as rapidly as in other countries of the region. In the Ukraine, on the other hand, up to 50% of service is now operated by the private sector, typically in minibuses; however, a poor regulatory environment persists (Gwilliam 2000a).

Asia. Finally, the large and diverse region of Asia has a high share of publicly operated (and, typically, low-quality) services in India, Bangladesh, Sri Lanka, and Pakistan, each of which has experimented — to varying degrees — with allowing formal forms of private operations. China's publicly run systems underwent important changes in response to economic liberalization, varying city by city and including state enterprise reform, service contracting, commercialization, and some degree of franchising and competitive route tendering (Gwilliam 2000b). In Kuala

Table 4-3. Overall average travel speeds in Nairobi — bus versus matutu

	Bus	Matutu	Matutu Advantage
Average wait time (min)	24	14	44%
Average trip time (min)	65	38	42%
Average travel time (min)	90	52	42%
Average fare ($/km)	0.03	0.02	28%
Average trip speed (km/hr)	13	18	42%
Average travel speed (km/hr)	9	13	41%

Source: Koster and Hop (2000), p. 311.
Note: Overall average based on AM/PM Peak and Off Peak.

Lumpur and the major cities of Indonesia, private operations are strictly regulated.

Again, paratransit seems to be playing a larger role in many parts of the region. In Bangkok, a state-owned monopoly, BMTA, took over the ailing private bus companies in 1979; a few private companies remain operating as partners under BMTA's control. Filling BMTA's service gaps are some 3,000 unlicensed minibuses offering suburban commuter services, nearly 8,000 three-wheeled tuk tuks, and 100,000 unlicensed motorcycle taxis. In the Central Asian Republic of Uzbekistan, bus availability by the state-owned enterprises has suffered severely from the fallout from post-Soviet era reform, declining at an average of 10% to 15% per year. Owner-operated minibuses have stepped in to fill the gap, with 7- or 11-seat minibuses now accounting for anywhere from 20% to 50% of passenger trips (Gwilliam et al. 2000).

Urban Rail Transit

Due to high capital costs and a lack of flexibility to adapt to changing travel patterns, fixed rail public transportation systems — metros and suburban rail systems — have been much more the exception than the rule in most cities of the developing world. Most existing suburban rail systems date to earlier eras, often operating on links in the national rail network. Today, significant suburban rail services exist in Buenos Aires, Mumbai (Bombay), Chennai (Madras), and several Brazilian, Central/Eastern European, and South African cities. Overall contribution to total urban trips remains low — 7% in Johannesburg, 4% in Chennai, and less than 3% in São Paulo.

Since the 1970s, many developing countries have been investing heavily in metros, sometimes through joint partnership with the private sector, but more often through public investments alone. The historic role of technology vendors and foreign governments has been pivotal. For example, the French have been active in selling metro technology through the provision of loans for construction and other significant capital outlays.

The principal aim and success of metros is their ability to increase mobility. In central travel corridors with heavily burdened roads and buses, metros provide by far the most able method of transporting large volumes, capable of carrying up to 60,000 passengers per hour per direction at operating speeds of 30-40 kilometers per hour. Theoretically, they can increase passenger-carrying capacity in a corridor by a factor of three, although in practice the range varies greatly depending on system configurations and actual demand levels.

High-passenger capacity comes at a cost, however. Depending on construction methods and management and system alignment (i.e., aboveground, at-grade, or underground), costs can range from $40 to $150 million per kilometer. This high expense typically relegates metro deployment to the upper-tier cities in the developing world, with the exception of China, where metros exist in Beijing (44 kilometers), Tianjin (7 kilometers), and Shanghai (16 kilometers), because of very high urban densities and demand requirements. Beyond China, metros and light rail can be found in many of the major cities of Latin America, Central and Eastern Europe, and Southeast Asia (see Appendix Table A-3).

Despite their importance in serving heavily traveled corridors, metros' role in satisfying total urban trips remains marginal — 5% in São Paulo, 7% in Santiago, and 14% in Mexico City (note, also, that the Mexico City system's share is only motorized trips, meaning that its share of total trips is even lower). Even where extensive systems do exist, metros still make fewer daily passenger trips than road-based public transport. In fact, in Mexico City, which boasts one of the world's largest systems, ridership has been declining in recent years, despite fares two to three times cheaper than competing public transport modes. The city's population simply continues to grow beyond the system's reach. There and in the rest of the developing world it is likely that the average person's mobility needs will continue to be fulfilled primarily by road-based public transit.

Metros rarely, if ever, recover their construction and other capital costs through operating revenues. Many systems' revenues do not even cover their operating costs, although others do. For example, a 1990 study (Allport et al.) calculated the "farebox ratio" (the ratio of revenues to operating costs) for 10 systems and found that:

- Five systems had a farebox ratio of less than 1.0 (Mexico City, Cairo, Porto Alegre, Rio de Janeiro, São Paulo).
- Two had a ratio in the range of 1.0 to 1.5 (Pusan, Seoul).
- Three had a ratio above 1.5: Santiago (1.6), Manila (1.8), and Hong Kong (2.2).

These results can be a product of deliberate public policy (i.e., fares kept low for political purposes), poor system planning (overestimated demand projections), and/or inefficient operations.

A final note is that metros do provide significantly greater mobility, but they do not relieve congestion. Few metro riders are former auto users, and any who are are quickly replaced by new auto users. As a result, for almost all metros in the developing world, the question remains whether the significant initial capital outlays were reasonable.

Land Use and Transportation: The Architecture of Cities

At the metropolitan level, the distribution of residences, offices, schools, etc. defines a city's accessibility and determines virtually all transportation activity. As in the developed world, the structure of developing-country cities and their growth patterns play a critical role in the mobility of citizens and their access to employment and other opportunities. In developing cities, however, land use and city structure are more critical to residents' accessibility than in developed cities, because the individual mobility of citizens is much lower.

While it is impossible to generalize, there are many characteristics that the cities in developing countries share to some degree, which profoundly influence transportation patterns and system performance:

- A historical concentration of trip attractions in the city center.
- Generally higher densities than cities in industrialized countries.
- Socioeconomic segregation, forcing long trips for the poor, who are usually isolated on the urban fringe.

Fast economic growth and urbanization, and increasing suburbanization, are driving rapid changes in cities across the developing world. Perhaps the most important characteristic differentiating developed and developing country suburbanization is that both the rich and the poor are found in the urban fringe of the latter, in segregated swaths of housing. The poor often settle there as "squatters" or are relocated by government housing programs; the rich move there to enjoy suburban amenities. In the middle, typically, lies the middle class, living in or closer to the inner cities.

Developing-country cities, like their developed counterparts, have been undergoing rapid urban expansion, many for several decades. The urban area of Santiago increased by more than sixfold during the second half of the twentieth century, while in the case of Mexico City, the urban area at the end of 1995 was 13 times greater than in 1940. In large part, this urban expansion was fueled by population growth, particularly due to rural migrants. Expansion was also fueled by the depopulation of more central city areas. Today, perhaps the greatest changes to urban structures are occurring in the former socialist countries of Eastern and Central Europe, as well as in the cities of China (see feature box), where market forces have been increasingly introduced to the existing planned-economic systems.

As in the developed world, suburbs are preferred by those wealthy enough to buy homes and access them in automobiles, but they impose costs and problems on metropolitan communities as a whole. The first challenge is similar to what developed cities face: suburbs cannot be adequately serviced by public transport, thereby forcing a rise in the use of automobiles or paratransit, which add to the air contaminants and the congestion problems of the central city. The second problem is possibly more acute to the developing world: suburbs are devouring valuable agricultural land. The significance of this issue depends on the locality. Egypt, for example, is mostly desert; only 3% to 4% of its land is suitable for agricultural use. The cities are located almost entirely in this small quantity of agricultural land, and consuming it at an alarming pace. Likewise, the cities of India, Peru, China, and many other developing countries are facing the same loss of agricultural land.

Today, urban expansion in the developing world may well be accelerating, not unlike the "sprawl" being seen in the industrialized world. Many transportation-related factors feed into this process, such as: the construction of ring-roads and high-speed radial highways; underpriced highway travel; congestion; and flat public transport fares (a vicious circle, since flat fares are critical to ensuring affordable mobility for the peripheral poor, while also continuing to make the periphery affordable to the poor). Other factors relate more closely to the real estate market. For example, in Prague, recently identified trends include the formation of large real estate companies purchasing large tracts of peripheral lands for residential and commercial megaprojects (i.e., hypermarkets and shopping malls); the difficulty in redeveloping urban lands due to contamination (i.e., brownfields); competition among local jurisdictions for land uses; and private pressures for change to public land-use plans (see, for example, Garb 2000). In his oft-cited book on "edge cities" in the United States, (Garreau 1991) indicated that the edge-city phenomenon was already underway in places like Bangkok and Budapest, with Mexico City, Santiago, and many other cities close behind.

In the developing world, while potentially alleviating the heavy central-city focus of current trip flows, urban sprawl may well produce suburb-to-suburb travel patterns that burden many cities' existing transportation systems even more heavily. The problem will be particularly acute for both the peripheral and central-city poor without autos — a problem that will

Shanghai Expands

Shanghai is evolving from a densely populated city with one predominant core to a less compact urban area with multiple centers, resulting in significant changes in the distribution of travel patterns. The 1984 Shanghai Master Plan added 252 square kilometers of land area east of the Huangpu River to Shanghai for major urban expansion. The core development project is a 30-square-kilometer financial district on the east bank of the river (Pudong New Area), across from the existing Central Business District (CBD) on the other side of the river. The new area is planned to house two million people and to provide 1.2 million jobs by 2020.

only be exacerbated by the unplanned nature and inadequate infrastructure of many poor settlements, and the lack of finances to improve them.

CONSEQUENCES: CHALLENGES TO SUSTAINING MOBILITY

The growth in motor vehicle use across the developing world raises several troubling issues and begs the question of whether current growth rates are sustainable. It is clear that many cities cannot currently build or even maintain the infrastructure necessary to support their growing levels of motorization; their operational system is simply overwhelmed. Equally significant is the impact current growth rates have on the three pillars of sustainability — the economic, social, and environmental health — that societies need to flourish.

The growth of private automobiles in the developing countries has undoubted benefits for their users: Increased economic, educational, shopping, and recreational opportunities are now within their grasp. Furthermore, for those who can afford them, private motor vehicles offer status and prestige: "The automobile is used to communicate messages to other people — makes the owner visible, indicates socioeconomic standing, indicates tastes" (Thynell 2000). Some analysts suggest that auto ownership actually plays an important socioeconomic role in middle-class formation (Vasconcellos 1997). Japanese commentators dubbed the 1960s the "Decade of the Three Cs," to mark their compatriots' widespread purchase of the three new indicators of middle-class status: color televisions, air-conditioning, and most importantly, cars.

The increase in mobility and social status that auto owners enjoy, however, comes at a price for the majority of their fellow citizens who cannot afford cars; the use of cars often impinges on the mobility/accessibility of other system users (bus, other public transport, and nonmotorized users). In fact, it is clear that in many cities the ownership of autos by the upper class is worsening many social inequities. Auto infrastructure consumes space for other uses and pushes cities farther out, making nonauto modes less convenient, less viable, less attractive, and less safe. Most developing cities are growing at such a rapid pace that not only is new infrastructure not being built, the current systems are deteriorating at an alarming pace.

Congestion levels clearly affect the fragile economies of the developing world. The vast majority of the middle and working classes in developing cities must endure long commutes on crowded public transportation. Motor-vehicle-related accidents and fatalities present a serious public health problem whose principal impact is on lower-income pedestrians and bicyclists. Airborne pollution and the loss of wetlands and species habitats attributable to changing land use are on the rise, as well.

In short, mobility in developing cities is not achieving its purpose of increasing accessibility. Current transportation means are not increasing the majority of citizens' access to increased economic benefits, greater social interactions, and higher qualities of life. This section details and assesses the consequences of deteriorating mobility; congestion; air and noise pollution; damage to the environment, and their effects on social equity.

Safety

Traffic accidents are a serious health hazard in many developing-country cities, where traffic fatalities are a major cause of death among economically active individuals (Ross and Mwiraria 1992).

Table 4-4 shows fatality rates in a selection of developing-country environments. Traffic safety in the developing world poses a problem proportionally larger than its "cause." The World Bank (1996) shows that low-income countries suffer some 80 times more traffic fatalities per vehicle than high-income countries (although the fatalities-per-capita figure is approximately one-half), indicating a high level of traffic risk, and poor quality of emergency health care. Motor vehicles are almost always involved in traffic fatalities; whether or not they are the "cause" is most often difficult to establish in the aggregate because of problems with reporting and data collection. Also similar to the case of air pollution, it is difficult to understand the overall "size" of the traffic-safety problem because of data problems.

At issue is not the number of motor vehicles, but rather the lack of institutional, engineering, and infrastructure interventions, combined with a high degree of mixed and often conflicting road users. For example, there is often a lack of driver training, public education or sufficient enforcement of traffic laws. Driver error is responsible for the majority of accidents; and penalties for offenses such as drunk driving are often low (see, for example, Oladiran and Pheko 1995). Even in places with laws on the books, social patterns often negate their effects. In Kuala Lumpur, for example, despite mandatory seat belt use laws, a small survey of taxi drivers found that 60% did not use their seatbelts (Hauswald 1997).

There is a widespread lack of respect for nonmotorized users (pedestrians and cyclists), and these users bear an undue accident burden. In Delhi, for example (see Table 4-5), cyclists, motorcyclists, and pedestrians were all disproportionately represented in 1994 traffic accident fatalities. The danger to nonmotorized users in Delhi also directly affects the use and safety of buses, since all bus trips start and end as pedestrian (and sometimes bicycle) trips (Mohan and Tiwari 1999). Pedestrians in São Paulo are also highly vulnerable; although they are involved in only 6% of acci-

Table 4-4. Traffic fatalities in selected regions

	Year	Traffic Fatalities	Fatalities/ 100,000 People	Fatalities/ 10,000 Vehicles
Brazil	1995	27886	18.3	11.0
Bombay	1986	NA	NA	11.6
Bogota	1996	1073	16.8	18.9
Mexico City	1993	2179	12.8	6.1
Santiago	1994	394	7.2	6.3
Bangalore	1995	678	16.1	10.4
Delhi	1993	1783	21.3	8.55
Durban	1996	637	29.7	16.0
Johannesburg	1991/92	524	33.3	NA
Harare	1998	391	23.0	9.8

Sources: Vasconcellos (1999); Vasconcellos (1996); COMETRAVI (1999), vol. 1; Zegras and Litman (1997); Sachdeva (1998), p. 508; Chakravarty and Sachdeva (1998), pp. 60–61; Durban Metro (2001); Mbara (2000), pp. 10–11; Guruprasad (2000), p. 478; Granne et al. (2000), p. 906.
Notes: For Mexico City, Delhi, and Santiago, the fatalities per vehicle includes all vehicles; for other cities not entirely clear in source.

dents, they represent 54% of all traffic fatalities (Wright 2000).

Congestion

One of the immediate consequences of rapid motorization is traffic congestion. Although data are rarely clear or comparable, downtown weekday traffic speeds in developing cities are dismal. They reportedly average:

> 9 kilometers per hour or less in Seoul and Shanghai.
>
> 10 kilometers per hour or less in Bangkok, Manila, and Mexico.
>
> 17 kilometers per hour or less in Kuala Lumpur and São Paulo.

Partially as a result, average commute times are high and increasing. The average one-way commute in Manila is 120 minutes. In Jakarta it is 82 minutes. Indeed, of the 19 developing cities with journey-to-work times reported in the World Development Indicators, 12 have an average one-way commute time of 45 minutes or longer (World Bank 2000).

Of course, without data on trip lengths or relevant data over time, it is difficult to comment comparatively on congestion levels and/or their evolution in the cities of the developing countries. It is clear, however, that while all vehicles suffer in congestion, public transport bears a disproportionate burden, with average peak-period bus speeds up to one-half as slow as those of automobiles. Estimates from several Brazilian cities offer evidence: Buses' travel speeds are 30% to 40% lower than autos in peak congestion (see Table 4-6).

Infrastructure decay and institutional weakness. The rapid growth in motor vehicle fleets across the developing world is creating massive pressures for infrastructure expansion, but developing-country cities often find themselves unable to maintain existing infrastructure, much less able to finance the new. The problem is in part an institutional one. Poorly designed and inadequately funded public finance systems hamper the maintenance and construction of infrastructure across the developing world. Further, infrastructure development must always compete with other public policy objectives such as the provision of health care, education, and other public works. Even if an urban transportation system generates sufficient revenues to sustain itself (i.e., through vehicle registration fees and dedicated fuel taxes), the

Table 4-5. Mode share and road accidents in Delhi, 1994

Mode	Mode Share (%)	Fatalities (%)	Ratio (fatalities/ mode share)
Car/taxi	5	2	0.6
Bus	42	10	0.2
Motorized two-wheelers	12	27	2.3
Bicycle	5	14	2.8
Pedestrian	32	42	1.3

Source: Mohan and Tiwari (1999).

Table 4-6. Average, evening peak auto and bus speeds in Brazilian cities

City	Auto	Bus
Belo Horizonte	23	16
Brasilia	45	27
Campinas	24	17
Curitiba	22	19
João Pessoa	26	18
Juiz de Fora	30	21
Pôrto Alegre	29	20
Recife	24	14
Rio de Janeiro	26	19
São Paulo	16	11

Source: Vasconcellos et al. (2000), p. 628, fig. 1.

money often leaks into other sectors, is allocated to a higher level of government, is poorly managed, and/or is used as a means of, for example, income redistribution. Finally, the failure to introduce real marginal cost pricing (or a rough proxy) creates excess infrastructure demand and hampers "rational" planning. While by no means unique to the developing world, these problems are arguably more dire there, where resources are more constrained and equity impacts are potentially larger.

Perhaps the greatest short-term impact is on maintenance of existing infrastructure. The state of road maintenance in developing countries is particularly poor. Analysts estimate that from 1964 to1984, US$45 billion worth of road infrastructure assets were lost in 85 developing countries because of inadequate maintenance (Gwilliam and Shalizi 1996). In the early 1990s, the European Bank of Reconstruction and Development (EBRD) estimated rehabilitating existing roads and upgrading conventional railways in Central and Eastern Europe would require US$44 billion (EBRD 1993). South Asia and Africa have suffered disproportionate neglect: South Asia in particular has under 20% of paved roads in good condition (See Table 4-7; disaggregate data on the conditions in individual cities is not readily available).

The costs of annual maintenance are estimated to be a fraction of the cost of rehabilitating a badly maintained road that has deteriorated. Also, regular maintenance generates significant benefits in the form of lower vehicle operating costs and general productivity gains. It is estimated that on balance maintenance expenditures can generate returns in the range of 30% to 35% (World Bank 2001a). However, the tendency to underfund maintenance persists, with significant investments made in the 1960s and 1970s crumbling through the 1990s. At an aggregate level, roads in developing countries are managed almost without exception by local governments and national agencies suffering from a large backlog of maintenance projects. More so than their counterparts in the developed world, these agencies are insulated from political pressures for better maintenance, and suffer from low irregular revenue.

Beyond the need for maintenance comes the heavy pressure to satisfy projected future demand, with subsequent requirements placed on government coffers. For example, to help alleviate Bangkok's notorious congestion, 30 to 40 transport "megaprojects" were in some stage of consideration, planning, or construction by the mid-1990s — the estimated price tag for which was $35 billion! Again, however, weak (if any) transportation-financing mechanisms are typically in place. Furthermore, planning and investment decision-making processes are often unclear. Finally, the question remains: Will developing-country cities ever be able to "build their way out" of the problem? Major road expansions in several large Chinese cities have barely managed to keep pace with motorization: Guangzhou has a new orbital expressway and inner ring road; Beijing constructed two ring roads and has a third under construction; Shanghai's road area grew by 42% in the first half of the 1990s; Shenzen has completed construction of 139 kilometers of highways — and yet in all of these cities, average peak-period traffic speeds remain below 20 kilometers per hour (Mohan and Tiwari 1999).

Local Air Pollution

Transportation air pollution problems in developing-country cities generally follow the path taken by the industrialized world, with problems reaching crisis point before being confronted. The pollution problem in many cases is "cruder," as cities confront gross levels of contamination due to leaded gasoline, or excessively smoky vehicles emitting high levels of particulates. These problems are relatively "easily" addressed with technical fixes, such as eliminating lead from gasoline and adequately tuning and maintaining engines, then moving toward cleaner fuels such as lower-sulfur diesel. However, as these "gross" problems are addressed, more tenacious problems often arise — those attributable to ongoing motorization, such as the ground-level ozone formation as seen in Santiago, Chile.

Transportation often accounts for a majority share of criteria pollutants — although not all of these cities confront the same levels of pollution and thus the same degree of "problem" — despite the low motorization levels in most cities relative to the industrialized world. For some cities in the earlier stages of motorization (i.e., Beijing), the motor vehicle contribution appears to be growing, as would be

Table 4-7. Condition of main roads by region

Region	Paved			Unpaved		
	Good	Fair	Poor	Good	Fair	Poor
Eastern and Southern Africa	42	32	26	42	30	28
Western Africa	52	23	25	20	36	44
East Asia and Pacific	20	59	21	41	34	25
South Asia	19	45	36	6	39	55
Europe, Middle East, and North Africa	41	35	24	30	46	24
LAC	44	32	24	24	43	33
Average	32	42	26	31	36	33
United States	31	57	12	—	—	—
United Kingdom	85	12	3	—	—	—

Source: World Bank (1988).
— Indicates not applicable.

Table 4-8. Motor vehicle contribution of total air pollutants in selected developing-country cities

City	Year	CO	HC	NO_x	SO_2	SPM
Beijing	1989	39	75	46	NA	NA
	2000	84	NA	73	NA	NA
Bombay	1992	NA	NA	52	5	24
Budapest	1987	81	75	57	12	NA
Cochin, India	1993	70	95	77	NA	NA
Delhi	1987	90	85	59	13	37
Lagos, Nigeria	1988	91	20	62	27	69
Mexico City	1990	97	53	75	22	35
	1996	99	33	77	21	26*
Santiago	1993	95	69	85	14	11
	1997	92	46†	71	15	86‡
São Paulo	1990	94	89	92	64	39

Sources: WRI (1996); West et al. (2000); CONAMA (1998); Fu and Yuan (2001).
* PM10.
† Does not include evaporative emissions from refueling.
‡ PM10, includes fugitive road dust.
NA: Data not available

expected (see Table 4-8). The available evidence suggests that Santiago's relative transport contribution may be improving, while Mexico City's record appears mixed.

In many cases, the problem derives from particularities of developing-country vehicle fleets: long-lasting vehicles with deteriorated emissions profiles; low technological requirements for new vehicles; poor maintenance practices for public and private fleets; institutional/political challenges to inspection and maintenance; vehicle tampering; and a lack of public awareness of the scope of the problem. In the places with some of the worst chronic pollution, important strides have been made and pollution has often been the impetus for such draconian measures as vehicle-use restrictions and "no drive" days.

Noise Pollution

Transport is a major cause of this oft-neglected urban policy problem for which the data are scarce. In Santiago, research in the late 1980s indicated that 80% of the population living or working along the city's principal transportation arteries suffered some risk of hearing loss, and nearly 70% of residential or mixed-residential land is, according to international standards, considered inadequate for these uses due to noise levels (Intendencia 1989). On Lima's principal avenues, measurements taken by the municipality indicated noise levels almost two times higher than recommended norms. Some intersections recorded levels high enough to pose a serious risk of permanent hearing damage (Iturregui 1996). In the Slovak Republic, over 7% of the urban population suffers exposure to road transport noise levels considered dangerous for human health (Slovak Republic 2001).

Traffic noise is a particularly acute problem in the warmer cities of the developing world, where the climate encourages open architecture and open windows in dense residential neighborhoods. The problem is compounded by the abundance of aging, large vehicles such as diesel buses, and a plethora of small, shrill vehicles, such as mopeds, small-engine motorcycles, stick-shift automobiles with inadequate mufflers, and hybrid vehicles like Bangkok's ubiquitous tuk-tuks. Along major thoroughfares in Ho Chi Minh City, average noise levels exceed the standard by 26% to 40% (Nguyen Duc 1996).

Transport noise may actually increase urban decentralization trends because of the reduced quality of life in inner cities. A major point is that public transport is often the culprit — buses are noisy — which in itself is often an important policy dilemma.

Other Environmental Impacts

The diverse range of urban transport's deleterious effects on the environment —such as induced consumption of open space, the disruption of delicate ecosystems by highway construction, runoff from pavement, vehicle disposal, fuel leakage, etc. — all exist in the developing world in patterns similar to what we have seen in the developed world. They have not yet been widely studied or documented, however, and therefore analysis and comparison are difficult. Nonetheless, concern is on the increase. For example, in Panama City, local and international NGOs have blamed several environmental impacts — on areas of important biodiversity and on coastal water pollution levels — on a toll highway built 40 meters off the coast and related real estate development projects (Wing and Saladin 2000). Road-building and associated developments in the Andean foothills of suburban Santiago have been linked to increased incidences of flash flooding, and may be inducing microclimatic changes due to loss of vegetation (Romero et al. 1995).

Developing cities' consumption of petroleum and subsequent contribution to global climate change is currently minor, but growing. Although industrialized countries currently account for 75% of transportation energy use and greenhouse gas emissions, estimates suggest that the developing countries could generate the majority of transportation-related emissions by 2025 (IPCC 1996). Nonetheless, their emissions in per capita terms will likely remain lower than those of the industrialized countries.

Social Equity

The poor. Throughout the developing world the poor are faced with disappointing choices concerning mobility. Because they cannot afford cars, they are increasingly unable to gain full access to the changing spatial opportunities in their societies. This lack of mobility has a disproportionate and regressive effect. The poor are often located at the periphery of the city, in informal settlements that are far from public transportation and at a substantial distance from the central city. They have to endure long commutes in inadequate public transport, high levels of urban air pollution, and unsafe conditions for cycling and walking. In addition, the poor disproportionately suffer from the "barrier effect" of being isolated by major highway construction, and from outright dislocation due to increased land values and the confiscation of land for transportation projects. In addition, transportation projects are a major public expenditure. In economies where many basic needs such as water, sanitation, and education are not met, it is important to recognize that there is an opportunity cost to the funds invested in transportation projects.

Often, transportation policy in developing countries is based on the idea that the best way to help the poor is to promote economic growth. Thus, investments in growth-inducing transportation projects are justified as aiding the poor. Though the benefits of general economic growth do often "trickle down" to the poor, it is abundantly clear that the poor also suffer disproportionately from transportation strategies that focus on motorization as their primary goal.

Women. Women in the developing world face additional hurdles to full and free mobility because of the gender-based division of roles and responsibility in the family and the community. Men are the traditional breadwinners who typically make one round trip to and from work per day, at peak hours of service. Women, on the other hand, to fulfill a variety of tasks and responsibilities, typically make multiple trips throughout the day, paying several different single-trip fares, waiting through non-peak service, and carrying heavy physical loads. Personal safety and comfort are critical factors that deter women from using public transportation. Women are vulnerable to sexual harassment, attack, and abuse while traveling in the public transportation system. Finally, there is the issue of income: One study found that almost 30% of women's incomes each month was spent on transportation (Shrestova and Barve, 1999).

Trade in Used Vehicles: Opportunities and Dilemmas

Often vehicles rendered obsolete get eliminated from a country or region, without necessarily leaving the world's roads. After all, motor vehicles are durable goods that can, with great resourcefulness on the part of their owners, sometimes last up to 30 years or more. Since there seems almost always to be a demand for cheap vehicles, used vehicles that have lost their usefulness to one owner can bring value to another. In recent years, the reduction of barriers to global trade has opened up a large market for used vehicles, taking those vehicles across borders to where demand is high. For the original owner, typically in an industrialized country, the trade in used vehicles offers financial reward for a good that has otherwise lost its value. For the buyer, the used vehicle offers motorized mobility, at a relatively cheap price.

Despite the apparent market efficiency behind the trade in used vehicles, this issue raises certain questions and dilemmas. For example, might the benefit of a used vehicle's low up-front cost be offset by the higher life-cycle costs associated with operating and maintaining an older vehicle? Many of the worst-polluting vehicles in developing cities are old, secondhand vehicles "passed down" from developed nations after they were no longer desirable, or were unable to pass US or European emissions tests. Is the trade in used vehicles increasing air pollution and energy consumption (and greenhouse gas emissions) in recipient countries? Is the trade in used vehicles bringing unsafe, inadequate or inappropriate motor vehicles to recipient countries? Is the trade in used vehicles accelerating motorization rates in recipient countries, thus exacerbating congestion, pollution, and public expenditures for road infrastructure in recipient countries?

These are challenging questions, with no clear answers at present.

Source: Zegras (1998).

Another study of rural women who commute into Calcutta for employment found that "54% of the respondents spend more than twelve hours outside their homes every day. Only 5% stay away for less than eight hours. Time is wasted waiting to change from one mode of transportation to another; on average 55 minutes per day. In addition, women walk for part of their journey, on average for 90 minutes, but in some cases 150-180 minutes" (Mukherjee, 1999).

If a family is able to afford a car, usually the man drives it to work. The same holds true for bicycles. A study in Havana, Cuba, where bicycles were the most popular mode of transport, found that women accounted for only 13% of all bicycle riders (Peters, 1998). There are also socio-cultural deterrents that prevent women from riding bicycles. Bicycle riding is considered unsafe and "unladylike." In many countries in Africa, if a woman rides a bicycle she is considered "loose" or overly independent (Peters, 1998). In Iran, the cultural taboo about women riding bicycles has been institutionalized in a law that bans women from riding in public places (Peters, 1998). The unfortunate result is that in many places where bicycles would help solve women's transportation needs, they are left to walk or rely on public transport to be able to carry out their daily tasks.

There is a significant lack of data on women's mobility throughout the developing world, but what is clear is that women have different needs and requirements that have not traditionally been met by transportation planners. Fulfilling those needs is critical to the social and economic equity of developing cities.

Assessing the Impacts

Despite the individual and social benefits of modern transportation systems, it is widely recognized that their negative impacts imply real economic costs. The data on developing cities are meager, and there is no consensus on the methods of analysis. Nonetheless, most estimates suggest that transportation systems can have external costs in the range of 5% to 7% of Gross Regional Product (GRP; see Table 4-9; Willoughby, p.3, 2000a), comparable to results in the industrialized world.

Other recent World Bank estimates suggest that the total economic costs of air pollution alone represent up to 10% of GRP in polluted cities such as Bangkok, Kuala Lumpur, and Jakarta. For six developing country cities with a total population of over 50 million (Mumbai, Shanghai, Manila, Bangkok, Krakow, and Santiago), the costs of particulates and other vehicle emissions are estimated as equivalent to 60% of the import cost of gasoline, and over 200% of the import cost of diesel (World Bank 2001).

The estimates in Table 4-9 help shed light on the relative magnitude of the various problems posed by transportation externalities in developing-country cities. In general terms, congestion, air pollution, and accidents seem to impose roughly equal burdens, although firm conclusions are difficult to draw. Again, this is due to the fact that the estimates are often based on uncertain data and unclear methodologies (i.e., are pollution cost estimates based on willingness-to-pay, human capital costs, how value of life is calculated, etc.), and do not all cover the same cost categories.

For Asian cities, one recent estimate showed that air pollution costs far dominate congestion costs (Shah 2001), although again details on the data and methodologies underlying these estimates are unavailable.

Accurate external cost estimates could, in theory, help better understand transportation improvement priorities, by including them in economic analyses and subsequent project selection based on internal rates of return. An equally significant step

Mobility as a Force for Economic Development in Developing Countries

Transport infrastructure is an important factor in regional and national economic development. The availability and efficiency of the available transport infrastructure influences economic development in at least three different ways.

First, both the size of an urban area and the efficiency of urban economic activity depend on the quality of the transport infrastructure. Higher speeds and reduced travel times lower production costs and raise productivity by reducing fuel, labor, and land costs. Improved accessibility makes more land available for building and reduces the cost of land. Reduction in travel delays leads to higher labor productivity. There is significant evidence linking the quality of transport infrastructure to firms' location decisions. Studies of Seoul and Bogotá have found that city centers with good infrastructure facilities promote the growth of new industrial enterprises, particularly small and medium-sized firms (Lee, 1985; Lee, 1989). Cities with inadequate transport infrastructure are unable to provide this impetus, thus constraining industrial and economic growth. Severe limitations imposed by a highway and urban street system that never anticipated today's rapid increase in number of motor vehicles have left China with one of the world's most severe infrastructure shortfalls. This problem is widely recognized by the government in China as a threat to continued economic growth. In China's Pearl River Delta, new industrial development is increasingly located in low-density settings in the province of Guangdong, away from the congested cities of Guangzhou and Hong Kong, to ensure high mobility. In Thailand, a study of Bangkok has shown that poor transport infrastructure constrains the growth of small firms in the city, and there is evidence that that recent trends to locate industrial establishments on Thailand's eastern shore are in response to congestion problems in Bangkok. The adverse impact of the lack of adequate transport infrastructure is most evident in places such as the low-income countries of sub-Saharan Africa, where producers' need to provide private transport infrastructure damages their competitive edge.

Second, an efficient and safe transport infrastructure facilitates labor market participation and is a necessary component to an efficient labor market. A study of city center residents in Mexico City has found that advantageous location, which implies better transport and accessibility, contributes significantly to the success of these residents in the formal and informal labor sectors (Eckstein, 1990). Studies by Rémy Prud'homme are in the course of showing that major cities with better access systems expand the potential labor market for given locations, thereby improving city productivity. Indeed, there are several examples of industrial and residential development that have been systematically located to take advantage of access provided by new transportation facilities. In Curitiba, Brazil, industrial centers accessible by high-speed bus access corridors were systematically located at the outskirts of the city. In São Paolo, Brazil the substantial new public housing sites were developed in the outskirts of São Paulo once the metro system made them accessible to the city center. The development of new metropolitan centers around Chinese cities, such as Nanjing are also examples of this phenomenon.

Third, direct expenditure on construction and maintenance of transport infrastructure is an important source of employment for many regions. In particular, government spending on infrastructure is often used as an important employment-generating policy tool to provide economic stimulus during recessions. Labor-based approaches to transport projects are also an effective instrument for economic growth in developing countries with abundant labor forces. Many governments in developing countries have pursued domestic production of automobiles as a way to promote their local manufacturing industries. It is widely known, of course, that the automotive industry stimulates a great deal of "upstream" industrial development because of its multisectoral requirements for many components — electronics, sheet metal, foundry work, plastics, rubber, glass, textiles, and so forth. The eventual result is new products in all these sectors, which generate other markets and more employment.

There has long been a debate as to whether infrastructure precedes development or vice versa. This debate is not very productive for our purposes, since development and transport infrastructure clearly depend on each other and inch along, each supported by the other. As a result, there is a strong association between the stock of transport infrastructure and national level of income; countries with higher GDP per capita tend to have more paved roads. Furthermore, it is noticeable that the share of transport sector in overall infrastructure investment increases with income levels. The World Bank reports that a 1% increase in per capita GDP means a 0.8% increase in paved roads.

In all, there is evidence that, as a public investment, transport infrastructure yields a high rate of return. For example, the estimated rates of return of investment in transport infrastructure are 77% in Taiwan and 51% in Korea (Uchimura and Gao 1993). Another study has also estimated the returns on transport investment in developing countries to be as high as 95% (Canning and Fay, 1993). The high rates of return are not entirely unexpected, considering that many of these projects are in regions where existing networks are limited. These figures may have been overestimated, due to other variables that affect output growth and infrastructure investment but are not included in the studies. The average economic rates of return on transport projects supported by the World Bank are reported to be lower at about 18% (1974–1982) and 21% (1983–1992) (World Bank 1994). Even accounting for inaccuracies, however, these figures are still higher than other types of basic infrastructure. In this context, it is important to note that adequate transport infrastructure is necessary but not sufficient to facilitate economic growth. Economic development depends also on other favorable economic conditions and appropriate government policies. Transport infrastructure can contribute significantly to economic development only when it provides services that respond to effective demand.

Table 4-9. Road transport externality estimates for developing-country cities (as % of GRP)

City	Year	Land and Parking	Congestion	Accidents Net Insurance	Noise	Air Pollution	Subtotal	Road Revenues	Net
Mexico City	1993	0.1	2.6	2.3		0.6	5.6		5.6
São Paulo	1990		2.4	1.1		1.6–3.2	5.1-6.7		5.1–6.7
Buenos Aires	1995		3.4	0.5–2		1.0	5.6–7.1	1.0	4.6–6.1
Bangkok	1995		1.0–6.0	2.3		2.6	5.9–10.9		5.9–10.9
Santiago	1994	2.0	1.4	0.9	0.2	2.6	8.3	1.64	6.7
Dakar	1996		3.4	0.2–4.1		5.1	8.7–12.6		8.7–12.6.6

Source: Willoughby (2000a), p. 5.

would be for transportation planners to expand their definitions of costs, and try to put an appropriate value on the costs of such burdens as pedestrian safety, noise pollution, and environmental and community disruption.

THE CURRENT POLICY AND STRATEGY ENVIRONMENT

Current Conditions and Needs

The developing world is meeting mixed success as it struggles to confront transportation problems. In the absence of central, long-range planning, haphazard or uncoordinated growth is common. Many state agencies are unable to monitor, let alone manage or improve, their constituents' transportation needs. Indeed, a frequent hurdle throughout Eastern European and former Soviet nations is confusion about which government agency is responsible for transportation, and in which regions. Poorly funded municipal agencies may be expected to maintain roads previously built by a national authority. All of the former Communist nations are suffering from severe cutbacks in their subsidies of public transport.

The results of this vacuum of government authority are that motorization and congestion are mounting, public transport service is deteriorating, and already precarious pedestrian and cyclist conditions remain unaddressed. Loosely managed, sometimes completely unregulated, paratransit operators have moved swiftly to fill their cities' transportation needs; but as private entrepreneurs, they respond only to the most demanding market pressures instead of their society's needs as a whole, which does not always produce an equitable transit solution (see Vasconcellos 2000). Nonetheless, some developing cities have achieved modest success in meeting their citizens' transportation needs, and in a few notable cities, most notably Hong Kong and Singapore, transportation policies have worked in concert with economic development programs to drive substantial gains in economic growth, rising incomes, and social equity.

The readily available, affordable solutions include small, yet significant, steps such as vigorous enforcement of the rules of the road, increased use of signals, safer sidewalks and bike paths, and rational regulation of parking. A more significant hurdle is managing the private operators who now dominate public transportation in many developing cities. Infrastructure maintenance also looms large. Finally, rationally planning and deploying new infrastructure, roads, and in some cases rail, will prove critical in many circumstances.

Perhaps the greatest challenge is to strengthen the institutions that plan, manage, and finance urban growth and transport. Government agencies need to be able to perform such basic and necessary steps as regulating their public transport concessionaires; collecting and analyzing the meaningful traffic data needed to understand their city's problems and plan appropriately; and creating the kinds of networks and urban structures that will enhance accessibility and improve mobility for all of their citizens.

Despite the daunting nature of the challenges and the current lack of funds for large-scale infrastructure investments, there are reasons for optimism. Some countries, most notably China, have strong central and local governments that can streamline the planning and execution of new transportation solutions. The cost of labor is cheap compared to capital costs, which can result in some useful solutions, e.g., cities can deploy more police for traffic control. Also, there are often fewer regulatory and legal barriers to development and innovation. The freedom that less litigious societies provide, such as the ability to test new technologies in cars and buses without the threat of lawsuits, must, however, be balanced against a frequent lack of detailed environmental reviews and public input to the process. Moreover, in the best of cases there is widespread public acknowledgment of the issue, and a corresponding willingness to be more bold and innovative in seeking solutions.

Let's examine the record.

Infrastructure Maintenance and Expansion

Key questions for the developing world include in which existing infrastructure should countries invest precious maintenance resources; and in which types of infrastructure should they invest, and where should they build it? Yet, few if any infrastructure finance mechanisms exist, and they are weak and poorly structured. Even ignoring the issue of externalities discussed in the previous section, it is rarely clear whether or not users are paying more or less of "their own way" for infrastructure provision and maintenance in urban areas. This problem is not unique to the developing world per se, but is perhaps compounded there because of the lack of money and institutional expertise, more potential inequities, and more possibilities for corruption (see Gwilliam and Shalizi 1996).

A lack of money constrains most local efforts to build new roads and bridges. Few local governments can float bond issues or engage in other means of capital formation, and private investors are likely to be hesitant in the face of government instability. As a result, planners are likely to shoot for ambitious large-scale projects in the hope of finding some external lender to support the project — however dim that prospect may be. This tendency, while entirely understandable, is disruptive for developing nations that should be aiming for fiscal responsibility as a principal goal. Grandiose, if fiscally untenable, projects are most prevalent in the currently or formerly planned economies, where the lack of fiscal discipline and budgeting experience often reduces transportation planning to a wish list.

Transport sector "accounting" is notoriously difficult, particularly at the urban level, since revenue sources and expenditures — which often involve significant transfers among levels of government — are rarely clear. Isolating costs imposed by and charges paid for by urban infrastructure users is also difficult, since suburban commuters and out-of-town visitors, particularly freight trucks, are heavy users of a city's roads. By at least one account the road transport sector in Buenos Aires, in general, pays costs specific to road use that more than cover road infrastructure and maintenance costs. There are, however, cross subsidies from automobiles to heavy freight trucks and among users of different fuel types (i.e., subsidies to CNG vehicles) (Libonatti et al., 1996). Similarly, in Santiago in 1994, road users paid $220 million more in related road-user fees than direct government road expenditures (Zegras and Litman, 1997). It can be argued that part of these resources went to financing the city's metro construction during this period, although even considering this expenditure leaves a surplus. If this is indeed the case, then road revenues in Santiago (Zegras and Gakenheimer 2000):

- Are implicitly used for income redistribution.
- Serve as a proxy for transport external costs.
- And/or show a general underfunding of investments in road maintenance and new construction.

Irrespective of the situation of transport sector "accounts," most indications are that the sector is dominated by tendencies for infrastructure expansion at the cost of maintenance. One tool to help deal with the situation is the creation of road-sector funds. A wave of "first-generation funds" designed to deal with failed budgetary systems was established in the 1970s and 1980s under periods of fiscal stress in several developing countries. These funds centered on ensuring that maintenance actually occurred. However, the lack of an overarching vision for institutional reform, loose earmarking subject to siphoning, and the failure to implement marginal cost pricing resulted in widespread failures (Heggie and Vickers, 1998). Some signs of a renewal in the use of road funds specific to the urban sector exist. History suggests that their success will hinge upon transparent institutional oversight, detailed management of the accounting procedures, and vigorous prosecution of inappropriate or corrupt transfers of funds.

International financial institutions play an important role in developing transportation infrastructure and in leveraging policy reforms in the developing world. The World Bank wields perhaps the most influence of any institution. A review of Bank lending from 1983 to 1993 (IIEC 1996) showed that most of its loans were directed at intercity transportation infrastructure, particularly roadways. During the same decade, the Bank lent roughly $2.5 trillion to the urban transport sector across the globe; 60% of this went to road building or maintenance, 17% to bus and rail systems, 10% to traffic management, and 14% to technical assistance. The major share of nonroad lending was in Latin America. Important funding was dedicated to urban ring road construction in, for example, Budapest, Hungary, parts of Asia (i.e., China), and in Latin America. The Bank also played an important role in financing busway development — for example, it made a series of loans to Brazil during the 1970s.

For urban areas, a major problem relates to financing new local infrastructure development to support the travel demands brought about by urban expansion. Again, institutional barriers often crop up. In Mexico City, a major challenge to adequate highway provision lies in the need for coordination between city, state, and national institutions and the often vague allocation of responsibility among them. In many cities, land developers are responsible for developing all local infrastructure — which

Urban Road Funds

To date, most road funds have been for inter-urban road networks that carry the bulk of national traffic. Urban funds are variants put forth by some policymakers as a way to assume financial control of the high costs of building urban roads. Current examples include:

Kyrgyzstan: The capital city Bishkek of this small central Asian country is facing a maintenance crisis. The recently established National Road Fund is permitted by law to allocate up to 10% of its funds to urban areas, but in practice it allocates much less because the needs of the national network are perceived as more pressing. The city government receives some transfers from the central government, but almost all of it is earmarked for health and education services. It also has limited revenue-raising authority. As such, the city has resorted to ad hoc lotteries and festivals to fund road finance. A working group of city and central government is working on ways to increase central road fund revenues so that urban areas get a higher share. The consultative process is an essential component of road fund management. Urban road finance is thus part of the wider national system.

Honduras: The city of San Pedro Sula set up a road fund in 1996 under a municipal decree. The nine voting members on the board consist of representatives from the business community, the engineering profession, organized labor, the road transport industry, and even the press. The revenue stream includes local improvement taxes, vehicle registration fees, traffic fines, parking charges, and other income channeled through the municipal budget, totaling about US$2 million per year. Maintenance is the road fund's priority, although it can finance other road expenditures. It is subject to an annual audit. Here, urban finance is quite detached from the national system.

South Africa: The national system for urban road support in South Africa shows that although urban costs are higher, user charges cannot always be differentiated according to location, as this is costly to implement. Urban roads are financed through local government rates and grants from a national Urban Transport Fund administered by a subcommittee of the South African Roads Board. Although the original plan was to support the Fund in part through congestion pricing, as with many first-generation road funds, this was never introduced. Instead, the Fund receives money from the national road fund and a central government grant. The long-term aim is to devolve the fund to the provincial level, as in the Honduras example, but this has not been possible in the short run.

Source: World Bank (2001), Heggie and Vickers (1998).

can lead to several problems if they do not coordinate their efforts. Furthermore, development of regional-level infrastructure to connect new developments to the rest of the urban area can prove problematic to finance, although in a limited number of cases, real estate developers have been charged impact fees to finance such roadways.

The private sector to the rescue? The role of infrastructure concessions — broadly defined as granting rights to levy user fees to cover construction and/or operational expenses, usually for a fixed period of time, to an entity outside the public sector (often a for-profit private sector entity) — in the development of new infrastructure and the rehabilitation/upgradation of existing infrastructure, is on the rise. A noteworthy early entry into this arena was Bangkok, which turned to the private sector to fund a series of proposed megaprojects beginning in the mid-1980s, with limited success to date. At the end of the 1990s, private-sector concessions were involved in an estimated 15 urban transport infrastructure projects under development or operation in developing Asia (including eight in Bangkok) and another 20, at least, in Latin America (including 14 in Buenos Aires) (see Menckhoff and Zegras 1999).

Concession projects usually focus on roadways, although Buenos Aires embarked on an aggressive privatization of its subway and suburban rail system as well. Through its concessions program, Buenos Aires upgraded 840 kilometers of subway and suburban railways, as part of projects costing some $1.4 billion. The concessions encountered some political opposition and recent challenges to transparency in their renegotiations, but they also coincided with an increase in public transport ridership — which actually exceeded projections in most cases. The subway no longer requires operating subsidies. The city's concession program also leveraged over $1 billion in private-sector investments to upgrade and expand over 300 kilometers of motorways. Several Brazilian cities followed Buenos Aires into the private capital markets to finance their infrastructure. The city of São Paulo's attempts at concessioning 240 kilometers of exclusive bus corridors were thwarted by lack of financing available to the private-sector concessionaires, although the State was able to concession the upgrade and completion of a 33-kilometer trolleybus line (Rebelo 1997). In Rio de Janeiro, the 41-kilometer Metro was "concessioned" to the private sector in 1997, with the suburban rail line following soon after in 1998 (Rebelo 1999).

Ultimately, incorporating concessions successfully requires several conditions: economic stability; a clear urban transport policy and overall strategy; a reliable and competent government; proper institutional, legal, and regulatory frameworks; and a strong, effective, accountable regulatory body with enforcement capability. The key is to prevent urban transport investment decisions from falling to market forces; otherwise coherent urban transport programs are unlikely (Menckhoff and Zegras 1999).

What future for the busway and urban rail? Compared to its investment in urban roads and railways, the private sector expresses little interest in busways, yet they are among the most cost-effective means of improving urban mobility. The great benefit of dedicated busways is their ability to move large numbers of passengers — typically up to 25,000 passengers per hour per direction — at relatively low cost, typically $1 to $3 million per kilometer, 50 to 100 times cheaper than subways. Despite such a compelling economic case, the use of busways remains limited. One reason is that busways lack the technological luster of subways, which often gain favor among politicians and the general public looking for a modern high-tech solution. Another reason is that busways must overcome several practical engineering challenges, such as the need to integrate with automobile traffic, avoid road conflicts, and protect passengers coming and going from stops.

Latin America is a pioneer in dedicated busway deployment, led by Brazil and the storied example of Curitiba (see feature box). Today, busways exist in Quito (Ecuador), Bogotá (see feature box), Lima, Santiago, and the Brazilian cities of Recife, Porto Alegre, Goiania, São Paulo, and Belo Horizonte. Beyond being relatively cheap, busways can be deployed quickly, which makes them popular in cities enduring difficult political and financial conditions.

Regarding metros, the international development community has only recently come to support their new construction as a way to increase mobility. International agencies long held the view that metros were far too expensive to be reasonable solutions for urban transportation problems in developing cities. For example, the World Bank's transportation policy papers of 1976, 1986, and 1996 scarcely mention metros. After a 1973 project in Tunis and a 1980 project in Porto Alegre, Brazil, there was a 13-year hiatus at the Bank in which no metro projects were undertaken. More recently, since the early 1990s, the World Bank has expressed a renewed interest in metros as potential development projects (Mitric 1997). The Bank's current consultation draft (World Bank 2001a) for a new urban transport policy gives metros considerable attention and presents an encouraging picture of the experience of new metros.

Many developing-country cities will continue to pursue construction of metros, despite their high costs. As cities' wealth increases, the cost of the technology becomes more accessible and the economic benefit of travel-time savings (a major justification for metro construction) grows — and so too demand for metros may well increase. Plans exist to expand Santiago's metro, as well as those in several Brazilian and Indian cities. The private sector has contributed to metro system development in Bangkok, though the financial viability of the investment remains to be seen. Kuala Lumpur and Manila have also garnered private-sector support, although the government may actually be assuming most of the financial risk. There are signs that the private sector may also play a growing role in upgrading and operating existing systems, as in Buenos Aires and Rio de Janeiro. In the case of suburban rail systems, most emphasis will be placed on maintaining and upgrading existing systems.

Public transport service buses. Road-based public transport is the principal travel mode for most developing-country urban residents, which makes enhancing the quality of service provided the key challenge. Cities understand that, on one hand, service must remain affordable to the poorest users; on the other hand, service quality must be high enough in order to maintain public transportation as a viable option for those with a choice. Efforts at improvement have aimed at enhancing overall service quality (wait time, reliability, travel time, safety, etc.); finding and maintaining the appropriate role for "paratransit" operators and vehicles; implementing effective mechanisms to target subsidies to relevant users; and improving the overall status and public perception of the system. Ensuring reliably competitive travel times through bus priority in infrastructure (i.e., bus lanes, busways) is vital, and examples of implementation indicate good results.

As we saw earlier, a growing private-sector role is the general, though by

Mexico City's Roadways: Chasing Urban Expansion?

During the last 20 years, the provision of highway infrastructure has struggled to keep pace with Mexico City's massive population expansion. During the early to mid-1970s, major accomplishments included the construction of the "Circuito Interior" (first ring road) as well as several feeder roads toward the west. An important development was the implementation of the ejes viales in 1979–80, which created a system of high-capacity boulevards through downtown. The early 1990s saw the completion of the Pereferico, the Federal District's beltway. Other modernization projects focused on introducing grade separations to improve traffic flow on key routes. Recent construction includes a new toll highway in the west/northwest (La Venta-Lechería), highway expansion in the north (Cuautitlán-Tlalnepantla), and expansions and new construction in the east. As of 1995, the entire northern half of the third ring was completed (as a toll highway), with the southern half under construction. In general terms, future highway construction is most restricted in the north and northwest, due to topography. Source: COMETRAVI (1999), SETRAVI (1999).

no means exclusive, trend in road-based public transport. The greatest obstacles to overcome include:

- Ensuring competitive route bidding.
- Service and fare integration.
- Adequate enforcement of service conditions (frequencies, fares, etc.).
- "Formalization" of companies.
- Reducing "incumbents' advantage."

Some progress has been made.

The current wave of formal private provision of public transportation services finds its roots largely in the early to mid-1970s. One of the first countries to embark on this path was Chile, as part of general neo-liberal economic reforms brought on by the military regime. After 1975, the government completely liberalized the bus systems in the nation's cities, allowing virtually anyone with a vehicle to operate a bus route. The policy did significantly expand the coverage and frequency of road-based public transport services, but by the late 1980s it also manifested a darker side: excess supply and dangerous, competitive driving conditions; pollution and congestion; as well as increasing bus fares due to widespread collusion among operators (see, for example, Correa 1991, Thomson 1993). In the early 1990s, a new democratic regime came into power and began to address some of these excesses of deregulation. In Santiago the first step was outright state purchase of the oldest vehicles on the streets — 2,600 buses at a cost of US$14 million to the government. Later, the government launched a transparent and apparently effective route-bidding process that produced remarkable results: The size of the bus fleet was reduced from 13,500 to 9,000, and average age reduced from 14 years to 4 years, implying a private-sector investment of US$500 million in vehicle stock; service quality improved (uniform signage, more comfortable vehicles, etc.); vehicle emission characteristics improved (more than half the fleet complies with EPA-91or 94 standard); bus companies were modernized; and, importantly, bus fares were stabilized (Dourthé et al. 2000) with no direct subsidies to the companies.

Many cities remain dependent on unregulated private markets for their transport. Santiago illustrates the problems — political, institutional, and technical — produced by completely deregulating the public transport market as well as the challenges to and potential for overcoming these problems. Other cities, particularly in Brazil, offer a different model

Privatization: Concessions of Transport Infrastructure in Bangkok

Since the mid-1980s, the Thai National Economic and Social Plans have relied heavily on the private sector for transport infrastructure development. The government is attempting to solve Bangkok's world-renowned traffic congestion through concessions for the construction and operation of several expressways and mass transit systems. So far, three expressways and one mass rail transit line are complete, and one subway system is expected to open in 2002. Over the past decade, concessions have been able to attract private-sector funds of about US$3 billion from both foreign and local sources to finance transport infrastructure in the city. If all projects under construction are completed, the city will have a rail transit network of 45 kilometers and an expressway system of 355 kilometers .

Despite the impressive amount of capital assembled and construction completed, all of Bangkok's megaprojects faced major problems. All suffered substantial delays, from problems with some basic designs to contractual and legal conflicts between the government and private concessionaires. In fact, several of the originally planned projects were scrapped or suspended.

The most controversial project was the Second Stage Expressway. In 1993, serious conflicts erupted over the appropriate toll level and revenue sharing between the Thai government and Kumagai Gumi, a Japanese construction contractor. The contractor simply refused to open the expressway to the public after its completion. Later, the Thai government forced the opening of the road, and convinced Kumagai Gumi to sell their stake to local investors.

Some of the other megaprojects have been abandoned or converted into publicly owned and operated enterprises. The ambitious Hopewell Project, which was to build a US$3.1 billion multilevel structure for an expressway and a rail transit system, was abandoned. The viability of the project was closely related to the associated property development, and the bust of the local real estate market and the financial crisis of 1997 were mortal blows. As of March 2001, the Thai government and Hopewell Holdings of Hong Kong, the project contractor, continued to wrangle over compensation for losses on the project. On the other hand, the new subway system, the concession for which was first awarded to SNC-Lavalin of Canada in the late 1980s, is now under the control of a new public agency, and scheduled to open in 2002. SNC-Lavalin backed out when it could not secure financing commitments from its equipment suppliers.

Several institutional weaknesses must share the blame for Bangkok's disputes with its concessionaires. The lack of well-established legal, regulatory, and investment frameworks hampered the projects, as did the absence of an effective dispute resolution mechanism to resolve contractual difficulties. Jousting between government agencies competing for control of the concessions confused matters, and above all, the absence of a comprehensive transport plan and policy — managed by one agency — doomed many of Bangkok's dreams for new development.

Source: Menckhoff and Zegras (1999).

The Shifting Tides of Policy: The Vehicle Size and Paratransit Debates

It is useful to note the historical shifts among transportation analysts for and against small transit vehicles offering paratransit service. In the 1970s, some analysts concluded that small vehicles were the most effective form of transit. A.A. Walters of The World Bank was the most prominent and vigorous advocate of this view. More generally, proponents argue that paratransit services, usually served by small vehicles, often serve areas not covered by formal, speedy, flexible, and affordable service. Small vehicles can provide accessibility to the areas where larger vehicles would be unprofitable or physically impossible, and they provide mobility for those in outlying neighborhoods who cannot afford private cars. In effect, paratransit sustains collective mobility for the poor who are left behind in the motorization process. Restricting paratransit would reduce the mobility of the poor while enhancing automobility of the middle-class and the rich.

But paratransit has several external costs. The additional small vehicles on the street add to congestion. Many of the private transport vehicles are the biggest contributors to urban air pollution because they are old, poorly maintained, and have aging or nonexistent pollution controls. Paratransit vehicles are often driven in an unsafe, even reckless manner. (Deaths and serious accidents from automobile injuries are disproportionately high in developing cities.) Because of overcrowding and a lack of stewards and conductors, many women are loath to ride public or paratransit alone for fear of harassment, robbery or rape. In several developing cities, most notably Mexico City, public institutions are unable to manage or regulate effectively the entrepreneurs who run paratransit.

As a result the vigorous interest in small-scale public transport has yielded to a broader concern for system-wide support of public transit. On balance, it appears that small vehicle paratransit operators are part of long-term, sustainable mobility in developing cities. Policy-makers need to find ways to integrate the small vehicle operators into a more efficient system that includes larger public transport vehicles while retaining the speed and flexibility that make small vehicles attractive.

of regulation and payment, one in which the public sector has a more prominent role. For example, in Curitiba, ten private bus companies operate services for the entire city, under concession to the Municipality. The concession controls the number and type of vehicles and the frequency of trips on each route. An important aspect of the system is the way revenues are distributed to each company. Instead of being determined based on the number of passengers carried (which often produces dangerous on-street competition for passengers), companies are paid according to kilometers traveled, with payment based on a financial analysis that includes a 12% return on capital. The user pays a single fare, which allows for transfers. Five service types are offered — including express and executive buses, providing differentiated "products" for public transport "market segments." The Curitiba scheme also includes bus-only transitways with prepayment stations and other features that enhance service (see feature box). Curitiba's busways offer a sophisticated model of public-private partnership, one that is being copied by dozens of Latin American cities, most notably Bogotá.

Ultimately, public transport depends on a city's history, topography, and current structure, its goals, and the political management and willpower to achieve them. Experience suggests that balancing buses, cars, and metros in a manner that is equitable to all citizens is easier with only a few operators and a Curitiba-style revenue distribution system. Maintaining affordable service requires well-managed competition. Effective public-sector management is key: service planning separated from provision; strong technical capacity; and enforcement abilities (World Bank 2001a). In the end, the critical question is whether public transport can be a viable commercial business in the face of increasing use of private automobiles, and the concurrent changes in land use and real estate development that rarely favor public transportation.

Managing the private operators. Managing competitive bids and city-wide service by private bus companies is a difficult exercise for public authorities. The terms of competition among bidders are problematic because the terms of service are all at fixed levels — the fare, the seat-miles required, the service schedule, the vehicle type, and so forth. And at the end of a contract, the private companies often collude to ensure that their own contracts are renewed. Political ties and lobbying by the operators also distort the bidding system.

An equally thorny political problem is local governments' reluctance to raise transit fares, since they are a very visible part of the cost of living to the ordinary citizen. Governments and transit systems sometimes face violent revolts when they attempt to raise fares. Additional problems result from the lack of personnel or leverage to enforce contractor responsibilities adequately. Often, a concessionaire will bid on an unprofitable low-density route segment at the outer end of his own normal route, to keep a new concessionaire from becoming a competitor when bringing passengers into the city. As soon as he gets the contract for the extended route, however, he reneges on serving it because it is not profitable. Some renege on serving the central business area because the congestion slows the buses down.

The problems of transit management basically arise because:

- It is very difficult to make the service self-supporting at a good level of quality, though low-quality, self-supporting transit systems survive in most developing cities by default.

- Adequate management requires a complex arrangement between private contractors and public authority that is difficult to achieve.

- The service is highly political, both in terms of the government's relation to the public, and the relation between the government and private contractors, who are likely to be strong and combative.

Enhancing urban rail ridership. Irrespective of future investments in metros, it is clear that many existing systems could better manage their routes and stations and the land uses around them. For example, in both Mexico City and Santiago, less than 40% of the system accounts for 70% of all passengers. A challenge is to increase ridership on the underused metro lines. One possibility is to promote attractive retail and residential development around metro stations. Hong Kong, for example, concessioned station development rights to real estate developers. The Singapore government, enjoying strong controls over land development, focused a significant portion of housing and retail activity around its mass rail transit. Nonetheless, widespread examples of deliberate "transit-oriented development" in the developing world do not yet exist.

Nonmotorized Transport (NMT): From the Foot Path to the Bike Path and Beyond

NMT's dominant role in much of the developing world's cities poses a policy dilemma. On the one hand, walking and bicycling are part of an environmentally and economically sustainable transport policy. They are cheap, they have almost no environmental impacts, and they require very little investment to make them safe and attractive. On the other hand, nonmotorized travel can be extremely burdensome — not an option of choice for travelers, rather one of necessity. NMT trips can be excessively long and dangerous — a fact that automobiles exacerbate, by lengthening trip distances (pushing out urban area origins and destinations) and producing pollution and safety risks that only further discourage NMT use.

The efforts a few cities are making to improve options for pedestrians and cyclists are vital; otherwise, these modes of transport will continue to be relegated to "second-class-citizen" status. The challenge for policy-makers has been to recognize the NMT trips that most travelers would prefer not to make — typically walk trips over 1 kilometer and bike trips over 3 to 5 kilometers. Recognizing this, there are four general areas for intervention in which some progress can be observed:

- Attempt to plan land use and real estate development that can accommodate short trips.

- Ensure that people can easily walk or bicycle to public transport stations for longer trips.

- Improve the safety, comfort, and convenience of walking or cycling by building adequate sidewalks and bike lanes, adding bike racks at public transport stations and other common destinations, and educating drivers to respect pedestrians and cyclists.

- Make bicycles more affordable through technological improvements and innovative financing schemes.

For pedestrians, the primary hurdle is the lack of sidewalks, or their encroachment by parked vehicles and vendors. In Bogotá, Mayor Enrique Peñalosa targeted the sidewalks of certain business areas, widening them substantially, planting them with trees, and forbidding customary parking on them. Abutting businesses at first complained, fearing they would lose customers for lack of nearby parking, but they soon realized that the improved pedestrian environment enhanced sales. The city now has a nearly 1 kilometer long pedestrian street. Wealthier cities and neighborhoods have high-quality pedestrian facilities — including pedestrian-only zones in downtown Santiago and Buenos Aires. Lower-income urban environments also sometimes have quite functional pedestrian ways, often self-created and self-enforced as pedestrian concentrations slow down and crowd out motor vehicles. The traditional market district of Cairo's Khan el Khallili is an example. Elsewhere, however, in dense downtowns with multiple types of road users and little available space (i.e., Bangkok), people walk at their own risk. Furthermore, pedestrians are often pushed aside by efforts to ease congestion for automobiles and buses — traffic signals timed for high-speed traffic, multi-lane high-speed motorways, and other schemes for motor vehicle priority leave pedestrians behind. Cumbersome pedestrian overpasses or dimly lit, uncomfortable, and expensive underpasses offer little respite.

Bicycle infrastructure — bike lanes, segregated bike paths, and secure parking facilities, for instance — can greatly enhance the cycling experience, improving safety and comfort and promoting bicycle use. However, as noted earlier, there are some indications that widespread bicycle use requires something of a bicycle "culture" (such as in the Netherlands, China, or Vietnam). These are often places where there have been enough bicycles initially to create a sustained presence in the streets. Nonetheless, there are examples that policy can play an important role in creating such a culture; in Germany, for example, public policy has been credited with producing a bicycling "renaissance" in many cities over the past 20 years (see Pucher 1997). Some developing nations are following Germany's lead. In Poland, for instance, the Parliament passed a national traffic code aimed at improving cycling conditions. Cyclists now have the right of way when crossing small streets. They are also allowed to use the sidewalks when the speed limit on the road is more than 50 kilometers per hour. NGOs also staged a successful No Car Day with 500 cyclists, and involved local governments in planning for NMT. The city of Wroclaw plans to build 100 kilometers of bike paths, and Cracow aims for 350 kilometers. In Bogotá, the Mayor's office launched the Bicycle Master Plan (BMP), which aims to build over 320 kilometers of bicycle paths, provide bicycle parking, integrate cycling with other forms of transport, and provide links to municipalities near Bogotá. Another important part of creating a bicycle "culture" has to do with overcoming societal biases and customs that in some countries virtually prohibit women from using bicycles.

At the same time, there is considerable room for improving existing nonmotorized vehicle technologies as well as improving people's ability to access these vehicles (financing). Unfortunately, improvements to vehicle design (such as lighter cycle rickshaws with gears) typically come with considerable relative cost increases, rendering them out of reach for many. An affordable, lighter, modern cycle rickshaw has been introduced in several Indian cities over the past few years, however, and affordable, productive trailers have met with considerable success in parts of Africa. In an effort to increase low-income earners' access to nonmotorized vehicles, the World Bank introduced a revolving loan fund in Lima, through which workers can finance bicycle purchases, with repayments made through monthly pay checks in agreement with industrial employers. The program was poorly promoted and marketed, however, and has met with modest success to date.

Traffic and Infrastructure Management

Many cities in the developing world are aware that management of traffic and infrastructure is fundamental to improving mobility. The high cost of roads and busways, and the lack of money to pay for them, suggest that the first priority should be to maximize the use of existing facilities. Key steps include establishing a clear network hierarchy, an adequate maintenance system, well-functioning signals and clear traffic signage, strong traffic enforcement capabilities giving priority to public buses, and ensuring that bus stops are convenient, well-maintained, and easy to use. Beyond gains in traffic efficiency, such steps can reduce traffic accidents (Ragland et al. 1992).

Again, Brazil is something of a role model for public transport priority in infrastructure, starting with Curitiba's busway efforts in 1974, later to be followed by other cities (São Paulo in 1975, Goiânia in 1976, and Pôrto Alegre in 1977). In Brazil today, "there has been a clear tendency for policies that give privileges to public transport by bus. It is assumed by all levels of government that it is possible to improve bus transport capacity through different measures, such as a high level of travel ways segregation, operation of trunk and feeder systems, better on-board or off-board automatic fare collection systems, improved layout and operation of bus stops, implementation of bus-actuated traffic-signal systems, and improvement of bus quality design, comfort and performance" (Meirelles 2000).

If successful, results can be impressive. Kunming, China, introduced a dedicated bus lane in 1999, including stop islands and bus priority at traffic lights, connecting the airport and dense residential areas with the city center. Initial results have been impressive: a 13% increase in ridership, a 60% decrease in passenger boarding time, a 70% increase in average travel speeds, and a 50% reduction in the number of buses required to provide service (Joos 2000).

Bogotá: It is Never Too Late to Start Improvements

Bogotá's "Transmilenio," which started operation in December 2000, was built upon the concept of "Troncales" (busways) drawn from Curitiba. Bogotá's first "troncal" was actually built in the 1980s on Caracas Avenue. Although never operated as originally designed, this two-lane-per-direction busway was used by nearly 500 buses and carried, under difficult conditions, an estimated 35,000 passengers per hour per direction — astounding levels for a busway, surpassing the practical ridership levels often obtained by metros. The Transmilenio project modified the infrastructure and operational standards of Caracas Avenue and implemented busways on two other main arteries. Current costs of busway development are estimated at $5 million per kilometer, with financing coming from a 20% increase in the gasoline tax as well as from national government transfers. Currently, 20 additional corridors for busway development are being considered to expand the system. The stated goal of the city government is eventually to have 85% of the city population within 500 meters of a bus stop.

Bogotá has also taken important steps toward building a "car-free" culture. For example, "Pico y Placa" restricts the use of 40% of the private autos during weekday peak hours. To date, Bogotá has avoided many of the negative consequences that plague a similar program in Mexico City. In addition, the city implemented two car-free days (in February 2000 and 2001), aimed at educating the population about alternative ways to move in the city. Building on the relative success of these initiatives, the city government put its policies to the test in a public referendum, which the voters approved. The referendum includes the "celebration" of a "Car-Free Day" the first Thursday of every February, and the restriction of all private autos during weekday peak hours starting in 2015. The government has also embarked on an aggressive program to link the entire city by nearly 200 kilometers of bike lanes.

Curitiba, Brazil: Bus-Based Public Transport That Works

Curitiba, Brazil, is a city of a million people in southern Brazil, in the province of Parana. For over 30 years Curitiba benefited from the leadership of Jaime Lerner as, alternately, mayor and director of planning. Lerner constantly supported the same, simple principles of transportation and land-use planning, and he had the sagacity and political capital to advance his policies with notable success.

The Curitiba "model" is based on four fundamental principles:

- Land use and transport integration — focus urban expansion along busways and promote dense land use along them through zoning, regulations, and fiscal incentives.
- Public transport priority in infrastructure — busways on major roads, segregated bus stops with preboard ticket payment.
- Service integration — use transfer stations and terminals, include circumferential and feeder routes, and use an integrated fare.
- "Affordable" innovation —articulated and bi-articulated (locally built) buses, express buses with specialized boarding tubes, public services and other activities located at terminals.

Not only did Curitiba benefit from the vision of one man, but also from the institutional framework he helped create. At the same time Curitiba's plan was drawn up in 1965, Municipal Law created an urban research and planning institute, IPPUC, which has broad responsibilities for integrated planning in the city. In 1980, a newly created public transport authority, URBS, began administering bus stops and stations, parking meters, the taxi system, and traffic enforcement. URBS also administers the distribution of the Urbanization Fund, which comes from bus fare collection, as follows: 90% returned to private-sector bus operators; 6% to infrastructure development; and 4% to financing URBS.

Lerner's plans and oversight made Curitiba a widely hailed model. Bi-articulated buses whisk up to 250 passengers along their commutes at 90% the speed of autos, the smallest differential between auto and bus peak travel speeds of all the major cities in Brazil. Many of the negative consequences of motorization, such as accidents, pollution, and noise, are greatly ameliorated by the use of high-speed corridors with appropriate buildings abutting them, which buffer residential and retail areas from the unpleasant side effects of traffic.

It is noteworthy that Curitiba owes its transportation system largely to the vision, energy, and political power of one man. Few urban areas anywhere are led so vigorously, for so long, by one farsighted leader. Lee Yuan Kew's leadership of Singapore is one of the few political tenures to match Lerner's. Considering that most cities will not have a Jaime Lerner or Lee Yuan Kew to lead them for a generation, it is important that planners build as much political and social support for their visions as possible, so that their plans may survive the vicissitudes of partisan politics and shifting urban leadership.

Demand Management

As is the case in the developed world, economists advocate charging autos for the social, environmental, and congestion costs they create, and argue that this would help foster lower, more sustainable levels of traffic. However persuasive such proposals may be in theory, the use of such fees is limited in practice, either because of practical politics, institutional barriers, and technical challenges, cost considerations related to implementing a congestion pricing scheme or a lack of widespread understanding of full-cost pricing among politicians, technocrats, and the general public.

Instead, cities often resort to another alternative — the use of physical traffic management measures for purposes of demand management. These are also subject to criticism and political resistance, but actions of this sort are in place in many cities. They include improved conditions for pedestrians, parking restrictions and charges, limits on the use of trucks or two-wheeled motorized vehicles in parts of the city or time of day, and other more widespread vehicle restrictions. For example, Mexico City, São Paulo, Santiago, and Bogotá each uses some version of automobile use restrictions, based on the last digit of a vehicle's license plate. Mostly geared toward reducing air pollution (typically used during the pollution "high season"), these vehicle restrictions have proven to be highly imperfect. In Mexico City, for example, the measure is criticized for several reasons, one of which is that it promotes the purchase of additional vehicles (to avoid the ban), and that these vehicles tend to be secondhand and more polluting. The measure is also criticized for being inequitable (since the wealthy could avoid the ban with second vehicles); inducing additional overall travel (freeing up a second vehicle for days with no restriction); and draining political and administrative resources for ban enforcement. In Bogotá, on the contrary, where somewhat different limits on the peak-hour use of vehicles are in place, observers widely agree that they have been effective.

Another alternative to charging road users full prices is to subsidize public transportation operations directly, a move that can be justified for the many social and environmental benefits it generates. Yet subsidizing public transport operations to offset the uncharged "external" costs of auto use is a less-than-desirable approach, particularly since those subsidies themselves may create perverse incentives and inefficiencies in operations. Furthermore, the overall climate favoring privatization of bus services and the general bias against maintaining public transport subsidies where they exist (i.e., Central and Eastern Europe) makes their long-term viability questionable.

Singapore: The Paragon of Land-Use Planning and Traffic Management

Singapore is a success story of how to achieve mobility through the effective use of travel demand management. Of all the high-income countries, most of whose cars-per-thousand population figure ranges from 350–550, Singapore's figure remains as low as 120 cars, above only Hong Kong at 55 (World Bank 2000). Due to its rapid economic growth over the last 40 years in a confined physical space, Singapore has had to promote innovative transportation policies to prevent excessive congestion. Through use of the pricing mechanism in particular, Singapore has experimented with successful policies including the Area License Scheme (1975), the Vehicle Quota System (1990), and the Electronic Road Pricing Scheme (1998). Despite inevitable imperfections in policy design, the overall outcome is that motorization restraints have had no major negative side effects on economic growth or the improvement of social welfare (Willoughby 2000b). In addition, price-mechanism-generated revenues have resulted in large funds that have, in turn, been used to invest in social improvements well beyond the realm of traffic management and transportation infrastructure. The geographic and political particularity of Singapore, as an island-state with a strong-willed leader, Lee Yuan Kew, provided perhaps the impetus and conditions for its innovative policies. And it is questionable if other societies would accept such sweeping oversight of their mobility. Yet the lessons Singapore learned have much to inform policy-making in most areas of the developing world. This is particularly true given the phases of development from poor developing country to rich developed country that Singapore went through in these years.

Ultimately, the most effective demand management tools may come from technology. For instance, electronic road pricing allows time- and place-specific congestion fees via advanced telematics, without the burden and delay of toll booths. Technologies for more accurate pricing have now become viable, but area-wide application exists only in Singapore. The World Bank began advocating road pricing for Asian cities like Bangkok and Kuala Lumpur in the 1970s. Legislation allowing for congestion pricing has been languishing in the Chilean Legislature since 1990. Implementation seems no closer in most places than it does in the industrialized world. However, the potentials for implementation should not be ignored, if only because the political equation theoretically still stacks in its favor — most of the voting public still does not own automobiles and these people, plus potentially powerful political allies such as bus operators, would stand to benefit greatly.

Mobility and Land Planning

The current rapid urban expansion and transformation gripping many developing-country cities poses both a major challenge and a great opportunity to enhance mobility. While urban growth creates demand for new transportation infrastructure and services, it also offers the chance to direct real estate development in dense clusters and corridors. Such land planning can, for example, help maintain and promote public transport usage. Unfortunately, land planning in the interest of mobility has a dismal record in most countries — developing or developed. The appropriate tools of land planning, growth boundaries, impact fees and exactions, density guidelines, and housing subsidies are used in some developing cities, but rarely have they been pursued with specific mobility goals. Again, the case of Curitiba stands out as a model, with land development strategies linked closely to the construction of its busways. Recent planning for Bangkok includes land-use planning for improved mobility. Based on a plan prepared by an MIT team, a series of new neighborhoods and business districts is planned about 20 kilometers from the center of the city, beyond the wave of current development. These centers are to be developed through the use of a revolving fund with which the government acquires minimal land for urban services and installs basic infrastructure. The cost is then refunded to the government by arriving developers. Land has already been acquired for the first of these centers at Lot Krabang, near the site of a new airport.

Hong Kong and Singapore offer other examples of mobility-oriented land-use planning. Neither of these can be characterized as a developing area anymore, but they were both low-income areas not many decades ago. Their strict attention to land development is one of the cornerstones of their ascent into high-income, highly developed cities. However, these cities have benefited from relatively strong centralized authority, with broad powers for land acquisition and development controls. The reality of most developing countries is much different — the relevant tools will often be spread across several institutions with different goals in mind, with varying ultimate impacts on mobility. A recent analysis of the tools for managing urban growth in Santiago sheds light on these complications (see Table 4-10); in few cases are transportation authorities directly involved.

Transport Planning and Institutions: Daunting Tasks Ahead

Urban transportation involves multiple institutions, some of which have competing interests and responsibilities. Institutional difficulties are frequently the principal barrier to implementing coherent policies in the sector, in both developing and developed countries (Anderson et al. 1993, Gakenheimer 1993). Even establishing an overarching authority does not guarantee success, because of the multiple political and economic inter-

Table 4-10. Differing responsibilities and goals in transport and land planning in Santiago

Instrument	Responsible Institution	Objective	Practical Transport Effects
Land-Use Plans	Municipal governments, National Ministry of Housing and Urban Development	Ensure land development meets public needs — zoning, adequate infrastructure, etc.	Historical disconnect between responsible authorities; no serious transport analysis behind land plans.
Urban Growth Boundary (UGB)	Municipal governments, National Ministry of Housing and Urban Development	Control urban expansion.	Somewhat slowed urban outgrowth, but likely led to uncoordinated/poorly equipped suburbanization.
Low-Income Housing Subsidies	Ministry of Housing and Urban Development	Providing housing to low-income residents.	Have exacerbated transport conditions by fueling urban expansion.
Urban Revitalization Subsidies	Ministry of Housing and Urban Development; Municipality of Santiago	Revitalize center city neighborhoods with residential development.	City center residential revitalization has likely reduced some travel demand.
Roadway Impact Studies (EI/ST, EFVs)	Municipal governments, Ministry of Transport	Ensure that real estate projects and land plans have adequate transport provision.	Have improved project and plan development recently; continued emphasis on infrastructure.
Environmental Impact Studies	National Environment Commission	Ensure real estate projects comply with environmental norms.	Currently have produced nil transport effects.
Transport Exactions and Impact Fees	Municipal governments, Ministry of Transport	Ensure that real estate projects "pay" for their transport impacts.	Have increased developers' transportation infrastructure responsibility.
"New City" Regulations	Municipal governments, Ministry of Transport	Regulate the widespread suburban "megaprojects" under way.	May create more self-sufficient communities, but also longer net travel distances.

Source: Zegras and Gakenheimer (2000).

ests involved, not to mention the sector's inherent complexity. The future holds a great deal of uncertainty, making it hard to picture technology, demand, and economic conditions as a platform for proposals.

Developing countries, however, face additional challenges related to shortages of human and financial capital, institutional flux (often linked to decentralization), and weak regulatory frameworks. The presence of international assistance — in the form of donors, consultants, international agencies — often is a mixed blessing. Foreign expertise often comes ill equipped to deal with local problems, and foreign aid often comes linked with particular technological solutions in mind. The result can be a constantly rotating team of experts, each with a different technical and methodological style, harboring different unexpressed expectations about the future, and leaving a different legacy of professional beliefs and operational models. In the case of transportation planning in Cairo over the last two decades, for example, there have been at least 10 different national professional cultures participating in the planning of various components of the urban transportation system. This situation is clearly changing in many industrializing countries — particularly those middle-income countries with growing cadres of technically savvy experts in the field.

Nonetheless, as technical capacity increases, so do the number and types of challenges, such as effective regulation of privately owned public transportation; a legal and regulatory framework for managing and enforcing infrastructure concessions; modeling complex travel supply and

Rural Transport in Developing Countries

Rural citizens use means of transportation very different from that of their urban cousins. In general, rural dwellers experience very limited mobility and accessibility to the most basic services, such as local and regional markets, health clinics, and schools. Transport conditions are often difficult, and traveling takes up a large amount of time and physical effort. Most rural, peasant communities have limited accessibility to areas outside their immediate vicinity. It is not entirely clear, however, how much rural dwellers suffer low-mobility levels because of their rural settings or their economic conditions. For example, at least one study finds a strong similarity between factors explaining urban and rural travel trip generation — income and household characteristics dominate (Deaton et al. 1987). In fact, controlling for income, rural households in the developing world are more likely to own vehicles than urban households (Deaton et al. 1987). So, the transportation problem in rural areas of the developing world derives, in part, from their very rural nature: dispersed activities make accessing various opportunities difficult, particularly given the low-income levels and lack of vehicular alternatives. (Indeed, rural migration to urban areas focuses specifically on improving access, particularly to employment and educational opportunities.)

Thus, in rural transportation, the question arises: How much are poor levels of accessibility in rural areas a transport problem or a development problem, and what role can transportation play in improving rural development?

Although each rural area in developing countries experiences different transport problems and situations, some common characteristics of rural transport can be observed.

- The rural population of many developing countries moves mainly by walking and undertakes very few motorized trips. For example, in Kenya, pedestrian trips account for 92% of the traffic volume on community roads (Gaviria 1991). Another study has shown that 87% of trips in rural Africa take place on foot (Barwell 1996), while bicycles make 81% of vehicle trips on some main roads in Uganda (Grisley 1994).

- The lack of ownership and access to means of transport constrain the mobility and accessibility of rural people. Again, low incomes prevent all but very few households in rural areas from owning any form of motor vehicle transport. Walking, cycling, and animal-traction are therefore the common modes of transport. The most common ways of transporting goods are head-loading and/or other forms of physical porterage.

- The majority of the trips are within and around the village, with the purpose of collecting basic necessities, such as fuel and water, and to cultivate farms and fields for subsistence needs.

- The gender division of labor is a key determinant of transport demand and use of transport services. Women are often exhausted from meeting transport needs, a task that can consume most of their day. This is particularly true in most African societies, where women are responsible for the bulk of cultivation tasks. Women spend more than 65% of the household time and effort on transport in rural Africa (Barwell 1996).

- The poor are worst located when it comes to accessing services. They make shorter and fewer trips than the rich, but take a longer time doing it. For instance, in a rural area in Tanzania, a household with five persons undertakes more than 1,600 trips annually, which in total require more than 2,500 hours. The procurement of energy and water requires annually more than 1,000 hours (Sieber 1996; et al.).

As transport conditions are closely related to poverty in the rural areas in developing countries, the focus of rural transport planning has been on how to improve transport accessibility and mobility. The objective is to increase opportunities for income generation through improving access to labor and product markets, which are important for the poor. Improving rural transportation serves to evolve the rural economy from subsistence to market economy. An inefficient transport system is a significant constraint on the agricultural sector in rural areas, both by raising the costs and effectiveness of production inputs and by delaying the sale of harvested crops. In fact, alleviating this problem has been the rationale and justification for road projects in rural areas in developing countries since the 1960s.

A study of the impact of 56 rural roads projects funded by the World Bank in six African countries found a close relationship between the performances of the agricultural and transport sectors (Gaviria 1991). Another evaluation of a World Bank road project in Morocco found that the project helped increase agricultural activity by improving the volume of production, productivity of land, and monetary values of output. Rural roads could also lead to the development of off-farm employment opportunities (Khandker et al. 1994).

In the case of healthcare, a study shows that new rural roads have made it possible for hospitals to attract more patients who live farther afield (Airey 1992). In education, the presence of a paved road in the community significantly increased the school participation rates of children in rural areas in Morocco (Khandker et al. 1994).

Nevertheless, many argue that the conventional rural transport planning approach has overwhelmingly focused only on paved roads, conventional motor vehicles, and marketable agriculture. Many women spend their days collecting water and crops instead of selling their crops. The focus on conventional motor vehicles does not serve their needs (Ahmed 1997).

Furthermore, there is the complex problem of the impacts road construction in rural areas has had on ecosystems and traditional cultures. Roads have been blamed for contributing to the loss of tropical forests, by opening previously inaccessible areas to logging and agriculture. One of the most notorious examples is Brazil's Polonoreste highway project; because of poor planning and implementation, the project induced large-scale migration to the area, and widespread environmental degradation. Such projects highlight the need to be able to quantify the impacts of rural road-building on development and the environment in order to assess the tradeoffs adequately (Chomitz and Gray 1996).

demand interactions and air quality conditions; and developing and implementing adequate vehicle inspection and maintenance programs.

Progress requires the political will to develop an adequate understanding of reality through data collection, and then develop the analysis tools appropriate for local conditions. Without quality baseline information on transportation and land uses, it is difficult to make the necessary evaluations and analyses of potential solutions. Nonetheless, even with such transport analysis capabilities, the need to estimate environmental impacts requires another level of detail, including the wide variety of vehicle types and their emissions characteristics, operating conditions, and so forth. Developing mechanisms to reduce the range of transportation's other external effects (congestion, accidents, noise pollution, etc.) requires data management systems, decent monitoring, and efforts at economic valuation of these external costs. This requires close collaboration between vehicle inspection authorities, environmental authorities, traffic police, planners, etc. — never a simple task in any political-institutional setting. More widespread citizen involvement, though not yet a "requirement" in transportation planning in developing countries, is on the rise. Certainly a welcome movement in helping to make planning processes more transparent, not to mention ensuring all needs are heard, "public participation" also can further complicate the process.

The rapid pace of change in developing countries suggests something of a "state of emergency." The natural response to such a condition is to make large infrastructure investments — to "show" that something is being done about the problem. Nonetheless, despite the short-term political profitability of launching large infrastructure projects, the greatest long-term return may well lie in investing time and resources into adequate information and problem-solving tools and skills — "software" over "hardware." The fact remains that transportation policy is an inherently political process. Successful policy prescriptions at the technical level may be hampered by the nature of the institutional and political arena. Pricing in particular has achieved a highly contentious political status when people perceive of roads and transport services as public goods in the hands of the state. As a result, pricing for full-cost recovery has met with limited success in all countries except those willing to take the political risks to enforce it.

Some observers suggest that it is no surprise that Curitiba and Singapore, two widely cited examples of good planning and management, were developed in periods of unitary government under strong leadership. Others point out that strong unitary governments with definite visions not modulated by a participative planning process are at least as likely to produce planning disasters as they are to produce role models. Given the political complexity of individual nations and cities, it should be no surprise that the experience in developing countries has been incredibly diverse, and it is important to remember that there is "no single transposable solution" from one country to another (Godard and Diaz Olvera 2000).

NOTE

1. Contrary to the general trend of increasing trip rates with increasing incomes, trip-making seems to be stagnating/declining despite apparent increases in income in at least one, possibly two documented cases. Beyond the possibilities of some inconsistencies in data collection, these apparently declining trip rates could come from a variety of factors, including: deteriorating travel times, declining public safety, or changes in urban form.

five

trends in intercity travel

Intercity passenger travel accounts for a relatively small share of total trips but for a much larger and growing share of total passenger-kilometers. In the developed world, intercity passenger travel is by automobile, air, and rail. In the developing world, intercity passenger travel is less common. What intercity travel there is uses bus, rail, and to a small but rapidly growing extent, air.

Although the automobile accounts for a large share of all developed world intercity trips, the use of the auto for intercity travel is usually a byproduct of travelers' decisions to own an auto primarily for local use. Likewise, most road systems have been developed primarily to meet local or regional rather than intercity travel needs. The German Autobahns, Italian Autostradas, British Motorways, French Autoroutes, and American Interstates make up a small part of each country's road system, though they carry a disproportionate share of the road traffic.

Intercity bus travel is very important in the developing world, as is "conventional" rail. Bus travel is growing as a share of total developing world passenger kilometers, though it is uncertain how much of this growth reflects urban travel and how much reflects intercity travel. The shares of both "conventional" rail and bus are substantially smaller in the developed world and are shrinking.

In Japan and Europe, high-speed rail plays a significant and growing role in intercity travel. (In Japan, high-speed rail accounts for approximately 4% of all passenger kilometers; in Europe, the figure is approaching 1%). Even in the United States, high-speed rail has shown it can be an effective competitor to air under the right circumstances.

Air accounts for a large and growing share of intercity travel in the developed world. However, air travel is projected to grow especially rapidly in the future in the developing world. Air travel, especially in the developed world, faces a number of significant challenges. Many airports are becoming overcrowded, and citizen opposition prevents their expansion or the construction of new airports. Airport noise is a perennial concern, but airport-related emissions pollutants, such as nitrogen oxides, are attracting growing attention in many urban areas. So is the traffic congestion associated with airport passengers, employees, and transporters of cargo. Air transport is an inherently energy-intensive mode of transportation. Jet fuel is the fastest growing transport-related petroleum product. This by itself would tag air transport as an important source of greenhouse gas emissions. However, air transport's role in greenhouse gas emissions is believed to be significantly amplified by the fact that these emissions occur at high altitude, where their influence on the climate is believed to be greater pound for pound.

This chapter focuses on intercity passenger travel.[1] Travel between cities accounts for a relatively small portion of trips, but a much larger and growing portion of total person-kilometers. US data suggest that while intercity travel accounted for only about 0.25% of the total trips made by residents in 1995, it accounted for about 19.5% of total person-kilometers traveled. This is up from 17% in 1977 (US DOT, BTS 2000). Between 1975 and 2000, intercity travel, especially travel by air, grew at explosive rates, making it one of the most noteworthy aspects of global mobility.

Although this distinction — travel between cities versus travel within and around urban areas — is intuitively easy to understand, it is difficult to define. What would be considered a short intercity trip in a particular place at a particular time may be considered just a long urban trip in a different place, or sometimes even in the same place at different times.

One way to distinguish between intercity and urban travel is to look at how the two categories of travel fit within a typical individual's daily activity patterns. Trips that are made every day, or as part of one's normal daily routine (e.g., a daily commute to work) are part of urban travel. Indeed, information on commuting patterns plays a prominent role in most formal definitions of what constitutes a metropolitan area (US Census Bureau 2001). In contrast, intercity trips are atypical and made infrequently. An example would be a family's annual summer vacation, or a trip to an extended family gathering at a remote location.

This distinction highlights an important fact: intercity trips are infrequent because they are costly, both in terms of time and out-of-pocket expense. Intercity trips could be defined in terms of thresholds of either time (trips longer than some amount of time) or distance. Each definition has its own advantages. A focus on trip time could potentially circumvent wide differences in the travel options that are available or in the quality of the available infrastructure. A trip of 100 kilometers might in one setting be regarded as a reasonable daily commute, and in another as an arduous and infrequently made trip to a remote location. On the other hand, a distance-based measure is more consistent over the range of available means of transportation. Certainly, it is easier to comment on, since much of the data on intercity travel across the world use distance-based definitions.[2]

In the next section, we present some data on trends in intercity travel as a whole. This is followed by a discussion of the nature of demand for intercity trips. We then review mobility trends and associated sustainability issues related to the use of four modes of transport that account for virtually all intercity passenger travel: auto, bus, rail, and air.[3]

TRENDS IN THE VOLUME OF INTERCITY TRAVEL

Because of the way in which travel statistics are maintained, it is difficult to assemble a clear picture of trends in the volume of intercity travel. Some of the difficulty stems from the fact that autos, buses, and trains are used for trips between cities and also for trips in and around them. Available statistics often describe the overall level of demand or usage for automobiles or buses without specifying how that usage is divided between the two categories of travel. Further compounding the problem is the fact that all four modes, and the trips one takes in them, differ substantially in terms of speed, distance, travel time, and vehicle occupancy. The American Travel Survey is a household-based survey that provides an overview of intercity travel in the United States (US DOT, BTS 1997b). Although the US experience is not fully representative of mobility trends elsewhere, it is representative of intercity travel in the developed world. The abundance and consistency of the US data offer a rich tableau for analysis and projections. In the United States, most intercity travel is made via auto (or other personal vehicles), or via air. Table 5-1 shows a breakdown of domestic intercity trips and passenger-kilometers by mode. The figures reflect only trips to US destinations, and so exclude international journeys. A large majority of these trips are made by auto. Considered from the perspective of passenger-kilometers, however, the dominance of the auto is considerably diminished. Air is more important in passenger-kilometer terms than in trip terms because air trips are much longer than trips by auto. By either measure, however, bus and rail play relatively minor roles in the United States. Canadian figures show a similar pattern, with over 90% of Canadian domestic intercity trips made using automobiles (Transport Canada 1996, slide 21).

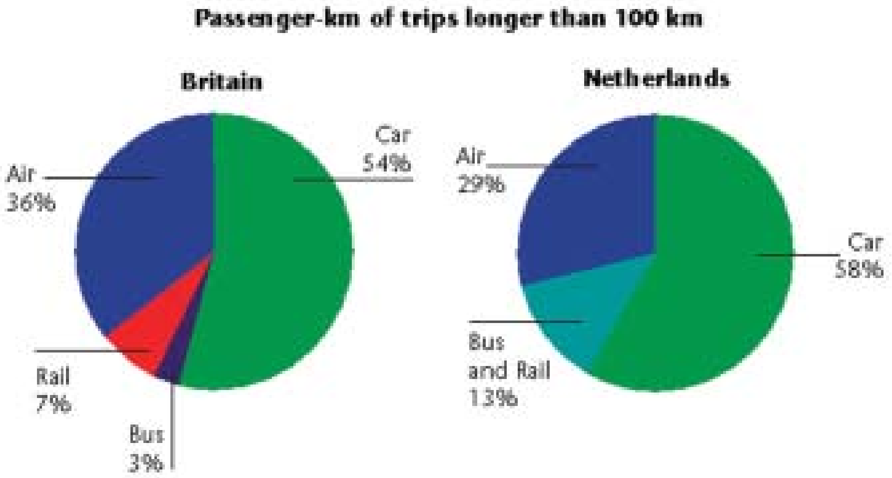
Although they are marginal in the United States and Canada, rail and bus are more significant elsewhere. Rail travel remains important in

Table 5-1. Distribution of 1995 US Domestic Intercity Trips and Passenger-Km, by Mode

	Distribution by Mode (percent)		Average Trip Length
	Trips	Passenger km	
Auto	81.3	54.6	894
Air	16.1	43.0	3549
Bus	2.0	1.6	1048
Rail	0.5	0.5	1404

Source: US DOT, BTS (1997b); US Census Bureau (1977).

Figure 5-1. Intercity travel in Britain (1990) and the Netherlands (1990)



Source: Updated database based on Schafer (2000); calculations by study team.

Western Europe, Japan, and some parts of the developing world. Figure 5-1 shows the composition of intercity travel in the United Kingdom and the Netherlands. Unlike the US data, these figures include international travel. Although the data for the Netherlands do not allow us to differentiate between bus and rail, other data suggest about 70% of the Dutch public transport travel is on rail. In sum, the figures indicate that the most significant difference between intercity travel trends in the United States and those in the two European countries is the role of rail. Rail accounts for about 7% of the passenger-kilometers traveled in Britain, most of which seems to come at the expense of air. Bus travel is increasing in the developing world, especially in regions not served by rail.

Table 5-2. Change in US Domestic Intercity Trips and Passenger-Km Per Person, 1977 and 1995

	1977	1995	Annual Growth
Annual Trips per Person	2.5	3.9	2.5%
Annual Passenger-km per Person	2,982	5,038	3.1%
Average Trip Length (km)	1,182	1,330	0.7%

Source: US DOT, BTS (1997b), US Census Bureau (1977).

Table 5-3. Change in US Domestic Air Trips and Passenger-Km per Person, 1977 and 1995

	1977	1995	Annual Growth
Annual Air Trips per Person	0.30	0.61	4.0%
Annual Air Passenger-km per Person	937	2,175	4.5%
Average Air Trip Length (km)	3,093	3,549	0.8%

Sources: US DOT, BTS (1997b); US Census Bureau (1977, 1979, 1997).

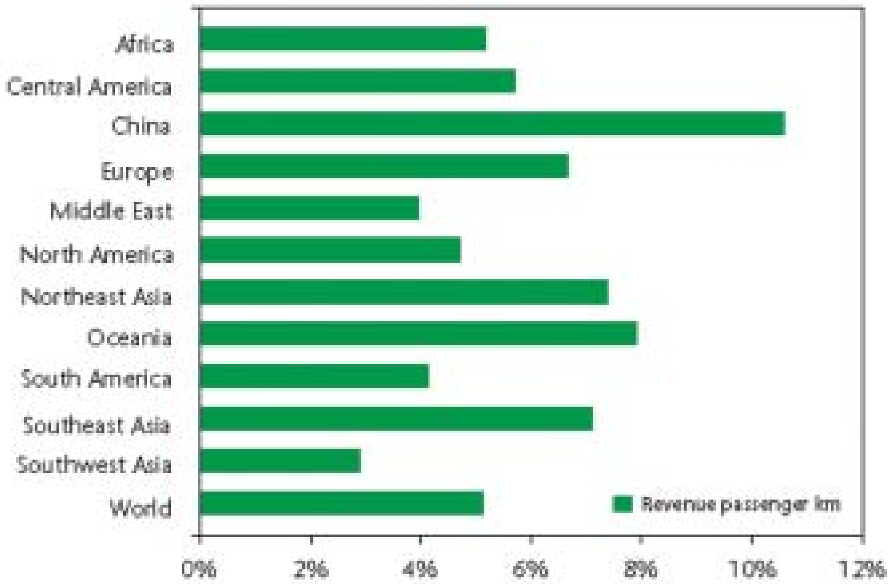
The volume of intercity travel is growing at a remarkable rate, even after adjustment for increases in population. The relevant figures are shown in Table 5-2, which again reflects only domestic travel. The period from 1977 to 1995 saw substantial increases in the number of trips per capita, in the length of those trips, and hence also in the total number of passenger-kilometers per capita. These rates of increase exceeded by a large margin the increase in real per capita income over the same period, which grew at a rate of 1.6% per annum (US Census Bureau 2000).

One of the most significant developments in global mobility over the last few decades is the rapid growth in air travel. As Figure 5-2 shows, passenger air travel measured by revenue passenger-kilometers has grown at an average of over 5% annually worldwide and at as much as 12% annually in the last 15 years in places like China (Airbus 2000, p. 12; Boeing 2000, p. 23).

These same trends are visible in data from the United States. As Table 5-3 shows, in the 18 years between 1977 and 1995 air trip rates in the United States more than doubled, and average trip lengths increased by 15%. As a result, annual air passenger-kilometers per capita increased by 132% in this period, an average of 4.5% annually.

These figures raise the issue of whether air travel is diverting passengers away from other means of travel, or if it represents a new, independent source of travel demand. Table 5-4, which shows the growth of intercity auto travel in the period, sheds light on this issue. The data indicate that although the number of intercity trips made by auto increased substantially over the period (52%), the average length of intercity auto trips remained almost unchanged, at approximately 850 kilometers. Trips via air are substantially longer. These data suggest that although some of

Figure 5-2. Annual compounded growth in air traffic by region (1985–1999)



Source: Airbus (2000).

the increase in air travel may have come at the expense of auto (primarily by way of substitution of longer-distance air vacations for short-distance auto vacations), a majority of the growth in air travel reflects the creation of and growth in an independent travel market comprising different and longer-length trips.

The figures shown in Table 5-4 indicate that a substantial portion of the growth in auto trips is related to growth in auto ownership. Given the relatively small fraction of auto use represented by intercity travel, it is unlikely that such travel plays a major role in auto purchase decisions.

Trips from the United States to other destinations account for a relatively small fraction of intercity trips by Americans. Table 5-5 shows that international trips accounted for only 4% of the total number of intercity trips made by US travelers in 1995, although this was a 20% increase from 1977, when international trips constituted only 3.3% of total trips. It is worth noting, however, that these trips are likely to be considerably longer than most domestic trips. Thus, on a passenger-mile basis, they represent a more significant element of intercity travel by US travelers.

In many respects the role that international travel plays in the lives of residents of the United States is atypical. With its large land area and population, the United States is more self-contained than many other nations. One can travel much farther without crossing national boundaries than is the case for many other countries. Hence, international travel constitutes a correspondingly smaller fraction of the intercity travel of US residents.

One aspect of international travel that the United States does share with other countries is its rate of expansion. Such travel is among the most rapidly growing components of intercity passenger travel.

THE DEMAND FOR INTERCITY TRAVEL

Intercity travel is both a reflection of geographic patterns of social and economic interaction, and a factor shaping the evolution of those patterns. The two must really be considered simultaneously. A trip by a European national to an East Asian destination may be motivated by a desire to meet with a business partner or associate based there. However, it is highly unlikely that a European national would have such relationships at all in the absence of sophisticated transportation and telecommunication infrastructure. Myriad business and personal relationships stimulate travel between cities. Businesses relying upon distant suppliers or maintaining a far-flung network of production facilities will need to visit them. International migrants will return to their home countries to visit family and friends. Scientists and researchers will travel to confer with professional colleagues.

Intercity travel depends to an important degree on accessibility, i.e., how far the destination is, the cost and quality of traveling there, and the costs of travel alternatives. How often people travel will be strongly influenced by how much a trip costs, both in money and time. Which relationships are formed, which are maintained or abandoned, and how strong specific relationships become will all be influenced by how easy or difficult it is to communicate and interact.

Table 5-4. Change in Domestic Intercity Auto Trips and Passenger-Km per Person, 1977 and 1995

	1977	1995	Annual Growth
Annual Intercity Auto Trips per Person	2.0	3.1	2.5%
Annual Intercity Auto Passenger-km per Person	1,713	2,768	2.7%
Annual Intercity Auto Trips per Registered Vehicle	3.2	4	1.2%
Annual Intercity Auto Passenger-km per Registered Vehicle	2,660	3,679	1.8%
Average Auto Trip Length for Intercity Trips	840	894	0.3%

Source: US DOT, BTS (1997b); US Census Bureau (1977, 1979, 1997).

The role of institutional factors in defining the level of social and economic interaction between regions merits discussion. Perhaps the most important factor is the international border. Studies show that passenger travel demand between two cities in the same country is seven to ten times greater than what it would be if the two cities were located in different countries. Obviously, a shared language, culture, and history can drive relationships and travel. However, other institutional barriers such as trade restrictions and national immigration policies also play an important role in shaping international travel. In the coming years, considerable change is anticipated in the structure of this global institutional framework. Three related trends — two economic and one demographic — are worth highlighting.

First, a variety of international organizations (such as the World Trade Organization) and regional trading blocks (such as the European Union and Mercosur) are working to reduce trade restrictions across national borders. These efforts range from elimination of tariffs to allowing free movement by citizens of member states, or unification of standards for the conduct of business in the free trade area.[4]

Second, the role of international investments in the global economy, particularly those made by multinational corporations, is increasing. Globalization in economic activity creates a demand for travel: markets are now global, creating multinational firms that operate all over the world, and production networks now span the world. A multinational market has emerged for an array of products ranging from most consumer goods (cars, Pepsi®, CDs) to specialized services such as technical consultancy (McKinsey, URS).

Not only do finished products sell all over the world, but products are increasingly manufactured within global production networks. There has long been extensive international trade in raw materials and finished goods. The rapid expansion of trade in components and subassemblies is a more recent phenomenon. Autos and computers are increasingly assembled in locations and countries different from those where the parts are manufactured. This trend now extends to businesses such as computer programming and customer service. A significant percentage of the computer programming in the United States and Europe is outsourced to India (*Business Week* 2000), and many global firms are consolidating customer call services to Asia (*NYT* 2001b). A key feature of this phenomenon is a dispersion of production activity away from the industrialized OECD nations to nations in Asia, Eastern Europe, and Latin America.

The implications of global sourcing for passenger travel are noteworthy. Manufacturers and suppliers must often collaborate closely over questions of design or performance specifications, or to resolve technical problems. Such economic relationships generate a higher number of face-to-face meetings, and a corresponding rise in international business travel. For example, estimates suggest that international travel went from a share of about 6% of total US corporate business travel in 1994 to about 20% in 1997 (Johnson and Sherlock 1998).

Finally, an important demographic trend — increases in the amount of international migration — underlies some of the recent growth in international travel. In absolute terms, the United States and Germany are the principal receiving countries, although migration to these countries tended to decline somewhat toward the end of the 1990s. During the same period, the upturn in migration that began earlier in the decade in

Table 5-5. International Trips of US Residents, 1977 and 1995

	1977	1995	Annual Growth
International Trips Per Capita	0.1	0.16	2.6%
Percent of All Intercity Trips	3.31	4	1.1%

Sources: US DOT, BTS (1997b); US Census Bureau (1977, 1979, 1997).

most other countries of Europe and in Japan and Australia was sustained and increased. Migration creates a network of personal ties between sending and receiving countries that in turn stimulates subsequent intercity travel.

The Role of Telecommunications

At least to date, telecommunications appear to be a complement to, rather than a substitute for, intercity travel. To some degree, developments in telecommunications substitute for travel in the short run, but ultimately result in enlarged spheres of operation, more extensive networks of business and personal relationships, and ultimately, more travel.

There have been significant developments in worldwide communication technology deployment in recent years. Estimates suggest that the number of Internet users globally increased from 49.8 million in 1996 to about 258.2 million in 2000 (*PulseOnline* 2000). The installation of submarine fiber-optic cables has also exploded and is expected to grow 40% annually for the next few years. For instance, a group called Global Crossing recently reported that it completed construction of a high-speed fiber-optic network linking 27 countries in Europe, the Americas, and Asia in less than four years (Global Crossing 2001). In other words, ubiquitous, high-capacity, low-cost telecommunications technologies are fast becoming part of the environment in which intercity travel is conducted.

The development of such technology networks can, in principle, either substitute for some travel or spur the demand for new travel by facilitating the development and maintenance of long-distance social and economic relationships. The empirical evidence suggests that the latter effect seems to dominate the former. A 1997 empirical study on the impact of telecommunications on travel by Mokhtarian and Salomon (1997) found that "the preponderance of evidence suggests that the net impact is one of complementarity, and continued growth in both telecommunications and travel should be expected."

This suggests that for the foreseeable future, telecommunications is likely to stimulate the growth of intercity travel. Current expectations based on systems and technologies being developed and deployed are for telecommunications services to continue to fall in price and grow in bandwidth. Barring some major shift in human behavior and expectations regarding face-to-face contact, such trends can be expected over the long term to lead to more communications over longer distances, and eventually also more long-distance travel.

Intercity Trips — Various Kinds for Various Reasons

In order to go beyond these basic trends in the volume of intercity travel and gain insight to the nature of travel demand, it is necessary to consider the goals of different trips.

Business travel. The 1995 American Travel survey conducted by the US Department of Transportation found that 23% of all intercity trips and 47% of air trips in the United States were made for business travel. This share is consistent with estimates of business travel by air and on high-speed rail from other parts of the world: on the Tokaido Shinkansen line linking Tokyo, Nagoya, and Osaka, about 59% of the travel is for business (Doi and Shibata 1996). In developing countries, the share of business travel is even higher; business travelers are estimated to constitute between 70% to 75% of total air traffic in China (*Airfinance Journal* 2001).

Business trips tend to be shorter in duration than nonbusiness trips; a large number of them are completed within a day. Also, a large fraction of total business trips are made by a few travelers who travel frequently. Estimates from the United States, for example, suggest that 8% of passengers making more than 10 trips a year accounted for 44% of the business travel in the United States in the year 1993 (ATA 1993).

Business travelers are generally more concerned with ease of travel — faster and more conveniently scheduled trips — than cost. Destinations for intercity business trips are usually predetermined. Decisions regarding how to travel, what time of day to travel, and (to the degree it is discretionary) the duration of the trip, are generally made to favor convenience over costs. Costs influence the level of travel in the long term but have little impact on the level of travel in the short term. Business travelers tend to patronize the fastest, most convenient mode of travel, usually air or high-speed rail, and they generally choose the fastest, most convenient, and most flexible of the options available.

Nonbusiness travel. Discussions of intercity travel often draw a distinction between trips made for business and trips made for other reasons. Although both subcategories undoubtedly include a variety of different types of trips made for a variety of different reasons, nonbusiness travel is likely to be especially heterogeneous. To understand the factors driving nonbusiness travel growth and the ways in which this element of intercity travel demand is likely to respond to environmental or economic constraints, it is useful to draw a distinction between trips made for recreational purposes, and trips taken to visit distant friends or family members.

Vacation and recreational travel currently accounts for a large share of total intercity travel generated from the OECD countries. In the United States such travel accounts for about a third of total intercity travel and 20% of air travel. Although data for vacation/recreational (V/R) travel are difficult to obtain, indications are that rising incomes and demographics contribute to sustained high growth in V/R travel. V/R travel is directly related to levels of disposable incomes, and aggregate demand for V/R travel is related strongly to levels of prosperity. Societies that are more prosperous, such as those of the OECD, generate more V/R trips than less prosperous developing countries. Further, within any particular region, V/R travel booms in good economic times and suffers in recessions.

In addition to rising incomes, the greying of the population in the OECD countries also contributes to high growth in V/R travel. The retiring baby-boomer generation — a substantial population with ample disposable income and free time — will create the perfect market for V/R travel.

V/R travelers exhibit a very different set of behaviors from business travelers. Fundamentally, they are more responsive to changes in costs than are business travelers. Costs often affect the choice of mode for V/R travel: cheaper, slower modes may be favored over faster, more expensive choices, although segmentation of airfares has allowed airlines to serve both recreational and business travelers. V/R travelers even exhibit considerable flexibility in destination choice. Vacation destinations do compete with each other. Paris competes with Rome and they both compete with a beach resort in the Caribbean or a ski resort in Switzerland. Transportation costs influence these decisions. Many vacations formerly taken at the local beach resort were replaced by trips to Europe following the emergence of post-deregulation cheap fares in the United States. As incomes increase, people spend a greater proportion of their income on leisure, and V/R travel is no exception; travelers make choices in favor of faster, farther, more comfortable leisure travel as their incomes increase.

V/R travel tends to be highly seasonal, with peaks corresponding to common vacation times such as the summer. These strong seasonal peaks often push against the capacity of the transportation system. Anyone who has attempted to fly from New York City to Miami at Christmastime, or drive on the usually free-flowing main A6 route between Paris and Lyon on the days that the traditional French summer vacation begins and ends, is familiar with this phenomenon.

Visiting friends and relatives (VFR) is a major component of nonbusiness travel across the world. US estimates suggest that such travel constitutes about one-third of all intercity trips (US DOT, BTS 1997b).[5] VFR travel shares some characteristics with business travel and some with leisure travel. First, as with business trips, destinations are usually predetermined. However, costs do affect the mode of travel — driving versus flying or taking the train — and the frequency of trips. VFR travel follows in the wake of migration/change of residence: every immigrant generates a continuing flow of VFR travel to friends and relatives left behind. Current labor trends that are leading to increasing globalization of labor markets — free labor markets in the EU, the importation of professionals into the Middle East, and large-scale immigration of IT professionals from Asia to the United States and Europe — are leading drivers of demand for increased air travel.

AUTO

Although the auto accounts for a large proportion of total intercity trips, its use for intercity travel is usually a byproduct of a person's decisions to own an auto primarily for local use. Intercity travel is rarely the primary factor driving auto purchase decisions by households. Available data from the Netherlands indicate that intercity travel accounted for less than 5% of total auto trips and about 10% of total auto travel (measured in passenger-kilometers) in that country. Similarly, data from the United States indicate that intercity travel accounted for 8% of auto passenger-kilometers (US DOT, BTS 1997b; ORNL 1995).

Much of the world, especially the developed world, enjoys extensive intercity roadway networks. The extent to which residents of developed countries rely on the auto to meet their intercity travel needs obviously depends not just on the availability of a highly developed road network but also on the availability of autos to use on it. Thus, the demand for intercity auto travel has grown with the level of motorization of the population.

Just as intercity travel is rarely the primary motivation for household auto purchase decisions, intercity passenger travel needs have rarely been the primary motivation for intercity highway construction. The extensive interstate highway system in the United States was originally proposed as a network of strategic high-capacity long-distance connections, justified by national defense considerations. In other countries, the construction programs were more frequently based on economic and national integration motives. The United States, Western Europe, and Japan built extensive intercity motorway networks in the decades following World War II, a construction program motivated in part by the need to replace or upgrade roadway infrastructure that had been destroyed during the war or had deteriorated in the years immediately following. In the developing world, freight considerations frequently drive construction of intercity highway networks.

Trends in intercity auto travel raise many of the same sustainability concerns as do local auto travel, with regard to safety, energy use, and CO_2 emissions. However, there are some important differences. For instance, since much of intercity auto travel takes place in regions with sparse population and (generally) low absolute levels of traffic, local air pollution and noise pollution are of less concern except at the points where these intercity trips begin and end. There are other significant differences related to disruption in the natural habitat, congestion, and financing.

Because of significant differences in mobility trends, these concerns differ between the developed and developing worlds. In the following sections we highlight the mobility trends relating to intercity auto travel in the developed and developing world separately, and discuss the most significant sustainability concerns that arise.

Intercity Auto Travel in the Developed World

Intercity motorway links in the developed world generally do not suffer from capacity problems once travelers drive beyond the congestion of large cities. There are some important exceptions, however, such as the heavily urbanized Northeast corridor in the United States. Although many intercity links carry a significantly higher portion of truck traffic than do typical urban links, for the most part they are adequately dimensioned to handle prevailing traffic levels. Unlike many urban roads, intercity motorways have not had to confront significant travel demand growth induced by unexpectedly strong land use–transport interactions.

Congestion may occur on selected facilities that are heavily used for vacation or recreation trip purposes, particularly in countries where such traffic exhibits extremely sharp peaking characteristics. In France, for example, intercity links between Mediterranean tourist destinations and major population centers are highly congested in August because many people take vacations at that time. Similarly, capacity can be an issue at times of peak demand in particular corridors at the interface between urban and intercity networks. For example, it is common for residents of Greece to visit their ancestral villages during major holidays such as Easter. At the end of the holiday, the large number of people returning to Athens at nearly the same time create very long vehicle queues on both the urban motorways and the intercity facilities that connect to them.

Intercity Highways Affect the Cities they Link

In most places the intercity road network merges directly into the urban road network, providing a seamless route for intercity auto and bus travelers. As a result, at their beginning and end, intercity auto and bus trips are susceptible to all of the congestion of urban travel. Autos and buses making intercity trips both contribute to and suffer from problems such as congestion and air pollution. Usually intercity trips constitute only a small proportion of total trips — thus suffering more than they contribute to congestion — in major urban regions. However, intercity travel may well constitute a significant proportion of total traffic passing through small towns and villages. In situations when the road system is not limited-access — as is common in the developing world — such traffic is often a significant safety and environmental concern.

In general, significant new additions to the intercity networks of developed countries are becoming rare. These networks are mostly built out, providing a connection between major population and economic centers. In small and densely populated countries (e.g., Belgium), there is very little available land left on which to build major new intercity roads. Finally, groups opposed to new highway construction are adept at applying political pressure to stop such projects, although such pressures are generally felt more strongly in urban than in intercity settings, because of the significantly larger numbers of people affected.

Intercity Auto Travel in the Developing World

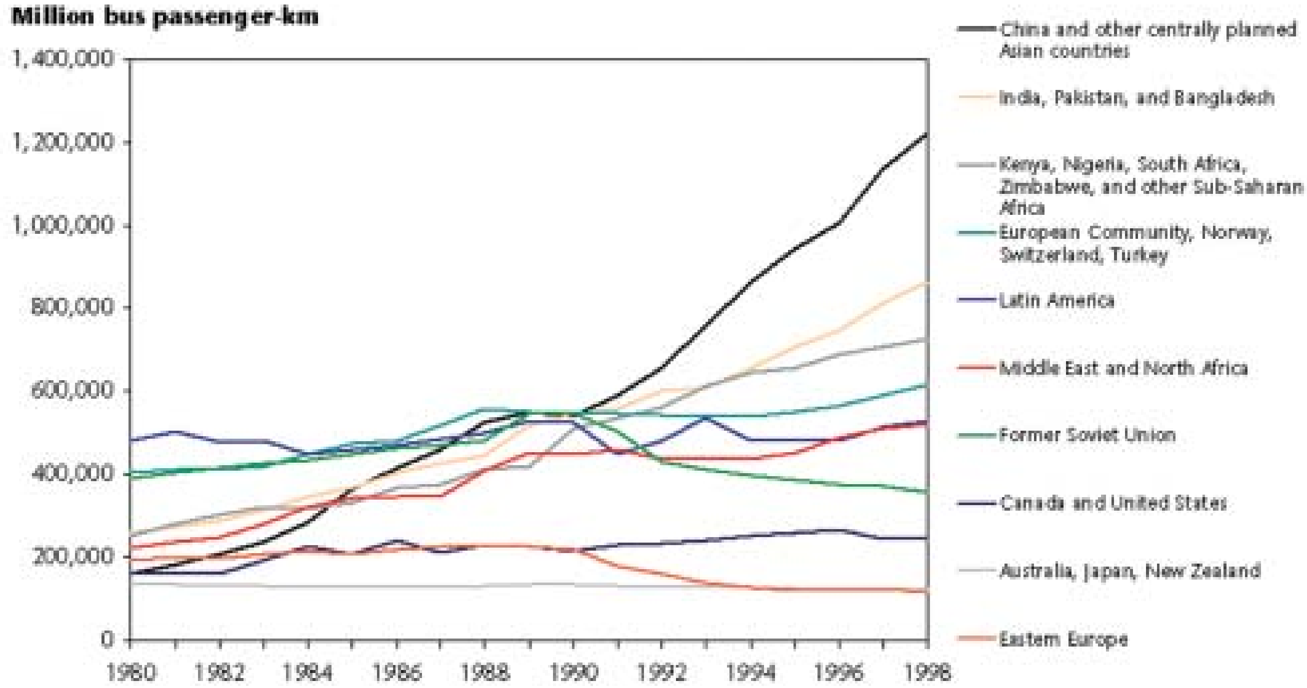
The situation with regard to intercity roads and automobile use is quite different outside the developed world. Roadway networks are generally less extensive and of lower quality than those found in the developed world. Important population or economic centers are often poorly connected to the rest of the country. In some cases, bridges are lacking, and ferries serve in their place. (The connectivity of the highway network in Eastern Europe and the former Soviet Union is somewhat better than in the rest of the developing world.)

The intercity road infrastructure that does exist is frequently of poor quality. Design and construction are often deficient, and management of traffic is often inadequate, resulting in poor control of trucks with excessive axle loads. Maintenance and upgrades are often neglected because of funding constraints. For example, on roads in hilly or mountainous terrain with inadequate climbing lanes, underpowered trucks may cause temporary backups of traffic.

More generally, the roads are rarely designed to be high-speed or high-capacity. Congestion is more likely to be an issue than in the developed world. Although intercity traffic volumes are generally low, they are climbing with economic development and rising motorization levels. On many links traffic is increasing to levels that cannot be served adequately by existing networks. For instance, travel times on the 97-kilometer Mumbai Pune highway in India reached approximately four hours by the 1990s because of congestion.

Accordingly, many developing and emerging countries have a backlog of intercity road construction projects, the cost of which far exceeds local financing capabilities. In some cases, countries rely on overseas development assistance through bilateral agreements or loans from international lending agencies such as the World Bank. Private financing is increasingly seen as an attractive option, through build-operate-transfer (BOT) or similar schemes. For instance, a new six-lane expressway financed on a BOT basis using a 30-year toll concession is being constructed to enhance capacity in the Mumbai Pune corridor in

Figure 5-3. Trends in bus use (1980–1998)



Source: Updated database based on Schafer (1998).

India mentioned above. Some countries (e.g., Mexico) have constructed significant lengths of intercity roadway under private financing schemes. The conditions required for such projects to be both financially interesting to a private group and economically interesting to a national government are not always met, however (Gómez-Ibáñez and Meyer 1993).

Among the most significant sustainability concerns related to intercity auto travel in the developing world are the social and environmental costs of road construction. In the past, the few road projects in developing countries were designed and built almost exclusively on the basis of engineering and cost considerations, with minimal weight given to environmental and social impacts. Under pressure from international lending agencies and some national governments, these concerns are receiving increased attention. It is fair to say that this attention is still not as institutionalized as it is in the developed world, but progress is being made. Road planning is becoming more participatory, for example, including inputs from the local populations living near the planned construction. Environmental impacts of road construction are being more widely recognized and more thoroughly studied and mitigated. These include, among others, disruption of local human populations, damage to natural wildlife habitats, and physical consequences associated with the construction itself. Although environmental impacts are probably most severe when new highways penetrate hitherto rural regions, virgin forests, and remote mountain areas, they can also be a concern even in more developed areas.

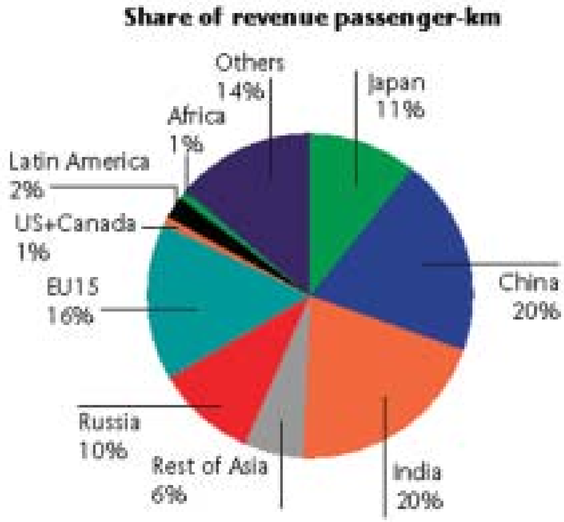
One example is the city of Baguio, located in the mountainous north-central area of Luzon Island. It is the second largest city in the Philippines north of Manila. Road connections between Baguio and the rest of the country have long been a problem because of the combination of steep and unstable terrain through which the roads must pass. Road construction disturbs the natural compaction of the soil and accelerates the deforestation of the surrounding areas. During the rainy season, eroded soil is washed down to the coastal areas, where it fills the riverbeds and leads to extensive flooding and damage.

BUS

Bus travel, combining low speeds and minimal privacy with low cost and widespread access, is widely considered an “inferior good.” Buses are used extensively when incomes are low and replaced by other means — autos that offer privacy and flexibility, and rail and air that are faster — as incomes increase. Thus the bus is not a very important means of intercity travel in the developed world. Bus’s share of trips in Western Europe has declined by close to 50% in the last 20 years (European Commission 2000). In the United States and Canada, bus’s share of intercity trips is marginal (US DOT, BTS 1997b; Leore 1991). Unfortunately, outside the developed world, a systematic study of trends in bus use is undermined by the paucity of data. Indeed, even in the developed world, available data do not separate urban bus travel from intercity travel. Figure 5-3 shows trends in bus use across the world, using what data are available.[6]

The majority of all intercity passenger-kilometers traveled by bus are outside the developed world. Much of this travel is concentrated in China, India, and the countries of Africa and Latin America, which do not have high incomes, widespread auto ownership, or well-developed passenger rail systems. The bus remains an important source of mobility, especially for the poorest, everywhere in the developing world. The drop in total bus travel in the countries of the former Soviet Union over the last 10 years reflects a drop in overall intercity travel. In Russia, it is estimated that 60% of all intercity trips are presently made using buses (Nikoulichev 1998). It is expected that the bus will continue to play an important role in Latin America, India, China, and Africa in the coming decades, despite forecasts of rising motorization and increasing incomes.

Figure 5-4. Where is rail passenger traffic?



Sources: Updated database based on Schafer (1998). World Bank (2001b), Estimates for EU 15 include urban travel. Japan ITPS (1999).

Most (if not all) intercity buses operate on diesel fuel. When well designed, efficiently maintained, and operating at high load factors, buses have the potential to be among the most energy-efficient means of intercity transport. Indeed, buses can be as emission-efficient as the most efficient passenger trains; however, the buses used outside the OECD are likely to be older, badly maintained (with both factors leading to lower fuel efficiencies), and more polluting. As a consequence, intercity buses in the developing world often operate with relatively high CO_2 intensity, even though they operate at generally high load factors. Indeed, upgrading the entire bus fleet in the developing world to modern fuel-efficient OECD standards would be a relatively inexpensive (though institutionally challenging) and significant step toward global sustainable mobility.

RAIL

Well-managed passenger rail systems have the potential to be a very efficient provider of sustainable mobility. At its best, rail is far more energy-efficient than the auto or aircraft and slightly more efficient than the bus.

Currently, passenger rail is an important source of mobility in Asia and Europe. Figure 5-4 shows that about 70% of global rail travel takes place in non-OECD countries, most of it concentrated in India, China, and the countries of the former Soviet Union. In the developed world, rail is concentrated primarily in Japan and Western Europe. There is little intercity passenger rail travel in Africa, the Australian continent, or the Americas.

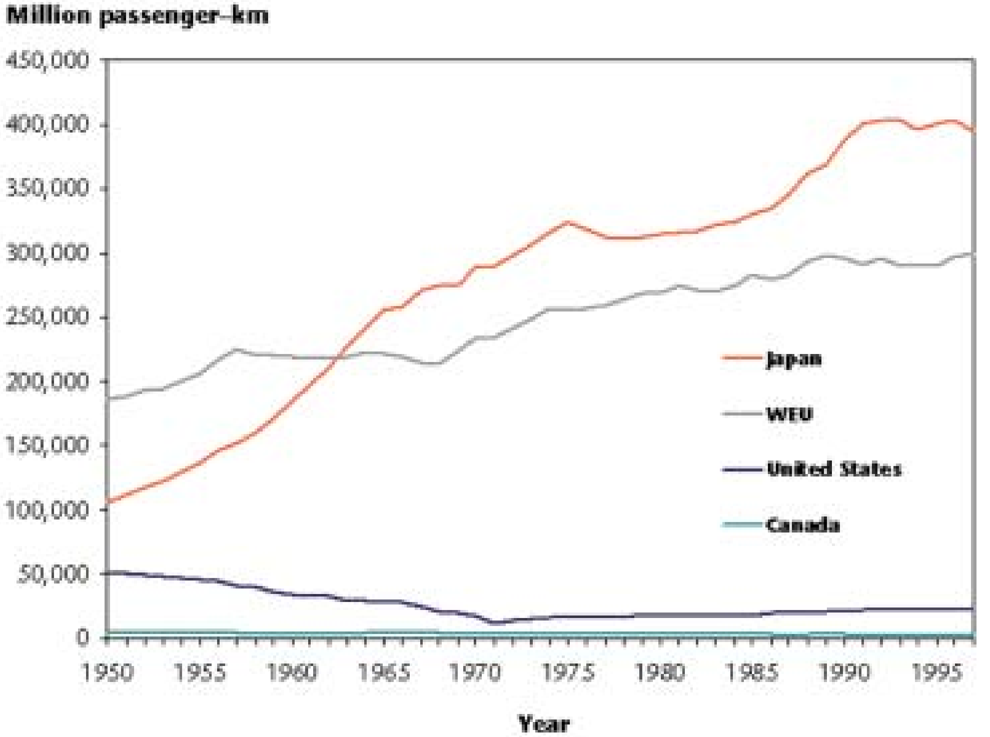
The level of mobility that rail provides, and its implications for sustainable mobility, vary widely across the globe. In non-OECD countries, rail plays a crucial role in promoting mobility but faces critical economic and environmental sustainability dilemmas. In the OECD countries, rail provides an environmentally sustainable and important source of mobility, but its financial sustainability is often in doubt even in the OECD countries.

Rail in the Developing World

Trains provide 871 billion passenger-kilometers of intercity transportation in India, China, and Russia alone, and serve a vital social and mobility role in many countries in the developing world. Rail is a dominant source of intercity mobility in India, with a share of 25% of passenger-kilometers in 1997. Rail had a market share of 20% in China and 18% in the former Soviet Union. Trains are still an important source of mobility in Eastern Europe and many countries of the former Soviet Union, though their role has diminished in the last decade. Low incomes place auto ownership and air travel out of reach for a majority of the residents of these societies, and for them rail is the superior form of available intercity travel. In addition, rail serves an important social role in terms of employment: World Bank data suggest that the railways (including both the freight and passenger divisions) of India, China, and Russia provide employment for about 6.3 million workers (World Bank 2001b).

However, the level of mobility provided by rail across the developing world is not uniform. For instance, 1997 data indicate that speeds on Indian Railways average between 18 kilometers per hour for the slowest passenger trains and 48 kilometers per hour for the fastest trains (Indian Railways 2001). In addition, most of these rail systems are operated by national governments, and are not economically self-sufficient. Though passenger rail covers operating expenses in Russia and China, passen-

Figure 5-5. Trends in rail ridership in the United States, Canada, Western Europe, and Japan



Source: Updated database based on Schafer (1998). Estimates for Japan and the EU include urban travel. Note: Data for Japan for the period 1992–1997 (Japan ITPS, 1999) indicate that intercity travel accounts for about half of the total rail travel.

ger fares in India are heavily cross-subsidized by high freight rates.[7] High staffing levels are partially responsible for this subsidy requirement: Indian Railways incurred a wage bill of US$2.6 billion in 1997 for their 1.58 million employees, which was equal to about 43% of their gross revenue (Indian Railways 2001). World Bank data measures of productivity indicate that the biggest railways are also among the least productive. For instance, the Indian, Chinese, and Russian railroads employed 25, 33, and 12 employees per kilometer of track compared to 8 per kilometer in Japan and between 6 to 8 per kilometer of track in most Western European countries (World Bank 2001b).

In the entire developing world, rail infrastructure is old, undercapitalized, and inadequately maintained, resulting in immediate implications for system safety. The most high-profile case is that of Indian Railways. Though differences in reporting and classification standards make it difficult to compare across rail systems, Indian Railways has experienced a number of very serious accidents in the past decade, including several collisions with casualties in the hundreds (Fry 2001).

Old infrastructure and equipment, combined with inadequate maintenance, can severely affect the energy efficiency of rail and increase pollution. Partially full trains, sleeper and diner cars needed to accommodate long-distance journeys, frequent locomotive idling, poor maintenance of track and locomotives, and poor aerodynamic design, all reduce energy efficiency. Although precise data are not available, anecdotal information suggests that, in many instances, rail in the developing world operates at energy-efficiency levels that are significantly higher than what is technologically possible.

Finally, though the highest-density lines are electrified, much of the rail system still runs using diesel technology. For instance, though Indian Railways operated 42% of its passenger-kilometers in 1997 under electric traction, only about 21% of the Indian Railway network is electrified. Diesel systems are heavier and less energy-efficient than electricity (though transmission losses in electricity transmission can obviate much of this advantage). Further, electricity offers at least the possibility of zero carbon generation.

Rail in the Developed World

Japan and the countries of Western Europe together account for over 95% of the total passenger-kilometers traveled by rail among the OECD countries. Figure 5-5, which presents trends in rail ridership across the developed world, suggests that this concentration is consistent with ridership trends in the past 10 years. Market share of rail in these countries has remained constant between 6% and 10% in Western Europe and at 33% in Japan.[8]

One of the most interesting elements of rail in the OECD is that it is increasingly powered by electricity. European statistics suggest that 48% of the track in the 15 EU countries is electrified (ranging from 2% in Ireland to 75% in France). In a few cases much of the energy is even generated using emission-free sources, such as nuclear energy in France.[9] Though this is not true broadly, and although most of the electricity for rail travel is still generated using coal (in Germany, Italy, Japan), rail in the OECD is more environmentally benign than air and auto.

Rail in the United States and Canada

In contrast to Western Europe and Japan, rail ridership in the United States and Canada is insignificant, both in absolute terms and as a share of total intercity travel: estimates from the 1995 American Travel Survey suggest that less than 1% of intercity trips in the United States is made on rail. It is worth noting that this is true despite the fact that both the United States and Canada have well-developed rail networks that used to be a significant source of passenger mobility. Indeed, rail ridership in these countries has *fallen* significantly from the high levels of about 50 years ago: it is estimated that in 1939, rail had a market share of 15% of all intercity trips in the United States (Eno 1994). In the United States these trends have coincided with others discussed elsewhere in this chapter: development of a high-quality road network, post-WW II prosperity that saw a steady rise in incomes and auto ownership, and the development of the domestic US air network. Cheap gas and high levels of auto ownership favored the auto over rail for short-distance trips and a well-developed, efficient, and relatively cheap air transport system has disadvantaged rail for long-distance trips. As a consequence, in the United States, the relevance of rail is limited almost solely to the congested Northeast corridor.

The US and Canadian experience merits attention, and it is worth considering its implications for currently successful rail services elsewhere, especially in Europe. If the deregulation of the markets for air travel in Europe currently underway leads to lower airfares — as was the case in the United States — there is a possibility that air travel will be able to capture some market share away from rail in the longer rail markets. Similarly, in the unlikely case that prices of gasoline — currently kept at high levels in most of Western Europe by taxation policies — fall, autos may take some of rail's market away, especially for the shorter trips.

New High-Speed Rail Technology

The technology underlying current high-speed rail (HSR) systems is little different from that used in conventional electric-powered trains. The most significant advance in rolling-stock design involves the use of tilting car bodies to increase passenger comfort on high-speed turns. Other design changes are aimed at reducing weight or lowering air resistance. A more significant difference between high-speed and conventional rail relates to track requirements. Operation at speeds greater than 240 kilometers per hour often requires specially designed track with concrete foundations, and wider track spacing and broader curves than those required by conventional trains. Thus operation at speeds greater than 240 kilometers per hour usually involves construction of new track on new rights of way, though slower services can also run on such tracks.

From a technological standpoint, the most interesting development in high-speed ground transportation is the emergence of magnetic levitation or maglev technology. Maglev technology uses magnetic forces to provide noncontact suspension, guidance, and propulsion at speeds up to 500 kilometers per hour. No maglev systems are currently in operation, but two systems based on the technology have been tested extensively. One has been developed by the Magnetschnellbahn GmbH group as part of the TRANSRAPID program in Germany; another has been developed by Japanese Railways as part of the Linear Express initiative in Japan. It is possible that an operational maglev system will be built in the coming years. At present there is interest in both the United States and China in developing an operational maglev line.

Rail's Link to Cities

Rail stations usually are located in the heart of the central city. This is the case in cities as diverse as New York, Paris, and Delhi. Downtown stations that are conveniently located for large numbers of travelers can be very significant assets — both in terms of facilitating mobility generally, and specifically the ability of rail to compete with air and auto.

On the other hand, when new rail connections are being planned, the "last mile" into a city can be a significant issue. The costs of right-of-way in urban settings have deterred many rail projects. (The rail networks in Chicago are not connected, and Boston's two rail stations — North and South — have never been linked.) The cost of building rail lines and stations in cities limits the potential for significant new rail network developments.

The magnitude of the advantage offered by a downtown station depends, however, on the structure of the urban region — the denser it is and the more important the downtown is, the bigger the significance of a rail station downtown. Thus, in low-density cities where the downtown is not the focus of business activities, such as newer US cities like Phoenix and Los Angeles, the downtown station is not a very significant advantage. Indeed, in the sprawling Los Angeles metropolitan area served by

What Is the Potential of HSR?

Evidence suggests that the markets in which HSR systems are likely to be the most effective are characterized by:

Rail travel times that are competitive with both air and auto. Auto usually dominates rail for trips shorter than 150 kilometers. Air travel usually dominates rail for trips over 650 kilometers (see Figure 5-6). HSR has the potential to be competitive for trips of intermediate distance.

A large number of center-city-to-center-city trips. For such trips, rail, which usually serves central cities directly, is often significantly superior to air in terms of terminal access.

Relatively expensive/inconvenient air and road travel.

In addition, HSR is economically most attractive in circumstances when:

Right-of-way is inexpensive.

The terrain is friendly, requiring little or no bridging or tunneling and permitting wide-radius curves.

Network effects exist. A segment that is part of a larger system can generate traffic in addition to the origin-destination traffic between its two ends.

as many as six commercial airports, rail serving the region predominantly from downtown Los Angeles faces a competitive disadvantage relative to air in terms of ease of access.

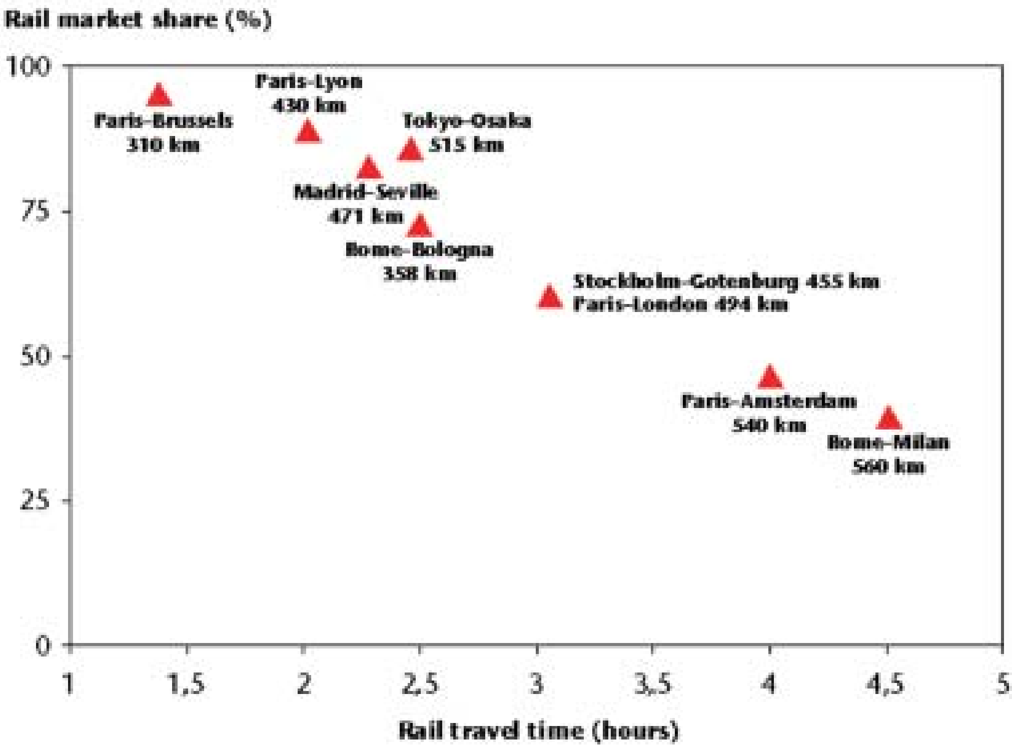
High-Speed Rail Services

A significant development for the rail systems in the developed world is the emergence of high-speed rail (HSR) services that are competitive with or even superior to air and auto. These services are in operation currently in Western Europe and Japan, and there is interest in developing HSR services in other locations, including several corridors in the United States and Asia (e.g., Korea, Taiwan, and China).

Services using "conventional" rail technology operate as fast as 300 kilometers per hour. The last two decades have seen progress toward the development of an alternative technology based on magnetic levitation (maglev technology), which in tests shows promise of achieving speeds of as high as 500 kilometers per hour (see feature box).

The most significant impediments to the establishment of HSR corridors are likely to be related more to questions of demand than to technology. HSR systems are very expensive to

Figure 5-6. Curve of the rail/air modal split (distances between 300 and 600 km)



Source: UIC (2000).

build and operate. For instance, the 412 kilometer Seoul-Pusan HSR system in South Korea is estimated to have cost about US$14.5 billion dollars — i.e., about $34 million per kilometer (KTX 2001). In addition, almost all HSR lines need operating subsidies. Evidence from existing HSR networks, as well as research across the globe, suggests that HSR requires a particular set of geographic and economic conditions to be effective (see feature box). Corridors where such a favorable set of conditions exists are limited at present, though it is possible that some of the features of the economic and competitive environment will change over time.

AIR

Air travel is the fastest growing means of travel in every part of the world, and every indication suggests that it will continue to grow at impressive rates. For instance, forecasts of air travel made by Airbus Industrie and Boeing, the two major manufacturers of commercial jet aircraft, indicate that global air travel alone will continue to grow at a rate of just under 5% a year for the next 20 years (Airbus 2000; Boeing 2000). These numbers are consistent with the official planning estimates developed by US and European authorities (e.g., US DOT, FAA 2000).

The air transportation system makes a unique contribution to global mobility. No other mode of transportation offers comparable range or speed. It would be difficult to imagine the global economy existing in anything like its present form without the support of the air transportation system.

This section addresses a wide range of issues relating to the evolution and future growth of the air transportation system. We consider the regulatory framework for the airline industry, the evolution of the hub and spoke system, the role of air cargo, trends in aircraft size and technology, the environmental impacts of air transportation, aviation's effects on cities, and infrastructure constraints on future growth.

Regulatory Environment

The airline industry is profoundly influenced by the regulatory structure under which it developed. In most countries this regulatory structure dates back to the infancy of the industry and reflects a perception at that time that the industry needed to be protected and fostered. The desire to support the growth of a national airline industry was based largely on a sense of its importance to economic growth and national security. National pride also played a role, as demonstrated by references to a country's "flag" air carrier. The regulatory regimes that emerged out of these concerns often subjected decisions regarding where a carrier could fly and what fares it could charge to the review of regulatory authorities. Firms seeking to enter the industry were required to seek regulatory approval. Existing carriers were shielded from competition in an effort to assure their stability and economic security. In exchange, they were required to provide services that were unprofitable, or only marginally profitable, but that were thought to be important for economic, social, or political reasons. A nearly universal regulatory feature was a prohibition against the provision of domestic air service by foreign-owned carriers. The ability of a foreign carrier to transport passengers between two points within the boundaries of another country is referred to as "cabotage."

In 1978, the United States decided to end regulation of its domestic airline industry, although it retained the prohibition against foreign ownership. Over the next few years the structure of regulatory controls over pricing and entry was eliminated. A substantial restructuring of the industry ensued. Many new airlines were launched. Few survived. Some small carriers grew substantially. Mergers reduced the number of carriers in the market. The surviving carriers established hub and spoke networks, whose structure is described below. Average fares fell substantially relative to inflation and the volume of air travel grew enormously. Competitive pressures forced carriers to reduce costs.

Regulatory authorities around the world watched developments in the United States with cautious interest. Although the general trend around the world is toward a loosening of the regulatory restrictions on airline conduct, few nations are willing to go as far as quickly as the United States. Most have opted for a more measured pace of liberalization.

The international framework for the regulation of air travel was established in the 1949 Chicago Convention. Signatories refrained at that time from setting up a multilateral system for the regulation of air travel between nations, specifying instead that air services between any pair of countries would be governed by a bilateral agreement between those countries. The system of bilateral agreements that emerged was the result of extensive negotiations aimed in each instance at assuring an equitable division of benefits between the residents, businesses, and flag carriers of the two countries. The outcomes of these negotiations were highly variable, reflecting the domestic and foreign policies of the various countries and the relative bargaining positions of the two nations.

Following the deregulation of its domestic airline industry, the United States adopted an international policy promoting "open skies," a system in which carriers would be free to establish new services and to vary frequencies and later fares, unhindered by the regulatory restrictions of the bilateral system. Over the succeeding years the United States succeeded in liberalizing the provisions of many of its bilateral agreements.

In 2001, a number of changes to the international regulatory regime are being discussed that could have profound implications for the structure of the world's air transportation system. One such change would involve the emergence of multilateral agreements as a replacement for the present bilateral system. Such agreements could grow out of negotiations between a multinational trading block such as NAFTA or the EC and either individual countries or other trading blocks. A second potential change could involve removal of prohibitions against cabotage. A third and still more radical possibility would be a decision to end the special treatment of air transportation and instead treat it simply as another service to fall under the provisions of the General Agreement on Tariffs and Trade (GATT).

Although it is impossible at this point to say with confidence that any of these changes is likely to occur, all are currently being discussed, and any could result in a restructuring of the international air transportation system as profound as that which occurred in the United States following deregulation.

General Aviation

General aviation (GA), the term applied by the US Federal Aviation Administration to privately operated aircraft, is the aerial equivalent of the personal-use auto. This category encompasses a number of different aircraft types, including single-engine piston-powered aircraft, twin-engine piston-powered aircraft, and smaller turboprops and turbofans.[13]

Globally, the general aviation market has declined in recent years. From 1990 through 1997 there was a 10% reduction in aircraft operating hours (GAMA 2000, p. 14). During this period, North American aviation hours fell by approximately 8%. In contrast, however, the Asia Pacific region saw a doubling of aviation hours.

North America accounts for a disproportionate share of global GA activity. In 1997 it represented 64% of total general aviation hours flown (41,990,000). On average in the 1990s, North America had five times the aircraft and logged 4.5 times the aviation hours logged by Europe. Europe had three times the aircraft and logged 1.2 times the aviation hours logged in the Asia Pacific sector.

General aviation has evolved to fill a number of significant niche roles in business use, including provision of high-end corporate transportation, ferrying personnel and materials to remote production sites poorly served by scheduled air service, supporting overnight package delivery service, and agricultural operations.

As a source of mobility, general aviation plays a minuscule role overall. The passenger-kilometers logged on general aviation aircraft are dwarfed by those logged on the scheduled air transportation system. Because of their smaller size and more limited carrying capacity, however, they account for a disproportionately larger fraction of total aircraft movements.

There is little evidence of a major trend in aviation away from mass transportation and toward personal-use aircraft. The evolution occurring in surface transportation seems unlikely to take place in the air anytime soon. Despite advances in technology, aircraft continue to have ownership and operating costs that place them beyond the reach of most individuals.

Evolution of Hub and Spoke Operations

A distinguishing feature of modern airline operation is its reliance on the hub and spoke system. This system involves the scheduling of a large number of flights within a short period of time into a centrally located airport. After a short period of time designed to allow passengers to disembark and connect to other flights, a large number of flights is scheduled to depart to a variety of different destinations. The central airport is the hub, and the routes between the hub and other points are the spokes. Such a collection of incoming and outgoing flights is called a "bank." Many such banks of flights will be scheduled at a hub airport over the course of a day. This system is familiar to most people who have traveled by air within the United States and elsewhere.

The efficiencies associated with a hub and spoke operation arise from the fact that any particular spoke route out of a hub will carry not just passengers traveling between the hub and the spoke airport, but also a large number of other passengers traveling between the spoke airport and other spoke airports. The increased passenger volumes on the spoke route make it possible for the hubbing carrier to offer more frequent service with larger aircraft than would otherwise be possible. Across the entire system, it is possible by using a hub and spoke operation to connect efficiently a far, far larger number of routes than would be possible with direct point-to-point service. The economics of this system are so compelling that it has become the dominant form of operation within the United States and in many places around the world.

Hub and spoke operations existed in the United States before deregulation of the airline industry, but they reached their full state of development only after US carriers acquired freedom to enter and exit routes. Hub and spoke operations require coordinated scheduling across a large number of routes, and such coordination is easier to achieve when carriers are free to choose which routes they will serve and how often.

Relationship between intercity air passenger and cargo operations. Many of the aircraft in scheduled commercial air passenger service also transport cargo. This is especially likely to be the case with wide-body aircraft, for which the below-passenger deck cargo capacity typically exceeds passenger luggage requirements by a large margin. Most major passenger airlines thus have sizable air cargo businesses. Although such businesses often make noticeable contributions to the carriers' bottom lines, they are a byproduct of their main business of providing passenger transportation, and are generally managed accordingly.[10] For the most part, scheduling and operational decisions are dominated by the requirements of the passenger operation.

For a long time, there has been a limited number of aircraft dedicated exclusively to cargo service. Historically these have been older aircraft that have been retired from passenger service and converted for cargo use, although this is by no means exclusively the case. Some have been in the hands of carriers specializing in air freight. Others have been operated by passenger airlines as part of their cargo operations.[11]

One noteworthy trend in air freight has been the rapid growth of integrated carriers such as Federal Express, UPS, and DHL that operate both air and ground networks in a coordinated manner to provide expedited door-to-door delivery services.[12] Although their combined fleets are small relative to those of the major passenger airlines, they are growing rapidly and can be expected to become a significant element of the commercial airline industry in the years ahead.

Trends in Aircraft Technology and Fuel Efficiency

Since their introduction in the late 1950s, jet-powered aircraft have come to dominate the fleets of the world's commercial airlines. By the 1980s virtually all of the large aircraft in commercial fleets relied on turbojet or turbofan propulsive technology. Turboprop propulsion was limited to smaller aircraft with capacities ranging from 15 up to perhaps 50 seats. Recently, with the introduction of so-called regional jets, turbofans have begun to replace turboprop aircraft at the lower end of the commercial aircraft size range. Thus, in discussing changes in aircraft technology and fuel efficiency, it is appropriate to focus on turbofan-powered aircraft.

Using energy intensity (EI) as the figure of merit relative to total emissions, the most convenient unit of technology for discussion purposes is the system represented by a complete aircraft. A combination of technological and operational improvements has led to a reduction in the EI of the entire US fleet of more than 60% between 1971 and 1998, averaging about 3.3% per year. In contrast, total revenue passenger-kilometers (RPK) have grown by 330%, or 5.5% per year over the same period. Long-range aircraft are approximately 5% more fuel-efficient than short-range aircraft, because they carry more passengers over a flight spent primarily at the cruise condition.

Lee et al. (2001) have presented a physical model and historically based statistical models that together explain the relationships among technology, cost, and emissions performance. Their analysis suggests that 57% of the reductions in energy intensity during the period 1959–1995 were due to improvements in engine efficiency, 22% resulted from increases in aerodynamic efficiency, 17% were due to more efficient use of aircraft capacity, and 4% resulted from other changes, such as increased aircraft size. The authors combined an understanding of historical trends and of the pace of future changes in technology and operation to estimate the impacts of these changes on operating and capital costs. These historically based projections indicate that typical in-use aircraft energy intensity can be expected to decline at a rate of 1.2% to 2.2% per year, a pace of change that is not sufficient to counter the projected annual 4% to 6% growth in demand for air transport.

Trends in Aircraft Size

The past two decades have seen two contradictory trends in aircraft size. On the one hand, manufacturers have introduced increasingly larger aircraft with ever-increasing seating capacities. The upper end of the size range has increased steadily over the period from 1960 to the present, with the proposed Airbus A380 capable of seating about 550 passengers. On the other hand, for at least the past 20 years the greatest growth in the commercial aircraft fleet has occurred at the lower end of the size range, with the result that over time the average number of seats per aircraft in commercial service has remained stable or tended to decline.

The relative growth in the use of smaller aircraft in domestic service results from efforts by air carriers to meet the service demands of their passengers. Airline scheduling decisions are often driven by the requirements of the lucrative business travel market. Business travelers are less price-sensitive than nonbusiness travelers, but more exacting in their demands for conveniently scheduled departure times and a wide range of return options to accommodate last-minute changes of plan. In addition, the general movement in the United States toward hub and spoke operations led to growth in service on relatively thin spoke routes connecting second-tier metropolitan areas to airline hubs. The net results of these factors favor the operation of smaller aircraft at higher-service frequencies rather than larger jets at the lower frequencies that would be needed to accumulate sufficient passengers to fill them.

The evolution of the international air transportation system followed a different path. Frequency of service is less of a consideration on these routes. As trips become longer, the likelihood of being able to make a single-day round trip decreases. For such trips, the possible advantages of frequent service become minor compared to the overall duration of the trip, the schedule disruption caused by time-zone changes, and the inconveniences of international travel formalities. Traveler preferences regarding arrival and departure times may interact with required flight times and noise-related restrictions on late-night or early-morning arrivals to limit feasible departure times to one or two limited intervals during the day. In such circumstances, airlines rarely offer the frequencies one sees in short-haul service.

The international air transportation system was traditionally organized around a limited number of gateway airports, typically located in large cities that were centers of international business and trade. International flights from a variety of different origin points would converge on these locations; arriving passengers would disembark and clear customs, and those destined for other domestic points would then transfer to the domestic air system for the remainder of their journey. The resulting operation resembled in some ways that of a hub and spoke system, although with significant differences. Travel and departure time constraints limited the opportunities for scheduling of multiple banks connecting flights. The necessity of clearing customs and possibly resting after a long journey meant that the connection process often proceeded at a slower pace than in most domestic air hubs. Concentration of passengers on a limited number of routes between the origin and destination countries facilitated the use of high-capacity, long-range aircraft.

More recent trends in international air service have been away from gateways and toward greater provision of point-to-point service to multiple destinations. Presumably this shift reflects an effort on the part of international airlines to respond to their passengers' service demands, and a judgment that point-to-point service represents the most profitable international air service expansion opportunity. It is facilitated by the introduction of twin-engine aircraft such as the B-767, B-757, and A-330, which have the range and reliability for transoceanic operation. As a result, growth in the international air fleet has shifted to some extent toward smaller aircraft.

Some observers express concern over the greater use of smaller aircraft. Generally, energy use and operating costs per seat decline as the size of the aircraft increases. Moreover, many potential constraints of the growth of air travel, such as noise exposure or overcrowded airports, are more closely related to the number of aircraft movements than to the number of passengers transported. For these reasons some critics see the movement toward smaller aircraft as a sign of short-sighted market forces. Though consumer preferences and current prices favor such high-frequency services on relatively smaller aircraft, these services actively increase the two greatest operational challenges to the airline industry: noise complaints and overcrowded airports.

Impacts of Air Transportation on the Global Environment

The environmental effects of air travel are highly significant because of a combination of many factors. First, aviation accounts for a significant fraction — estimates range between 8% and 12% — of transportation-related carbon dioxide emissions (UN 2000; IPCC 1999). Further, the rapid growth forecast for aviation activity makes it among the fastest-growing sources of transportation-related CO_2 emissions.

Second, significant though it is, aviation's share of CO_2 emissions *understates* the impact of aviation activity on global climate change: emissions from aviation activity have a disproportionately large impact on global warming relative to comparable surface emissions. Much of this impact is related to the high altitude at which aircraft emissions are injected into the atmosphere, typically 9 to 13 kilometers above sea level into the upper troposphere and lower stratosphere. At this altitude the effect of aircraft exhaust on global warming is two to four times greater than if the exhaust were CO_2 alone. In contrast, the overall contribution from all fossil-fuel–based activities is estimated to be about 1.5 times that of the effect of the CO_2 alone. In other words, the impact of burning fossil fuels at high altitudes is approximately twice the impact of burning the same fuels at ground level (IPCC 1999).

Two related factors are responsible for exacerbating the impact of emissions at high altitudes:

> First, high-altitude emissions and surface emissions interact with climate in different ways. In particular, water vapor emitted by aircraft combined with certain other components of aircraft exhaust contributes to the formation of contrails (visible line clouds that form behind aircraft flying in cold weather) and high-altitude clouds. These produce a cloud cover that inhibits the radiation of ground heat back into space. High-altitude emissions can also alter atmospheric chemistry and ozone levels.
>
> Second, aircraft engines emit many pollutants besides CO_2 and the altitude at which these other pollutants are released affects the dynamics of their passage through the atmosphere. In contrast to CO_2, which can circulate within the atmosphere for 100 years or more regardless of where it is emitted, the residence times of other pollutants such as soot and sulfur mass particles can be much longer when emitted at high altitudes than on the earth's surface. In the case of soot and sulfur particles, for instance, the longer residence times contribute to the enhanced formation of contrails with global warming properties.

Little attention has been paid thus far to mitigating the impacts of greenhouse gas emissions from air transportation. Though the prospects of reducing the impacts of aviation emissions through technology are as yet uncertain, it is clear that there are trade-offs. For instance, CO_2 and H_2O are produced by hydrocarbon fuel combustion and are directly related to aircraft fuel consumption. Emissions of CO_2 and H_2O can be reduced through improvements in fuel efficiency. However, increasing engine fuel efficiency enhances the prevalence of contrails, which also contribute to global warming.[14] Similarly, NO_x emissions become increasingly difficult to limit as engine temperatures and pressures are increased — a common method for improving engine efficiency. NO_x emissions can alter ambient ozone levels.

Furthermore, even if it were possible to achieve dramatic improvement in the emissions characteristics of new aircraft, the relatively long life span and large capital cost of individual aircraft, and the resultant lag in the adoption of new technologies throughout the aviation fleet, necessarily imply that a considerable period of time would be required before the effects of these changes would be felt on a large scale. Also, the impact of any efficiency improvements in flight is diminished by fuel wasted in airborne or ground travel delays or in flying partially empty aircraft. Further, we do not know the financial cost of change.

Aviation's Effects on Cities

Many of the most significant environmental sustainability concerns about air travel arise because most airports are located in or near major cities. Large numbers of urban residents are affected not only by the noise and pollution from airplanes, but also by the ground traffic generated by travelers coming and going from airports. In the following sections we discuss the effects of airports on nearby residents and their environments.

Ground access. In order to board an aircraft one must first travel to the airport. And it is almost always necessary at the other end of the trip to travel from the airport to one's final destination. Thus airports are significant traffic generators.

Airports typically offer a rich menu of public transportation services, including public and private buses. Airports are favorable environments for high-quality public transportation since they have high densities of travelers. Most ground transportation to and from airports is connected to the region's public transportation system, although these linkages often provide only limited service. The trip from a remote airport location to a city center can be long and slow, especially on a public transportation vehicle making local stops. The trip is likely to be even longer and more arduous for travelers destined for points outside of the urban core. Increasingly, such trips involve personal-use vehicles — vehicles either owned by the traveler, rented, or hired for the particular trip (i.e., taxis).

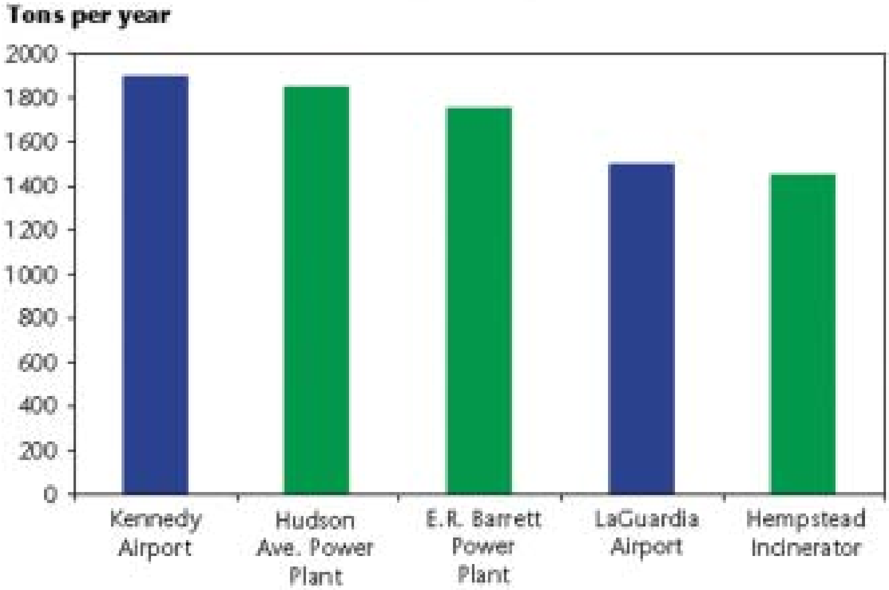
Impacts of air transportation on the local environment. In addition to its impacts on the global environment, air transportation has substantial localized impacts. Airline traffic is highly concentrated, with the result that a relatively small number of airports account for a very large fraction of all commercial air traffic. There are emissions from aircraft that are idling on the runway, taxiing, landing, or taking off, and from those circling while waiting to land. There are also substantial emissions from the ground transport of passengers, freight, fuel, and food, and from other related ground activities, all of which combine to make a major airport one of the most significant point sources of pollution in the metropolitan area it serves. Airports expose surrounding neighborhoods to high levels of noise, which have significant effects on health, quality of life, and real estate values. Historically these localized impacts have been the primary focus of concern over the environmental impacts of air transportation.

Local air quality issues are focused on the regional ozone production related to emissions of NO_x, CO, and HC. In addition, soot emissions contribute to ambient particulate levels and SO_x emissions can contribute to acid rain. While contributions to acid rain are considered small, particulate emissions are gaining more importance as regions focus on ambient levels of smaller-size particles, and on contributions by airports to this problem. Airport NOx, HC, and CO emissions, which are primarily a combination of aircraft-related and other ground operations, are important contributors to regional ozone levels. Figure 5-7 compares the contributions of Kennedy and La Guardia airports around New York City to other major point sources in the region. Figure 5-8 shows current and projected contributions from regional airports to cities across the United States. Los Angeles airport is the second-largest industrial smog source in the Los Angeles region.

Regulation of aircraft emissions. Nonbinding international regulations developed through the International Civil Aviation Organization (ICAO) control fuel venting, smoke, HC, CO, and NOx for several classes of subsonic aircraft engines. ICAO standards are formally instituted in US regulations as emissions standards. The European Union also conforms to ICAO standards. Controls were (and still are) based on a landing-takeoff (LTO) cycle that extends to an altitude of ~915 meters (3,000 feet), as represented by specified times in operating modes defined by engine power setting. Emissions above 915 meters, where aircraft spend most time in flight, were not (and still are not) controlled.

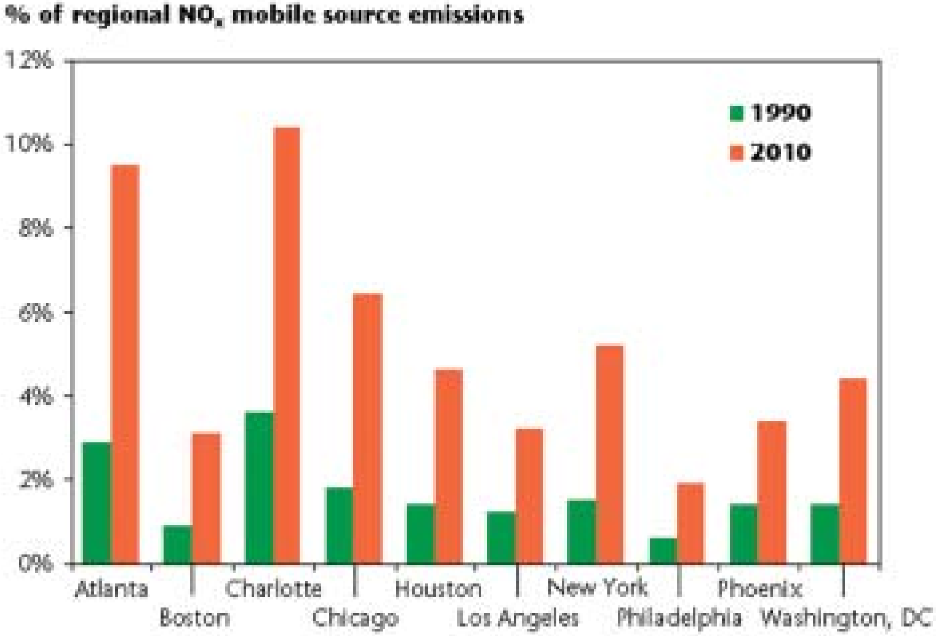
Local, state, and federal agencies around the globe are all pushing for improvements in the environmental performance of aircraft, driven by concerns over local air quality and

Figure 5-7. Point Sources of VOC and NO_x emissions — airports versus other major sources in New York metropolitan region



Source: Stenzel et al. (1996).

Figure 5-8. Comparing current and future airport contributions to regional NO_x levels

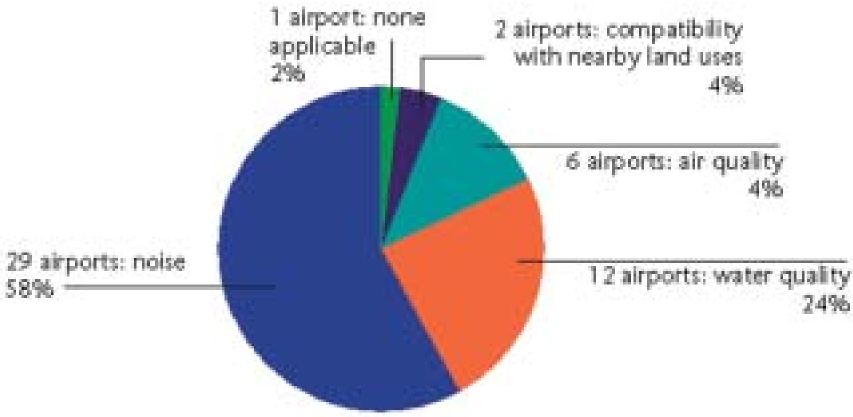


Source: US EPA (1999), table 4-2.

global climate issues. Elements of the ICAO Committee on Aviation Environmental Protection (CAEP), an international regulatory body, have pressed for further stringency in NO_X regulations. The proposed PM-2.5 regulations promulgated by the US Environmental Protection Agency constitute a potential restriction on aircraft particulate emissions. The proposed Kyoto Protocol to the United Nations Framework Convention on Climate Change specifically requests that industrialized countries reduce emissions from aviation bunker fuels. Further, local actions also have an impact on emissions decision-making. For example, Sweden and Switzerland have instituted landing fees based on aircraft NOx and HC emissions performance at national airports.

Aircraft noise. A recent survey by the US Government Accounting Office (GAO 2000) found that noise is the single greatest environmental concern facing air carriers today (see Figure 5-9). Noise remains a major concern in spite of the fact that technological advances and regulatory actions have substantially decreased the number of people affected by aircraft noise. Noise restrictions continue to increase in both number and stringency, constraining aircraft operation and leading to reduced mobility (flight delays and capacity constraints), increased operating and capital costs, and increased ticket prices. Further, noise is often a principal focus for community groups and larger nongovernmental organizations that act to oppose airport construction and expansion.

Figure 5-9. Environmental issues that most concern airports in the US



Source: GAO (2000).

A variety of technological and operational advances have reduced the average perceived noise from aircraft operation. There was a large reduction in noise levels in the late 1960s and early 1970s as a result of the introduction of the turbofan engine. While the primary motivation for the use of turbofan engines was reduced fuel consumption, lower noise was an important ancillary benefit. In the 1980s and 1990s, changes have been slower and more evolutionary, with increased bypass ratio engines, better acoustic liner technology, and the gradual introduction of other engineering changes. However, over the same period the average capacity of aircraft models introduced has tended to increase. Larger aircraft require higher-thrust engines that produce more noise, offsetting some of the technological gains made. At the same time, however, the average number of engines per aircraft in the fleet has dropped from 3.2 to 2.3, which tends to reduce overall noise levels (averages are weighted by number of aircraft in service in the fleet).

To assess the impact of noise from a specific airport, it is more useful to consider an appropriate average of the noise produced by the flight operations from that airport over a 24-hour period. One such measure is the Day-Night Noise Level (DNL), a metric adopted by the FAA for assessing annoyance from aircraft noise. It is assumed in forming this measure, for example, that operations occurring between 10 p.m. and 6 a.m. are twice as annoying as those occurring at other times of the day, due to sleep disturbance and lower background noise at night. It is currently believed by many that a DNL of 55dB is an "acceptable" intrusion on daily life and is consistent with current EPA guidelines for acceptable noise exposure for outdoor activities requisite to protect public health and welfare with a reasonable margin of safety. Note however, that the World Health Organization recently suggested that 50dB DNL is an appropriate level to ensure no adverse impacts of noise.[15] Further, as has been apparent in recent history, public perception of aviation noise impacts can change, and is not always consistent with the guideline cited above.

Federal assessments of noise impacts typically concentrate on those areas with DNL greater than 65dB. However, although the number of people highly annoyed is 4 times higher for 65dB relative to 55dB, the number of people living within the 55dB contour can be 5 to 30 times the number of people living within the 65dB contour. (Note that the land area within 55dB is typically only double that within the 65dB contour. However, the airport itself occupies much of the space within 65dB, whereas the land between 55dB and 65dB is typically used for other commercial and residential purposes.)

As shown in Figure 5-10, the number of people affected by aircraft noise in the United States has significantly decreased over the last 25 years. The figure shows an estimate of the number of people living within 55dB and 65dB DNL areas around airports in the United States as a function of time. The noise exposure estimates for 65dB DNL from 1975 to 1996 are from various sources the FAA used to track people who were affected during that time. The estimate of the population exposed to 55dB DNL is based on scaling from current population distributions around airports. The estimates and projections from 1998 to 2020 were calculated using the FAA MAGENTA model. The large reductions in affected population shown in this figure resulted primarily from three factors: 1) improved technology; 2) low-noise aircraft operations enabled by advanced aircraft control, navigation, and surveillance technology and advanced air traffic management technology (CNS/ATM); and 3) phase-out of high-noise aircraft as a result of regulatory action. The noisiest aircraft made a significantly disproportionate impact on noise, and regulation that helped to phase them out of service in the United States made a significant impact on lowering the level of noise around airports in the 1990s. When the US Congress enacted the ANCA (Airport Noise Control Act) in 1990, phased-out aircraft accounted for 55% of the US fleet but contributed to more than 90% of the total DNL levels at airports. The phase-outs mandated by the 1990 legislation are now complete in the United States, and over the next 20 years, estimates by the FAA suggest that reductions in affected population in the United States will be small, since the current fleet is relatively young and further phase-outs are not currently planned. The roughly constant number of affected people results from a balance between projected improvements in technology and projected increases in flight operations.

Infrastructure Constraints

Inadequate infrastructure capacity is presently both an immediate and a long-term threat to air travel in North America, Europe, and the Asia-Pacific region. Capacity constraints at airports and in the airways are causing increasing levels of delay.

In the United States, delays have been receiving high attention. The number of flights delayed by more than 15 minutes of scheduled gate departure and arrival times increased by 11% between 1995 and 1999, a period in which aircraft movements grew by only 8% (Mead 2000). Cancellations during this time increased by 68%. Overall, one in four flights was either canceled or delayed in 1999, with each delay averaging 50 minutes. Available data for the years 2000 and 2001 suggest that all of these trends have grown steadily worse.

The statistics are similar in Europe. In its 1999 Annual Report on Delays to Air Transport, the Central Office for Delay Analysis of the European Organization for the Safety of Air Navigation reports that a 6% increase in traffic between 1998 and 1999 was accompanied by a 54% increase in the number of flights delayed over 15 minutes (EUROCONTROL 2000).

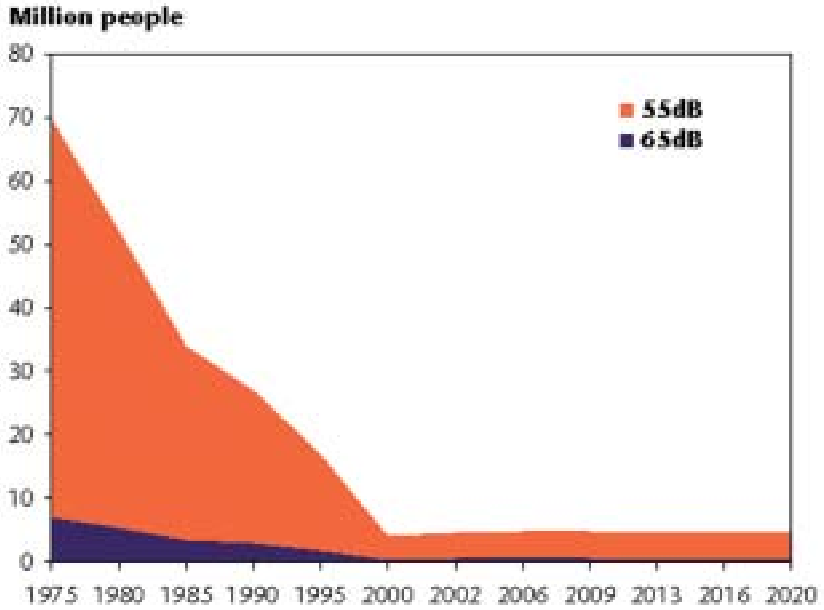
Much of this delay is attributed to airport congestion. Airports are limited in the maximum number of operations they can handle in an hour. In addition, noise concerns limit nighttime operations at many airports, especially in the United States and Europe. One result of the rapid growth in air travel described above has been that many of the busiest airports worldwide are presently operating at close to capacity, at least at peak periods and oftentimes throughout the day. The hub and spoke structure that increasingly characterizes most airline operations exacerbates this by concentrating large flows of aircraft in and out of hub airports.

Much of the delay experienced in the air transportation system is concentrated in the busiest airports. The FAA found that 10 large US airports that accounted for 31% of total enplanements in 1999 accounted for 64% of the flights delayed (US DOT, FAA 2000).[16] Similarly, the 10 busiest European airports (in terms of operations) accounted for 42% of the total flights delayed in the top 48 airports (EUROCONTROL 2000).

The problem is expected to worsen. A survey conducted by the General Accounting Office of the 50 busiest US airports, depicted in Figure 5-11, found that 13 of the airports were already operating at capacity and all but five of the 50 expect that they will be operating at full capacity within 10 years (GAO 2000).

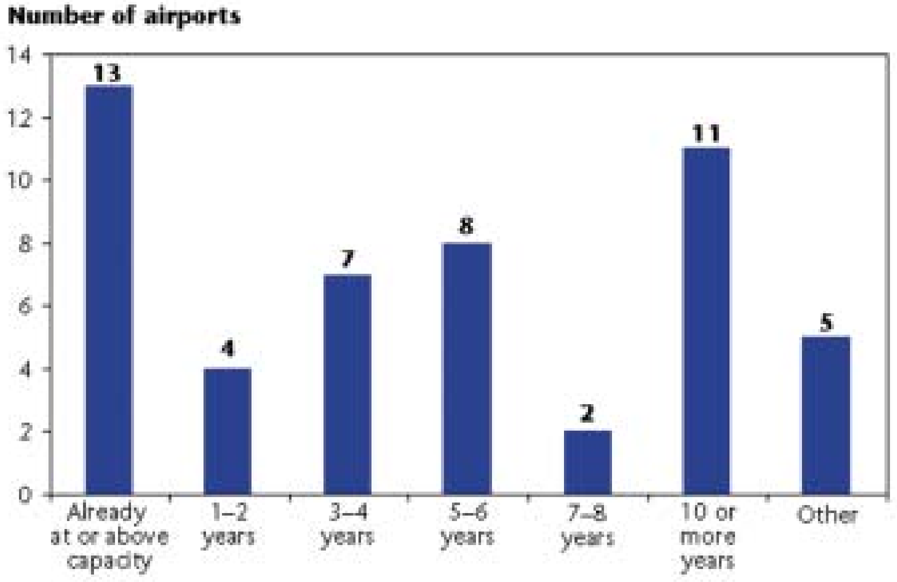
Given present growth trends and the capacity constraints outlined above, a key question is whether the capacity of the airport system will expand to keep pace with demand. There are reasons to doubt whether this can be done. As a practical matter, it is often very difficult to build new capacity at congested airports. First, there may just not be any space. This is true of airports such as Washington's National and New York's La Guardia. Most often, however, local community groups actively oppose airport expansion because of noise and/or environmental concerns. Though noise concerns are the basis for the most significant opposition to airport expansion, they are not the only reasons.

Figure 5-10. People affected by aircraft noise in the United States — number within 65dB and within 55dB DNL as a function of time



Source: Personal communication, FAA Office of Energy and the Environment.

Figure 5-11. Anticipated time for the 50 largest airports in the US to reach capacity



Source: GAO (2000).

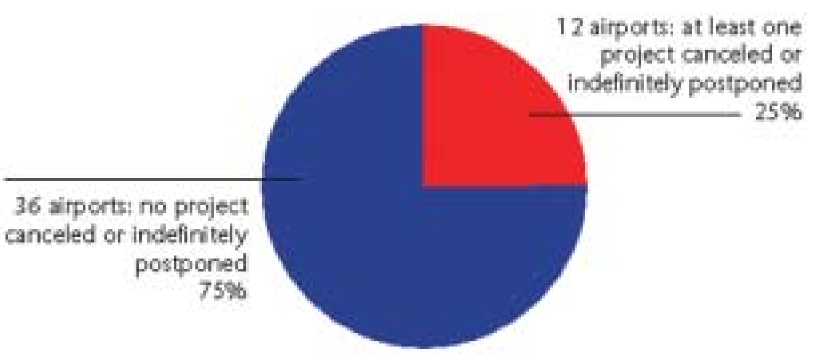
Runway projects at other airports such as San Francisco International face significant opposition from environmental groups concerned about the airport's effects on San Francisco Bay.[17] Figure 5-12 shows that environmental issues, including noise-related concerns, have led to indefinite postponement or cancellation of plans to expand airport capacity at 12 of the 50 busiest US airports surveyed by the GAO. Indeed, of the 10 large US airports, accounting for 64% of the delays in 1999, only four have any definite plans currently to expand their airside capacity before the year 2005.

Building a new greenfield airport is not much easier. Proposals for constructing a new airport encounter the same strenuous local opposition generated by expansion plans. In addition, new airports face the difficulty of identifying a suitable site. New airports require a lot of space. Consider the new Denver International Airport, built in 1994 on a 137-square-kilometer site located a 50-minute drive from downtown Denver; such space is rarely available close enough to major metropolitan regions to be useful. It is instructive in this context that two of the significant new international airports completed in the last decade — Kansai airport in Japan, and Inchon airport in Korea — were built on expensively constructed man-made islands.

These constraints on new airport development have resulted in a trend toward the building of ever-larger facilities located at ever-greater distances from the center of the metropolitan region. Knowing that new airports may have to serve for a very long time, developers have sought sites that allow ample room for subsequent capacity expansion. The need to provide a buffer zone to limit exposure of surrounding residents to aircraft noise further expands land requirements. To find such sites, one must search far from existing development. There is every reason to believe that these trends will continue.

In time, the growing difficulty of getting to the airport may limit growth in demand for air travel. Growing congestion in urban areas, combined with the increasing remoteness of airport sites, is likely to make the non-air portions of a journey increasingly burdensome and time consuming,

Figure 5-12. Large US airports canceling or indefinitely postponing expansion projects because of environmental issues



Source: GAO (2000).

offsetting in a growing number of cases the travel time advantages that air travel offers.

Air traffic control issues. The air traffic control (ATC) system, another critical component of the infrastructure supporting the air transportation system, is a source of growing concern. As travel delays and disruptions become increasingly common, many have begun to question whether the air traffic control system is capable of reliably handling its current workload, much less the greatly expanded workload expected in the future.

The ATC system in developed countries is made up of a network of navigational aids, communication systems, and manned control centers and towers that work together to direct and coordinate the safe movement of aircraft. ATC personnel will generally remain in communication with commercial aircraft throughout their flights. A particular aircraft will fly under the direction first of the airport tower; then of a terminal center charged with coordinating the movement of aircraft into and out of the metropolitan region; and then of one or more en route flow control centers, before passing through an analogous process at its destination. ATC personnel control aircraft movements by specifying altitudes, heading, and routings.

When congestion or disruption at any point chokes the flow of traffic, the ATC system must manage the resulting queue. ATC personnel will attempt to manage the flow of aircraft to make sure that each facility receives no more than the number it can safely handle. This is accomplished through a variety of measures, such as metering the flow of aircraft into the system through ground holds, rerouting, increasing the separation of en route aircraft, diversion of flights to secondary airports, or ordering an aircraft to circle until the system clears.

Growing airport congestion results in growing ATC congestion and delays. As more and more airports spend more and more time operating at the limits of their maximum feasible capacity, the system becomes more “brittle,” and more prone to turn small problems into large ones. A temporary disruption at one airport creates a queue of aircraft. Once that airport resumes normal operation, there may be so little excess capacity that it can take a long time to eliminate the queue. When such a queue persists, it can cause problems throughout the system. Aircraft delayed on the ground because of congestion at a destination airport can cause additional problems at the facility where they are held. Aircraft delayed at the start of the day may never get back on schedule, resulting in missed connections and passenger inconvenience.

In the developing world, air traffic control problems can take different forms. Air traffic demands are generally lighter in relation to population and land mass, and so congestion may be less of a problem. Facilities are sometime less well developed, however, and the system is less able to warn aircraft of hazards and impending danger. In some regions pilots may be forced to rely heavily on onboard navigational systems and radio communication with other aircraft to guide their craft safely to its destination.

A variety of technological solutions to improve the capacity, reliability, and performance of the ATC system have been proposed. Over time, the electronic infrastructure of the system in most parts of the world has been replaced and improved. New equipment frequently offers a higher degree of automation and better support for controller activities. New capabilities have been added, such as direct data links between aircraft and air traffic control computers. Satellite-based navigational systems have come into widespread use. Proposals have been made for scrapping the existing system of ground-based navigational aids in favor of an entirely satellite-based system. Together, these various developments offer the potential for “free flight,” in which aircraft are freed from the requirement to follow fixed routes, and instead are permitted to fly their own course, relying on satellite-based positioning systems, onboard route guidance, and direct aircraft-to-aircraft communication to maintain separation and safety. Proponents of free flight argue that it will reduce costs and increase the effective capacity of the airways. The extent to which these advances will facilitate improved management of crowded terminal areas is unclear.

A number of institutional issues have shaped the development of the ATC system. In many parts of the world, large areas of airspace are reserved for military use. In many countries the military shares responsibility with civilian authorities for airspace management. Concerns over national defense and national sovereignty have at times inhibited efforts to improve operations and efficiency through international coordination of policies and procedures. The technological underpinnings of the ATC system are complex, and the history of efforts by ATC operators to replace and upgrade aging equipment is characterized by delays and overruns. Some major initiatives have been abandoned after the expenditure of significant sums of money. In parts of the developing world, financing the system has proven to be a challenge, which accounts for the underdeveloped state of ATC in some regions.

Whether the ability of ATC systems to handle growing volumes of traffic will prove to be a binding constraint on the growth of air travel is unclear. Many knowledgeable observers argue that a large majority of ATC problems actually can be traced to shortages of airport capacity, and to the frequent backups of traffic that these shortages cause. As long as such shortages exist, however, the performance of the ATC system is likely to remain a topic of debate and concern.

CONCLUSION

Intercity travel both reflects geographic patterns of social and economic interaction and shapes the evolution of those patterns. A number of significant social, political, economic, and technological trends increase and strengthen the long-distance relationships of people around the world, and stimulate the demand for international travel. These trends include:

- Efforts to lower barriers to international travel and trade.
- Increasing globalization of the world economy.
- International migration.
- Increases in the availability and reductions in the cost of telecommunications.
- Increases in the quality and quantity of information available about people, cultures, economic opportunities, and recreational possibilities in distant locations.

As such travel has become faster and less expensive, demand for international travel has grown enormously.

Available evidence suggests that intercity travel is a superior good in the sense that an increase in income leads to a disproportionate increase in the demand for travel. Growth in income makes it easier for travelers to use faster but more costly modes of travel (auto, and especially air), thereby easing the considerable time requirements of intercity travel. At the same time, growth in income also increases the demand for high-quality recreational experiences, stimulating the demand for nonbusiness travel.

Four modes account for the bulk of all intercity passenger trips: bus, rail, auto, and air. The general trend around the world has been away from the low-cost, low-impact, lower level of service of buses and trains, and toward the higher cost and higher level of service of autos and air. This general trend, however, has manifested itself in different ways around the world.

In the developing world, bus and rail constitute the backbone of the intercity passenger transportation system. Although autos and airplanes are present, their roles are limited, and air transportation is too costly for many of the residents of these countries. Low levels of auto ownership and the underdeveloped state of the intercity highway network limit the availability and the convenience of auto travel. Bus and rail are the low-cost alternatives that most intercity travelers in these countries rely upon.

In developing countries without well-developed rail networks, and in the unserved portions of countries with such networks, bus is the primary source of intercity mobility.

In the developed world, most intercity travel is by auto or air, although in Europe and Japan rail plays an important role.

Aided by widespread auto ownership and a highly developed intercity road network, the use of auto for intercity travel by residents of developed countries has grown substantially over the past several decades. To some extent this growth is a by-product of the growing use of automobiles for urban travel. Intercity travel accounts for only a relatively small fraction of overall auto use, and does not appear to be a significant factor in most auto purchase decisions. Once an auto becomes available, however, it is likely to be used for long-distance trips.

Air travel is growing rapidly throughout the world, typically exceeding that of the overall economy. Forecasts of air travel made by Airbus Industrie and Boeing, the two major manufacturers of commercial jet aircraft, suggest that global air travel alone will continue to grow at a rate of just less than 5% a year for the next 20 years. These estimates are consistent with the official planning estimates developed by US and European authorities.

A critical question from the point of view of the long-term sustainability of the intercity transportation system is the extent to which the modal choices of the developing world come to mirror those of the developed world.

Although air travel accounts for only a relatively small portion of transportation-related greenhouse gas emissions, its significance is larger than its current size would suggest. Unlike other modes of transportation, aircraft emit the vast majority of their greenhouse gases in the upper troposphere and lower stratosphere. The impact of burning fossil fuels at this altitude is approximately double that of burning the same fuels at ground level. Moreover, air travel is one of the fastest growing segments of the overall transportation system. Thus, whatever its current impact may be, trends suggest that the effects will increase substantially over time.

In addition to its impacts on the global environment, air transportation has substantial localized impacts. Airline traffic is highly concentrated, with the result that a relatively small number of airports account for a very large fraction of all commercial air traffic. This necessarily results in a high concentration of activity at these locations. Emissions from aircraft that are taxiing, landing, or taking off and from related ground activities combine to make major airports one of the most significant point sources of pollution in the metropolitan areas they serve. Airports generate large volumes of ground traffic. They also expose surrounding neighborhoods to significant noise.

Over the past four decades, technological improvements have substantially reduced the adverse impacts of air transportation, and the energy efficiency of the world air fleet has improved markedly. Emissions per passenger mile of the principal greenhouse gases have declined in step with this improvement in energy efficiency, although some of the technological trade-offs have increased output of other emission components. Major strides have been made in reducing the noise associated with aircraft takeoffs and landings, but the reductions achieved in impacts per passenger mile or per operation have been offset in whole or in part by growth in the total volume of air travel. Although improvements in energy efficiency are likely to continue, they are unlikely to be of sufficient magnitude to offset projected growth in traffic. As a result, energy use in air transportation — and the associated greenhouse gas emissions — are likely to increase. Similarly, projected improvements in noise suppression technology are unlikely to offset growth in the number of operations or in the number of people living near airports.

As the volume of air traffic has grown, it has proven difficult to expand the capacity of the airport system proportionately. The noise, traffic, and pollution associated with major airports have in many cases generated strenuous opposition to their expansion. Such opposition has halted airport expansion in many locations. In others it has slowed the pace of expansion and increased its cost. Another issue constraining the pace of airport expansion is the huge amount of space required for new airport construction, and the resulting difficulty of locating suitable sites that are accessible to the population the facility is intended to serve.

In short, air travel is the fastest-growing means of transportation in the world. But it faces severe environmental and operational sustainability problems, with no technological or infrastructure solutions on the horizon. There is little margin to improve airplane emissions at this time. The improvements achieved in noise reduction are being overwhelmed by the overall growth of air traffic. Major airports are frequently so crowded as to cause severe delays throughout the air transport system. Yet local opposition to airport expansion and to the construction of new airports is so fierce that the building of new runways and airports is rarely a viable solution.

NOTES

1. Intercity passenger and freight transportation are linked because the systems providing these two types of transportation service share common facilities, and at times even common vehicles. This chapter focuses on passenger transportation. Freight transportation is discussed in Chapter 6.

2. Not surprisingly, though, the definitions used to define and report data on intercity travel differ across the world. In the United States, for example, travel surveys use a distance threshold of 100 miles to define an intercity trip; in the United Kingdom, the threshold is 50 miles. Though the nature of the available data frames much of our discussion, in this chapter we define intercity travel to include all trips of over 100 miles (161 kilometers) in length.

3. Although cruise ships represent a vibrant industry, such vessels are better regarded as floating resorts than serious modes of travel. Apart from a few locations (e.g., China), intercity travel by water-based modes is not a significant factor.

4. The two largest trading blocks are the European Union (EU) and the North American Free Trade Agreement (NAFTA). Other prominent blocs include the Association of South East Asia Nations (ASEAN); the Asia Pacific Economic Cooperation forum (APEC); and Mercosur, a tariff union comprising Argentina, Brazil, Uruguay, and Paraguay, with Bolivia and Chile as associated members.

5. About one-third are explicitly to visit friends and relatives. Another 15% were for "personal business," which in all likelihood also has to do with friends and relatives.

6. Though it is often possible to obtain bus travel data for many countries, it is difficult to isolate intercity travel. Further, in the case of most regions outside of the OECD countries, little or no reliable data is available and many of the figures presented are estimates. In all cases, intercity and urban travel bus data are combined, so trends are less likely to reflect actual levels of use.

7. "To reduce the burden on the common man, IR has deliberately kept passenger fares and freight rates for items of mass consumption less than the cost of operation" (Indian Railways 2001, finance). IR estimates that input prices have increased 2.2 times the rate of increase in receipts between 1970 and 1997. Available at http://www.indianrailway.com/railway/overview/finance.html. Last visited March 2, 2001.

8. Many of the data issues raised with intercity bus data are also true of rail. In particular, urban rail statistics are often combined with those for intercity rail.

9. This is not to say that nuclear energy is environmentally benign. At the very least there are considerable safety issues associated with generating nuclear fuel and disposing of waste safely.

10. Carriers differ in the extent to which they actively manage and optimize their cargo operations.

Some regard it as a major profit center, market it aggressively, and strive to meet shipper expectations. Other adopt a more passive role.

11. There have also been a limited number of "Combi" aircraft. These aircraft carry both passengers and freight, but devote a larger fraction of their capacity to cargo than do typical configurations.

12. Traditionally air cargo services have been offered on an airport-to-airport basis. Responsibility for arranging ground transportation at the two ends of the trip was left to either the shipper or an agent such as a freight forwarder.

13. General aviation is defined on the basis of mode of operation rather than aircraft type. But the economics of aircraft ownership and operation are such that general aviation aircraft as a group are dramatically smaller than commercial aircraft considered as a group. The upper end of the general aviation size spectrum does, however, overlap the lower end of the range of aircraft types used in commercial service.

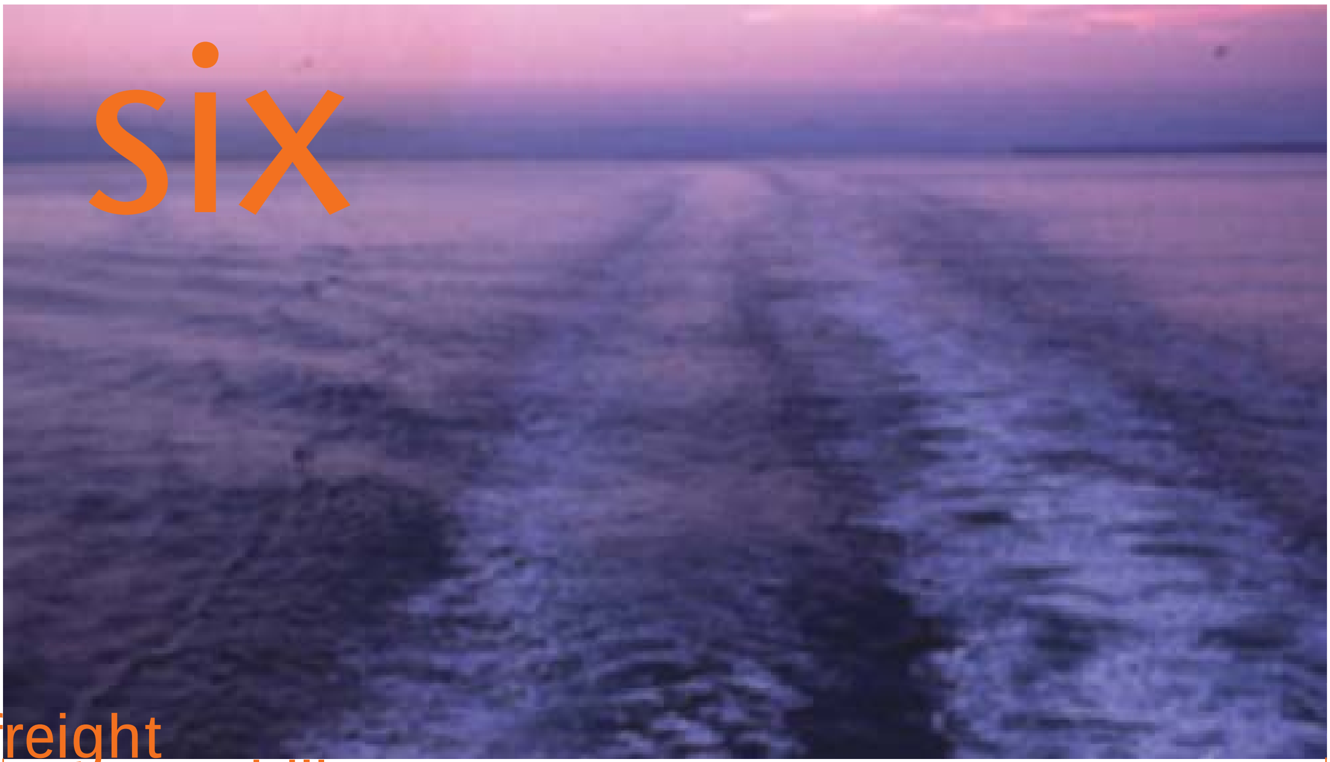
14. As engine operating efficiency increases, reductions in the temperature of the exhaust stream are greater than the corresponding reduction in water vapor concentration. This leads to increased contrail formation.

15. "To protect the majority of people against moderate annoyance during the day, exterior sound levels should not exceed 50 dB LAeq." (WHO 2001).

16. US DOT, FAA 2000, fig. I-1. The 10 airports are Chicago O'Hare, Newark International, Atlanta Hartsfield, New York La Guardia, San Francisco International, Dallas Fort-Worth, Boston Logan, Philadelphia International, John F. Kennedy in New York, and Phoenix Sky Harbor International.

17. San Francisco International Airport's runway reconfiguration project, if implemented, would need to fill in up to 1400 acres of the San Francisco Bay. This would require special dispensation from the California state legislature, given a 1965 Law that prohibited any fill of the Bay (San Francisco 2001).

18. US DOT, FAA 2000, fig. I-2. Runway projects are planned or underway at Newark, Atlanta, Dallas–Fort Worth, and Phoenix. Though the table lists Boston as an airport with definite runway expansion plans, other information suggests that these plans are still not final and face considerable community opposition.



six

freight mobility

The ability to move goods easily and inexpensively over long distances makes modern life possible. Yet discussions of sustainable mobility often ignore freight. Freight transportation consumes about 43% of all fuel used in transportation and is responsible for a major share of transport-related emissions of nitrogen oxides, unburned hydrocarbons, and fine particulate matter. Trucks delivering their loads compete with cars for space on city streets and on intercity expressways. Rail operators often must choose between optimizing their systems for the hauling of freight or for the hauling of passengers. Terminals where freight is collected, exchanged between modes, and distributed require large amounts of land in urban areas and are major sources of congestion and noise.

Freight mobility must be preserved and enhanced if society is to grow and prosper. But the challenges to freight mobility will not be easy to solve. Considering the importance of freight movement, attacking these problems must rank high on the scale of priorities for achieving sustainable mobility.

Freight transportation is one of the major underpinnings of modern society. Freight transportation systems bring water and fuel to our homes, food to our stores, and allow the economic and social specialization that enables cities to grow and modern societies to flourish. Cheap freight rates promote international trade and allow countries and regions to benefit from their comparative advantages in the world economy. Freight mobility has allowed many countries to achieve dramatic improvements in their incomes, standards of living, and quality of life. All of the exporting nations of Asia — Japan, Hong Kong, Singapore, Taiwan, and Korea — are based upon the inexpensive, reliable movement of freight. Freight can even save societies from starvation. The ability to distribute grain over India's railways has played an important role in eliminating the fear of famine for millions. Indeed, the worldwide grain market created by the ability to move huge amounts of grain virtually anywhere in the world is a crucial safeguard against the famine and misery that would otherwise accompany local crop failures.

Freight mobility is not without its costs, however. The movement of freight consumes approximately 43% of all transportation energy. Freight-hauling trucks clog highways and emit large volumes of pollutants. Even freight transportation's role as an enabler of globalization has its downside. Low-cost, reliable freight transportation has opened up vast, hitherto untouched regions of the world to economic development, but this development has often been accompanied by environmental disruption related to the dredging of harbors and the building of roads and railways. Some developing countries have used their new access to world markets to engage in destructive agricultural practices or to sell their valuable raw materials for prices that may not reflect the true costs of their production.

Modern railways, highways, ports, and airports are essential for integrating a nation's economy and for reaching world markets. Good regional freight systems support economic growth and world trade by giving manufacturers and consumers bountiful and cheap choices of materials and products. In most cities, local and regional movements predominate, and trucks — of all shapes and sizes — are the most visible element of the freight transport system. Trucks are frequently viewed as a nuisance by commuters on congested city streets, but they are the life blood of the city. They carry fuel for homes and businesses, resupply stores and markets, distribute food and other goods to households, restock inventories and inputs for local businesses, and remove garbage and waste. Trucks are also the typical means of moving freight to the ports, airports, and rail terminals that provide links to regional, national, and international markets. Pipelines are critical mobility systems for the supply of water and natural gas, as are sewer systems for the removal of wastes. Where such services do not exist, households and small businesses are often forced to spend large amounts of time obtaining water and fuel and disposing of waste.

What Does "Freight Mobility" Mean?

"Freight mobility" is not a widely discussed issue. Some of the concepts of personal mobility may also apply to freight, e.g., the cost and time required to move freight between various locations in a city, a region, or the world. Without trying at this point to define freight mobility, we can at least suggest that it should incorporate the following considerations:

- Manufacturers' ability to obtain raw materials from distant sources.
- A city's ability to obtain food, energy, construction materials, and other goods at costs that do not discourage development and growth.
- The ability for manufacturers to consolidate production so as to achieve economies of scale and sell to a larger market.
- Ability to achieve lower density within metropolitan areas (because it is easy to transport goods within the region) while the metropolitan areas themselves grow (in part because economies in freight movements make it possible to achieve economies of scale and density in public services, production, housing, and other areas of the economy).
- Individuals' ability to obtain groceries, energy, and other goods without increased costs, disruptions in service (e.g., of natural gas delivered to customers through pipelines), or greater expenditures of time.
- Producers and individuals being able to send and receive packages or other shipments of many different sizes without excessive cost or time.

The systems that provide international and intercity freight mobility will likely continue to grow, both because of their efficiency and because of the needs they fulfill on a daily basis. Regional and urban freight mobility faces greater problems, because freight in general is moving on the same roads as automobiles (prone to congestion), in the same urban areas (where air quality is a concern), and using fossil fuels (contributing to CO_2 emissions). Environmental problems could therefore be quite important for the small shipments and automobile movements (e.g., grocery shopping) that typify urban goods movements. The land-use patterns of metropolitan areas might have to be revised if substantial limits to freight mobility emerge. Congestion is an immediate concern for freight mobility; restrictions based upon either energy use or emissions (as opposed to payment of higher prices for fuel or emissions) will be a concern for business and development.

Components of the Freight System

This section provides an overview of the components of the current freight system, highlighting average capabilities, major trends, and issues related to networks, performance, and capacity.

Urban freight movements.

Within urban areas, the primary function of the freight system is to support the local population by distributing food, water, energy, information (mail, newspapers, magazines, catalogs, etc.), clothing, and other essentials to individual households and businesses, along with the collection and removal of trash and wastes. These are the most complex and costly elements of the freight transportation system, as the freight must be delivered or picked up in very small units and everybody must be served. For cities to exist at all, these services must be provided. For cities to prosper, they must be provided effectively.

This clearly is an area where personal mobility is related to the requirements placed upon the freight system. The size and location of stores is related to the time and expense that people are willing and able to devote to traveling. In cities, if people must walk to the grocery store, then there will be numerous small stores, requiring relatively complex and expensive deliveries. If people can drive several miles to stores, then they will, in general, find larger and more efficient facilities, with a larger selection of goods and lower prices. When people drive to centralized facilities, the complexity of the freight system has shifted from the carrier and the supplier to the consumer.

A second function of the freight system is to provide materials for the development and maintenance of urban infrastructure. It is necessary to obtain lumber, sand and gravel, steel, and other construction materials and supplies to build housing, other structures, roads, ports, and so forth. For a large city, these movements will be substantial, requiring special terminals and outlets. As with food, there is a link between freight and personal mobility. Construction firms or individuals can drive many miles to buy building supplies; they are not dependent upon local suppliers nor do they require a nearby rail terminal. Increasing mobility for individuals and small businesses again leads to larger distribution centers.

A third function of the freight system is to provide logistics support for local businesses. The urban freight system allows local businesses to assemble raw materials and supplies from local sources and — more commonly — from remote locations via local warehouses, storage facilities, local freight terminals, or local connections to the intercity freight networks. Likewise, the urban freight system must support the distribution of local products within the metropolitan region or to other regions via local sources.

Importance of Freight Transportation to the Local Standard of Living

"Household freight services" is another aspect of freight transportation that is intimately tied to personal mobility. Local in scope and usually overlooked, household freight is surprisingly important for quality of life and essential to sustainable city life. Household freight services support three requirements for healthy living:

- Obtaining sufficient quantities of water suitable for consumption, cooking,bathing, cleaning, and other household functions.
- Obtaining food and other supplies for the family.
- Removing wastes.

Most of the developed world takes these services for granted. Hot and cold water runs within the home, gas lines or routine oil deliveries heat houses, and — most importantly — electricity is there at the flick of a switch. Other household essentials are a quick trip away or, increasingly, available for home delivery. Indeed, household trash is taken to the curb, toilets are flushed, bottles recycled, and urban residents seldom give a moment's thought to the disposal of these wastes. The ease with which urban residents of the developed world can acquire essential supplies, buy new goods, and dispose of their wastes defines "household freight services." In rural areas of the developed world, household freight may involve slightly more cumbersome tasks and longer trips, but it is still managed with relative ease.

In the poorest areas of the world, however, the situation is dramatically different. Lack of access to cheap, clean water and the inability to dispose of wastes are fundamental problems affecting large portions of the population; 15% of the world's population live in conditions where lack of sufficient quantities of clean water and insufficient sewerage systems are constant threats to health (Potter et al., 1999, pp. 245–46). Moreover, the time and labor spent acquiring water and firewood are major drains on household budgets and time. Residents of those regions, usually the women of the household, spend much of their day manually acquiring essential supplies and are unable to engage in more rewarding economic, educational, or leisure pursuits.

Trucks dominate urban freight. Distances are usually too short for rail or water transport to be viable, although a few highly specialized movements do exist. As the demand for specialized goods and services grows, the demand for smaller, more specialized trucks increases. In Japan, restaurants often want deliveries of fresh fish twice daily. Consumers buy many different items from catalogs or from on-line outlets — and these will be delivered to their door by a specialized truck. In Bangkok, many small manufacturers move their day's production to a market or a storage facility in a truck smaller than most cars.

Small-package delivery is an increasingly significant element of urban freight mobility, for individuals and for businesses. Many new retail (and e-tail) services depend upon the post office or specialized carriers like UPS to deliver their products to consumers. In some industries, parcel transportation is the mainstay of the logistics system. For example, in the United States, over 75% of ophthalmic or opticians' goods move by parcel, postal, or courier services (US DOT, BTS 1997a, p. 203).

Of course, in large urban areas, freight transportation becomes an important activity in itself, and it is important to consider the national and international networks that pass through the city. Ports and major freight terminals become a focus for regional, national, and international logistics activities. Through freight movements may be an important

The Lunch Box Carriers of Mumbai

Mumbai, India, is home to one of the most labor-intensive yet efficient personal freight systems in the world. Every day 4,500 dabbawallahs, as the delivery men are known, pick up thousands of hot lunch boxes (dabbas) from customers' homes, transport the boxes to the customers' offices, and then return the empty dabbas in the afternoon. In the morning, the first team of dabbawallahs fan out across Mumbai and its suburbs, picking up an average of 30 dabbas each from customers' homes. They pick up and transport the dabbas by motorcycle or bicycle and deliver them to the second team at local train stations. The second team delivers the dabbahs by train to central train stations, where the third team sorts through the thousands of lunch boxes in less than 10 minutes and delivers them to their lunch customers by noon. After lunch, the process is repeated to bring the dabbas home.

This legendarily popular and efficient system depends on the hard work of the dabbawallahs and their simple coding system. For instance, Shomik Bhakelar's dabba is coded 3MC4; 3 for the carrier who delivers in the Nariman Point business district, MC for Bhakelar's office building, and 4 for the floor where his office is. The cost to Bhakelar? A very affordable 150 rupees per month. The dabbawallahs contribute the money to their local cooperatives, such as the Nutan Mumbai Tiffinbox Suppliers' Charity Trust, which pays them a monthly salary of 3,000 rupees.

The dabbawallahs have weathered recessions, changes in work patterns, widespread mill closings in the 1980s that robbed them of thousands of customers, and the proliferation of office canteens and food courts in the 1990s. Adept at new marketing opportunities, the dabbawallahs now offer their services online, at www.webrishi.com. And lest one doubt their efficiency, Forbes Global recently conducted an in-depth study of the dabbawallahs and awarded them a 6 Sigma performance rating, a quality assurance rating indicating a percentage of correct deliveries of 99.999999 or better. (*Unnithan,* 2001)

The Role of Rail in Regional Freight Movements

The railway network is no longer critical for regional mobility. Once it is possible for a truck to move 15 to 20 tons of freight at 20 to 40 mph over reasonable roads, then the truck will be cheaper and often more energy efficient than the railroad for general freight. Trucks do not need a high-speed, interstate highway to take most of the short- and medium-length shipments of general merchandise from the rail. Thus, the extensive regional rail networks that were critical for nineteenth-century development were really not a factor for development in the latter half of the twentieth-century. The decline of the railroad around the world was to a large extent a slow, painful adjustment of the transport system and of economic geography to the development of a superior mode of transport. There were simply too many rail lines for a world with paved roads and large trucks.

component of highway traffic, and a large portion of the local economy may benefit from freight activities. Hong Kong, Singapore, Rotterdam, and the other large ports derive tremendous benefits from international trade. Chicago's location enabled it to become the gateway to the American West and a natural center for production and distribution throughout the Midwest.

Regional freight movements. Regions are areas that may include a dominant city, several other cities, numerous smaller cities and towns, and a rural hinterland. The distances involved in regional freight movements are in the 100- to-500-kilometer range. Regions are best defined in terms of economic geography, which seldom follows political borders. An appropriate region might be a state or a province within a large country, an entire country, or several small countries.

At the regional level, moving food and other essentials directly to or from households and small businesses is no longer a prime concern. Instead, the issue is moving goods to, from, and between production facilities, warehouses, storage facilities, and regional connections to the national and international networks. Though shipments are generally larger and hauls longer than is the case for urban movements, trucks dominate regional freight movements, much as they dominate urban movements. The difference is that the most economical trucks will likely be larger than the myriad small trucks seen in the city. At this scale, the use of rail is usually limited to the movement of bulk commodities such as coal or sand and gravel, depending upon the location of the mine or the gravel pit relative to the power plants or the major construction sites.

The highway network is the key to regional mobility for freight. If a town has restricted load limits because of the quality of local streets or bridges, then it will not be an attractive site for a shipper wanting to use the largest trucks. On the other hand, if a town has good access to the highway, then the entire world is open to it.

In most countries, water transport is useful primarily for specialized movements of bulk commodities. In countries without a good road network, water transport remains valuable for general freight. And in countries or regions with exceptional access to good waterway systems, such as Germany and the midwestern United States, water transport plays a major role in the location of economic activity and in freight transport.

National or continental freight movements. There are two strategic freight-related concerns at the national level, where the distances are in excess of 500 kilometers. The first is the ability to move goods throughout the country or continent at low cost, so as to allow economies of scale in production and distribution. The second is the ability to serve export and import markets. Lower transport costs allow a country to compete in international markets for a broader variety of goods.

Ubiquity of service is not important; it is not essential that every city have immediate access to the best freight system — or even that most cities have reasonable access. For long-distance trips, by road or rail, there will be many alternative routes to follow; going an extra 50 kilometers to get to a good route is not the problem it would be for urban or regional trips. But it is critical that there be efficient ways to cover the continental distances and suitable sites for locating new industrial or other economic activity.

As distances get longer, the cost advantage of rail becomes more attractive. Railroads are well suited to hauling large shipments of coal, grain, and other bulk commodities. For container traffic, the line-haul cost savings on the railroad become enough to offset the costs of moving trailers or containers on or off rail cars. As a result, intermodal transportation linking rail and truck becomes an option. However, such intermodal movements require specialized facilities and minimum levels of traffic to be economical. For the most part, they are concentrated in North America and Western Europe, e.g., the dedicated double-stack container trains that are common in the United States and Canada. In Europe, trucks are moved under the Swiss Alps using a single, articulated rail car that has room for 10 to 20 trailers, with an easy way for truck drivers to drop their trailers on the platform (or to park their entire truck and trailer on the platform). Appendix A-4 describes the operational characteristics of the most significant kinds of rail technologies used for interregional freight transport.

Air Freight

Air freight is the newest, fastest, and most expensive freight mode. The speed and reliability of air service allow dramatic innovation in business practices and open new markets for certain types of commodities. The expense of air freight limits the tonnage that is handled, but the high value of shipments makes air freight an important factor in international trade.

There are three types of air cargo services: freight moving in commercial passenger aircraft (“belly” cargo), freight moving in aircraft specially dedicated to freight, and express services for small packages. The first two services compete with surface transportation for high-value shipments.

Every air freight move is an intermodal move, as a highway move is required at each end of the shipment. Businesses that depend upon air freight often locate at or next to airports to minimize the time and expense of the local move. For example, large companies may keep inventories of expensive parts at a warehouse next to an airport; when need for the parts arises, they can be dispatched by the next available flight. The expense of air freight is justified by the savings from consolidating inventories at one location; it may even be quicker to deliver the parts by air freight than by using highway transport from a closer warehouse.

Express services are decidedly different, as the focus is on small shipments, including many shipments direct to consumers or end users of the product. Typical shipment weights are 2 kilograms for domestic services in North America and 20 kilograms for intercontinental shipments. Door-to-door service is key for express services, and carriers offer customers a variety of options, e.g., next morning, next afternoon, or second-day delivery. For such services, the cost of the air transport is actually secondary to ordering and billing costs. Once the packages have been picked up, the key is to minimize the amount of sorting required and to minimize the time required to make the delivery. Using aircraft for moving the packages to and from a central sorting facility allows overnight deliveries to be made across an entire continent. The speed of air transport is essential for these express services; the cost, at well under $1 per kilogram, is inconsequential. As traffic volumes rise beyond the capacity of a single sorting facility, carriers may open additional sorting hubs, and they may begin to do more preliminary sorting at the local terminals in order to allow some use of trucks for deliveries to regions that can be reached in an overnight drive. A highway-based system will work fine, but only if the maximum distances are less than 500 miles and if there is enough volume to support the added cost of the truck.

Historically, inland waterways are linked to the development of cities and trade routes. The major river systems have long been critical for movement of grain, lumber, coal, and until the development of the railways, everything else. These systems can move very large shipments with a minimal expenditure of energy. Where the rivers are reasonably straight, barge transport is much more fuel-efficient than rail. Though waterway transportation is slower than rail (and much slower than highway transportation), it remains cost-effective for the movements of agricultural products, coal, ores, and other commodities that are relatively cheap and shipped in high volume.

For instance, the Paraná River in South America allows shipment of soy beans and grain from the fertile interior of Brazil and Bolivia through the port of Buenos Aires. Although the river does not yet support large barges or large tows, the costs are so low that they are competitive with shorter rail moves to closer ports. In general, when rivers are broad and deep, as in the lower Mississippi River, 40 or more 10,000-tonne barges can be lashed together into a single tow for movement down the river. Such an operation is both cheap and energy-efficient. This is no longer true when rivers are narrow, or if locks need to be built. Locks and

Table 6-1. Ocean shipping demand (trillions of tonne-km)

Year	Crude Petroleum Plus Petroleum Products	Dry Bulk Cargo*	General Cargo†	Total	Containerized Share of General Cargo
1975	15.7	5.0	4.5	25.2	Nil‡
1980	14.7	6.6	6.0	27.3	20.7%
1985	8.3	7.2	5.6	21.1	30.1%
1990	12.6	8.5	6.5	27.6	35.1%
1995	15.0	9.4	8.1	32.5	43.7%

Source: WEC (1998).
*Materials shipped unpackaged — coal, grain, ores, fertilizer material.
†Materials and goods shipped packaged.
‡Containerized shipping did not exist as a mode until the mid-1950s and was not significant until the 1970s.

dams are both expensive and environmentally disruptive.

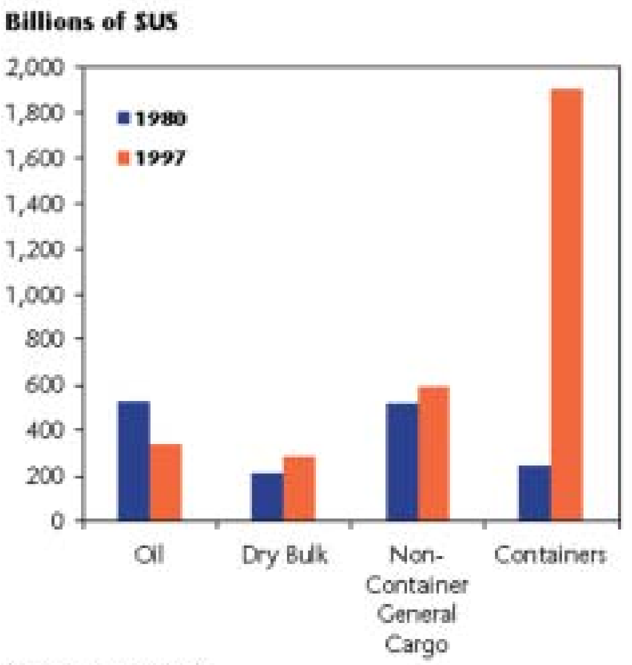
Though they do not dominate the longest moves, even here, trucks play an important role. Large trucks on high-quality highways are key to intercity trucking movements. Better highways increase service and the use of resources, while larger trucks reduce the unit costs of transportation. Limited-access highways allow trucks to travel more than 800 kilometers per day or 100,000 kilometers per year. If two drivers are used for each truck, these distances can be doubled. The larger the truck, the lower the cost for equipment and drivers, whether measured in terms of cost per unit weight or cost per unit of capacity. For bulk commodities, the carrier desires heavier payloads; for many other commodities, the carrier and the customer want more space.

Air freight, which requires a combination of truck and air transportation for the complete trip, accounts for a small, but valuable portion of national and international trade (see feature box).

International freight movements. Ocean shipping is the dominant mode for overseas freight tonnage, although air freight can be significant in terms of the value of freight shipped. Ocean shipping is highly efficient. Extremely large ships, operated with remarkably small crews, move great tonnages vast distances at minimal costs. Competition is fierce, keeping prices low and encouraging international trade. While almost any commodity can and does move in ocean shipping, three dominate: oil, grain, and containers (Table 6-1).

In terms of value of freight shipped, containers have come to dominate (Figure 6-1). The maritime sector provides a critical backbone to global economic sustainability. For example, according to the World Bank (2001c), seaborne freight accounts for 80% of developing countries' trade as measured by tonnage shipped. In the European Union, approximately 90% of trade with third countries and 35% of intracommunity trade occurs via the oceans, with EU ports handling 2.3 billion tonnes annually (ESPO 2001). The English Channel exemplifies the importance of sea trade to Europe — with approximately 47 ves-

Figure 6-1. Value of freight shipped, 1980 and 1997



Source: Drewry (1999).

sels, over 40,000 deadweight tonnes (DWT) crossing every day, the Channel has some of the highest traffic densities of any stretch of water in the world (Owen 1999). In the U.S., waterborne trade exceeded 1.1 billion tonnes in 2000, with goods valued at US$740 billion (AAPA 2001).

The Merchant Fleet. In recent years, the world's ship fleet, in terms of total DWT, has been increasing, albeit slowly — at a rate of 1.3% from 1998 to 1999 and 1.6% from 1997 to 1998 (UNCTAD 2000). The largest fleet types — oil tankers, bulk carriers, and general cargo ships — have been increasing at the slowest rate (1.1%, 0.2%, and 0.2%, respectively), while container ships and other types of ships — each less than 10% of the global fleet — have been increasing at 4.1% and 5.7%, respectively (UNCTAD 2000).

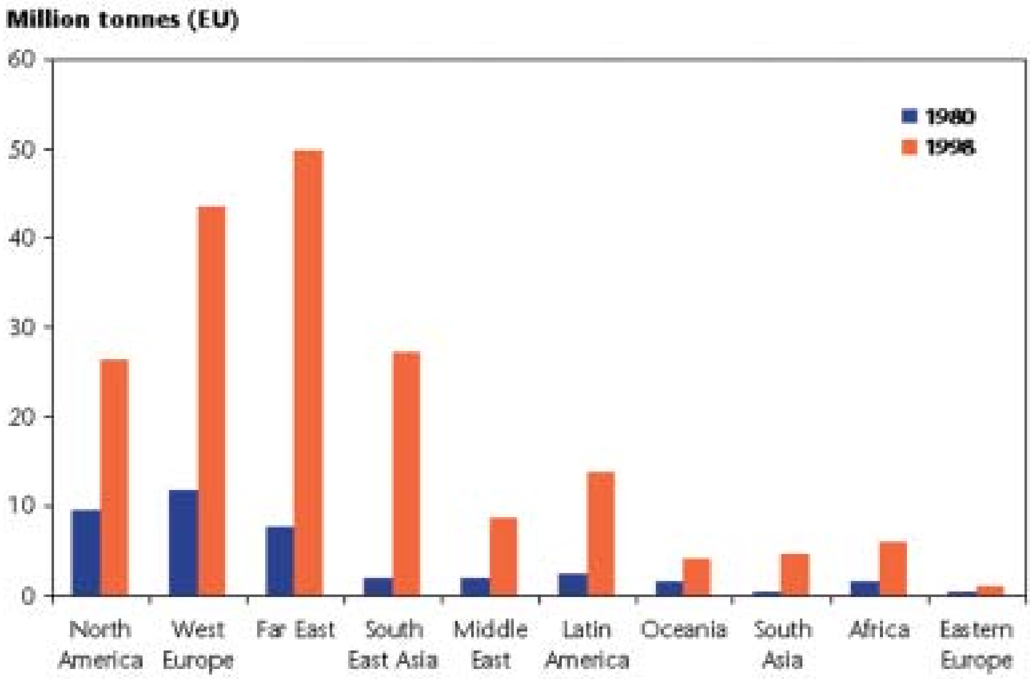
Of the various vessel types, dry bulk cargo ships are often called the "workhorses" of the world's fleet (IMO, 1999), comprising 33% of the all vessels. Oil tankers comprise an almost equal share. Both of these vessel types are among the largest plying the oceans, although container ships are also increasing in size. The continuous growth in tanker and bulk cargo ships has paralleled growth in trade of their respective commodities (i.e., oil and grains). Container ships are a more recent addition to the global fleet, with the first purpose-built vessels entering service only in 1965. They have grown substantially in both numbers and average size.

This growth in the number and average size of container-hauling ships has paralleled the growth in global container movements. The number of containers handled in world ports increased from 39 million TEU (20-foot-equivalent units) in 1980 to 185 million TEU by 1998 (Drewry 1999). Growth in container movements in North America, West Europe, the Far East, and Southeast Asia has been particularly rapid (see Figure 6-2).

Marine architecture has successfully increased the size and strength of ships so that infrastructure, not technology, limits ship size. For many years, the largest ships were designed to slip (barely) through the locks of the Panama Canal. Today, with many ships deployed within the Atlantic or within the Pacific, the Panama Canal no longer caps the size of ships. For instance, the largest container ships were once the "Panamax"-class ships capable of carrying 4,000 20-foot containers; today, Post-Panamax ships can carry 6-8,000 TEUs. The size of these behemoths is now limited by the ports, as only deep-water ports can handle the largest ships. These trends are also true of tankers and grain ships.

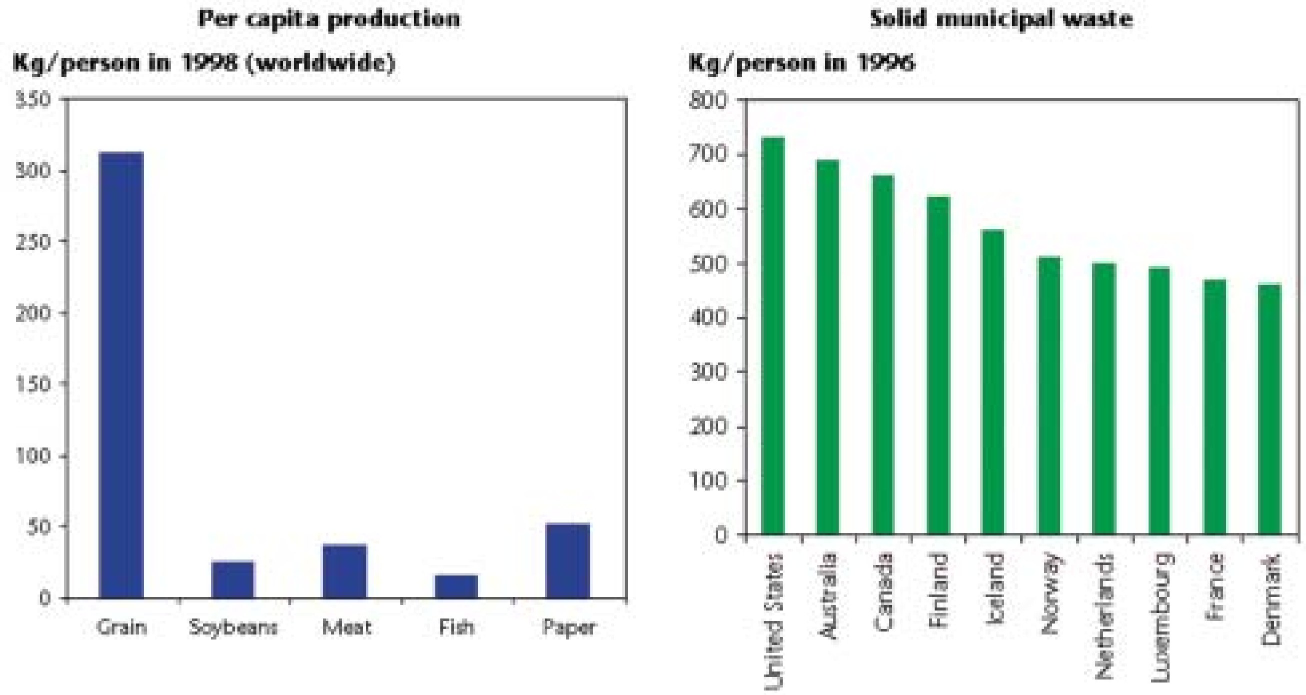
The economics of ocean shipping are characterized by low line-haul costs, ship costs that get lower per unit of capacity as the ship gets bigger, and significant costs of port operations. Taken together, these three factors cause the costs of international shipping to be dominated not by the ocean voyage but by the land side costs — the rail or truck movement to the port and the handling at the port. As a result, if it is possible to get bulk commodities or containers to a major port at a reasonable expense, it is then possible to ship those commodities or containers to any other major port in the world at a modest additional expense (on the order of

Figure 6-2. Global container activity by region — 1980 and 1998



Source: Drewry (1999).

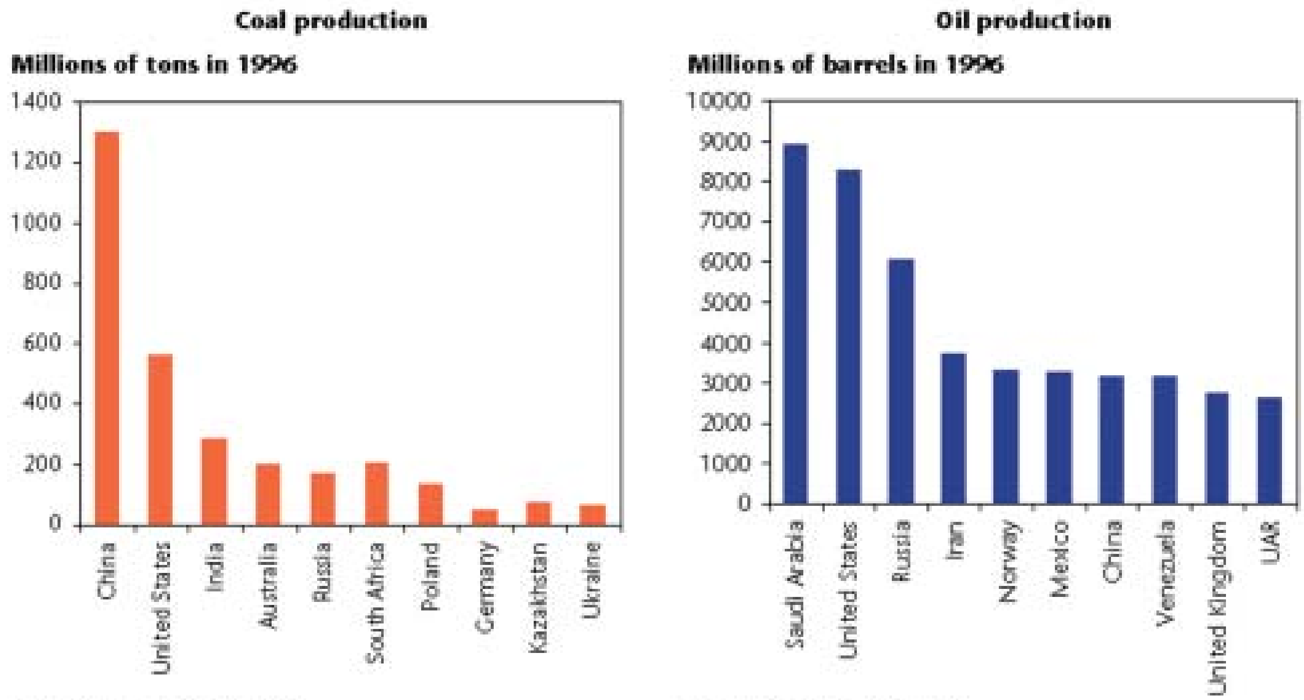
Figure 6-3. Elements of urban freight: food, paper, and solid waste



Source: Vital Signs (1999), pp. 31, 33, 35, 37, 79.

Source: *Economist* (1999), p. 93.

Figure 6-4. Energy production in selected countries



Source: *Economist* (1999), p. 49.

Source: *Economist* (1999), p. 49.

$100 per thousand kilometers per container).

WHAT IS BEING MOVED AND WHAT IS MOVING IT?

Freight transportation can be distilled to a few key concepts: tonnages, shipments, and tonne-kilometers. Tonnages reflect the level of production and consumption of the economy. Shipments reflect the vehicles, vessels, and technologies available to move the freight, as well as the amount of freight produced and consumed at specific locations. Tonne-kilometers reflect the distances of shipments as well as the tonnages and are used to indicate effort required to move freight. Costs are a function of all three factors, with the relative importance of each factor varying by vehicle, technology, and the characteristics of the commodity.

To understand freight transportation, it is important to begin with the freight itself. This section starts with a brief discussion of the commodities that constitute the large majority of global freight movements.

The Commodities that Constitute Freight Movements

A small selection of primary commodities, food, fuel, and ores dominates the total tonnage of freight moved globally. In 1994, coal, farm products, chemicals (and allied products), nonmetallic minerals, metallic ores and stone, and clay and glass products constituted over 70% of the tonnes transported by US railroads, and 64% of the tonnes shipped in US domestic waterborne commerce in 1994. (WEC 1998).

Grain is the key agricultural commodity requiring transportation. In some form it is basic to the diet of every culture, both as food and as feed for livestock, and it is easy to store and transport. China is the largest producer of grain in the world, growing approximately 100 million tonnes of wheat, 200 million tonnes of rice, and 250 million tonnes of other grain. Canada is a major exporter, with a vast rail network linking the production areas in the western plains to ports on the Great Lakes and the Pacific. The United States and Brazil are the world's biggest exporters of soybeans. Brazil is noteworthy because its soybean production has grown significantly in recent years as new lands are opened to agriculture in the fertile western portions of the country. With more fertile soil, more efficient farms, and an improving transport infrastructure, Brazil is challenging the United States for soybean exports.

While annual production varies with the weather and other factors, the demand for grain is driven by the demand for food. Figure 6-3 shows that the per-capita production of grain is just over 300 kilograms per year worldwide. This may seem to be a large amount (i.e., two loaves of bread a day per person), but it includes feed grain for livestock, which is converted to meat. Figure 6-3 shows that grain dominates agricultural production: per-capita production of meat is about 40 kilograms per year, and the numbers for soybeans and fish are lower. To put the statistics for food production in perspective, the figure also shows that per-capita production of paper is about 50 kilograms per year. Food indeed is the primary product for the consumer society. But, as shown on the right side of Figure 6-3, the primary product of the consumer society may be waste. The United States produced over 700 kilograms of solid municipal waste in 1996. Picking up, consolidating, transferring, and disposing of the waste is a major freight transport activity.

Different forms of fuel constitute another primary freight commodity. Figure 6-4 shows that the production of perhaps the two most important fuels, coal and oil, is highly concentrated across a few countries. Production and transportation of fuel is on the order of 500 kilograms of coal and 10 barrels of oil per person per year; this exceeds agricultural production, but is considerably easier to manage as freight, because production and consumption are highly concentrated.

Coal is the most important commodity shipped by railroads, usually transported directly from mines to power plants and large industrial users. The major producers are China and the United States, with substantial production in India, Australia, Russia, South Africa, and Poland. In addition to being the single largest commodity transported in North America, coal is also estimated to be one of the most profitable commodities shipped on the North American railroads. It is a major export commodity as well, and significant technological advances in rail and ocean transport allow worldwide distribution.

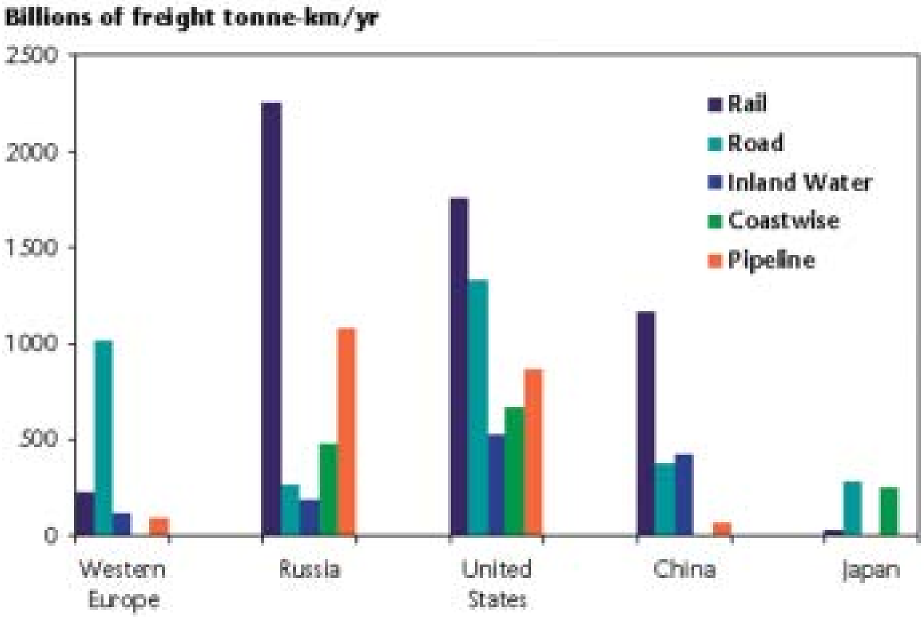
How Freight is Moved in Different Parts of the World

Freight can be moved by many different transport modes, including numerous combinations of tanker, rail, and truck. Figure 6-5 shows how much freight moves on rail, truck, waterway (inland and coastwise), and pipeline, in a selection of countries and regions. This figure shows both the quantity and modal share of freight tonne-kilometers as of the early 1990s.

The differences among the countries and regions shown in Figure 6-5 are striking. The United States had the most balanced distribution as well as the highest total amount of freight traffic. In Russia, rail and pipelines carry higher volume but little use is made of trucks. China had some balance among rail, road, and waterway, with rail by far the most important. Western Europe and Japan had almost no rail freight and were highly dependent on road freight.

The split across different modes reflects several factors. First, geogra-

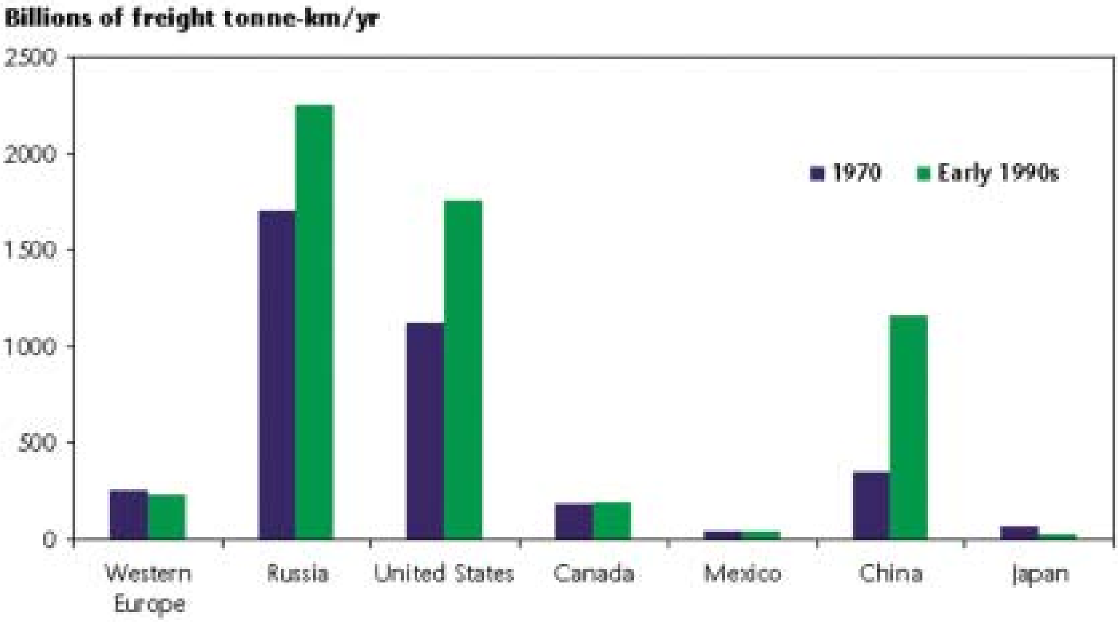
Figure 6-5. Freight traffic in selected countries, early 1990s



Source: US DOT, BTS 1997a, pp. 250–61.
Note: Early 1990s—varies by country (1991, 1993, or 1994).

phy plays an important role in determining how freight is moved. Countries need coastlines to conduct ocean shipping; suitable rivers are needed to facilitate inland water movements. For instance, an island-country like Japan has a very high proportion of freight moving in coastwise shipping. However, being small and mountainous, it lacks the long hauls that are most suitable for rail. Infrastructure investments and political factors also play an important role. For instance, the United States, Russia, China, and Western Europe are all large regions with extensive rail networks. However, only the United States and Western Europe have an extensive network of good highways. Similarly, although Western Europe is large enough for long-haul rail service, it has not developed as an integrated economy. As a

Figure 6-6. Rail freight trends in selected countries, 1970 vs. early 1990s



Source: US DOT, BTS (1997a)
Note: Early 1990s—varies by country (1991, 1993, or 1994).

result it still does not have a unified heavy-haul rail-freight network.

Across the world, rail's share of freight is generally declining, even though the total magnitude of traffic moved on rail may well be increasing. For instance, Figure 6-6 shows that rail tonne-kilometers continued to grow in China, Russia, and the countries of North America. However, Figure 6-7 shows that in all of these countries, the growth in road traffic was even greater. China, with rapid economic expansion during the 1990s, experienced more than a 10-fold increase in road tonne-kilometers as the railways struggled to handle a tripling of traffic.

In Western Europe, rail traffic actually declined about 10%, while road traffic doubled between 1970 and the early 1990s. Not surprisingly, Figure 6-8 shows that rail share declined throughout the region over the last quarter of the twentieth century from about 30% of tonne-kilometers in the early 1970s to only about 15% in the early 1990s.

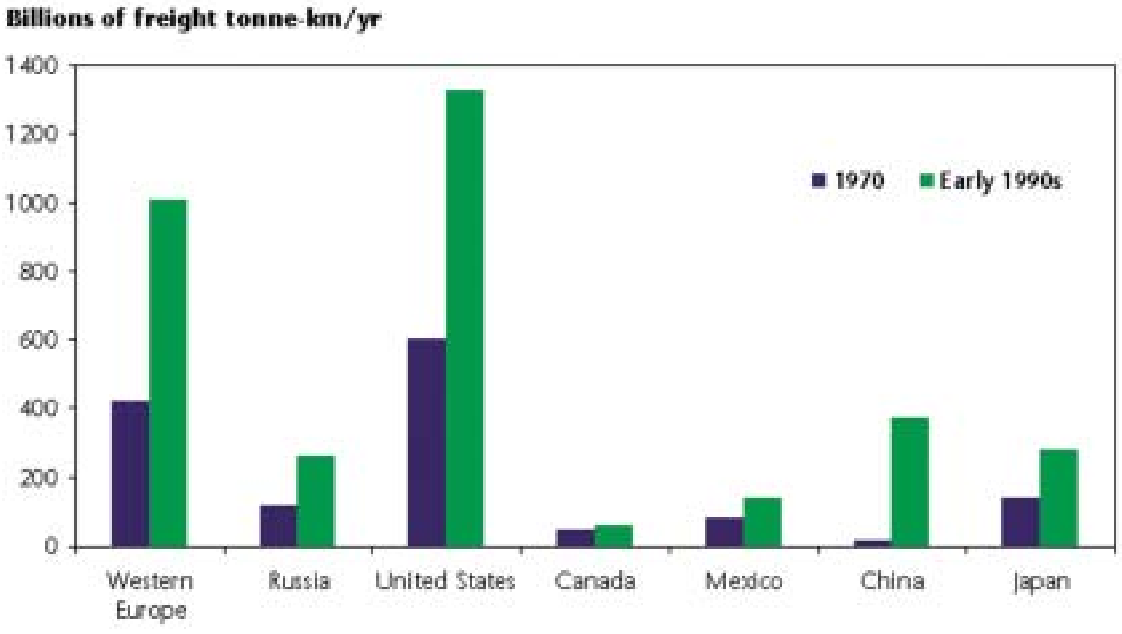
SUSTAINABILITY CONCERNS RELATED TO FREIGHT MOBILITY

Freight transportation raises a number of complex questions for sustainable mobility. The movement of freight contributes greatly to many of the problems associated with mobility — fatalities, air pollution, environmental degradation, congestion, and noise. Yet freight is absolutely essential for modern life. In a crisis, most citizens could reduce the amount they drive or fly and still conduct their lives. Modern societies could not function without regular deliveries of food and fuel and disposal of wastes. The old cry of the railroad men that "The freight must get through!" remains essentially true. Because of the important nature of freight, and the volume of goods transported, the operational sustainability of the freight system is a paramount concern.

Yet the operations of the freight system impose increasing burdens on the social, environmental, and economic fabrics of society. Each link in the transportation network carries individual costs and benefits, depending on its capacity and characteristics. Ocean tankers are silent and invisible to the majority of ordinary citizens, yet they generate air pollution. Trucks are the crucial beginning and end links in most freight transportation. Their ubiquity makes them the most visible and vexing elements of the congestion conundrum, and the most dangerous to their operators and to other drivers. Airplanes are the fastest, and also the loudest links in the system. Rail and barge are the most energy-efficient means of freight transport, and contribute the least to noise and congestion. Yet because they must operate on fixed routes, transport by rail and barge is declining worldwide. Three enormous national rail systems, those of Russia, China, and India, have barely begun to rationalize their passenger and freight operations and adjust to competition from trucks. The transition away from rail in any of those nations will mean painful adjustments for millions of workers, and expensive infrastructure investments for their fellow citizens.

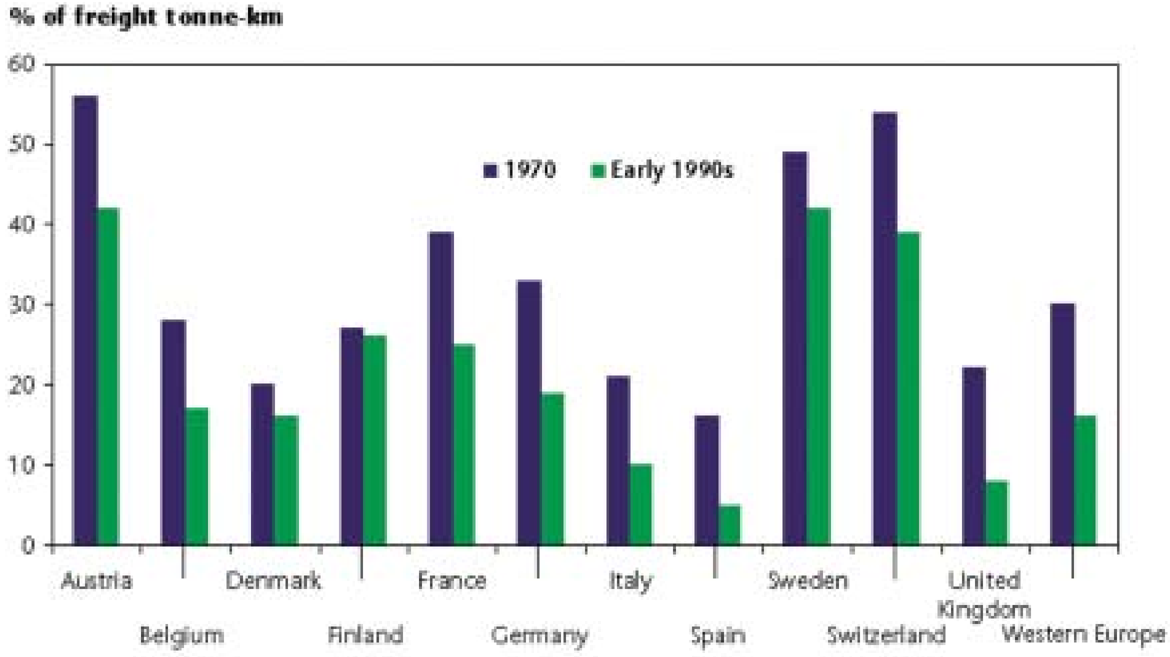
To complicate matters, freight facilitates and highlights the complex,

Figure 6-7. Road freight trends in selected countries, 1970 vs. early 1990s



Source: US DOT, BTS (1997a).
Note: Early 1990s—varies by country (1991, 1993, or 1994).

Figure 6-8. Rail freight traffic in Western Europe, 1970 versus early 1990s



Source: BTS (1997), p. 254.
Note: Early 1990s—varies by country (1991, 1993, or 1994).

interdependent nature of the global economy. One reason so many delivery trucks clog the streets of cities is that goods can now be shipped to and from almost any market in the world — and they are, in increasing numbers. Managing national and international trade and freight requires the attention of governments at every level, from heads of state negotiating global pacts on trade, to county councils regulating the hours in which trucks can rumble through their streets.

The challenge of freight transportation is to maintain operational efficiency yet minimize the many deleterious side effects of the system. This means freight operators must navigate political interests, public concerns, hazards to safety and tranquility, land-use limitations, environmental problems, yet still make their pickups and deliveries on time. Because of the volume and importance of freight, it poses some of the most demanding and acute challenges to sustainable mobility.

Cheap Freight Rates as the Key to the Global Economy

The costs of high-volume transportation between essentially any two ports in the world are very low. For manufactured goods, costs are on the order of $0.01/tonne-kilometer. For comparison, a 1000-kilometer movement of a container costs about 10 times this by truck and about 5 times this on the best rail intermodal service. The modal comparison shows that ocean transport is cheaper than ground transport, but fails to convey how cheap that service really is. Consider what it means to the consumer for companies to be able to ship a container halfway around the world for, say, $3,000. A container can hold about 20 tonnes of merchandise, so the cost per tonne would be on the order of $150 and the cost per kilogram would be less than $0.15. Compare these two figures to the cost of, say, a $40 book marketed in the US by a European publisher or a $200 electronic device manufactured in Japan. The value of other manufactured goods can be higher, about $20,000/tonne for automobiles, much more for computers and consumer electronics. Shipping products like these internationally adds less than 1% to their cost, which is why international shipping is growing so rapidly, and consumers can enjoy a global variety of goods and products.

Operational Sustainability Concerns

Capacity and congestion.

Capacity and congestion are general problems for trucking, especially in and around cities. Congestion reduces mobility and increases fuel consumption and emissions. Congestion and the high costs of home delivery also threaten to limit Web-based retail commerce, where the final delivery of products to homes and small businesses can be very costly. Alliances are developing among the major express carriers and the national postal services to deal with this issue. Congestion is also a concern at the regional level, especially where choke points limit flow through a region.

Infrastructure availability.

Ground- and air-based freight transportation face infrastructure limits in several regions of the globe. High-speed, high-capacity, limited-access highways are primarily available only in North America and Europe. As a consequence, trucking costs are higher in other parts of the world, although the opening of even a dirt road provides access to new regions.

Timescales of Change

In economics and in transportation, theoretical analyses often refer to systems in which price mechanisms cause an equilibrium between supply and demand. The concept of an equilibrium is perhaps worthwhile for educational purposes, as it allows very elegant theories to be postulated. Nevertheless, we must recognize that in economics, as in the physical sciences, the timescale is important. Though systems might ultimately reach equilibrium, this can take a long time.

With transportation systems, the timescale for changes must be measured in decades (or centuries) for some systems, while other systems can be changed quite quickly. New vehicle technology can be introduced in a matter of months or years, but the new vehicles themselves will likely be introduced slowly as older vehicles wear out or as demand justifies fleet expansion. A motor carrier might change over its entire fleet of tractors in 5 to 10 years, but a railroad will take 20 years or more to change over its fleet of locomotives or freight cars. Public outcry and strict legislation, such as the US Oil Pollution Act of 1990, passed in the aftermath of the Exxon Valdez disaster, can hasten change, but such instances are rare. Adjustments in the route structure are much slower; it is not difficult to add or delete a few links in the network or to upgrade a few terminals, but it takes generations to adjust the nature of the network. The major transportation routes may last, in one form or another, for hundreds of years.

Railroad rationalization is an example of a process that requires a long time to reach equilibrium. In the United States and Canada, the railroads took approximately 70 years (beginning in about 1925, when the network reached its route-mile peak) to rationalize their networks from what was suitable when rail was dominant for both freight and passenger to what is appropriate for a modern heavy-haul railroad devoted to freight transportation. This sounds like a long time, but the transition has not yet taken place on a large scale anywhere else in the world.

The freight systems in China and India are a good example. In these large countries, the railroads still handle vast amounts of passengers and freight. Powerful political forces would like to see the railroads maintain their dominant positions and continue to employ millions of laborers; however, these countries have yet to deal with the capabilities of motor carriers. It is one thing for the railroads to handle vast amounts of freight because there are no options; it is another for the railroads to handle the freight because they are in fact the best option. As China and India plan for the future, they must consider not only the best transportation systems, but also the financial means to pay for their development, and the political obstacles to change.

The successful transition from the traditional to the modern heavy-haul railroad system that has been made in the United States and Canada, has also occurred in portions of South Africa, Australia, and Brazil. China and India also have extremely high-density rail networks, but they have not yet faced intensive highway competition. Both these countries have worked with the World Bank and others to develop strategic plans for increasing system capacity and improving rail efficiency. In Eastern Europe, the rail system was designed for an economy that once faced east, but now must now also face west. In Africa, there never was an integrated continental rail system, as the rail networks were designed to link cities, mines, and regional economic activity to the ports.

Major projects may also be needed to increase the connectivity of the system. In Latin America, for example, the Andes provide a formidable barrier to transportation. Although there are roads and railroads across the mountains, these are difficult, low-capacity routes that would be inadequate for major freight movements. Argentina and Chile are considering construction of new highways or railways over or through the Andes. Bolivia is evaluating the potential for what they call the "Interconnection," a new rail line that would link the railroads in the eastern and western parts of the country.

The Panama Canal is operating near capacity and can no longer serve the largest ships; an additional set of locks will be needed to provide a long-term solution. However, such a project will require more water (which is periodically in short supply already) or a redesign of the lock system to allow reuse of water.

It is unclear whether there will be sufficient space within major metropolitan areas to sustain the growth trends in freight transportation. Ports have limited space, and there is strong competition for waterfront property. According to the World Bank (2001c), global port container throughput will reach 270 million TEUs by 2005, 55% greater than 1998 levels. This projected growth will require between 200 and 300 new container terminals. At the same time, trends indicate a growing concentration of traffic within a small segment of ports — a phenomenon strengthened by the growth in transshipment (akin to airport hubs in the airline hub and spoke system). The result is an increase in port congestion, both on the sea-to-land side as well as on the land side, as space for unloading, storing, and ultimately, transporting freight by land to its final destination becomes increasingly scarce. The trend toward larger ships will only exacerbate this problem, as well as continue to increase pressures for dredging port sea bottoms to allow for deeper berths. The greatest problems lie in the megacities in the developing world, where there is little history in dealing with large and sophisticated freight transportation, and where present land-use patterns and real estate development cannot accommodate intermodal freight.

System concerns: secure trade routes and stable financial markets. Security of trade routes has been an essential national security concern since ancient times. Indeed, much of history can be interpreted as competition for new markets, new sources of supply, and secure trade routes. Since the conclusion of World War II, there have been few sustained threats to international shipping lanes and air freight.

Stable, well-managed financial markets are also important for the smooth flow of freight. Trade flourished hundreds of years ago without the benefit of computers or electronic banking. Trouble in the financial markets could easily disrupt growth and reduce freight transportation, but the capability of financial institutions to deal with international shipments will be easy to sustain.

Economic Sustainability

The key concerns regarding economic sustainability are whether freight costs will remain low enough for national and international trade to continue to prosper, and whether freight transportation will remain sufficiently mobile to allow continued growth, development, and improvement in the quality of life worldwide.

Freight transportation has enjoyed tremendous productivity growth over the last 50 years. Better roads, better railroads, larger vehicles and terminals, improved communications and control, and cheap oil helped reduce transport costs, despite increases in the costs of materials and labor. In many regions and markets the productivity gains and low prices are a tribute to the vigor of free markets; freight transportation is one of the most competitive industries, with the lowest margins in the world. How long these trends can continue is uncertain. Symptoms of potential long-term problems include rising fuel prices, public antagonism to very large trucks, the difficulty in handling the largest ships at most ports, and the driver shortages experienced in the United States over the last 10 years.

Freight's "Public Relations" Problems

Freight transportation and regional economic activity are generally intertwined — and the relationships are easily understood at a local level. The employees of the paper mill know the importance of the trucks and railroads that deliver pulpwood and chemicals and pick up the newsprint and paper products. The workers, their neighbors, and their friends and relatives live with the noise of the local freight yard, the large trucks lumbering through their streets, just as they live with the smell of the paper mill. As the developed world becomes less dependent upon manufacturing and extractive industries, however, fewer people are financially dependent on, and tolerant of, the activities that generate the freight traffic. Moreover, people tend to view the supermarket and the mall as the source of the goods that they buy — they do not make a clear connection between the truck traffic and the goods they acquire.

As cities develop, and particularly as they shift from manufacturing to information economies, their residents are less tolerant of the disruptions that result from freight operations. The most widespread conflict is related to the treatment of trucks in traffic congestion. Capacity and congestion are general problems for trucking, especially in and around cities. Congestion reduces mobility and increases fuel consumption and emissions. Congestion and high costs of home delivery could also limit Web-based retail commerce, where the final delivery of products to homes and small businesses can be very costly. Alliances are developing among the major express carriers and the national postal services to deal with this issue. Congestion is also a concern at the regional level, especially where choke points limit flow through a region.

Cities across the world — from New Delhi to New York City — impose restrictions on truck activity, including prohibitions of large trucks and the limiting of truck activity to certain zones or to off-peak times. There are many more automobile drivers than truckers, and as the link between personal well-being and local freight becomes less appreciated, the initial political pressure is to restrain truck traffic, without considering the consequences to local economies and personal freight distribution. Around major intercity freight facilities, truck traffic may be perceived as a nuisance, particularly as residential areas expand and come into closer contact with the freight terminals. Noise, aesthetics, and night lights all become greater concerns. Similarly, ports around the world are under great pressure to release land for residential or office development. Areas once covered by port facilities, rail yards, and warehouses are now viewed as prime spots for expanding the real estate development in major ports around the world.

Throughout much of the world, great economies remain to be achieved through the development of modern highways, railways, ports, and intermodal terminals. Fuel availability and cost are ongoing concerns. Labor shortages are a growing problem in the developed world, although for the foreseeable future, driving a truck will continue to be a relatively high-paying job in the developing world.

Financing major infrastructure projects is a challenge everywhere. Theory suggests that if the service is worthwhile and provides economic benefits, then somehow these economic benefits can and will be tapped to finance the service.

However, a common problem is that carriers cannot afford to expand, because of competitive forces that keep rates low. Where this is true, as long as the low rates translate into broad public benefits, then the public and their governments need to find a way to deal with the financing problem.

Addressing Operational Sustainability Concerns

For the most part, the freight system is driven by cost, not by the utility of individuals. If costs change, then the system adjusts. Increases in fuel costs, taxes for emissions, restrictions on land use, and requirements for noise

When Is a Truck "Too Large"?

In North America, regulations governing size and weight limits for trucks remain a source of lively, often virulent debate. Truckers argue that larger trucks are more fuel-efficient (in tonne-kilometers per liter of fuel) and more economical than smaller trucks. Further, they argue that fewer larger trucks would relieve congestion on busy urban highways. However, strong countervailing arguments exist.

First, there are safety concerns. The public is concerned about the safety of large trucks — especially trucks pulling multiple trailers — and highways where the number of trucks impedes freedom of movement for automobiles. In some locations at certain times of the day, trucks fill up an entire lane (or more) on major highways, making it particularly difficult for some drivers to enter or exit the highway. Trucks pulling multiple trailers can also have stability problems. In response, the motor carrier industry argues that larger trucks operated by experienced drivers on appropriate infrastructure at reasonable speeds are no riskier per truck-kilometer and are less risky per tonne-kilometer than a greater number of smaller trucks.

The potential damage to pavement and bridges from heavy trucks is another concern, and a very complicated one. Maintenance costs and the physical load limits on a roadway are a function of its initial design, the quality of materials used, and the quality of the maintenance. Poorly designed roads can never survive heavy loads, nor can poorly maintained roads; however, better roads with stronger bridges can handle heavier trucks, especially when the trucks are designed with adequate axles and large enough tires to limit the stress on pavement and bridges. Many analysts argue that the economic and environmental advantages of large trucks are very considerable, so that it is well worth building roads and bridges that are sufficiently strong to carry heavy loads.

In summary, technologically it is possible to design highways to handle larger and heavier trucks, but it is not as clear whether the institutional case for heavier trucks will be won. At present, indications are that it will be easier to consider special truck lanes, or designs that allow larger and heavier trucks, when new highways are being developed rather than in cases where a well-developed highway link already exists.

control will change the relative costs of the system and the system will, over time, adjust. The freight will still move, possibly at a higher cost.

Because of the size of the vehicles and — compared to automobiles — the relatively small number of vehicles, conversion to other energy sources is an option. Railroads originally ran on wood or coal, and if pressed, could do so again, either through conversion to coal- or wood-fired locomotives or through electrification. Depending on the energy source and the technology used in the power plant, electrification might or might not help with emissions. Trucks can also be converted to run on alternative fuels, although the expense could be quite high. Both fuel efficiency and emission levels can be improved through replacement of the older, most inefficient vehicles.

Productivity improvements in freight transportation. Technological improvements such as streamlining trucks to minimize air resistance, maintaining proper tire pressure, and keeping the engine in tune, help fuel efficiency somewhat, though not as much as operational improvements that minimize empty miles and maximize the use of a truck's cargo space.
Historically, improvements in freight mobility occurred for three reasons:

- Government and, to a lesser extent, private investments in transport infrastructure resulted in more extensive networks that provided more direct routes capable of handling larger vehicles moving more safely at faster speeds.
- Technological innovations for vehicles and rights-of-way resulted in faster, cheaper, more reliable, and safer transport of larger and more diverse shipments.
- Institutional, regulatory, and political innovations improved the availability, service, safety, security, and cost of freight transportation.

Technological innovation made railroads possible, and support from governments and private investors created extensive networks. Regulatory and institutional developments allowed shipments to move across several systems, whether those systems were owned by different companies competing within the same region (the case in North America) or spanned several countries (the case in Europe). Likewise, paved roads and diesel engines make truck transportation possible, but government support and investment is necessary to create national and international highway networks capable of handling heavy trucks. Regulatory, institutional, and political innovations are needed to deal with the complex issues related to international truck shipments. Wherever trucks are used for international shipments, there are concerns about driver qualifications, truck condition, truck size and weight, empty backhauls, and other issues. These concerns have little to do with the technology or the network, but they must be dealt with to maintain or enhance mobility. The European Union's efforts to dismantle the regulatory hurdles to freight movement between its member states is probably the most important current example of deregulation. The lessons that the EU learns from lowering barriers to the free and rapid movement of freight will be closely watched.

Freight and Information Technology

"Intelligent Transportation Systems" (ITS) are technologies aimed at improving traffic management and coordination among providers and users of highway and intermodal transportation. ITS includes numerous applications that improve certain aspects of highway performance, e.g., automatic monitoring of traffic, quicker response to accidents and other emergencies, automated toll collection, weigh-in-motion scales for heavy trucks, and expedited customs procedures. For freight, ITS offers some hope of reducing congestion in cities and administration delays on highways. While the technologies have yet to play a major role in reducing congestion, the state of the art is advancing rapidly.

The Internet is becoming a critical factor for freight transportation. An obvious example is the rise in package deliveries due to online shopping. But more importantly, by providing new capabilities for exchanging data, facilitating business-to-business exchanges, and hosting supply-chain and inventory-management programs, the Internet serves as a platform for new types of business transactions that will affect freight flows, prices of commodities, and prices for transportation. These changes will improve the efficiency of the markets and reduce costs both for commodities and for transportation.

In the context of environmental and political sustainability, the same three forces are relevant. Technology can improve fuel efficiency, reduce emissions, and extend the life of materials. Better infrastructure facilitates operations that are inherently more fuel-efficient, result in fewer emissions, and reduce wear and tear on both vehicles and the roadways. Legal and regulatory guidelines must balance the environmental and economic concerns, and political activity will of course play a role in this.

Privatization and deregulation of the railroad industry. The privatization and deregulation of railroads in the United Kingdom, Argentina, and the United States have received a large amount of attention in the past 20 years. This report is not the forum to debate the success of those regulatory changes, and both sides still wage a vigorous debate. However, it does seem clear that the declining rail market shares relate much more to fundamental changes in the freight market — i.e., the clear advantages of trucks for so many shipments — than they do to inadequacies of regulation or of management. A more important, longer-term question is how to develop more systems around the world that provide efficient services in the market segments best served by rail:

- High-density, heavy-haul freight operations for bulk commodities.
- Containerized intermodal services for general merchandise freight.
- Specialized commodities like automobiles.

Efforts to boost the long-term viability of rail face many obstacles, not the least of which is the paucity of land to develop large intermodal facilities in and around cities, especially port cities. The operational sustainability of the system again clashes with issues of economic and social sustainability. Buying and developing land for intermodal facilities is a substantial investment of financial and political capital. Public assistance is generally needed to claim land by eminent domain and make the necessary infrastructure investments. Citizens in many cities resist new freight facilities because of the air pollution, noise, and congestion they generate. Opponents can cite a variety of other land uses that pay more visible dividends to city dwellers than freight facilities.

Operational Sustainability: Key Issues and Challenges

From this overview of freight mobility, we can identify the following issues and challenges:

- Can we maintain urban and regional freight mobility in areas of increasing congestion? To what extent will political pressure favor auto over truck mobility? Can we design better ways to move freight in cities? A starting point would be to build cleaner and more fuel-efficient trucks for urban areas.
- How can we promote rationalization of the rail industry to reflect a proper balance between and coordination among rail and trucking operations? One step would be to secure adequate amounts of land and build better intermodal systems for moving containers and trailers.
- We need to build more modern, heavy-haul rail corridors, and to develop modern highway systems that allow effective use of heavy trucks, perhaps by isolating trucks in their own lanes or highways. Both steps would reduce highway congestion and increase the safety and comfort of auto drivers.

These issues are large and complex. Their resolution would require substantial amounts of financial and political capital, and involve a great deal of institutional and public effort. Solutions would also have substantial impacts on the surrounding social and natural environments. These impacts are the subject of our next section.

Environmental and Social Concerns Related to Freight Transport

Energy use and CO_2 emissions. Freight is the "elephant in the corner" in energy-use and carbon-emissions debates. Overlooked in most public discussions, freight transportation is responsible for 43% of both items. Outside the OECD, trucks consume twice as much energy as light-duty and passenger vehicles (UN 2000). And the amount of freight that is carried on rail and domestic waterborne transport, the two means of freight transportation that use the least energy, is steadily declining worldwide. Overall, ocean freight accounts for approximately 6% of transportation fuel use and transport-related carbon-dioxide emissions.

Energy use in the freight industry is driven by the combined effect of two strong economic forces: cutting costs and increasing speeds. Reduction in transport cost is the dominant consideration for the vast majority of the tonnage that is shipped. The most powerful technological trend in cost reduction is the growth of larger, more efficient vehicles that are managed more effectively over wider networks. Per unit of freight carried, larger vehicles are inherently cheaper, lighter, and more energy-efficient. With larger vehicles, crew costs decline, line and terminal capacity increases, and the number of trips required to move the same volume of freight declines. This is true both across modes — trains have larger capacities and are more fuel-efficient than trucks, and barges more so than either — and for alternative choices available within a single mode.

Larger trucks are significantly more energy-efficient than smaller trucks, and the emergence of bigger trucks is clear, at least on American highways. Between 1977 and 1992, the largest trucks (Class 8 trucks, with average gross vehicle weights of more than 15,000 kilograms) grew from 29% to 41% of the total US medium and heavy truck fleets. And Class 8 trucks used 74% of the fuel used by trucks in Classes 3-8 (WEC 1998). The impetus to use larger vehicles is strong: although the main intent is not necessarily to reduce energy costs, that is the result. The long-term trend is to reduce the energy requirements per ton transported, for each mode and for each type of service.

Significant countervailing forces also exist, however. For more highly valued commodities, trip time and reliability are critical. The desire for speed, in particular, is driven by the possibility of reaching new markets for perishables, reducing inventory costs for highly valued commodities, and simplifying supply chains. This force tends to shift some freight toward smaller, more frequent shipments using the faster modes, from barge to rail, from rail to truck, from large trucks to small trucks, and from surface transport to air freight. Unlike the forces promoting cost reduction, this trend increases energy consumption and dependence upon oil.

These opposing trends are both evident today. Improvements in engines and in vehicle design have reduced fuel consumption in trucks. Large tractor-trailer units hauling 20 tonnes of freight typically consume 40 to 50 liters per hundred kilometers of diesel fuel, and the best trucks may consume 30 to 35 liters per hundred kilometers. The use of larger, high-adhesion locomotives greatly improved fuel economy for heavy-haul railroads. At present, freight moving in large trucks, trains, barges, or ships does not consume a great deal of energy per tonne-kilometer shipped, because large, fully loaded, well maintained vehicles are reasonably fuel efficient. At the same time, the gains in efficiency are more than offset in aggregate by growth in demand and the shift to more energy-intensive modes. The result is an increased use of energy in freight transport.

At the urban and regional levels, the use of energy by freight varies with the nature of the demand and with geography and street patterns. For instance, choosing the appropriate size of truck for local movements often involves a trade-off between energy consumption and congestion: a medium-sized truck is likely to use less fuel and road space than two or three smaller trucks but is also less maneuverable. The location of warehouses, the location and size of truck terminals, and the number of specific sites that require service, all affect the nature of trucks that will be used. As the number of sites to be visited increases, multiple smaller trucks will be required, as there may not be time for a single larger truck to make all the deliveries. Thus, concentration of retail outlets allows larger trucks to make deliveries and reduces the truck movements within a region. In a society in which most people have automobiles, the burden of local freight distribution is shifted from the freight carriers using small trucks to consumers driving their cars.

Essentially, freight moves on systems that offer the most appropriate mix of speed and cost. Attempts to force or encourage greater use of the more energy-efficient modes will fail if the total logistics costs and business opportunities truly favor faster transport. When options that are more

Energy Use of Ocean Freight

In ocean shipping, vessel speed capability trends have mirrored trends in fuel prices, since, as is true for other vehicles, higher speed requires more fuel. For container ships, from the 1970s through the mid-1980s, as fuel prices generally increased, average speed of new vessels declined. From the mid-1980s onward, speeds have steadily increased (Drewry 1999) — a trend likely mirrored for other ship types. The higher speeds offer greater schedule flexibility — in addition, the larger ships require faster speeds to make up for the increased port time these ships require. The smallest container ships (1,000 to 1,200 tonnes) average between 36 to 51 tonnes of fuel per day, while the larger ones (2,900 to 3,100 tonnes) consume between 74 and 157 tonnes of fuel per day (Drewry 1999).

How Much Energy Does it Take to Get Cereal to the Breakfast Table?

Consider the energy consumed by freight transportation related to producing and delivering boxes of breakfast cereal to families in a developed world city. For simplicity, assume that there are three main freight movements between the farm, the local grain elevator, the production plant, and the supermarket. We can estimate the fuel consumed by each leg of the move using typical trip lengths, vehicles, and fuel efficiency:

> Movement of grain in 10-tonne truckloads from the farm to a local grain elevator (50 km @ 3.4 km per liter for the truck => 15 liters for the trip or 1.5 liters per tonne).
>
> Movement of the grain in 90-tonne hopper cars from the grain elevator to a production facility (750 km @ 5 liters/1000 net tonne-kilometers => 3.9 liters per tonne).
>
> Movement of the grain in 20-tonne truckloads from the production plant 75 kilometers to a local supermarket (75 km @ 2.1 km per liter => 1.8 liters per tonne).

If we assume that it takes a tonne of grain to make 2000 boxes of cereal and that grain is in fact the only component of the cereal, i.e. no sugar and no preservatives, we find that it will take about 7 liters of fuel to get 2000 boxes of cereal to the supermarket. Since cereal sells for about $3 per box, the entire shipment is worth $6,000 and the cost of the fuel is inconsequential, whether the cost is $0.5 or $3 per liter (or more).

After the cereal is delivered to the supermarket, many individual shoppers will buy it and bring it home. If 1,000 people go shopping by car, traveling an average roundtrip distance of six kilometers to the supermarket, and if they each buy two boxes of cereal and the cereal accounts for only 5% of what they buy, we can also estimate the fuel that they use to bring the cereal home:

> Bring the cereal home from the supermarket (1000 6-kilometer roundtrips at 8.5 km per liter => 6000 automobile-kilometers and 700 liters of fuel consumed, of which 35 liters are attributable to the cereal).

In this simplified case, the amount of fuel used by consumers in going to the store to pick up the groceries is five times as great as the fuel consumed by trucks and trains to get the groceries to the store. The 2000 boxes of cereal in this example required the equivalent of just 5 kilometers of travel in the farmers' trucks, 8.3 kilometers in the railroad's covered hopper, and 3.8 kilometers in the delivery truck, but 300 kilometers in the shoppers' automobiles. The forces that created the supermarket have created an extremely efficient system for moving goods to the stores, but at the time required an increase in personal travel to buy the goods.

This example could be repeated for countless commodities, from clothing to kitchen supplies to consumer electronics. Economies of scale in production allow mass production and national or global distribution that produce great savings for customers. Concentration of retail outlets eliminates the neighborhood stores, but allows further economies in distribution and storage for the retailer and access to a wider variety of products for the consumer. We are less likely to walk to the neighborhood markets, even if we have them, and we are more likely to drive to the mall, where we can buy whatever we want. Energy consumption and emissions related to freight transportation in most urban areas may be dominated by how we make our grocery trips.

energy-efficient can also compete on a cost or service basis, however, the market will respond quickly. A good example is the rapid growth in the use of double-stack container trains in North America; these efficient rail services attract traffic directly from the motor carriers because their cost is very attractive and their service acceptable.

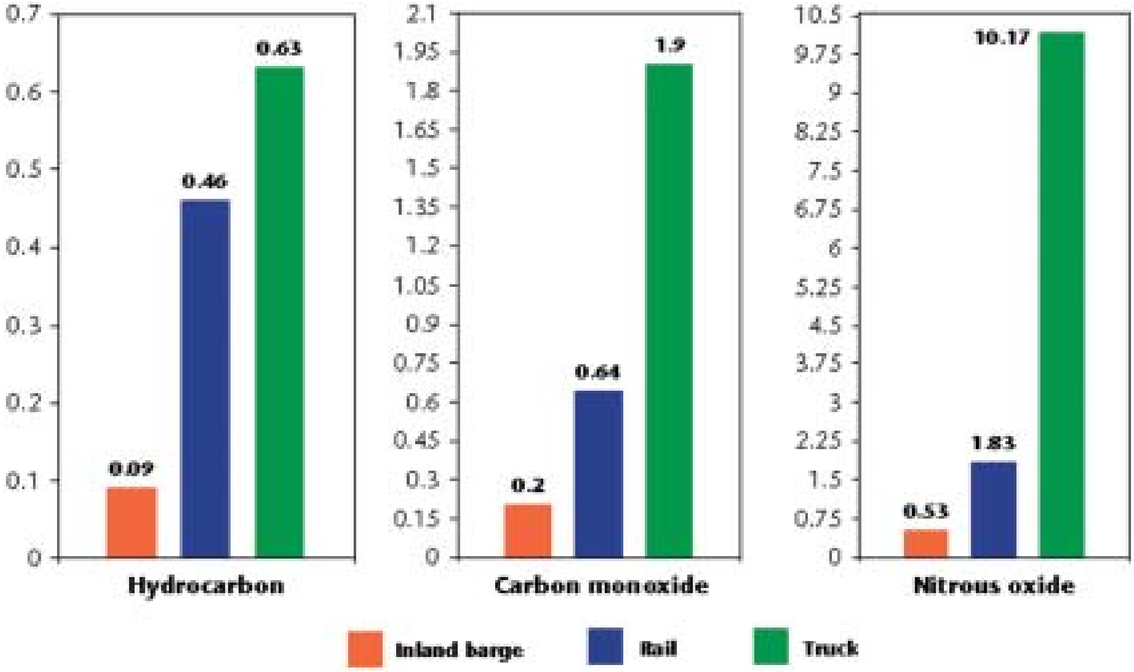
Air-quality impacts. The various freight modes have significantly different impacts on the local environment. Data from the United States (Figure 6-9) suggest that per unit of freight moved, trucks emit much more hydrocarbon, CO, or NO_X than either trains or barges. Once suitable channels exist, barges are significantly cleaner than either trains or trucks.

In general, heavy trucks account for a large share of certain elements of air pollution. Figure 6-10 illustrates results from a 1987 study of emissions in the Federal Republic of Germany. The total emissions in each category are shown as an index of 100. The middle bar in each cluster shows the contribution from traffic, including heavy vehicles (trucks and buses), automobiles, and light trucks. Transport is the major source for NO_X, hydrocarbons, and carbon monoxide. Heavy vehicles are most important in terms of NO_X and soot, accounting for close to 20% of the total emissions in each case. Newer trucks are cleaner, but a continuing problem is that many very old, poorly maintained trucks remain in service. Estimates from the American Trucking Association suggest that diesel-operated heavy-duty trucks and buses were responsible for 18.5% of all US NO_X emissions from mobile sources and for 27.5% of other particulate oxide emissions from mobile sources (ATA 1998).

The effects of trucks are particularly severe in urban environments. Analysis of air quality in Mexico City indicates that trucks, though constituting just over 10% of the vehicle fleet (Zegras et al. 2000), contribute between 35% (for carbon monoxide) and 81% (for PM_{10}) of all transport-related pollutants. (See Table 6-2).

In the United States, the Environmental Protection Agency recently released rules for implement-

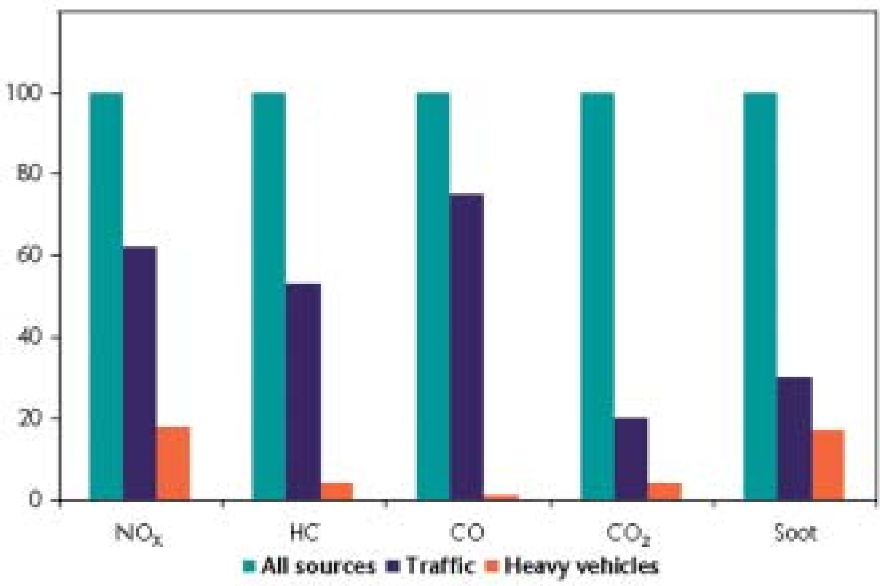
Figure 6-9. Pollutants produced in moving freight



Source: US EPA (1994).
Note: Pounds of pollutants produced by the movement of one ton (907 kg) of cargo 1000 miles (1610 km).

Figure 6-10. Importance of emissions from heavy trucks in Federal Republic of Germany, 1987

% contribution to total emissions



Source: Gorissen (1999).

Table 6-2. Transport contribution to total emissions — by vehicle type in Mexico City (1996)

	PM_{10}	SO_2	CO	NO_x	VOCs
Cars and pickups	2.3%	7.8%	43.9%	19.6%	12.7%
Colectivos	0.2%	1.0%	10.7%	3.7%	3.3%
Taxis	0.5%	1.8%	10.2%	4.6%	2.9%
Buses	1.8%	0.4%	0.2%	3.2%	0.3%
Trucks	20.8%	9.2%	34.3%	46.3%	13.5%
Transport share of total	25.7%	20.2%	99.3%	77.3%	32.8%
Trucks as % of total transport	81%	46%	35%	60%	41%

Source: CAM (1999).

ing more stringent controls for emissions from heavy-duty vehicles. The new standard calls for a 50% reduction in nitrous oxides, along with reductions in hydrocarbons from diesel trucks and buses. The EPA estimates the new standards will increase the purchase price of a truck by $803 (US EPA 2000b).

Big ships are more energy-efficient than trucks or trains, but they are also leading emitters of nitrogen, sulfur dioxide, and diesel particulate. Oil tankers, container and cargo carriers, and cruise ships typically run on bunker oil, the dirtiest and least expensive form of fuel. Bunker oil, the residue of high-grade fuels, contains high concentrations of toxic compounds banned from use in many other industries. The fuel is 5% sulfur and contains up to 5,000 times more sulfur than diesel fuel. According to the US Environmental Protection Agency, large vessels emit 273,000 tons of nitrogen oxide per year in the United States alone.

Overall, shipping contribution to total emissions remains relatively low—an estimated 4% to 6% of sulfur emissions (4.1 to 5.9 million tonnes per year), 7% to 14% of global nitrogen oxide emission (4.5 to 9 million tonnes per year), 1% to 3% of CFCs (2,700 to 5,400 tonnes), and 10% (272 to 363 tonnes) of halon emissions (IMO 1998b; Corbett and Fischbeck 1997). However, in 1997 a new Annex (VI) to MARPOL on air pollution prevention was added, partially due to increasing concern about emissions close to population centers (i.e., at ports) and in area's of dense ship traffic (i.e., the English Channel, the South China Sea, and the Strait of Malacca). When it comes into force, Annex VI will set limits on sulfur and nitrogen oxide emissions (including 4.5% m/m on the sulfur content of fuel oil) and prohibit the deliberate release of ozone-depleting substances. The Annex also allows for the establishment of special "SO_X Emission Control Areas" where the sulfur content of fuel oil used on ships must not exceed 1.5% m/m (alternatively, ships may adopt other technologies to limit SO_X emissions). Currently, the protocol designates the Baltic Sea Area as a SO_X Emission Control Area.

Social and environmental disruption to communities. The expansion of highway or railway networks can bring substantial economic opportunities to a region. Yet they also cause significant disruptions of natural and social environments. The disruptions vary in effect and magnitude depending on the previous condition of the region. The expansion of a highway around an already bustling city will have much less effect than building a new highway through a formerly pristine rain forest. Construction of a highway inevitably involves degradation and division of ecosystems, runoff, and other pollutants, and the resulting traffic produces substantial amounts of noise and air pollution. Highways and railways not only facilitate economic development at their end points, but also lead to peripheral economic development along their fringes, which can have further deleterious effects on the environment.

Similarly, human populations differ in their ability to absorb and manage the arrival of traffic and freight. Communities with agriculture and retail businesses may welcome new roads and rail lines, and the opportunities they offer to access new markets and new products. Communities that are more nomadic, or that survive by subsistence farming, may oppose freight infrastructure for the disruption it brings to their ecosystems.

An issue of considerable complexity is the role of freight in extractive industries that do little to add enduring value to the regions that host them. Freight transportation is not the cause of these activities, but it does enable them to exist. Examples include Africa, which has never had a transcontinental rail system. Rather, railroads developed to serve mines and other inland economic endeavors and deliver their products to ocean ports. Similarly, Western timber, mining, and energy companies developed freight roads into the rain forests of Latin America and Indonesia to extract the valuable resources in those regions. These industries and the freight infrastructure they build can cause tremendous

Freight and Environmental Trade-offs

Understanding the sustainability concerns related to freight transport requires an examination of trade-offs between different kinds of environmental and social disruption.

For instance, large commercial barges are among the most energy-efficient forms of transportation, and are widely favored for their ability to move large commodity shipments off roads and highways, thus reducing congestion, air pollution, and potential for accidents and noise. Nonetheless, their use can cause damage to the rivers and canals they travel, and in particular, they often require extremely disruptive damming and dredging operations in order to make waterways navigable.

Similarly, if a freight link is being added to a pristine virgin environment, air transport — being completely localized in its impact — can be much less disruptive to the local environment than a road or railroad. However, air is much more expensive and also much less energy-efficient. There are similar trade-offs in the choice of materials. For instance, rail ties treated with creosote cannot be recycled. One suggested alternative is the use of tropical hardwoods used to make very durable ties, avoiding the use of creosote. However, that promotes logging in tropical rain forests, which is often not an acceptable alternative.

Clearly, there are also important trade-offs with efficiency. Barges are slower than trains, and trains are slower than trucks. Trucks are the most energy-intensive of the three alternatives as well as the most polluting. They are also the most flexible, however, and offer a level of service significantly superior to that of trains and barges for the movement of many manufactured goods.

disruptions to the natural and social environments they enter. Moreover, it is unclear what long-term value or reward the majority of the inhabitants of those regions reap from hosting these activities, all of which are non-renewable and face resource depletion end dates. Some industries manage the social and environmental impacts of their operations better than others. Unfortunately, the poorly managed ones generate the most attention and have the greatest effect on public opinion regarding future operations.

Building infrastructure in developing regions often has unintended effects and consequences. For instance, a road built to accommodate timber companies may open a region to small farmers or ranchers who frequently engage in unsustainable agricultural practices.

As a result of such complex, often unintended consequences, plans for new transportation networks in remote regions often trade off likely economic benefits versus the environmental effects of (1) construction of the new link, (2) disruption or destruction of particularly important environments, (3) the fragmentation of the natural environment, and (4) the attraction of further development along the right-of-way. The first three issues also arise with the construction of pipelines in remote areas, where habitat destruction and interference with species' migration patterns are also concerns.

Environmental concerns related to domestic waterborne transport. Although barges on inland waterways are very fuel-efficient and low-emission modes of freight transport, the engineering projects required to make a river navigable and swift for commercial barges — the dredging and dams, levees, and locks — all have disruptive effects on a river's ecosystem and species. Perhaps the most notable effect is that eliminating thousands of acres of wetlands and marshes along a river's bank can make a river flow faster and straighter, but also leave the surrounding areas vulnerable to flooding.

Environmental concerns related to ocean shipping. Ocean shipping raises some of the same concerns as inland navigation: to facilitate the loading and unloading of large ships, ports often need to be dredged, causing significant disruption of the ambient ecosystem. However, the most high-profile and visible environmental concerns related to ocean shipping are the possibility of oil tanker accidents in the ocean.

The ultimate environmental impacts of shipping revolve around the major trade networks, which themselves overlay across a variety of ecosystems (marine and coastal). The environmental risk depends on the ecosystem — i.e., polar/subpolar, temperate, tropical/subtropical. For example, oil does not easily break down in polar areas or in fragile tropical environments (i.e., coastal mangroves, coral reefs), while in temperate areas — with greater variability in weather — the problem is less severe. The overall risk is proportional to traffic density and is thus highest in places like the southern North Sea and in approaches to major ports (Smith 1995).

The high-profile Torrey Canyon disaster, which spilled 120,000 barrels of oil into the seas off the British coast in 1967, created the momentum for the first major international convention to deal with shipping's environmental problems. By 1973, the International Maritime Organization (IMO) adopted the International Convention for the Prevention of Pollution from Ships, which was modified by protocol in 1978 and today is commonly known as MARPOL 73/78. As additional environmental concerns from shipping have become apparent MARPOL has been amended through several annexes, some of which are not yet in force (annexes come into force when they have been accepted by at least 15 states accounting for not less than 50% of world merchant shipping tonnage).

While major oil spills continue to garner the most attention related to oil pollution in the seas, the most common source of oil pollution is during normal operations — as much as 92% of oil that enters the sea does so as a result of cleaning of cargo residues and during loading and discharge (IMO 1998a). Nonetheless, the tragedy of major oil spills due to tanker accidents continues to be a concern. The current timetable targets the elimination of most single-hull oil tankers by 2015; since 1996, all new oil tankers must be built with double hulls. Evidence suggests significant progress already. The number of major oil spills fell from 36 recorded in 1979 to an average of around eight per year in the 1980s. In 1994, approximately 71,000 tonnes of oil spilled into the sea due to tanker accidents — 60% of the average (IMO 1996).

Concerning water pollution, the IMO (1997) estimates that ships and maritime transportation accounts for about 22% of the wastes dumped into the sea each year. Ship dumping can have considerable local impacts, since such activity is typically concentrated in specific marine areas of high transit.

Of growing concern is the transport of ballast water (used to provide balance for empty vessels). An estimated 11 billion tonnes of ballast water is transferred around the world each year, carrying at any one time some 4,500 marine species and introducing a marine species to a new environment every nine weeks (Pughiuc 2001). The IMO is currently drafting regulations covering ballast water as well as addressing the use of anti-fouling paints on ship hulls.

Another major environmental effect arises from dredging, the majority of which occurs to keep harbors, rivers, and other waterways open for passage. Dredging accounts for some 80% to 90% of all material dumped at sea, and approximately 10% of dredged material contains heavy concentrations of toxic metals, petroleum compounds, and pesticides (IMO 1997). Noise pollution related to maritime activity is also a concern. Shipping is the largest source of low-frequency, underwater noise, with noise levels increasing proportional to ship size, speed, and load. On busy sea lanes, continuous noise levels can be serious, and dredging can also be an important noise source. The ultimate ecosystem and species effects are not well known, however (Dotinga and Elferink 2000). The IMO has not apparently been active on this front, and there are not widespread experiences with options to address aquatic noise acoustic pollution. One option in particularly sensitive areas is the establishment of marine protected areas (MPAs) — wholly or partially banning navigation from certain areas — although history has seen that freedom of navigation has received priority over environmental concerns in the use of MPAs (Spadi 2001).

For ports and harbors, recent research suggests that the priority issues for management have been water quality, dredging, port development, dust, and noise (Wooldridge et al. 1999). As noted above in connection with the discussion of infrastructure issues, competition for alternative uses of land in urban-area ports will certainly be a major issue with ongoing growth in shipping; for the development of new ports, concerns over ecosystem effects will also prove to be a point of serious contention (see, for example, Kendra 1997).

Safety. The transportation of freight is associated with a variety of safety concerns. For example, although shipping safety has certainly increased over time, accidents, particularly sinkings, continue to pose a threat to those working on ships. An estimated 1,100 lives are lost at sea each year due to maritime disasters, with a comparable number dying due to other causes (i.e., on-board accidents, etc.) (Nielsen and Roberts 1999). The threat generally, but not always, grows with the age of the fleet. For example, according to the IMO (1999), bulk carriers' safety record began deteriorating in the 1990s — from 1990 to the middle of 1997, 99 bulk carriers sank, killing 654 people. The age of ships, and subsequent structural failure, particularly in heavy weather, is a major cause. And, while regulations and standards can help, they often result in a shifting of aged vessels from routes with strict inspections to those where regulations are not as rigorously enforced (IMO 1999).

Recent analysis of container ship incidents (Wang and Foinikis 2001) indicates that these account for about 7% of total oceangoing incidents. Unlike incidents for most other ship types, container ships suffer from a high share of incidents caused by shore error, which results in a significant share of cargo damage effects. Also, in contrast to other ship types, available data suggests that younger container ships have a higher incident rate — a rate that decreases with age. This may be due to crew and shore personnel accustoming themselves to new designs.

Railroad accidents, especially accidents involving hazardous cargo, are a concern in many places. Much hazardous cargo that might otherwise move by truck moves by rail because of the generally good safety record of the railroads. However, when a derailment does occur, significant volumes of hazardous material may be involved.

Although the media often sensationalize the danger of freight trucks, trucking is a dangerous profession and the fatalities to drivers and auto passengers are rising as more trucks come into service. In the United States in 1999 there were 758 large truck-occupant fatalities (US DOT NHTSA 1999b). Public concern over large trucks, especially those hauling two trailers, is one of the chief obstacles to the expansion of their use.

The principal cause of truck accidents is driver fatigue, a problem that governments and industry associations seek to curb with rules on length of trips and required hours of rest. However, such rules are hard to enforce effectively, and oftentimes fatigue-related accidents are associated with a violation of the rules.

CONCLUSIONS

The image of a tired trucker driving on a crowded highway is a fitting one to conclude our discussion of sustainable mobility and freight transportation. Trucks are the key vehicles that carry goods to and from their end users and link them to the other parts of the freight network. Trucks symbolize the economic and operational efficiency of freight transportation in 2000. Their flexibility enables trucks to penetrate the most remote jungles and, via a port and an ocean tanker, deliver goods directly to a consumer's doorstep. That capability allows trucks to take market share from rail and barges, their slower, but more energy-efficient competitors. Yet the ubiquitous service that truck drivers provide also puts them in the greatest contact with other citizens. Trucks create many of freight's hurdles to sustainable mobility, bringing in their wake air pollution, accidents, congestion, noise, and environmental and infrastructure degradation, and public protests of all of these problems.

Potential solutions for the problems generated by trucks demonstrate the financial, political, and technological hurdles to sustainable mobility throughout the freight system. More heavy-haul rail lines can be built, connecting more intermodal freight facilities, so that cargoes can move on railways, trucks, or ocean tankers as appropriate. Second, new routes for trucks — either isolated express lanes or entirely new roads — can be built. And third, quieter, more fuel-efficient, less-polluting trucks can be brought to market. Any one of these solutions would require substantial investments of money to achieve. Quite apart from the investment required, community and public concerns related to potential loss of land will need to be addressed, particularly where scarce urban space is involved. In many parts of the developing world, national freight networks are relatively immature, although more severe problems of a paucity of urban land and a lack of financing pose high hurdles. Russia, China, and India all face the prospect of massive transitions from rail-based to truck-based freight. There is much to learn from the experiences of the developed world in this context.

seven

world mobility and the challenge to its sustainability

Both personal and freight mobility is at an unprecedented level for the great majority of the population in the developed world. However, personal mobility varies significantly by age, income, and location. In contrast, most of the citizens of the developing world suffer either from poor or deteriorating mobility. The central problem is that cities in the developing world are growing and motorizing very rapidly. In order to achieve sustainable mobility by the middle of the 21st century, at least seven mobility-related “grand challenges” will have to be overcome. Moreover, an additional challenge going beyond mobility — the creation of the institutional capability able to taking on such “grand challenges” — will have to be faced. Indeed, the limited capability of the world’s institutions to deal with the sort of long-term, complex problems reflected in the “grand challenges” may turn out to be the greatest obstacle of all to achieving sustainable mobility.

At the beginning of this report, we observed that in most cases, mobility is not an end in itself but rather a means to an end — by overcoming distance, mobility makes people and goods more accessible. It can offer every citizen access to employment, education, health care, leisure activities with family and friends, and all the other economic, social, and cultural opportunities that can enrich modern life. We identified a number of measures that might be used as benchmarks in judging how well the world’s mobility systems are fostering accessibility. Then we reviewed the performance of the world’s current mobility systems, using our benchmarks in Chapters 2 through 6 to assess worldwide mobility and the challenges we face in sustaining it. This chapter summarizes the condition of mobility in the developed and developing world at the end of the twentieth century.

IN THE DEVELOPED WORLD

Personal mobility is at its highest level for the great majority of developed-world populations, but mobility (and accessibility in general) varies significantly by age, income, and location. High levels of freight mobility are providing residents of the developed world with an unprecedented degree of choice among goods and services. Light-duty vehicles (automobiles and light trucks) are the major providers of personal mobility, not merely in North America but in Europe and developed Asia. The number of light-duty vehicles per capita and the annual per-capita use of these vehicles continue to grow.

The share of developed-world population living in urban areas is high and increasing, albeit slowly. In 1975, the level of urbanization in the developed world was 70%; by 2000 it exceeded 75%, and is projected to reach nearly 85% by 2030 (UN 2001). At the same time, population density is declining in and around the cities of most developed countries. In Chapter 3 our data showed population density trends (measured as persons per square kilometer) for 15 major developed-world urban areas in Europe, North America, Japan, and Australia. Over the 30-year period from 1960 to 1990, population density fell in all of those 15 areas. Seven urban areas — Amsterdam, Copenhagen, Frankfurt, Hamburg, London, Paris, and Washington — experienced declines in population density of 30% or greater. These contrasting trends of cities growing larger, but at reduced densities, can be directly traced to two related causes. First, the widespread availability and growing use of the automobile, and second, the growth of suburbs around cities that are created for, and dependent on, automobile-driving residents.

Suburbs and low-density urban areas work against “conventional” public transport by reducing the number of “high volume” origin and destination pairs. The consequent reduced availability of public transport disadvantages individuals who do not have access to automobiles because of low income or age.

Road construction has not kept pace with travel growth — indeed, there are serious doubts that it could or even should do so. Congestion might not be as bad as those who are directly affected perceive it to be, but by virtually any measure, it is growing. In some major urban areas, congestion is no longer confined to traditional peak commuting periods; it extends through much of the day.

An extraordinarily high share (96%) of developed-world transportation depends on petroleum-based fuels. Developed-world transport energy demand accounts for about 65% of total world transportation energy demand.

Vehicle-related emissions of pollutants that contribute to adverse impacts on public health have stabilized and are declining in many developed countries. Public policy — principally lower vehicle emissions standards aided by technological improvements in fuels — has enabled major reductions in emissions per vehicle-mile. Slow fleet turnover and increased vehicle use have caused actual in-use emissions reductions to be lower than the technological improvements might suggest.

In contrast, transportation-related emissions of pollutants that contribute to global warming are increasing in virtually all developed countries. The improvements in energy efficiency are more than offset by increases in the number of vehicles, by changes in vehicle mix, and by increases in vehicle use.

Air travel is growing rapidly throughout the developed world, especially in North America. Even though load factors (the percentage of seats filled) have been rising, the average size of aircraft used in commercial service has been declining for at least the past decade. The increased use of smaller aircraft, combined with the growth of air travel, has offset technological improvements in energy efficiency. Energy use in air travel has grown at rates substantially higher than the rates of growth in the use of other transportation fuels, a trend projected to continue. According to the US Energy Information Agency, developed-country fuel use for air transportation will grow at twice the rate of fuel use for road transportation over the next couple of decades (3.0% per year versus 1.5% per year).

Air transportation’s contribution to air pollution is surprisingly large and growing. Airports are major local sources of emissions of “conventional” pollutants, which come not only from idling aircraft engines, but also from passenger ground traffic and from the freight, fuel, and maintenance vehicles that support an airport’s operations. In addition, airliners emit various substances, including carbon dioxide, at high altitude, which significantly magnifies the global warming potential of these emissions.

Air transportation is now a crucial means of travel between cities of the developed world, but capacity constraints relating both to airports and to airways are beginning to result in growing delays, especially in the “core” of Western Europe and the triangle formed by Chicago-Boston-Washington in the United States. Yet the obstacles to air travel, such as congested airports and the difficulty of building new runways or new airports, and the air pollution that results from air travel, are relatively neglected. Substantial attention is devoted to achieving reductions in aircraft noise. Technological improvements make new planes quieter, and in some cases older planes have been retrofitted to reduce their noise levels.

High-speed rail is making inroads against both air travel and the automobile in some markets. It is especially popular in high-density, shorter-haul intercity markets in Japan and Europe, and additional high-speed rail tracks and trains are being built in both regions. Interest in high-speed rail is growing in the United States, but it is still much too early to determine whether this increased interest will translate into high-speed train systems actually being built, and their being popular enough to make a measurable difference in US intercity transportation patterns.

Freight systems are moving larger and larger quantities of goods both within the developed world and between the developing world and the developed world. Containerized systems are replacing traditional "breakbulk" systems, especially for international and longer-haul domestic freight movements. The most efficient method for moving freight long distances over land is high-capacity, heavy-haul rail. Such systems are not common outside North America, however, and as a result, more and more developed-country freight is being transported by truck.

Developed-country freight systems consume a large and growing share of transportation energy. Excluding maritime, freight energy demand constituted 26% of total developed-country transportation energy demand in 1995; this is projected to rise to nearly 30% by 2020.

Competition is growing between freight and passenger systems for access to existing infrastructure (both highways and rail) and for the financial resources necessary to build and upgrade infrastructure.

A Developed-World Sustainability Scorecard

Figure 7-1 shows how the developed world performs according to the sustainability measures that were defined in Chapter 1. The measures are not ranked in order of importance. For each of them, we use a color key to show what we consider to be the performance of the developed world as a whole. Some areas of the developed world clearly perform better than others, but we do not attempt to differentiate. The figure also shows performance trends in each of the measures.

IN THE DEVELOPING WORLD

Most of the citizens of the developing world suffer from poor and/or deteriorating mobility conditions. The central problem is that cities of the developing world are growing and motorizing very rapidly. They have not had the time or the money to build new infrastructure or to adapt to new mobility technologies. The cities house and transport too many people, on insufficient numbers of poorly maintained roads and rails, and generally lack the money and institutional vigor to fix the problems.

In 1950, less than 30% of the world's population dwelt in urbanized areas. By 2005, that share will be 50%, and most of this increase is occurring in the developing world. "Megacities" of more than 10 million people are now a defining characteristic of the developing world. In 2000, 15 of the 19 megacities were in developing nations. By 2015, 18 of the 23 megacities will be in the developing world.

Population density trends in and around the cities of the developing world are not as unambiguous as in the developed world. Of six large urban areas in Asia — Hong Kong, Jakarta, Kuala Lumpur, Manila, Singapore, and Surabaya — three of them — Hong Kong, Kuala Lumpur, and Manila — show steady declines in population density over a 30-year period. Two of the remaining three — Jakarta and Surabaya — show declines over the 1980–1990 period. Only Singapore experienced an increase between 1980 and 1990, though its population density in 1990 was still below the levels of 1960 and 1970 (Demographia 2001).

In many developing countries, motorization rates (as measured by the number of vehicles per thousand persons) are still low compared to the developed world, but they are growing rapidly. Motorization rates are at the levels typical of Europe in the 1950s and 1960s and are growing at similar rates.

The majority of individuals in the developing world are unable to afford automobiles, and public transport remains their principal means of motorized mobility. Unfortunately, public transport systems are struggling to keep up with growing demand and to maintain service levels as they compete for space with autos and trucks. Congestion caused by the rapidly growing number of private automobiles, various forms of "official" and "unofficial" public transport vehicles, and freight-carrying trucks is causing gridlock conditions in many cities of the developing world. Congestion on the streets, combined with land-use and real-estate patterns that push low-income residents to the physical margins of their cities, disproportionately affects poor people. In addition, congestion, poor driving habits, and inadequate traffic controls make the search for mobility a hazardous endeavor; traffic fatalities and accidents are a serious public health issue in many cities of the developing world.

In contrast to the situation in the developed world, emissions of pollutants that contribute to public health problems are growing in the developing world. The ambient levels of these pollutants exceed — often by several times — their levels in developed-world cities because of several interrelated factors. The extremely rapid growth in the number of motor vehicles, the slow turnover of motor vehicle fleets, poor-quality fuel, lags in adopting advanced vehicle pollution control technologies, and poor vehicle maintenance all contribute to the environmental problems.

Transportation services are fueling a rapid rise in the developing world's use of petroleum. Total developing-world energy consumption for transportation grew from seven million barrels per day (oil-equivalent) in 1990, to 11 million barrels per day in 1999. It is projected to reach 23 million barrels per day in 2015. This means that the developing world's share of total worldwide transportation energy use rose from 33% in 1990 to 34% in 1999, and is projected to reach 44% in 2015 (EIA 2001).1 Transport-related greenhouse gas emissions in the developing world are growing even more rapidly as a share of the total.

Transportation infrastructure in the developing world is inadequate and suffers from lack of maintenance. For example, China has a road infrastructure of about one million kilometers, but most of this infrastructure is two-lane, with marked side paths for bicycles and tractors. Only about 6,000 kilometers can be considered "highway" as that term is conventionally understood in the developed world. China's rail system, though extensive in size, has been compared in scope (Alberts et al. 1997) to that of the United States at the time of the Civil War.

The construction and maintenance of roads, bridges, and railways are swamped by the growth in mobility demand. Air transportation demand growth is projected to be greatest in the developing world, yet construction of the airports to support this growth is lagging. Developing-world freight-transportation systems are heavily dependent on trucks except in the few countries with extensive rail networks, chiefly China, India, and Russia. However, these aging rail networks often are poorly positioned to serve the present freight transportation needs of their countries.

A Developing-World Sustainability Scorecard

Figure 7-2 shows how the developing world is performing with regard to the measures of sustainable mobility proposed in Chapter 1, and what the trends are.

MAJOR CHALLENGES TO ACHIEVING SUSTAINABLE MOBILITY

With Respect to Light-Duty, Personal-Use, Privately Owned Motor Vehicles

The developed world relies on personally owned, light-duty vehicles as its principal source of personal mobility in most urbanized areas, and especially in their suburban fringes. One major (perhaps even *the* major) challenge to sustainable mobility in the developed world is somehow to preserve the desirable characteristics of automobile-based systems while reducing (or, preferably, eliminating) their nonsustainable characteristics, which include:

- The adverse consequences of automobility for certain groups in society (especially the poor and the elderly) who often cannot obtain access to essential aspects of life: work, school, doctors, stores, friends, and relatives. In the case of the poor, loss of access to employment opportunities is a particular concern. Meeting this challenge will probably require either reversing the declining competitiveness of "conventional" forms of public transport as urban densities fall or, more likely, developing new and more appropriate "unconventional" public transport alternatives.

- The light-duty vehicle's contribution to various environmental and ecological problems. These range from emission of substances responsible for global climate change, to emissions of pollutants responsible for local or regional public health problems, to the effect of light-duty vehicles on other environmental and ecological problems such as water pollution and the destruction of habitats. Of these issues, the most difficult is likely to be global climate change. Although improvements in the energy efficiency of individual automobiles are certainly possible, achieving major and durable reductions in greenhouse-gas emissions from the developed world's light-duty vehicle fleet will probably require an eventual shift away from carbon-based fuels.

- The automobile's significant contribution to death and injury of occupants and pedestrians in motor vehicle accidents. Although the death rate per unit of exposure is down in almost all developed countries — and sharply down in some — the aging of developed-country populations will cause an increase in light-duty vehicle accidents and deaths. Much more attention will have to be paid to the particular requirements of elderly drivers, passengers, and pedestrians.

- The automobile's contribution to congestion in many of the developed world's urban areas. Although highway infrastructure needs to be increased and better maintained, it is not possible to "build our way out of congestion." Vehicles are going to have to use roads more efficiently. This may mean the widespread use of intelligent transportation systems that provide drivers with better information and permit more vehicles to occupy a given amount of space safely. It may also mean the widespread use of congestion charges or other means of pricing the use of infrastructure.

The sustainability challenges relating to light-duty vehicles in the developing world differ both in kind and in magnitude from those in the developed world. These challenges generally stem from the speed with which motorization is occurring in many developing countries.

Figure 7.1 Sustainability scorecard — developed world

	Level	Direction
Measures to be increased		
Access to means of personal mobility		+
Equity in access		–
Appropriate mobility infrastructure		–
Inexpensive freight transportation		+
Measures to be reduced		
Congestion		–
“Conventional” emissions		+
Greenhouse gas emissions		–
Transportation noise		+
Other environmental impacts		–
Disruption of communities		–
Transportation-related accidents		+
Transportations’ demand for nonrenewable energy		=
Transportation-related solid waste		+

Figure 7.2 Sustainability scorecard — developing world

	Level	Direction
Measures to be increased		
Access to means of mobility		+
Equity in access		?
Appropriate mobility infrastructure		–
Inexpensive freight transportation		+
Measures to be reduced		
Congestion		–
“Conventional” emissions		–
Greenhouse gas emissions		–
Transportation noise		–
Other environmental impacts		–
Disruption of communities		–
Transportation-related accidents		–
Transportations’ demand for nonrenewable energy		=
Transportation-related solid waste		?

Key:

- (black) the particular measure is at an unacceptable and/or dangerous level
- (medium blue) the level is of concern and needs improvement
- (light blue) the level is acceptable or shows signs of becoming so
- \+ indicates that the situation appears to be moving in the desired direction
- – suggests that the situation appears to be deteriorating
- = no clear direction is apparent
- ? available information is not enough to make a judgment

- Motorization in developing countries is permitting both urbanization and suburbanization. This tends to exacerbate the gap between the poor and the growing middle classes of these countries, with the latter gaining better access to jobs and other amenities because of their growing incomes. As in the developed world, motorization and suburbanization tend to undercut the viability of "conventional" public transport systems; more than in the developed world, "unconventional" forms of public transport have been springing up. The degree of reliance on public transport by the poor and the less wealthy in developing countries, however, means that the loss of competitiveness of public transport is an even greater burden in this part of the world. Although the age structure of the population in most developing countries is quite different from that in developed countries, with younger people constituting a much larger share, the number of poor and elderly means that declining accessibility likely puts even greater strains on urban life in developing countries. Those who are both poor and old find the situation especially difficult.

- The environmental challenges to light-duty vehicle sustainability are of a different order. In contrast to the situation in many developed-world countries, emissions of "conventional" pollutants from light-duty vehicles are increasing, sometimes rapidly so, in developing countries. Pollution concentrations of ozone, sulfur oxides, nitrogen oxides, particulates, and even lead are at very high levels and are rising in many developing-world cities. The construction of roads to accommodate the growing number of light-duty and commercial vehicles may well be contributing more to water pollution and to the destruction of habitat in the developing world than in the developed world. Also, because the total number of vehicles in the developing world is lower than in the developed world, greenhouse-gas emissions from light-duty vehicles in developing-world countries are not now nearly as large as in developed countries. But the rapid growth of the light-duty vehicle fleet, if maintained into the future, is threatening to change that picture drastically. Carbon emissions from transportation in the developing world (largely reflecting light-duty vehicle carbon emissions) are projected to equal carbon emissions from transportation in the developed world by about 2015 (EIA 2001, p. 185). To the extent that in-use energy efficiencies of developing-world, light-duty vehicles lag those in the developed world, this crossover could occur sooner.

- The level of traffic-related accidents and deaths is substantial and, in many places, on the rise. Though occupant-restraint systems are sometimes installed in vehicles, they are not widely used. The vehicles themselves are less crashworthy than those in developed countries. Roadside obstructions are much more prevalent, and often much less forgiving when struck. Pedestrians and bicyclists are particularly at risk, especially when they must share the road with cars, buses, and trucks.

- Congestion levels have become legendary in many developing countries, especially in Latin America and in developing Asia. The lack of highway infrastructure is acute, and poor maintenance of existing highway infrastructure contributes to congestion problems. The cost of intelligent transportation systems is likely beyond the reach of most developing countries, so this congestion remedy may have much less to contribute here. But congestion pricing mechanisms might find wide application in the developing world.

With Respect to Passenger Rail Systems

Although these systems — especially the newer, higher-speed systems in Europe and Japan — are attracting greater numbers of passengers, the economic sustainability of rail passenger systems remains a major concern. One can make the case that the social benefits of rail systems partially (or even fully) pay back the deficit between their revenues and their costs, but this is open to dispute. In any event, rail passenger systems around the world typically run substantial deficits, representing a drain on the budgets of the governments that support them.

- While rail passenger systems, if sufficiently patronized, emit far fewer "conventional" pollutants and greenhouse gases per passenger-kilometer than do other means of intercity passenger transportation, they are not necessarily environmentally benign. If they are powered by electricity, and if that electricity is generated by methods other than hydro or nuclear power, passenger rail systems are responsible for some level of greenhouse-gas emissions. All rail systems also generate emissions of nitrogen oxides, sulfur oxides, and particulates. Also, the construction of railways, like the construction of roads and airports, may involve the destruction of habitats and generate water pollution.

- Rail stations are usually located in central cities, and when their tracks are not underground, they may be major sources of noise and may divide communities physically. In addition, rail terminals need to accommodate large numbers of people, and they often cause significant traffic congestion in their immediate locale. Though rail terminals are often tied in to existing public transportation systems, such as subways, the declining competitiveness of these existing public transportation systems means that they serve less well to connect railroads with prospective passengers.

- Locating new passenger rail routes and terminals is in itself a major challenge. These systems require approximately as much land for their rights-of-way as do limited-access expressways. If they use high-speed equipment, they have less flexibility in their routing than do expressways — they cannot tolerate significant grades or sharp turns. If electrified, the overhead wires and support posts are considered unsightly, and their speed and relative silence of operation cause safety concerns in the communities through which they pass.

- Where new and dedicated passenger rail routes cannot be built, passenger trains must share the track with freight trains. In some countries, where the share of freight moved by rail is quite small, this may not present much of a problem. However, passenger trains' near-exclusive use of these rights-of-way severely limits the extent to which these countries can shift freight from their roads to rail. In other countries, such as the United States, the problem of coordinating freight, intercity passenger rail, and commuter rail is already quite significant and is growing more so.

With Respect to Air Travel

This mode of transportation may be strangled by its own success. In the developed world, many airports already exceed capacity, and delays are increasing. Air traffic control systems are heavily overloaded and, in some areas, are burdened with outmoded, productivity-draining jurisdictional arrangements. Opposition to the expansion of existing airports and the construction of new airports means that expanding the capacity of the air transportation system is likely to prove quite difficult. In the developing world, these challenges lie more in the future. Levels of air travel are quite low at present, but are projected to grow rapidly. Growth in air travel is viewed favorably by many governments and their populations, so siting airports seems to be less of a problem.

- The environmental challenges to the sustainability of air transportation relate to its growth and to the inherently poor energy efficiency of this mode. Air transportation presently accounts for about 11% of total transportation energy consumption. By 2015, this is projected to rise to 13%. These consumption levels alone would qualify air transportation as a major source of greenhouse gases; however, it is becoming understood that air transportation's contribution to global climate change significantly exceeds its share of energy use because airplanes release pollutants at high altitudes. Shifting to non–carbon-based fuels is less feasible for air transportation than it is for motor vehicles.

- Large airports, of which there are a significant number in the developed world, are a major source of emissions for pollutants such as nitrogen oxides. These emissions are produced not only by the aircraft, but also by the large numbers of service vehicles at these airports, and by the light-duty vehicles and buses that bring travelers to and from airports.

- Airports are also major sources of noise and traffic congestion. Although the noise produced by aircraft landing or departing has been greatly reduced in recent years, particularly in the developed world, the number of aircraft operations has been growing rapidly enough to offset much of the benefit. As far as traffic congestion is concerned, the tens of millions of passengers arriving at airports, often in single-passenger light-duty vehicles, cause these facilities to be major centers of traffic congestion.

For Motorized Freight Transportation

Trucks bear the greatest burden in providing freight mobility and have always been the principal motorized means of distributing freight locally. Until relatively recently (at least in the developed world), their role in the movement of freight between cities was secondary to that of the railroads. Over the last 50 years, however, trucks have eclipsed railroads in the movement of intercity freight in the countries of the developed world. As countries in the developing world move increasing volumes of freight from their hinterlands to their cities and ports, it is trucks that haul the bulk of these goods.

- Trucks create several environmental problems. First, most trucks are powered by compression-ignition (i.e., diesel) engines. This improves their efficiency relative to spark-ignition (i.e., gasoline- or natural gas–powered) engines, but diesels emit greater quantities of nitrogen oxides, sulfur oxides, and particulates than do gasoline- or natural gas–powered trucks. However, these nondiesel power plants cannot be used by the larger trucks for long-distance intercity freight haulage. Diesel emissions are being reduced in developed countries through a combination of improved combustion technology, particulate traps, and lower-sulfur diesel fuel. But fleet turnover for diesel trucks is even slower than for light-duty vehicles. Most diesel-powered trucks on the road today are several years old and emit far more pollutants than their newest, most advanced peers. Moreover, these existing diesel trucks seem particularly prone to poor maintenance, which degrades their emissions performance significantly. The emissions gap between aging and advanced diesel engines is most pronounced in the cities of the developing world. The truck fleets there are older, their maintenance may be less exacting, and their contribution to air pollution is significant.

- The sheer number of trucks used to haul freight means that these vehicles are major contributors to greenhouse-gas emissions. Worldwide, it is estimated that trucks emit approximately 30% of all transportation-related carbon emissions, a share projected to grow to 33% by 2020.

- Trucks are major sources of noise, especially in urban areas. Poor maintenance is a major contributor to the truck noise problem, as are certain driving practices, such as the use of engine compression as an assist in braking.

- Trucks are also major sources of urban congestion. Some urban areas have tried to deal with this problem by banning trucks from city streets during certain hours or certain days. While this may help to alleviate truck-related congestion, it can severely affect the ability of firms to move their goods in a timely manner. To compensate, extra inventory must be carried, increasing the total amount of freight that must be transported.

- In some areas, especially in important "corridors" between major cities, large numbers of trucks on the road may restrict the use of highways by passenger vehicles. Dense truck traffic on high-speed motorways also creates safety concerns. To be sure, much of the safety problem is the responsibility of the passenger vehicles and their less-experienced drivers, but the accidents that occur are a serious concern, whether they are caused by trucks or cars.

- Trucks also can contribute to infrastructure degradation. If roads are not built to handle high axle loads, truck traffic can literally pound roads and bridges to pieces. In developing countries, where road infrastructure is often poorly constructed and maintained, high volumes of truck traffic can be especially damaging.

For the Transportation of Freight Over Inland Waterways

Although this mode is extremely energy-efficient, diesel exhaust from towboats and from self-propelled barges can be significant in some locations.

- The greatest challenge to sustainability for this mode of freight transportation is associated with the construction and maintenance of the infrastructure it uses. The damming of waterways, the building of locks and canals, and dredging of channels to accommodate barge traffic are especially controversial because of the impact of these activities on water pollution and wetlands. Competition can be severe between water releases intended for two different purposes: to help assure that river channels are navigable by barges and to meet the needs of downstream (and sometimes also upstream) ecosystems.

SEVEN "GRAND CHALLENGES" TO ACHIEVING SUSTAINABLE MOBILITY

We believe it useful to group these mode-specific and regional-specific challenges into seven "grand challenges":

- Ensure that our transportation systems continue to play their essential role in economic development and, through the mobility they provide, serve essential human needs, and enhance the quality of life.

- Adapt the personal-use motor vehicle to the future accessibility needs/requirements of the populations of the developed and developing worlds (capacity, performance, emissions, fuel use, materials requirements, ownership structure, etc.).

- Reinvent the concept of public transport — provide accessibility for those lacking personal motor vehicles in both the developed and developing worlds; provide a reasonable alternative choice for those who do have access to personal motor vehicles.

- Reinvent the process of planning, developing, and managing mobility infrastructure.

- Drastically reduce carbon emissions from the transportation sector, which may require phasing carbon out of transportation fuels by transitioning from petroleum-based fuels to a portfolio of other energy sources.

- Resolve the competition for resources and access to infrastructure between personal and freight transportation in the urbanized areas of the developed and developing world.

- Anticipate congestion in intercity transportation and develop a portfolio of mobility options for people and freight.

These seven "grand challenges" are not necessarily independent. Meeting one may help in meeting others. But their successful attainment would go a very long way to assuring that mobility is sustainable.

INSTITUTIONAL CAPABILITY — AN OVERARCHING CHALLENGE

Most discussions of the challenges to making mobility sustainable tend to focus almost exclusively on the role that technology is expected to play. We imagine energy-efficient "super-cars," transportation fuel systems that are hydrogen- rather than petroleum-based, and magnetically levitated trains that speed people between cities using comparatively little energy. We envision telecommunications technologies that tell us how to avoid congestion as we drive and that automatically charge us for the full social costs of our personal mobility choices.

As intriguing as these technological possibilities might seem, history suggests that something far more mundane will actually determine the pace and direction of change in mobility systems. That something is institutional capability. Political institutions determine which transportation modes get favored through subsidies, regulations, and protection from competition. They also determine the type and cost of fuels that will be used to power vehicles. Political and social institutions exert enormous influence over whether transportation infrastructure can be built, where it can be built, how long it takes, and what it costs to build. Economic institutions — especially large corporations — can either take the lead in encouraging change or drag their feet and make change difficult and expensive.

Looking ahead 30 years, the mobility future is likely to depend on significant questions about institutional capacity in both the developed and developing nations. Three matters seem especially likely to affect the sustainability of mobility systems:

- Can governments and the private sector build and manage the transportation infrastructure required to meet surging worldwide demand for mobility?
- Can policy-makers and citizens effectively debate and resolve trade-offs between demand for mobility and demands for environmental protection, energy conservation, and safety?
- Can nations appropriately harmonize their regulation of transportation — on the one hand to assure that environmental and safety goals are met, and on the other, to permit effective, efficient, citizen-responsive provision of mobility capacity by private and public entities?

A World Bank Urban Transport Strategy Review now in preparation (World Bank 2001a) identifies several structural characteristics that distinguish urban transportation from most other urban service sectors. By and large, these characteristics also apply to transportation in general:

- The separation of decisions on infrastructure from those on operations.
- The separation of interacting modes of transport.
- The separation of infrastructure finance from infrastructure pricing.

These characteristics lead to what the Strategy Review describes as a fundamental paradox of transportation — excess demand accompanied by inadequately financed supply. Unless ways are found to address these structural deficiencies and thereby resolve this paradox, all the technology in the world will not make transportation sustainable. Either new technology will never be adopted, or if adopted, it will generate perverse consequences that offset much of its intended benefits.
While both developed and developing nations face major challenges with regard to institutional capability, the nature of the challenge that each region faces is somewhat different.

Developed Countries

In the United States, the European Union, Japan, and other developed nations, mobility concerns are increasingly likely to hinge on methods for providing and maintaining enhanced transportation infrastructure in crowded metropolitan areas, and on the ways in which further development will proceed in the less-settled hinterlands of these areas. Decisions will have to balance desired new economic development, the ills of traffic congestion, and public opposition to specific transportation infrastructure projects on environmental grounds.

One key institutional dimension is the relative role of public- and private-sector entities in meeting these demands. Many countries are sorting out these relationships in new ways. In the provision of new facilities that will be owned by public entities, for example, there is a trend toward a larger role for private firms in planning, design, construction, and operation of projects, which requires new competence among public authorities in managing competitive procurement processes and overseeing contracts. Where new facilities are to be owned by private entities, government must develop effective means of regulating safety and, for monopolistic or quasi-monopolistic services, regulating price — without surrendering the financial and efficiency advantages that private-service provision affords.

Whatever the form of ownership, new financing methods are likely to emerge. A key question is whether road pricing mechanisms can be used to accomplish policy goals — such as congestion reduction — as well as to finance new facilities or maintain existing ones.
Adequate maintenance of infrastructure to preserve and protect investments and to assure that facilities are used efficiently depends critically on institutional capacity. There is a pronounced tendency to shortchange maintenance of infrastructure — a matter of misaligned incentives for

both public owners (where the low visibility of maintenance encourages skimping on budget allocations) and, under some forms of private operation, for private entities as well. Institutional capacity also affects the rate of adoption and effective implementation of innovative mobility technologies — as clearly evidenced in the slow diffusion of Intelligent Transportation Systems and the backwardness of the US air traffic control system. In Europe, there are major questions of institutional capacity for dealing with mobility problems that overspill political boundaries, both within the European Union and across its boundaries to non-EU countries.

Another key question with clear connection to sustainability is mobility equity — how transportation services will be provided to low-income individuals. This concerns both those dependent on public transport, which under current circumstances of metropolitan development, travel patterns, and life styles, is less and less capable of providing adequate mobility; and those who own automobiles but may not be able to afford increased user charges imposed to ration road space. Will mobility be regarded as a right of citizenship, to be guaranteed at some level to all through public subsidy, perhaps ingeniously supplied; or will it be seen as another consumer good to be apportioned only according to ability and willingness to pay?

Last, but not least, sustainability is critically affected by institutional capacity for environmental and safety regulation. Key questions include the level of necessary regulation, whether cooperative or adversarial relations will characterize interactions between private-sector firms and public regulators, and whether regulation will focus only on industry or fall directly on consumers (i.e., voters) as well. Beyond national boundaries, the question of harmonizing public regulation looms large for industry. Lack of harmony will likely increase resistance to specific regulatory measures, reduce voluntary cooperation, and greatly increase the cost and effectiveness of compliance.

Developing Countries

It will be a tremendous challenge to build sufficient institutional capacity — in both public and private spheres — to deal with sweeping changes in developing nations' mobility systems. In countries like China or Indonesia — which face the prospect of rapid motorization and potentially explosive growth in private ownership of automobiles — the lack of adequate road infrastructure poses an enormous problem. Sustainability is a critical issue. Can these countries manage this process effectively? Governments want the economic development advantages of motorization, and increasing numbers of individuals desire and will be able to afford the personal freedom that vehicles provide. But the dangers of paralyzing congestion, local environmental degradation, and high rates of greenhouse-gas emissions that add to the threat of global change loom large. Institutional issues in the public sector include effective national decision-making that balances these considerations, as well as implementation capacity at the regional and metropolitan level. In the private sector, organizations with the competence to oversee large projects need to develop.

Adequate financing is another key institutional issue. Many priorities other than mobility — including enterprise investments as well as education and health — compete for limited private development capital and public resources. Access to international assistance is not likely to be sufficient for the full range of mobility needs in the developing world. These financing concerns will affect not only new facilities but also the maintenance of existing ones. Also figuring prominently in financing are the problems of providing equitable mobility opportunities to low-income populations. These citizens frequently live in areas poorly served by public transportation, and may lack funds even for the limited public transport options that do exist.

The opportunity to leapfrog the trajectory of technological development that developed nations have gone through is a potential advantage for some developing countries if the institutional capacity to adopt and implement these innovations can develop sufficiently. This will be true both for transportation and environmental technologies.

Environmental and safety regulation is in its infancy in developing nations. Institutionally, there are issues not only of capacity but of political will. Harmonization of regulation in this environment is not merely a matter of reconciling the relatively similar national schemes of regulation present in the developed countries; it is also a matter of making basic commitments to such regulation in international negotiations and national-level political decision-making.

IMPLICATIONS FOR THE SUSTAINABILITY OF PRESENT MOBILITY SYSTEMS

The list of challenges to the sustainability of current mobility systems is indeed a long one, but should not lead one to conclude that mobility cannot be made sustainable. Challenges that once appeared nearly intractable are yielding to solutions in some regions of the world. Lead has virtually disappeared from developed-world transportation systems except for its use in batteries, and the vast majority of these are now recycled in most developed countries. Conventional pollutants such as nitrogen oxides, volatile organic compounds, carbon monoxide, ozone, and particulates are well on their way to being controlled in the developed world. Moreover, citizens of the developed world have already paid the up-front development costs for the technologies that will enable these emissions eventually to be controlled in the developing world. Recycling of the materials used in motor vehicles is already at high levels in some places, and programs are in place to increase it in others. Control of transportation-related global pollutants such as carbon dioxide poses a much greater challenge, but promising approaches to improving vehicle efficiency have been identified. Controlling congestion, especially in the rapidly motorizing developing countries, is a major problem. It may end up being an even more difficult challenge than controlling global pollutants; intelligent transportation systems may provide some relief. Improving equity of access to mobility is also a major problem. Whether it can be addressed independently from the larger problem of social and economic inequality is an open question.

This report does not attempt to suggest strategies that might be used to overcome these complex problems. Its task has been one of assessment, not prescription. Devising strategies that will enable mobility to become and remain sustainable sometime before the beginning of the second half of this century is the task of *Mobility 2030*, the follow-up effort to *Mobility 2001*.

NOTE

1. The reason that the number shows so little change between 1990 and 1999 is the drop in FSU/EE energy use — 3.3 mmbd to 2.1 mmbd. Indeed, the 2015 number for the FSU/EE is projected to be only 3.4 mmbd, or 0.1 mmbd higher than 25 years earlier.

Table A-1. Mode shares in selected cities

City	Year	Auto	Bus	Taxi/ Minibus	Train	Metro	Walk	Bicycle	Other
Africa									
Abidjan (2)	1988	12					30		
Dakar (2)	1989	17					50		
Durban (1)	ca 95	43		24	8				
Greater Johannesburg (4)	1995	40	9	26	7		14	1	3
Marrekech (3)	1993	7	9	2			64	8	10
Nairobi (2)	1989	25	50				15		
Latin America									
Belo Horizonte	n.a.	20	38				42		
Bogota	2000	12	69	2			12	3	2
Campina Grande	n.a.	30	26				44		
Cuiaba	n.a.	22	38				40		
Fortaleza	n.a.	22	37				41		
Managua	1998	37	35				28		
Mexico City (6)	1986	25	42	11		22			
Mexico City (6)	1995	22	8	56		14			
Puebla (Mex)	1994	19	48	1			27	2	
Recife	n.a.	31	46				23		
Santiago	1977	11							
Santiago	1991	16	48	2		6	20	1.6	5
Sao Paulo (5)	1977	29	40.5		2.4	2.5	25		1
Sao Paulo (5)	1987	27	27		3	5	36		2
Sao Paulo (5)	1997	31	25		2	5	34		2
Asia									
Bangkok (2)	1984	24	60				16		
Bombay(2)	1981	9	65				26		
Jakarta (2)	1984	21	39				40		
Kuala Lumpur (2)	1984	46	42				12		
Shanghai (2)	1986	3.3	24				41	31	

Sources: Department of Transport, 1999, p. 26; Wright, 2000; IPCC, 1996, p. 687; Bogota Como Vamos, 2000; Bussiere, 2000, p. 98; Vorster et al, 2000, p. 330; Shoyama & Miyamoto, 2000, p. 442; SECTRA, 1991; Iacobelli et al, 1996; Companhia do Metropolitano de São Paulo, 1999, Table 9 & 11; Puong, 2000; Gerçek, H. and I. Tekin, 1996, p. 191; Midgley, 1994.
Notes: Percentages may not add to 100 due to rounding. 1. Durban % of peak period trips; 2. Auto trips include other private motorized modes (i.e., MC); 3. Bogota based on market survey of 1,500 persons (margin of error 3.5%); 3. Other is motorcycles; 4. Actually is urban trips for all Gauteng Province (Johannesburg, Pretoria), auto trips include motorcyles; 5. Auto includes taxi; 6. Data on non-motorized trips not available, metro includes light rail. 7. Data on non-motorized trips not available; other is waterborne transport; metro is light rail.
Note: n.a., not available.

Table A-2. Urban motorization rates for selected cities

City	Year	MV/1000	Autos/1000	Autos+2-Wheelers/1000	GRP (US$)/Capita
Africa					
Cape Town	1998		170.0		
Durban	1998		160.0		
Harare	1998	235.0			
China					
Shanghai	1985 1990 1995	11.5 16.4 32	n.a. 3.2 11.5		
India					
Kanpur	1993	93.6	7.3	87.0	
Pune	1993	128.4	12.0	108.6	
Ahmedabad	1993	138.4	14.1	118.7	
Bangalore	1993	159.2	22.6	143.9	
Hyderabad	1993	121.7	13.8	109.9	
Chennai	1993	119.7	23.7	109.9	
Dehli	1993	250.6	57.1	224.7	850.0
Calcutta	1993	47.6	17.9	38.3	
Mumbai	1993	43.5	14.9	34.5	
Asia					
Bangkok	1990		199.0	323	3826
Hanoi	1993		7.5	184	
Ho Chi Minh City	1992		16	149	490
Jakarta	1990		75.0	173	1508
Kuala Lumpur	1990		170.0	350	4066
Manila	1990		66.0	72	1099
Surabaya	1990		40.0	187	726
Latin America					
Bogotá	1999	112	99		3,300
Managua	1998	n.a.	43		620
Mexico City	1976 1986 1996		78.0 91.0 166.0		
Santiago	1977 1991 1998	 101 146	60.0 90.0 130.0		
São Paulo	1967 1977 1987		70 135 141		

Sources: Lu & Ye, 1998, p. 150; Puong, 2000; Chakravarty & Sachdeva, 1998, pp. 60-61; Ergun et al., 2000, p. 42; Mbara, 2000, p. 10; Barter, 1999, Appendix 2; SECTRA, 1991; Zegras & Gakenheimer, 2000; Zegras et al. 2000; DAMA, 2001a; 2000 Companhia do Metropolitano de São Paulo, 1999; Hai, 1995; Turley and Womack, 1998.
Note: n.a., not available.

Table A-3: Comparative metro indicators for select cities

City (Base, Actual)	Population (Millions)		Income/person (US$)		Fares (US cents)		Lines, Length	Patronage 000s/day/ year
	Base Year	Actual Year	Base Year	Actual Year	Base Year	Actual Year	Actual Year	Actual Year
Cairo (1988, 1998)	10.0	15.0	1,075	1,386	7.8	10.5	(2; 57km)	1,200 (line 1 only)
Hong Kong (1981, 1998)	5.3	6.3	5,498	17,804	31.4	60.8	(3; 43km)	2,326
Manila (1986, 1997)	8.9	10.0	1,020	1,724	17.4	21.9	(1; 15km)	440
Mexico City (1970, 1996)	7.0	8.5	1,800	3,452	4.8	9.7	(10; 178km)	4,750
Pusan (1988, 1998)	3.8	3.9	2,242	8,692	21.8	26.7	(1; 32.5km)	677
Rio de Janeiro (1979, 1995)	n/a	5.5	1,980	3,916	9.7	25.8	(2; 23km)	360
Santiago (1976, 1996)	n/a	4.3	n/a	4,751	17.0	27.8	(2; 27.5km)	595
Sao Paolo (1976, 1997)	9.9	16.7	1,980	3,916	15.0	68.3	(3; 43.6km)	2,123
Seoul (1975, 1995)	8.1	10.6	2,274	9,561	20.0	26.8	(4; 135km)	4,050
Singapore (1988, 1996)	2.6	2.9	7,162	23,863	37.1	49.0	(2; 67km)	927
Tunis (1986, 1995)	2.0	2.0	1,887	2,256	18.3	15.1	(4, 32km)	294

Source: Halcrow Fox (2000).

Table A-4: Characteristics of rail freight

Axle loads	33 metric tones
Vehicle dimensions	10.25 feet wide, 16-22 feet high
Maximum speed	90 km/hour
Train length	2 km
Train weight	16,000 tonnes
Locomotives	3 6,000-hp diesel-electric units with AC traction motors
Freight cars	110 steel aluminum cars, 108 tonnes of coal, and 33-tonne axle load
Siding length	3.2 km
Siding spacing	16 km
Signal system	Centralized traffic control

Characteristics of Rail Freight

Rail freight can be divided into five classes: bulk, intermodal, specialized freight (e.g., automobiles), general freight, and less-than-carload freight.

Heavy-Haul Rail

For heavy haul operation, the rail track structure must be able to support heavy equipment, assembled in long trains, operating at moderate speeds. Component durability and cost are more important than high-speed operation; minimizing track cost is more important than minimizing train delays. Hence, research and development produced the materials, inspection capabilities, and maintenance techniques that allow heavier and longer trains to operate safely and efficiently over single-track lines. A single-track line with the following characteristics can carry 40 or more heavy-unit trains per day or more than 100 million gross tonnes per year.

Only the very highest-density corridors in the United States require multiple tracking for bulk trains and then most often only for approaches to major terminals. This type of operation is extremely efficient, and the operating costs in North America are on the order of $10/1000 NTM. The keys to this type of operation are a) heavy traffic volume and b) modern heavy-haul track and equipment.

Operations similar to this are common in the United States and Canada, and there are heavy-haul lines in Australia, South Africa, and Brazil as well — often designed for movements of coal or ore from mines to a port.

Rail-Truck Intermodal

For traffic involving rail and trucks, the most efficient operations are double-stack trains. A typical double-stack has 125 platforms carrying 250 containers. The track structure required for these trains is similar to what is needed for heavy-haul operations; maximum speeds are higher (110 km/hour) requiring better track geometry, but the axles loads are generally lower, so the track components last a bit longer. The main difference is that higher clearances are needed. These trains are able to operate over much of the mainline network in the United States and Canada, but there are restrictions on the approaches to many cities, especially on the east coast.

Double-stack trains require terminals with cranes or front-end loading equipment. The largest terminals are those near ports, where peak demands relate to the arrival of large container ships. The largest terminal is the Intermodal Container Transfer Facility in Los Angeles, which can handle more than 20 double-stack trains daily for traffic originating or terminating at the nearby ports or in southern California. Typical terminals are much smaller, capable of handling 6 to 10 trains per day; the ideal design is to have two long (2 km) loading tracks with overhead cranes for loading and unloading the trains and a row of parking along each side of the terminal. This is a simple layout, but it is proving difficult to build new ports or expand current ones because of the paucity of flat, open areas that are large enough (2+ km long by at least 0.1 km wide) and that are situated close to the highway and railway networks in urban areas.

With double-stack trains, the cost per container drops nearly 50% relative to traditional trailer-on-flat-car (TOFC) or container-on-flat-car (COFC) service. This productivity improvement causes a dramatic shift in the competition between intermodal and truck transportation. The cost/km for double-stack is on the order of $0.20 to $0.30/km, compared to $0.40 to $0.60 for TOFC or COFC and $0.60 to $0.70 for truck. Since the traditional intermodal services are only slightly cheaper than truck, they can seldom aspire to either high profits or high market share. With the double-stack capability, the intermodal option suddenly becomes dramatically cheaper than truck. As a result, in North America, trucking companies have formed alliances with the railroads to use double-stack for the line-haul while the trucking companies serve the customers. The railroads have long tried to do this, with spotty success; today, the motor carriers choose to do this with widespread success.

The need for high traffic densities, good infrastructure, and high clearances are serious obstacles for widespread use of double-stack outside of North America. In Europe, where the traffic densities might be sufficient, the clearances are difficult even for TOFC and COFC operations. If lines are electrified, then clearances below the catenary will be insufficient for double-stack. In less developed countries, where clearances are not a major difficulty, traffic density may not exist to support double-stack operations.

Hence, we should not place all of our attention on double-stack intermodal service. Other options to consider include the road railer and variations on the traditional TOFC service. The road railer is a system where the railroad car is reduced to the absolute minimum, namely a pair of axles with a platform to hold a container or trailer. The road railer was initially deployed behind passenger trains in the 1950s in the United States; today it is used by Triple Crown, a subsidiary of Norfolk Southern, to provide service in the east. This technology has line-haul costs similar to those of the double-stack trains, along with much simpler terminal requirements. The drawback is that it takes longer to assemble a train, and twice as many trains (and track capacity) are needed to carry the same number of containers. Another drawback is that specialized trailers or containers are needed, as the equipment must be strong enough to absorb the lateral and longitudinal forces associated with train movement.

The third approach to intermodal is therefore to provide a means of moving ordinary trucks, trailers, and containers by rail. This approach will be more expensive than the road railer because of the need for substantial rail cars, but it could be more flexible and well suited to specialized operations. If the terminals are well situated, so that it is very convenient for the truckers to get on and off the train, then this type of operation could be used to shuttle trucks through congested or environmentally sensitive areas. In Europe, for example, this technology is used to move trucks under the Alps; in North America, there are a few applications of what is called the “Iron Highway.”

Specialized Services

Automobile transport is the best case of using specialized equipment to transport a particular type of shipment. At one time, automobiles were shipped in boxcars, and today they are sometimes shipped in containers, but the most common mode of transport is the “multilevel autorack.” The autorack is a superstructure that fits onto the 89-foot flatcar that was once the standard for TOFC transport. The modern autorack has two or three levels and is fully enclosed to protect the automobiles from damage. Multilevel cars can be staged at the assembly plant, 5 to 10 cars to a track. Automobiles, soon after coming off the assembly line, can be driven onto a mobile, adjustable ramp to the first, second, or third level of the first car and then driven through one or more cars until it reaches the spot where it is “tied down.” The multilevels are then assembled into trains, often with other types of freight, and moved to an unloading ramp where the automobiles are transferred to trucks for delivery to customers. Because of the high volumes of business and the relatively small number of origins and destinations, railroads are able to develop train schedules that give high priority to this traffic and minimize the number of times the cars must be classified.

This is the best example of a specialized service in which rail and highway equipment has been developed to serve a particular type of shipment. In North America, the availability of multilevel equipment allowed the railroads to retain a high market share in the transportation of automobiles from assembly plant to dealers.

Chemicals also require specialized equipment, and safety is a paramount concern. In most cases, the chemical companies own and maintain their equipment, which is handled in general freight service by the railroads.

General Freight

General freight moves in carload or multicarload shipments in a series of trains between classification yards. At each yard, cars from inbound trains are sorted, then assembled into outbound trains for the next leg of their journey. The classification yards are the only way to achieve the economies of trainload operation for shipments of, at most, a few cars. The boxcar is the symbol for moving general freight by rail, but general freight could include any different type of rail equipment.

When the railroad networks were designed, they were designed for general freight. Even with the delays associated with terminal operations, general freight service was much faster than any alternative prior to the availability of trucks. As the highway network developed, the time and expense of rail terminal operations became more and more problematic because the truck was much faster and more reliable.

The best general freight operations are those where a major customer ships high volumes of freight along major corridors to another major customer. If the shipper and receiver are both located near a major terminal, then the costs of local delivery are minimized. If the whole route is along a major corridor, then it will be possible to make the trip while going through only a few yards. Still, the best that can be expected for general freight moving 400–1,000 km over a widespread network will be trip times of three to five days with perhaps 90–95% on-time delivery. Shorter trips will not necessarily be any faster, as it is the time in the terminals that dominates. The costs for this service can be well under truck costs (perhaps 30–50% of truckload costs), but the poorer service will lead to higher logistics costs.

For general freight, the advances in track structure and equipment size do not offer much. A boxcar is already large relative to a truck, so that making the shipment larger will required less frequent shipments and higher inventories. The benefits of heavier axle loads and longer-lasting track components are minor for this traffic, since axle loads are seldom a constraint, and train, equipment, and terminal costs outweigh track costs.

The key for this traffic is more likely to be in finding appropriate niche services. Examples include shipments of paper to publishers, shipment of manufactured goods to major distribution centers, or shipments of exports to ports for resorting and transloading into containers.

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What is the WBCSD?

The World Business Council for Sustainable Development (WBCSD) is a coalition of 150 international companies united by a shared commitment to sustainable development via the three pillars of economic growth, environmental protection and social equity. Our members are drawn from more than 30 countries and 20 major industrial sectors. We also benefit from a Global Network of 30 national and regional business councils and partner organizations involving some 700 business leaders globally.

Our mission

To provide business leadership as a catalyst for change toward sustainable development, and to promote the role of eco-efficiency, innovation and corporate social responsibility.

Our aims

Our objectives and strategic directions, based on this dedication, include:

Business leadership - to be the leading business advocate on issues connected with sustainable development.

Policy development - to participate in policy development in order to create a framework that allows business to contribute effectively to sustainable development.

Best practice - to demonstrate business progress in environmental and resource management and corporate social responsibility and to share leading-edge practices among our members.

Global outreach - to contribute to a sustainable future for developing nations and nations in transition.

What is the Sustainable Mobility Project?

Sustainable Mobility is the ability to meet society's need to move freely, gain access, communicate, trade and establish relationship without sacrificing other essential human or ecological values, today or in the future. The Sustainable Mobility Project is a member led project of the WBCSD. The project aims to develop a global vision covering Sustainable Mobility of people, goods and services. The project will show possible pathways towards Sustainable Mobility that will answer societal, environmental and economic concerns.

Disclaimer

This report was prepared with the help of MIT and Charles River Associates. The report is released by the WBCSD. Like other WBCSD reports, it is the result of a collaborative effort between members of the secretariat and executives from several member companies. The report was reviewed by all project members to ensure broad views and perspective. It does not mean, however, that every member company agrees with every word.

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SUSTAINABLE MOBILITY PROJECT

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