DEDICATED TO MAKING A DIFFERENCE

mobility 2001

overview

World Business Council for Sustainable Development

mobility 2001

an overview

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 needed only 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 100 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. 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 in 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 environmental 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 congestion 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 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 or operate these vehicles. 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. It was produced by a team of researchers from MIT and Charles River Associates, 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 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 (see Figure 1). 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 (see Table 1). 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.

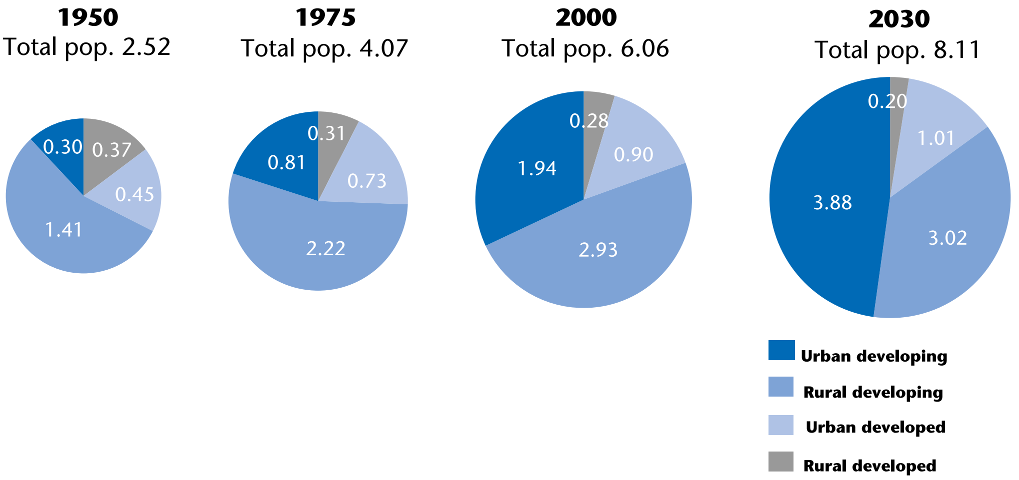
As population moves to the urban fringes, high-capacity radial urban expressways are often built to facilitate trips by suburban commuters to jobs in the urban core. Other activities follow residents, creating the edge cities seen in both developed and developing countries. Inexpen-sive land and easy 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 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.

Figure 1. World population growth, 1950–2030 (billions of people)



Source: UN (2001).

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

	Data for 1990			Annual Rate of Change, 1960–1990		
Metropolitan Area	**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).

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 permitted 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 twentieth 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 struggled 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

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

There is a nearly universal trend toward privately owned motor vehicles and away from reliance on "conventional" forms of public transportation (such as buses and subways). Figure 2 shows this trend in a selection of cities in the developed world in the period between 1960 and 1990. 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 "accoutrements" 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.

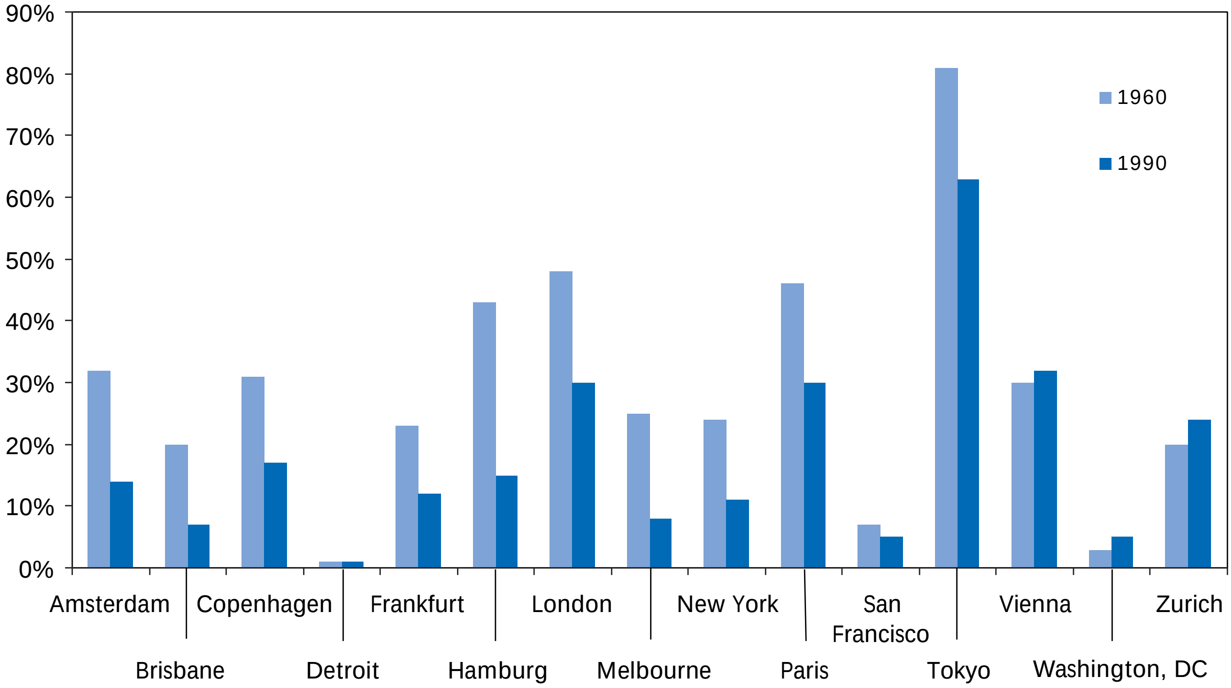
For these reasons, conventional public transport systems are best at serving high levels of travel demand concentrated in a relatively limited area or along well-defined corridors; environments where access difficulties are minimized and acceptable levels of service can be offered to many users in efficient 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.

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.

Figure 2. Transit share of motorized travel has generally been decreasing
Share of passenger - kilometers



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.

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

As we have already noted, the WBCSD 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 values today or in the future.” In short, 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 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 3 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 4 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.

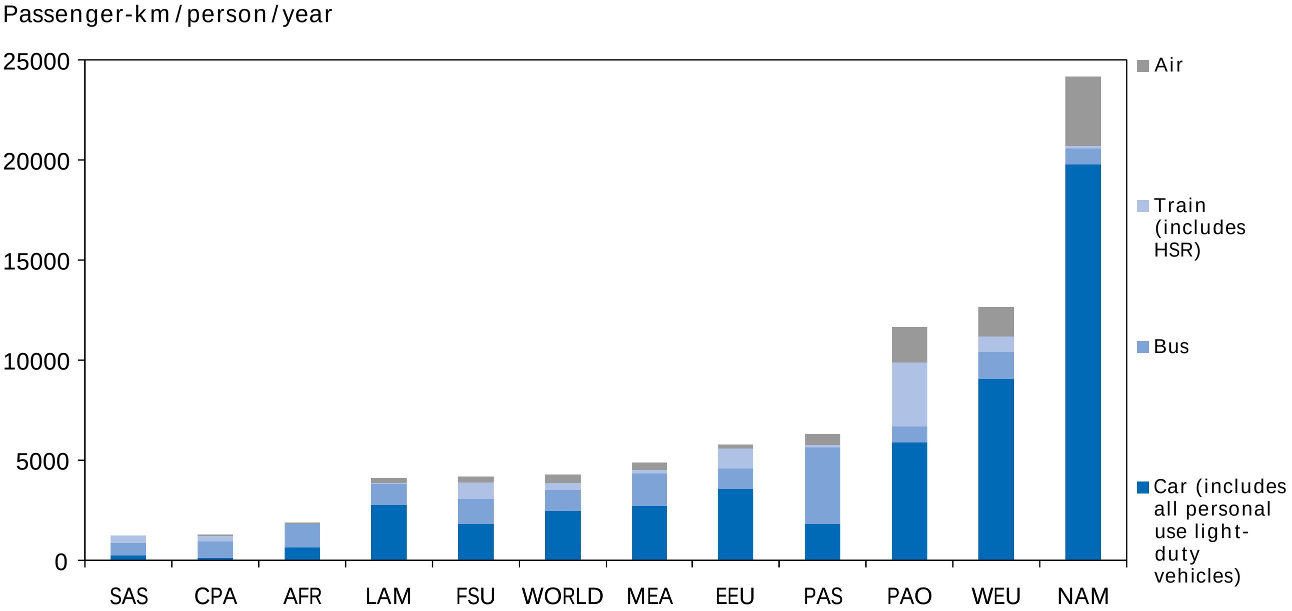
Equity in access. An increasing reliance on privately owned motor vehicles for transport means that those without access to such a vehicle may find themselves seriously disadvantaged in their ability to get to jobs and services. The limitations of conventional public transport in cities increasingly tailored to the private vehicle only serve to accentuate this risk. Particularly vulnerable are groups such as the elderly, the poor, those 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 2).

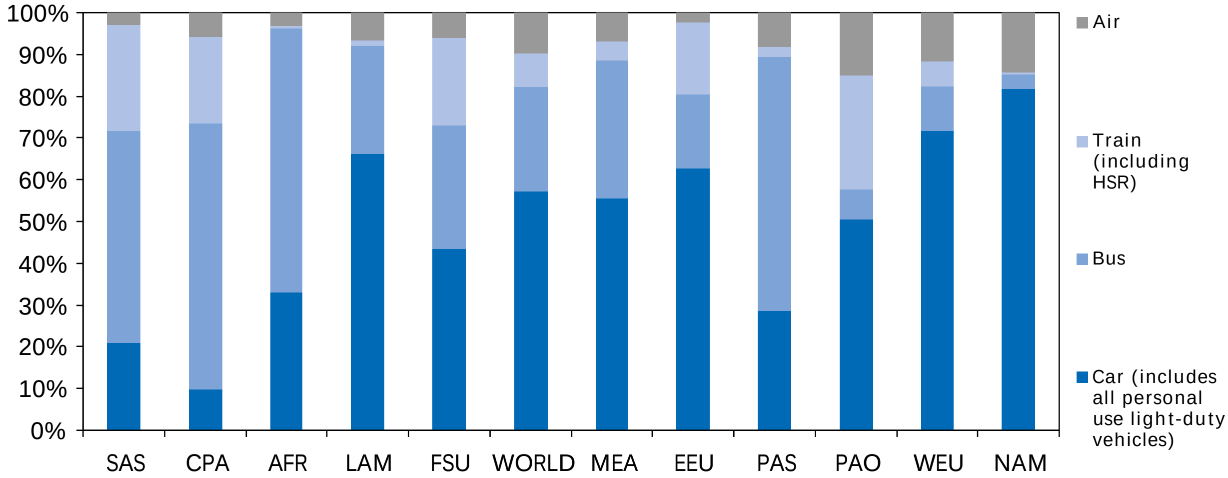
Lack of capacity is often a serious issue on both urban and interurban links. The basic connectivity of the road network may be deficient, with important population or economic centers poorly linked to the rest of the country. In some cases, specific individual facilities such as bridges are lacking, 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

Figure 3. Current (1997) levels of mobility in different regions of the world



Source: Updated database based on Schafer (1998).

Figure 4. 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).

Table 2. Surface Transportation Infrastructure per Capita (kilometers per million inhabitants)

	Intercity Rail	Urban Rail	Roads	Motorways
EU15	415	18	9,330	125
CEC	635	50+	7,880	24
United States	140[1]/890	7	23,900	325
Japan	210	6	9,200	51
World	210	4	4,750	35

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

(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 infrastructure 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 considerations relating to the cost of implementing a congestion pricing scheme, the idea has also 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 3), 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.

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 NO_X. 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 NO_X. "Overcontrolling" one of these pollutants when the other is the controlling factor can actually increase ozone formation.

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 vehicles, in part because exhaust treatment technologies — catalysts for NO_X, traps for particulates — are 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 chambers of these engines. Further reductions are likely to occur in the future.

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, mileage increases that offset improvements in emission control systems, and high emissions

Table 3. Emission Rates in London by Mode, 1997 (grams per passenger-kilometer)

	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

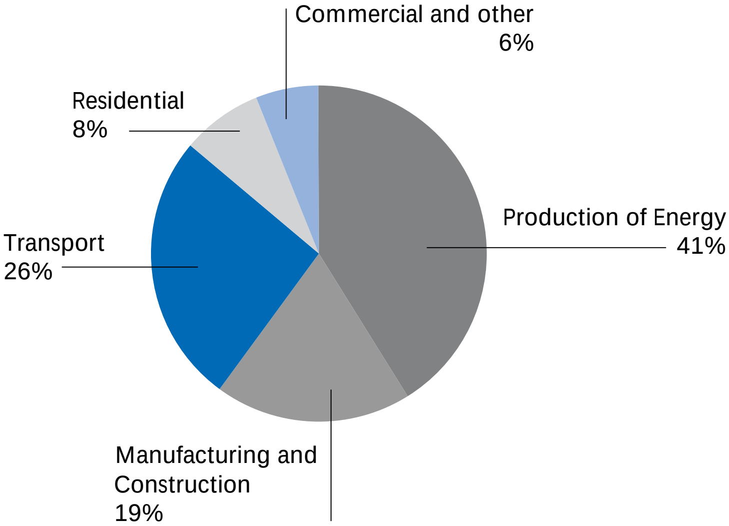
Source: London Transport Buses (1999).

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 5, 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).

Figure 5. Share of worldwide CO_2 emissions from the combustion of fuel, by sector — 1998



Source: IEA (2000a).

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 28% of total worldwide CO_2 production by humans, and this share has been increasing (IEA 2000b).

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 3) 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.

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.

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 (see Figure 6). 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.

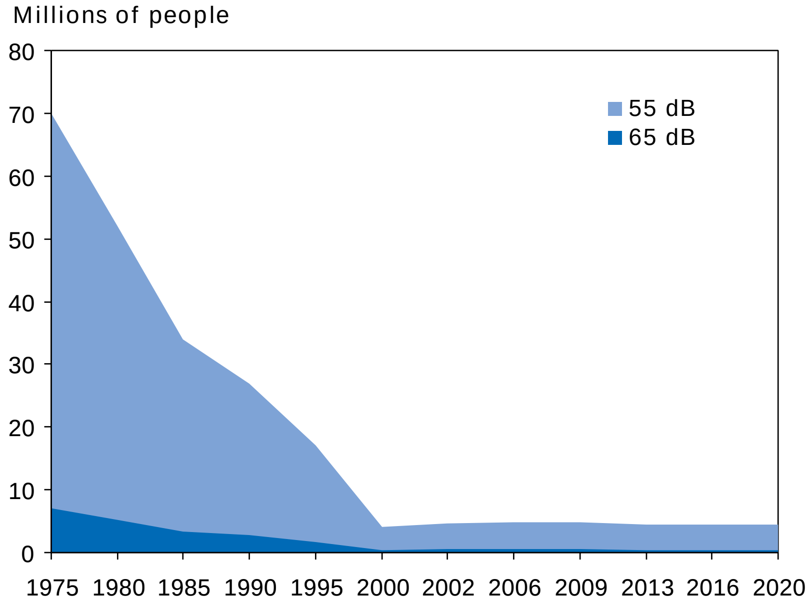
The longer-term ecological effects of these emissions outside urban areas are poorly understood. It is of increasing concern that all emissions from transportation vehicles, and the disruption of habitats and natural processes caused by the extensive transportation infrastructure system and its use, 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.

Figure 6. People affected by aircraft noise in the United States — number within 65 dB and within 55 dB DNL as a function of time



Source: Personal communication, FAA Office of Energy and the Environment.

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 de-registered 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). This is due to the differences in the steel industries of these regions and to different techniques of recycling and waste disposal.

MOBILITY 2001 — A ROAD MAP

We now summarize briefly, the salient features of the full report.

Patterns of Mobility Demand, Technology, and Energy Use

The average amount of time and the average share of income that the "typical" member of different populations has been willing to devote to personal transportation has been surprisingly stable over the last 50 years (Figure 7). 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.

Improvements in transportation technologies have substantially increased the performance and productivity of personal and freight transportation. With the exception of trains powered by externally supplied electricity, all motorized vehicles are powered by some form of combustion engine. We describe the various kinds of combustion engines, the substances they emit as they operate, and efforts that are being made to control or eliminate these substances. Improvements in materials have also contributed to these improvements in transportation productivity. 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 discuss prospects for transitioning away from our near-complete dependence on these fuels. We conclude that this transition may be more difficult and may take quite a bit more time than some others have forecast.

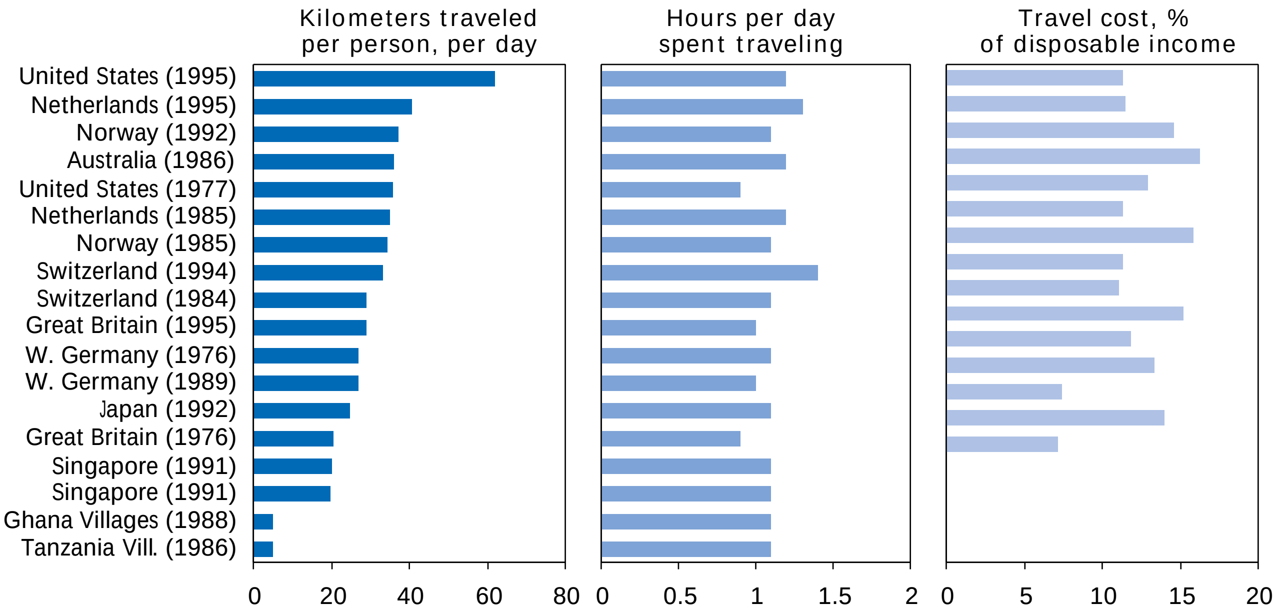
We also find that transportation technologies — both propulsion systems and vehicles — continue to improve. Several trends, such as the increased market share of the more efficient diesel engine in passenger cars and light trucks and the limited production and marketing of hybrid electric vehicles, offer 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.

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 (Figure 8).

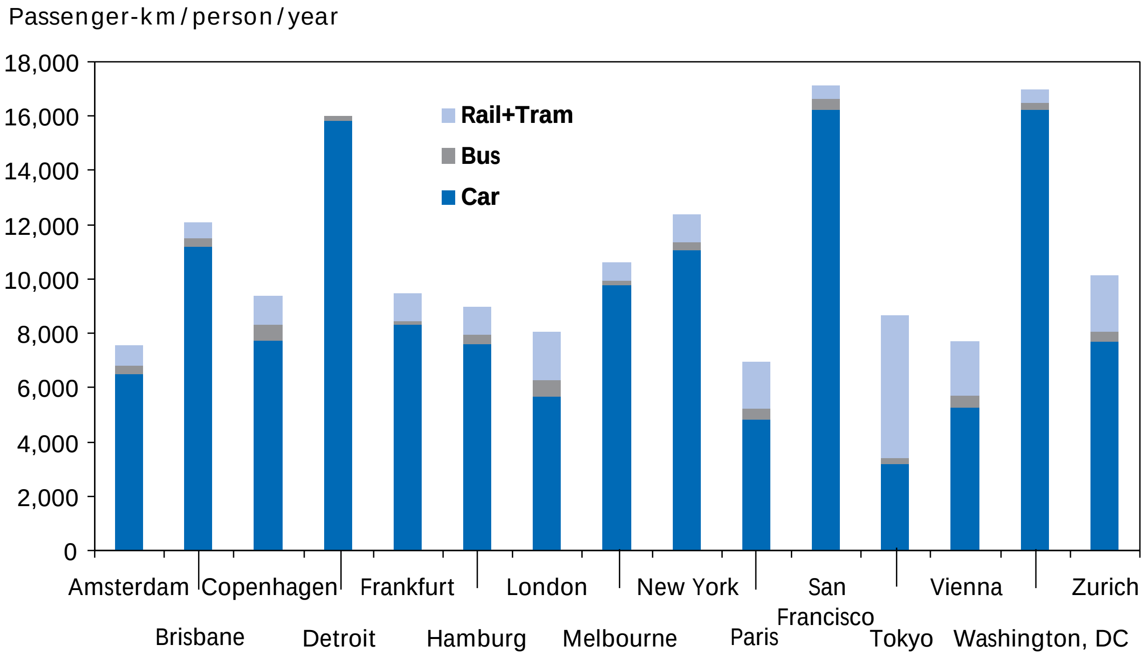
This very high degree of automobility has made possible a reduction in the population density of most urban areas, which in turn, has undercut the competitiveness of traditional mass transport, reinforcing the use of the private automobile, and disadvantaging those who, for one reason or another, do 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.

Figure 7. Distances change, time does not



Source: Database updated based on Schafer (2000).

Figure 8. Indicators of transport use, 1990



Source: Kenworthy and Laube (1999).

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 transportation" 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 its 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.

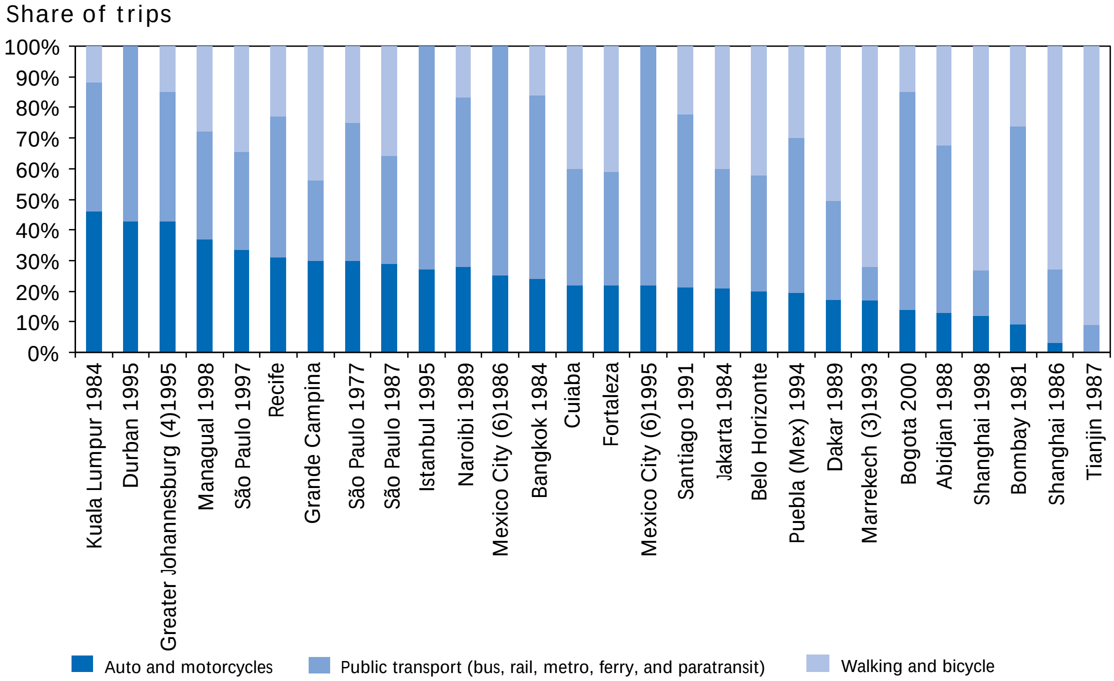
Personal Mobility in the Developing World

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, to school, and shop. The goods they produce and consume have to be transported from their factories and to their stores, and the waste they generate must be collected and disposed. All of 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 (Figure 9), 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 emit pollutants that can make air quality in these cities quite poor and unhealthy (Table 4). Most 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, in about a decade, aggregate developing-world greenhouse gas emissions will pass those of the developed world.

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

Figure 9. 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, Mexico City and Istanbul.

Table 4. 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

deteriorating in many areas where it had been improving in the past.

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 in this segment on rail and air.

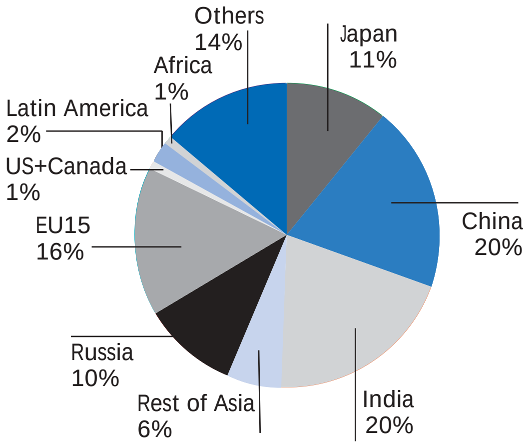
Rail passenger traffic is important in several countries, especially Japan, China, India, the countries of the EU, and Russia (Figure 10). Many passenger rail systems — India, China, and Russia come particularly to mind — are poorly maintained and have antiquated rolling stock. As these countries urbanize, 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 (UN 2000, IPCC 1999). 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, the importance of 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 important 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 (see Figure 11).

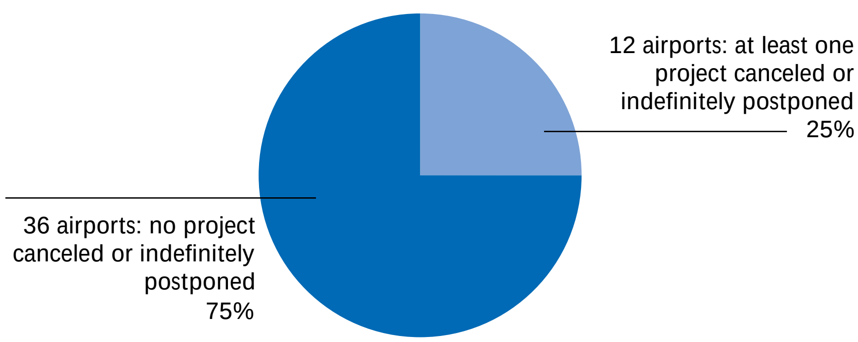
Figure 10. Where is rail passenger traffic?

Share of revenue passenger-km



Sources: Updated database based on Schafer (1998). World Band (2001b), Estimates for EU 15 include urban travel. Japan ITPS (1999).

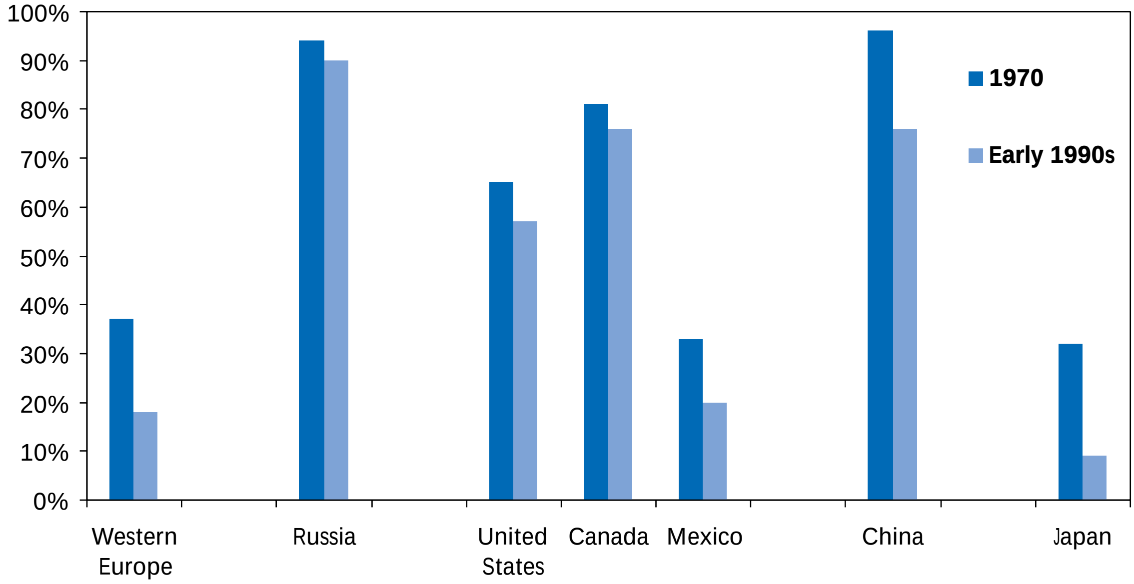
Figure 11. Airports canceling or indefinitely postponing expansion projects because of environmental issues



Source: GAO (2000).

Figure 12. Rail freight as a share of total rail and road freight. Trends in selected countries, 1970 vs. early 1990s

Billions of rail freight tonne-km/yr as a share of rail and road freight tonne-km/yr



Source: BTS (1997), pp. 250–51.
Note: Early 1990s—varies by country (1991, 1993, or 1994).

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 (UN 2000, p. 5). Vehicles transporting freight contribute in an important way to emissions of conventional pollutants as well as greenhouse gases, and 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 (Figure 12). This trend toward higher volumes of truck traffic is also offsetting improvements in truck energy efficiency, which reduces truck energy needs and truck-related greenhouse gas emissions. The growing use of air freight to move small packages is a trend that is increasing the energy used for (and the greenhouse gas emissions of) the air transportation system.

MOBILITY AT THE END OF THE TWENTIETH CENTURY — DIAGNOSIS AND PROGNOSIS

In the Developed World

Personal mobility is at its highest levels 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 utilization 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 Table 1 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 urban 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: the widespread availability and growing use of the automobile and 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, because of their low income or age, do not have access to automobiles.

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 a 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 13 shows how the developed world performs according to the sustainability measures that were defined earlier. 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 have not differentiated. 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 (UN 2001).

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 affect 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. 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 these 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

Figure 13. Sustainability scorecard — developed world

	Level	Direction
Measures to be increased		
Access to means of personal mobility	light blue	+
Equity in access	blue	–
Appropriate mobility infrastructure	blue	–
Inexpensive freight transportation	light blue	+
Measures to be reduced		
Congestion	blue	–
"Conventional" emissions	blue	+
Greenhouse gas emissions	black	–
Transportation noise	blue	+
Other environmental impacts	blue	–
Disruption of communities	blue	–
Transportation-related accidents	blue	+
Transportations' demand for nonrenewable energy	black	=
Transportation-related solid waste	blue	+

Figure 14. Sustainability scorecard — developing world

	Level	Direction
Measures to be increased		
Access to means of mobility	black	+
Equity in access	black	?
Appropriate mobility infrastructure	black	–
Inexpensive freight transportation	blue	+
Measures to be reduced		
Congestion	black	–
"Conventional" emissions	black	–
Greenhouse gas emissions	blue	–
Transportation noise	black	–
Other environmental impacts	blue	–
Disruption of communities	blue	–
Transportation-related accidents	black	–
Transportations' demand for nonrenewable energy	black	=
Transportation-related solid waste	blue	?

Key:
- black: the particular measure is at an unacceptable and/or dangerous level
- 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

to serve the present freight transportation needs of their countries.

A developing-world sustainability scorecard. Figure 14 shows how the developing-world is performing with regard to the measures of sustainable mobility proposed earlier, 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 contributing to 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 better designed, expanded, 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.

- 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. However, the degree of reliance on public transport by the poor and the less wealthy in developing countries 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 potential 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 is struggling with 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 transport 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 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.

- 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 "supercars," transportation fuel systems that are hydrogen-based 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 also what it costs to build. Economic institutions — including large corporations — can either take the lead in encouraging change or drag their feet and make change more 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 policymakers 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 financing 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 also 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 climate 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 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 emissions 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 highway 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.

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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.

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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.

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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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