SPECIAL REPORT 268

SURFACE TRANSPORTATION ENVIRONMENTAL RESEARCH

A LONG-TERM STRATEGY

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Cooperative Research Program Advisory Board

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This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Surface Transportation Environmental Cooperative Research Program Advisory Board

PREFACE

In 1998, as part of the Transportation Equity Act for the 21st Century (TEA-21), Congress called for the establishment of an advisory board to recommend a national agenda for environmental research in the domain of surface transportation.[1] Section 5107(c)(1) of TEA-21 states:

> In consultation with the Secretary of Energy, the Administrator of the Environmental Protection Agency, and the heads of other appropriate Federal departments and agencies, the Secretary shall establish an advisory board to recommend environmental and energy conservation research, technology, and technology transfer activities related to surface transportation.

To respond to this legislative mandate, the Federal Highway Administration (FHWA) contracted with the Transportation Research Board (TRB) to create the Surface Transportation Environmental Cooperative Research Program Advisory Board (Advisory Board).[2] The National Research Council appointed the board members, who collectively have expertise in state and metropolitan transportation planning and policy, travel behavior, transit and highway systems, vehicles and fuels, land use, roadside ecology, air and water quality, facility planning and design, management and organization, and decision making and community participation. The board members also represent a broad spectrum of the transportation and environmental communities,

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[1] The term "environmental" as used here encompasses energy conservation.

[2] In keeping with the language of the congressional directive to the Department of Transportation to establish an "Advisory Board" to advise the agency on environmental and energy conservation research, the ad hoc study committee appointed to carry out this study is referred to in this report as the "Advisory Board." This terminology is different from the normal use of the term "Board" in the National Academies to refer to standing units that have administrative and program oversight responsibilities.

including academia, state departments of transportation, state environmental protection agencies, metropolitan planning organizations, transit organizations, environmental groups, and industry.

The Advisory Board was formally charged with recommending a national agenda of energy and environmental research for the surface transportation community. During the board's first meeting, it became apparent that planning processes and methods would have to be a major focus of the board's work. The Advisory Board therefore agreed to amend its charge to develop a national agenda for environmental and planning research related to surface transportation.

For purposes of this report, surface transportation encompasses only land-based modes of transportation, thereby excluding water-related travel and all associated environmental impacts. Moreover, the Advisory Board followed the lead of the U.S. Congress in the Intermodal Surface Transportation Efficiency Act of 1991 and TEA-21 in using the term surface transportation to refer to the motor vehicle–highway system and public transit systems, along with pedestrian and bicycle facilities and their use. However, many of the board's findings and recommendations encompass, or could be extended to, other modes and facilities, such as railroads, canals and waterways, and airports. Taken literally, the term surface transportation would encompass all modes, since all modes use the earth's surface for all or a significant portion of the time. However, surface transportation has become a term of art in the United States during the past decade and is widely understood as used by Congress and the Advisory Board.

During the course of a 2-year period, the Advisory Board held six meetings at which members identified and prioritized research areas. At several of these meetings, the board heard testimony from representatives of federal agencies, including the U.S. Department of Transportation's Office of the Secretary, FHWA, and the Federal Transit Administration, as well as the Environmental Protection Agency and the Department of Energy. The board also convened a workshop on research priorities, inviting a broad range of experts from the transportation and environment communities to provide their ideas and advice on the highest research priorities. A summary of the workshop findings is contained in Appendix A.

The Advisory Board wishes to acknowledge the contributions of many individuals and organizations to the development of this report. Kris A. Hoellen managed the study and drafted sections of the report under the guidance of

the Advisory Board and the supervision of Stephen R. Godwin, Director of TRB's Studies and Information Services Division. Cynthia Burbank, Jill Hochman, and Debra Elston served as liaisons and project sponsors from FHWA; all three provided background materials and valuable insights to the Advisory Board.

The board also expresses appreciation to the following individuals for briefing its members on the activities of their respective organizations: John Horsley, American Association of State Highway and Transportation Officials; Donald Chen, Surface Transportation Policy Project; Alexander Cristofaro, Environmental Protection Agency; and Thomas Gross, Department of Energy.

In addition, the Advisory Board wishes to express gratitude to all those who participated in the workshop on research priorities and to those who took the time to provide written responses to questions posed by the board. Input received during the workshop was invaluable to the board in formulating its research recommendations.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

The Advisory Board thanks the following individuals for their review of this report: David G. Burwell, Surface Transportation Policy Project; Aaron Cohen, Health Effects Institute; Robert T. Dunphy, The Urban Land Institute; Gary L. Evink, Florida Department of Transportation (retired); David L. Greene, Oak Ridge National Laboratory; Susan Handy, University of Texas at Austin; Susan Hanson, Clark University; Michael D. Meyer, Georgia Institute of Technology; William W. Millar, American Public Transportation Association; and Neil J. Pedersen, Maryland Department of Transportation. Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the Advisory Board's findings and conclusions, nor did they see the final draft of this report before its release. Special appreciation is expressed to Michael D. Meyer, who re-reviewed two chapters of this report.

The review of this report was overseen by Lester A. Hoel, University of Virginia. Appointed by the National Research Council, he was responsible for

making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Suzanne Schneider, Associate Executive Director of TRB, managed the report review process. The report was edited and prepared for publication under the supervision of Nancy Ackerman, Director of Reports and Editorial Services. Rona Briere edited the report. Special thanks go to Frances Holland for assistance with meeting arrangements and to Alisa Decatur for production of the final report.

CONTENTS

EXECUTIVE SUMMARY

For the past 30 years,[1] Americans have addressed the environmental impacts of transportation through policy initiatives, planning and analysis, new programs, and new technologies.[2] Accomplishments have been significant, but much remains to be done. During the next 25 years, significant growth and changes in the nation's population and economy are expected to occur, posing major new challenges for transportation and the environment, but also offering important opportunities for advancement. Major new investments in transportation–environment research will be needed if these opportunities are to be realized.

Many of the challenges to be met stem from America's surface transportation systems, and in particular the motor vehicle–highway system. Private investments in the automobile and public investments in highways have brought Americans unprecedented freedom of movement. Most individuals today have access to automobiles providing them with the means to pursue interests, jobs, recreation, and schooling in ways and places that would have been out of reach for most Americans just a few decades ago. Goods move quickly and efficiently on truck and intermodal truck–rail systems, supporting economic growth. Americans have incorporated the automobile and truck into nearly all aspects of life—the economy, society, and popular culture.

At the same time, the costs of current surface transportation systems are high. As driving levels increase, roads are becoming more congested, and valu-

[1] The National Environmental Policy Act was passed in 1969. Its purpose was "to declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality."

[2] The term "environmental" as used here encompasses energy conservation.

able time is being lost in heavy traffic. Roads and parking are consuming large amounts of prized urban space. Residences and businesses are increasingly choosing to locate in the suburban fringe to avoid congestion, and the landscape is being fundamentally altered as new developments and new transportation facilities are built on land formerly devoted to farms and ranches, forests, and recreation. Thus traffic and roads are strongly implicated in many of the major environmental problems faced by the United States today: air and water pollution, heavy energy use, fragmented farmlands and habitat, wildlife and biodiversity losses, and community disruption. In turn, these problems are adversely affecting human and ecosystem health and the nation's overall quality of life.

In addition, the negative effects of surface transportation are unevenly distributed. The results of transportation investment decisions—facilities and networks—frequently have a disproportionate impact on inner-city neighborhoods and older suburbs. Outward movement often proves costly to the communities and businesses that are left behind. People who cannot drive have limited access to jobs, services, education, and recreation. Older people, low-income populations, persons with disabilities, and minorities bear a disproportionate share of these adverse impacts.

If the current situation presents significant challenges for transportation professionals, the next 25 years will add to those challenges. The U.S. population is predicted to grow by 60 million, with most of that growth in metropolitan areas. Gross domestic product is projected to reach $29 trillion (approximately 1.5 times today's levels in real terms). If current trends persist, the number of passenger miles traveled is predicted to grow even more rapidly than the population or the economy, swelling from 5 trillion in 2000 to 8.4 trillion in 2025. Americans will expect policymakers and transportation professionals to provide the transportation facilities and services needed to accommodate this growth efficiently, at low cost, and in a socially and environmentally responsible manner. The nation must find ways to deliver a transportation system that simultaneously promotes economic growth, adds to the health of communities and individuals, uses energy efficiently, is inclusive, and enhances the natural and built environments.

Purpose of This Study

The Surface Transportation Environmental Cooperative Research Program Advisory Board (Advisory Board) was formed by the Transportation Research

Board of the National Research Council to recommend a national agenda of environmental research for the surface transportation community that would address the challenges and opportunities discussed above. In the course of conducting this study, the Advisory Board concluded that a major new investment in transportation–environment research is needed to support the nation's growth and meet public expectations for improved transportation system performance. The nation's collective vision of a transportation system that is efficient, equitable, and environmentally benign is clear. To date, however, there exists no comprehensive strategy for realizing that vision.

Background

The United States has enjoyed a remarkable prolonged period of economic expansion since World War II. The standard of living for the average American has increased substantially, with annual personal expenditures tripling on an inflation-adjusted, per capita basis between 1950 and 2000. During this same 50-year period, the population of the United States has grown by 130 million; more than 33 million people were added through immigration and natural increases between 1990 and 2000 alone. Automobiles and trucks have been the dominant means of surface transportation in the United States throughout this period, and have played an important role in supporting and shaping the nation's growth and expansion. They have heavily influenced our consumer goods economy, development patterns, and popular culture. Access to a private vehicle has become the rule rather than the exception for those of driving age, and today more than 95 percent of our person-trips are made by automobile. Truck usage also has grown and now accounts for more than 90 percent of all shipments. The distances traveled are increasing as well: since 1970, Americans have more than doubled their total vehicular travel, and truck travel has more than tripled. There are now more than 200 million vehicles traveling greater than 2.6 trillion miles per year in the United States.

The effects of this level of vehicle ownership and highway use are substantial. Highway travel now constitutes the primary domestic use of imported petroleum. The costs of owning and operating personal vehicles represent 19 percent of the average American household's income—equal to the share of food and clothing combined, triple that of medical care, and second only to housing. Roads and traffic in the United States are estimated to affect

the ecology of more than a fifth of the nation's land area. High reliance on the private vehicle for travel has been a significant contributing factor in the broad spread of urbanized land areas, with the amount of land devoted to residential and commercial land, parking, and streets increasing much more rapidly than population.

Concerns about the environmental implications of surface transportation have assumed a high profile in public discourse. The National Environmental Policy Act of 1969, the Clean Air Act and Clean Water Act (as amended), Corporate Average Fuel Economy standards, and a number of other federal and state environmental laws and requirements have been put in place to help deal with the known and suspected impacts of surface transportation. Provisions of successive Federal-Aid Highway Acts, the Intermodal Surface Transportation Efficiency Act, and the Transportation Equity Act for the 21st Century (TEA-21) have called for stronger roles for metropolitan planning; systematic consideration of social, economic, and environmental effects; protection of parklands; and more public engagement in planning.

Certainly progress has been made: the air and water are cleaner, species have been protected, and many other adverse impacts have been avoided or mitigated as consideration of the environment has increased. Yet these policies have not yet produced what could be termed a "sustainable" transportation system. Changing community perspectives and constrained finances have combined to keep total highway expansion to approximately 2 percent (in lane-miles) during the past 30 years;[3] coupled with the massive growth in motor vehicle use, this constrained expansion has caused the existing road system to experience substantial increases in congestion.

Efforts to improve and expand public transportation in recent decades have resulted in increased usage in some areas, but the gains are uneven. Transit captures a significant share of travel in communities and corridors where services are competitive with the private automobile, such as urban areas, but only about half of the communities in the United States have public transportation systems, and in many other locations only limited service is provided. As of this writing, 47 of the 50 major metropolitan areas in the country have

[3] A recent study of 68 urban areas revealed that from 1982 to 1999, vehicle-miles traveled increased at a greater rate than either lane-miles of freeways and major arterials or population growth. Vehicle-miles traveled increased by 98 percent, freeway and arterial lane-miles by 37 percent, and population by 24 percent.

transit projects under way or under active study. That having been said, as a result of public policy that historically has favored highway and street construction, the United States has the lowest share of transit use of all the fully industrialized economies, at only 2 percent of total travel.

In addition, key trends are moving in the wrong direction. Despite large reductions in vehicle emissions during the past 30 years, many metropolitan regions still have not met basic health standards for air pollution, and several that had achieved compliance have experienced recent excessive violations. Moreover, evidence points to adverse health consequences for children and the elderly at lower pollution levels than were previously recognized. Meanwhile, fuel economy has been declining.[4]

Emerging technologies, policy innovations, and new planning processes offer opportunities for improvement. Relatively little is known, however, about the practical application of these options and whether and where they will succeed.

Findings

The Advisory Board has concluded on the basis of this study that the current state of knowledge and the tools available for environmental assessment are inadequate to ensure informed and effective decisions on transportation and the environment:

- The scale of investment in environmental research related to surface transportation is far too small in relation to the massive scale of transportation activity and its impacts.
- Coordination of the research that does take place is insufficient to derive the greatest benefit from the research effort or to ensure that gaps in the research agenda will be filled.
- Dissemination of research results is often inadequate, and the practical implementation of research findings is too slow. As a result, current

[4] The fuel economy of new cars grew from about 14 mpg in the early 1970s to about 28 mpg by the late 1980s, and that of light trucks slowly improved to about 20 mpg. But massive growth in the ownership of vans, pickup trucks, and sport utility vehicles, now representing about half of the private vehicles sold in the United States each year, has led to a decline in fuel economy. In fact, the average fuel economy of new light-duty vehicles sold is at its lowest level in 20 years.

practice is not up to date, and opportunities for improved performance are being missed.

- A long-term strategy for systematically addressing the environmental effects of transportation on the environment has not been developed, implemented, or integrated into transportation development and management programs. Current policies and investment strategies have tended to focus on short-term solutions.

The stakes are too high to continue to accept the status quo. As in the past, the major transportation system investments and private-sector land development activities occurring today will become fixtures in the landscape and economy of the nation. Better information and improved methods are needed to support policy and investment decisions in the near term, as well as in the long-term future.

Recommendations

National Research Agenda in Surface Transportation and Environment

The Advisory Board has identified six critical research areas for research in transportation and the environment:

1. Human health,
2. Ecology and natural systems,
3. Environmental and social justice,
4. Emerging technologies,
5. Land use, and
6. Planning and performance measures.

While each of these areas is the subject of current research, the Advisory Board believes much more focused and coordinated research is needed in each. More important, many critical transportation–environment topics are all but overlooked, or underfunded. Accordingly, in this report a proposed national research agenda in the above six areas is presented. This agenda includes both basic and applied research elements, as well as education and outreach tasks.

The Advisory Board also concludes that a long-term strategy is critically needed so that research needs in transportation and the environment can be systematically addressed. Current efforts have tended to focus on short-term

issues and short-term responses. These efforts are inadequate for ensuring that the U.S. transportation systems of the 21st century will deliver high-quality economic, social, and environmental performance. The overall strategy entails the development of a research agenda, the conduct of cooperative research, research coordination, and information dissemination.

Need for a Cooperative Research Program

By no means is the Advisory Board of the opinion that the proposed work needs to be done solely by the federal government, or more broadly by the public sector. Universities, public interest groups, and the private sector should be partners in transportation–environment research. The Advisory Board does, however, believe that there is a need for a new, independent entity that can engage all the parties in a cooperative research program on transportation and the environment. This program would be responsible for continuous renewal of the research agenda; sponsorship of substantial levels of new research; and increased coordination, cooperation, and communication among research entities to ensure that the most benefit will be derived from collectively invested dollars.

The Advisory Board recommends the establishment of a new cooperative research program for several reasons. First, the board recognizes that coordinating a comprehensive research program on transportation and the environment across numerous departments and agencies, levels of government, and the public and private sectors is inherently difficult. Yet such coordination is urgently needed. Research on surface transportation and the environment is being carried out today by at least half a dozen departments and agencies of the federal government, their state and local counterparts, academia, public interest groups, the private sector, and numerous international entities. Most of these research programs are functioning with limited resources that, if coordinated, could greatly enhance the ability to devise means of addressing the issues identified in this report. One function of the proposed research program would be to enable cooperative research among these groups, to support parallel investigations and shared efforts, and to aid in the effective dissemination of research findings from all sources.

Second, a new research program could focus resources on critical issues that cannot be resolved effectively by parties whose interests are at stake. For example, the Advisory Board recognizes that in many areas of the country, transportation–environment issues are hotly contested, and proponents and

opponents debate the "facts" on a variety of topics. In some instances the debate has reached—or may soon reach—a stalemate. Research by a credible institution not directly involved in the controversies could help inform these debates. The key is to ensure that this research is conducted in a manner that is both transparent to the parties and accepted by all as free from bias. Cooperative research programs are in a better position to perform this function than are other research sponsors.

Third, for many transportation–environment research topics, there has been little work done to date, or the work has been narrowly scoped or focused on short-term and primary impacts. In contrast, many of the emerging issues in transportation and the environment concern broad, long-term, multimedia, dynamic, and systems effects—for example, the potential effects of transportation emissions in one metropolitan area on air quality in other regions many miles downwind. Research that addresses these longer-term systems effects is needed, but as noted earlier, most existing research programs necessarily focus on immediate issues and the programmatic needs of sponsors. Here, too, a new cooperative research program would be far better positioned to work on the long-term, complex issues now emerging.

It is for all these reasons that the Advisory Board recommends the establishment of a surface transportation environmental cooperative research program, as originally called for in TEA-21. This program would be responsible for ensuring that the national transportation–environment research agenda was implemented, in certain cases by sponsoring the research and in other cases by serving as the coordinating body. Research under the auspices of the program would stem from a clearly articulated mission, be subject to the highest levels of merit and peer review, and be conducted in a manner that was transparent to all parties. The cooperative research program also would conduct an annual review of the research work being carried out by the various federal government entities and survey the work being done elsewhere throughout the world. This review would include development of specific recommendations for enhanced coordination; sharing of resources and findings; and identification of research gaps, with particular focus on long-term needs.

An effective cooperative research program would serve the needs of and therefore require the participation of government agencies, nonprofit organizations, academia, and the private sector. The board overseeing the cooperative research program should likewise represent the full range of interests to achieve a balanced and comprehensive perspective.

Characteristics of a Successful Cooperative Research Program

The Advisory Board reviewed the organizational structures of four leading cooperative research programs: the Health Effects Institute, the Environmental Protection Agency's Science to Achieve Results (STAR) Program, the National Cooperative Highway Research Program (NCHRP), and the Transit Cooperative Research Program (TCRP). Summaries of these programs are included in Appendix B. On the basis of this review, the Board identified a number of specific program elements that appear to be most important for success:

- *Core partners*—entities that should contribute to the overall governance of the program, the primary customers and recipients of the research products.[5] Three categories of core partners should be considered when forming a surface transportation environmental cooperative research program: public entities, the private sector, and nongovernmental/nonprofit organizations.
- *Institutional arrangement*—establishment of the research program in a setting that provides for independence and credibility. A partnership between industry and the public sector enhances a cooperative research program's ability to create a cohesive, integrated research environment and should offer the added attraction of securing private investments while establishing a firewall of independence around the program. Representatives from nongovernmental organizations can form the third leg of the partnership, thereby differentiating the model from that of the Health Effects Institute.[6]
- *Strategic focus*—program direction, as established by the core partners and stakeholders of the program and guided by the national research agenda. To ensure that all core partners and relevant stakeholders are in agreement on the priorities of the cooperative research program, a mechanism is

[5] For purposes of this report, core partners are classified as sponsors, a separate and distinct category from stakeholders.

[6] The primary drawback associated with this option is the customary lag time between the creation of a new entity and its full implementation. This problem can be solved by either establishing the cooperative research program in an existing independent, nonprofit entity with appropriate capabilities for managing such a program, as identified in Chapter 8, or by simply incorporating the lag time into the initial strategic planning stage and communicating clear expectations to all involved in the partnership.

needed for formulating, articulating, and periodically updating the program's strategic focus areas. The Health Effects Institute and STAR, for example, develop multiyear strategic plans.

- *Solicitation and evaluation of research proposals*—the ability to exercise vital quality control mechanisms through open competition and merit review. Establishing clear criteria aids in the selection of the most appropriate research projects, thereby ensuring a selection process that is transparent, fair, and subject to open competition. The Health Effects Institute, STAR, NCHRP, and TCRP all use clear selection criteria in addition to insisting that the selected research projects undergo external merit review. Although the merit review processes differ among the four programs, each incorporates the fundamental elements of both external and internal merit review, as well as open competition.
- *Evaluation of research*—peer review and other approaches designed to ensure the validity and credibility of both the research and the operating functions of the cooperative research program. In addition to evaluating specific research projects upon completion, periodic programmatic evaluations can serve to increase confidence in the operations of the program and may be important when a significant number of end users/customers/stakeholders are to be satisfied.
- *Dissemination*—mechanisms for effectively disseminating research findings. Too often, the research process ends with the publication of findings. Unless research programs make a concerted effort to inform other researchers and research institutions, practicing professionals, decision makers, and the general populace about those findings, a system of fragmented, uncoordinated research initiatives will continue to persist.
- *Funding*—stable funding that enables support of long-term basic and applied research (see below).
- *Competency and availability of staff*—the ability to attract and retain highly skilled and independent staff. Next to stable and sufficient funding, the support of competent staff is the most crucial element in achieving a successful program. If the program is to avail itself of the best and most experienced representatives of the multiple disciplines needed for the research efforts, long-term stable arrangements and flexible contracting processes must be offered with established and emerging institutions that can demonstrate the ability to assemble appropriate teams and complete the tasks assigned. The staffs and institutions involved must also be shielded from political interests and undue influence from

key stakeholders and core partners; that is, they must be granted full independence so they can apply the highest standards of scientific rigor to their work.

- *Stakeholder involvement/communication*—mechanisms for providing for meaningful stakeholder involvement in the selection, evaluation, and coordination of the research.[7] To maintain stakeholder confidence, the process for determining research priorities, selecting and structuring studies, and reviewing the final research products must be clearly understood and readily transparent. All four of the research programs reviewed share common features for actively soliciting stakeholder involvement. Stakeholders are invited to participate in the formulation of the program's strategic plan and strategic focus areas, to submit research proposals, to participate in merit reviews of the research proposals, to participate in workshops at which ongoing research is presented, and to participate in peer reviews of the research products. They are also apprised of the research findings and recommendations.

Funding

Adequate and stable funding must be available on a multiyear basis to support administrative, contracting, and sponsorship activities, including the ability to enter into partnerships with other public and private entities; to support long-term research, both basic and applied; and to sponsor workshops and demonstrations of implementation. Because transportation–environment research has been underfunded during the past 30 years, a significant investment is now needed to address both the backlog of issues that require attention and the issues that continue to arise. The Advisory Board recognizes that a large-scale research program requires a careful startup phase and review of success before a sustainable and effective annual level of research activity is determined. Thus it is prudent to anticipate that the full implementation should and will be phased in over several years. However, the Board finds little reason for the growth of the program to be constrained by a lack of funding. At current federal funding levels, as little as 0.5 percent of annual authorizations of certain federal-aid program categories produces approximately $150 million. While a

[7] For purposes of this report, stakeholders are defined as all entities, excluding core partners, who demonstrate an interest in the work of the cooperative research program or are fundamental to the successful completion of the program's work.

precise annual budgetary estimate for the eventual surface transportation cooperative research program cannot be established until after the start-up phase, it is the Board's opinion that the budget will not exceed such a small fraction of the overall federal transportation program. A national commitment of this scale would not pose a significant financial challenge to the federal transportation program, and given the importance of the environmental issues at stake in the proposed research program, could be expected to produce benefits many times as large.

1
INTRODUCTION

The next 25 years will present a significant challenge for transportation professionals as a result of the anticipated growth of the U.S. population, economic expansion, and increases in passenger-miles traveled (see Box 1-1). As the population grows and the economy expands, Americans will become increasingly more mobile and will expect policymakers and transportation professionals to institute transportation services that are capable of accommodating increasing demand in a manner that is not only efficient and inexpensive, but also both socially and environmentally sound.

While it is true that Americans consistently rank mobility and easy access to transportation[1] as a top priority,[2] they also value the environment. Tolerance for the loss of open space, community disruption, unhealthy air quality, and increased greenhouse gases[3] is diminishing. In this context, the Surface Transportation Environmental Cooperative Research Program

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[1] Currently, no policy has been established to quantify the full environmental costs of transportation; that is, there has not been a national decision to impose user fees or gas taxes to cover environmental costs. If such a policy were to be established, the current priorities of Americans might be altered.

[2] Without suitable means of transport, a person's access to jobs, child-care facilities, shopping centers, recreational facilities, and so on may be severely hindered. On average, Americans make 4.3 vehicle trips per day, equating to a total of 1,568 vehicle trips per person per year. Commuting to and from the workplace is no longer the predominant reason for transportation; work commutes account for only 1 of every 6 automotive trips taken and about 1 of every 5 vehicle-miles traveled.

[3] Despite tremendous improvements in emission technologies during the last 30 years, automotive emissions are still a major source of ozone precursors and other pollutants, and are responsible for about 16 percent of U.S. greenhouse gas emissions.

Box 1-1

Future Expectations Based on Present Trends

- By 2025, the U.S. population is expected to reach 337 million (an annual growth rate of .82 percent), increasing the population of 2000 by 60 million people.
- Annual passenger-miles traveled is predicted to increase from 5 trillion miles in 2000 to 8.4 trillion miles in 2025.
- Gross domestic product is projected to reach $29 trillion dollars by 2025, approximately 1.5 times today's level in real terms.
- By 2025, freight transportation will expand to just over 5 billion ton-miles, a 29 percent expansion. Trucks will continue to be the dominant mode for transporting freight, but total rail ton-miles is also projected to grow by 2 percent per year between 2000 and 2025.
- The age distribution of the population will change significantly. The median age is anticipated to rise from 35.2 in 1999 to 38.0 in 2025. Currently, 13 percent of the U.S. population is 65 or older; this figure will be 19 percent by 2025.

Source: DOT (2000).

Advisory Board (Advisory Board) was formed to recommend a national agenda of environmental research related to surface transportation.[4]

Study Charge

The Advisory Board was formally charged with recommending a national agenda of energy and environment research for the surface transportation community.[5] During the board's first meeting, however, it became apparent

[4] The term "environmental" as used in this report encompasses energy conservation.
[5] For purposes of this report, surface transportation encompasses only the land based modes of travel, thereby excluding water-related travel and all associated environmental impacts.

that two additional components would have to be incorporated into the board's formal charge. First, the board determined that a viable agenda for environmental research related to surface transportation would have to include a focus on planning processes and methods. Unless environmental concerns are factored into the transportation planning process, the secondary and cumulative effects of system-level transportation decisions on larger-scale environmental systems will remain insufficiently addressed in the early stages of the process. The Advisory Board therefore agreed to amend its charge to encompass development of a national agenda for environmental and planning research related to surface transportation, with the latter focus being directed specifically at the overlap between planning processes and environmental issues. The Advisory Board's statement of task is presented in Box 1-2.

Second, the Advisory Board believed that the identification of research priorities would be a productive exercise only if existing research programs

Box 1-2

Statement of Task

1. The Advisory Board will recommend a national agenda of environmental and planning research priorities and strategies.

   The Advisory Board members will be cognizant of current policy and decision-making processes, the design of institutions, the role of monitoring and education, and the general transfer of knowledge as they seek to develop a national environmental and planning research agenda.
2. The Advisory Board will support outreach and collaboration on research by identifying and recommending opportunities for partnership and collaboration on outreach, research development, and technology transfer and dissemination.
3. The Advisory Board will support the increased visibility of research programs on transportation and the environment.
4. The Advisory Board will provide guidance on assessment methodologies for effectively evaluating research programs.

were structured to implement the new priorities, or a new cooperative research program were created. To be productive, a long-term research agenda would have to be part of a long-term research strategy. Therefore, the Advisory Board's efforts were informed throughout by a long-term perspective on research needs.

Linkage Between Transport and the Environment

Historical Context

Concerns about transportation's impacts on the natural and built environments are hardly new. For example, in the early days of the United States, the building of canals interconnecting waterways and the operation of steamships adversely altered fish populations. The expansion of railroads westward was a factor in the near extinction of the American bison (TRB 1997). Coal-fired locomotives were a source of soot in cities and fires in surrounding farm fields and forests. And in many communities, horse manure had become a severe and growing problem by the late 1800s (FHWA 1976).

The rapid growth of cities during the industrial revolution of the late 19th and early 20th centuries led to concerns about congestion and overcrowding, and to a growing expectation that transportation systems should help alleviate such ills. At the first national conference on city planning held in Washington, D.C., in 1909, urban planners were implored to develop subways and public transit routes to the outer edges of city boundaries. Transportation was seen as the key to improving living conditions, lowering density, and generally enhancing the state of the human environment (Wachs 1999).

Ultimately, horses—and all the travails associated with them as a mode of transportation (e.g., horse manure, disease-infested horse flies)—would be replaced with clean, sterile machines. With the introduction of urban electric streetcars and then the automobile, many believed the transportation systems of the future would be clean as well as efficient. Indeed, both technologies greatly improved sanitation in addition to mobility and access. It would not be until the 1940s that motor vehicle exhaust would first become associated with urban smog and agricultural crop damage (TRB 1997).

The emergence of the automobile (and for freight transport, the truck) transformed American transportation systems. The growing popularity of the

automobile[6] generated demand for better roads[7] and calls for the federal government to become immersed in road development. In 1916 Congress passed the first federal-aid highway legislation—the Federal-Aid Road Act of 1916, establishing the Federal-Aid Highway Program. This act provided for the distribution of federal funds to state highway agencies, creating a financial incentive for the development of a system of improved farm-to-market, intercity, and interstate roads (FHWA 1999). The states also developed major road building and improvement programs, and quickly followed Oregon's lead in adopting a gasoline tax for highway finance.[8] During the same period, mass production of the automobile in the United States made it an affordable means of transport to growing numbers of Americans, who quickly adopted the new technology and began to use it for recreational, goods-carrying, and commuting purposes.

During the Great Depression, automobile purchases declined and expenditures on highway construction slowed, even though road building was used to create jobs and to stimulate the economy. Both automobile manufacturing and road building came to a halt during World War II as materials and industrial capacity were diverted to the war effort (Robinson 1971). When the war ended, housing and automobiles were in heavy demand. Automobile ownership skyrocketed, suburban land development flourished as new homes were built on former greenfields, and state and federal governments began building vast new highway systems (Anderson and Tregoning 1998). New expressways designed to meet suburb-to-city commuting patterns were built; beltways were added to allow long-distance travel to bypass city centers. States led the way with turnpikes and toll roads built in the late 1940s and early 1950s.[9]

Interstate highways, funded with a 90 percent federal share after passage of the Interstate Highway Act of 1956, became the centerpiece of American surface transportation, and land development patterns quickly reflected the greatly increased accessibility provided by the highways. The Interstate program both

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[6] In 1900 there were 8,000 automobiles in the United States. By 1905 there were 77,400 automobiles and 1,400 trucks. By 1910 the number of motor vehicles had grown six-fold to 468,500, and by 1915 the total was 2,491,000 (FHWA 1976).

[7] Bicycles were the first transport technology to necessitate better roads and pavements.

[8] On February 25, 1919, Oregon levied the first gasoline tax: a 1-cent-per-gallon tax on all motor fuel (Bruno 1993).

[9] It should be noted that states had built some limited-access highways in the 1920s, such as the Merritt Parkway and the Pasadena Freeway, and the Pennsylvania Turnpike was built even in the depths of the Great Depression.

supported suburban development and enabled it to accelerate; new forms of development, including the shopping mall and the office park, joined suburban housing tracts in areas served by new highways. By the late 1970s, commercial development lined the periphery of most North American cities (Anderson and Tregoning 1998).

In central cities and inner suburbs, however, new roads were not as easily embraced. In San Francisco, the elevated Embarcadero Freeway blocked city views of the historic Ferry Building; outraged citizens prevented further freeway construction. In New Orleans, a proposal to build an Interstate through the Vieux Carre was rejected. In Memphis, plans to build an Interstate through Overton Park were halted through litigation. Los Angeles' proposals to build freeways through the low-income and minority neighborhoods of Watts, Compton, and Hacienda Park were tabled after massive protests. And Boston's plans for an Inner Belt and a Southwest Expressway were scrapped after a massive restudy. Concerns about the potential adverse social and environmental consequences of highways were increasingly voiced: impacts on community cohesion, historical and cultural resources, and the natural environment became a rallying point for opposition to urban Interstates.

These growing concerns led to passage of the National Environmental Policy Act (NEPA) in the last days of 1969; thereafter, all federally funded highway projects were subject to environmental review. Air pollution from automobiles was a particular concern. With passage of the Clean Air Act of 1970 (and the subsequent amendments in 1977 and 1990), state implementation plans (SIPs) were required to document transportation's contributions to air pollution and to set forth strategies for reducing transport emissions, complementing federal requirements that greatly reduced emissions from new cars and trucks. While the federal government intervened directly on new-car emissions (and subsequently on energy consumption), and state environmental agencies and later metropolitan planning organizations (MPOs) often took the lead in developing SIPs, state highway agencies themselves were given an environmental mandate in the Federal-Aid Highway Act of 1972. That act, which required the detailed evaluation and consideration of social, economic, and environmental effects and increased public involvement in highway decision making, along with NEPA, led many state highway agencies to increase research and development on environmentally sound transportation planning and design practices (FHWA 1976).

As the Interstates were expanding and environmental and energy concerns were emerging as key public policy issues, the plight of American transit sys-

tems also was beginning to receive attention. The heyday of transit had predated the automobile; many systems had begun losing market share by the 1920s (Jones 1985). During World War II, however, heavy usage with little investment in the systems added to their wear and tear,[10] and when fuel and cars became readily available following the cessation of hostilities, many transit riders became automobile commuters.

Transit advocates argued for a federal role in funding transit, both to help rejuvenate the systems and to provide a mobility option that many deemed better suited to dense urban areas. In 1964, Congress responded with the Urban Mass Transportation Act, providing funding for capital grants to upgrade and expand transit services. Successive laws expanded the scope of the federal transit program to include formula-based grants to operators, as well as discretionary capital grants for major new starts, and to provide for rural transit and paratransit. New rail systems were built in several cities, including Washington, D.C.; Atlanta; Los Angeles; Portland, Oregon; Sacramento; and the San Francisco Bay Area. Systems were expanded in many other cities, including Pittsburgh and Boston. Bus services were started or expanded in a number of cities, such as Houston and Phoenix. Some of the services replaced the old streetcar systems that had been dismantled in the 1950s. While these investments generally produced ridership increases, transit's share of travel, even for work trips, remained in the single digits except in a handful of older, denser cities, including New York, Boston, Philadelphia, Chicago, and San Francisco. Still, transit's importance to city centers, its service to those who cannot or do not drive, and its relatively benign environmental impacts continue to attract support.

The story of freight transport in the United States has many parallels with the history of passenger transport. Freight was first transported via waterways, as well as along roads of varying quality. The advent of canals and then railroads in the early to mid-1800s opened up vast new territories for economic development and in so doing transformed the American landscape. Government helped fund the new transportation systems, both directly and through the provision of land. Later, concerned about economic impacts, government stepped in to regulate industrial organizations, tariffs, and conditions of service provided by the powerful railroads. Trucking in its turn was subject to economic regulation and conditions of operation. Yet competition from trucking grew as the automotive

[10] According to the American Public Transportation Association, 1946 was the year of the highest-ever public transportation ridership (23.4 billion).

industry developed and roads were improved and expanded, eventually causing many railroads to face financial difficulties. Partial deregulation, reorganization, and consolidation helped revive some railroads, though others (most notably the Penn Central) ended in bankruptcy. Deregulation of trucking, meanwhile, led to vast numbers of new entrants into the market, and to concerns about the resulting community and environmental impacts.

Problems and Opportunities

Today the nation's surface transportation system encompasses 3.9 million miles of roads, 1.4 million miles of oil and natural gas pipelines, 123,000 railroad route miles, and 26,000 miles of navigable waterways; in addition, 508 public transit operators are located in 316 urban centers. These facilities accommodate more than 5 trillion passenger-miles of travel and 3 trillion ton-miles of freight each year. Approximately 200 million automobiles and light trucks—an average of 1.8 motor vehicles per household—account for 87 percent of total vehicular passenger-miles traveled (U.S. Department of Transportation Report to Congress, 4th edition), and the trend is increasing. Specifically, in 1970 Americans averaged 4,485 automobile-miles per person per year; by 1993, this number had increased 41 percent to an average of 6,330 automobile-miles per person. Between 1983 and 1990, the average trip length for all purposes increased from 8.68 to 9.45 miles.

This growth in transportation activity reflects and supports the nation's economic development and the active social, cultural, and recreational lives of the nation's populace. At the same time, environmental interventions have helped make this growth more acceptable than would otherwise have been the case. Gains are particularly visible in the areas of air quality, with highway emissions having declined by almost 15 percent—from 74.4 million tons in 1993 to 63.7 million tons in 1999. This improvement can be attributed to advances in vehicle fuel systems, the use of catalytic converters, and the development of cleaner-burning fuels. Progress has also been made in energy efficiency, with the average fuel economy of automobiles and light trucks having increased by 54 percent and 63 percent, respectively, between 1975 and 1998. Less well known, perhaps, are the gains in water quality achieved through treatment of highway runoff; the reductions in roadkill due to new animal bypasses and tunnels under highways and railroads; and the decrease in highway noise attributable to the advent of noise barriers, vehicle controls (including quieter engines and improved mufflers), and improved vehicle maintenance (DOT 2000).

Nevertheless, much remains to be done—both problems to be solved and opportunities to be seized:

- While road building has generally slowed now that the Interstate highway system is complete, new roads are still being added both in the high-growth states of the south and west and in many other areas of the country where population and jobs continue to move to the suburbs and beyond. Designing these roads to be environmentally benign will require new planning approaches and new construction and operation methods. Further, as increasing numbers of existing transport facilities (roads, bridges, terminals) require reconstruction, there will be opportunities to introduce new designs that are more environmentally friendly for the natural or built environment.
- The Environmental Protection Agency (EPA) is currently predicting that by 2007 the downward trend in emissions of ozone precursors (nitrogen oxides and volatile organic compounds) will level off and subsequently begin to increase (nitrogen oxides in 2020 and volatile organic compounds after 2007) (EPA 2000).[11] This is cause for concern as epidemiologists have confirmed a link between air pollution and adverse impacts on human health; for example, ground-level ozone has been associated with weakened respiratory functioning, lung inflammation, and increased incidence of childhood asthma. Ongoing research and development will be required to devise additional means of reducing emissions to acceptable levels.
- If energy costs to build infrastructure, produce fuel, and manufacture vehicles were factored into the equation, transportation would account for more than 70 percent of total domestic oil consumption (Davis, 2000). Currently, the United States imports more than half of its oil reserves. Given the uncertainties associated with foreign supplies, growth in demand in other countries, and the finite world supply of oil, the development of methods to reduce petroleum dependence and/or increase energy efficiency may be a necessity.
- Motor vehicles are estimated to be responsible for approximately 20 percent of all U.S. emissions of carbon dioxide, a greenhouse gas[12] (EIA

[11] Should EPA's proposed rule introducing emissions controls on heavy-duty engines and vehicles and diesel fuels withstand court challenges and be adopted, the increases in ozone precursors would be postponed further into the future (EPA 2000).

[12] Passenger cars and light-duty trucks are responsible for approximately 60 percent of total carbon dioxide emissions from the U.S. transportation sector (EPA 2001).

2000). Additionally, 16 percent of all U.S. emissions of chlorofluorocarbons (Burwell et al. 1991), a critical element in the destruction of the ozone layer, can be attributed to motor vehicles. These impacts on the environment are increasingly receiving worldwide attention, and the United States needs strategies for managing greenhouse gases and ozone depletors that suit the nation's own social, economic, and political realities.

- Releases of zinc, cadmium, copper and nickel, chromium, and iron into the environment result in part from the abrasion of tires and brake linings. Deposition of these pollutants near highways can result in contamination of surface dust and soil. Moreover, leakage of brake fluid, antifreeze compounds, lubricating oil, engine oil, and grease onto the highway surface can lead to the contamination of surface water and groundwater. The chain of events of emission, dispersion, deposition, and removal of automotive pollutants—and the resulting impact on the natural environment in the short term—has been well-documented (Ball et al. 1991; EPA 2001), if not well understood. More work is needed to devise methods of reducing these releases and their environmental impacts. Moreover, relatively little is known about the long-term effects of these releases.
- It is increasingly recognized that cumulative, long-term impacts are important and may not be readily understood or managed within the context of the current system. For example, air pollutants when deposited frequently pollute the surrounding soil and water supply. Similarly, system effects are beginning to be understood; for example, it is now recognized that to protect endangered species, one must also protect their habitats and their genetic diversity. Furthermore, institutional approaches to the management of certain transportation-related environmental problems are proving to be inadequate, as in the case of air districts that do not span the pollutant transport area. These issues point to the need for research in a variety of fields, including basic scientific processes, management approaches, planning and forecasting methods, and institutional arrangements.
- Traffic congestion is a stressful experience for many Americans, causing elevated blood pressure and other stress-related health impacts, contributing to absence from work, and lowering tolerance for frustration (Burchell et. al. 1998). Congestion also increases vehicle operating costs, fuel consumption, and emissions and contributes to lost productivity. The Texas Transportation Institute estimated that in 1999, 50 major U.S. cities expended well over $78 billion in congestion-related costs—an estimate

that does not incorporate costs associated with stress-related illnesses. Strategies for managing congestion are being developed, but clearly more work is needed.

- Some population groups, including the young and some elderly, low-income, and disabled populations, have a limited ability to travel by automobile unassisted, and hence are transportation-disadvantaged in a society that uses automobiles for most trips. In addition, some communities are disproportionately impacted by transportation facilities and their adverse effects (e.g., increased traffic and pollution levels, barriers to physical activity, along with the actual physical division of communities by highway structures). Concern about these disparate impacts of transportation has led to calls for better planning methods, including means of developing community-sensitive alternatives, evaluating the distribution of benefits and costs, and providing for mitigation or amelioration of adverse effects.
- Public concerns regarding interactions between land use and transportation, as well as a broad range of community and environmental impacts, suggest the need to search for better methods of planning and achieving public involvement, new organizational approaches and assignments of responsibility, and new ways of managing the transportation system.
- New technologies—ranging from fuels and vehicles to methods for handling and displaying environmental data and forecasting transportation demand—offer possibilities for greatly improving transportation planning and transportation projects. But more work is needed to test, develop, and implement these technologies.

In short, research and development on transportation and the environment is needed to manage the problems of the coming decades. The potential for this research to pay off in substantial improvements and innovations is great.

Intermodal Surface Transportation Efficiency Act of 1991

A full decade ago, concerns about transportation and the environment led to the passage of landmark legislation—the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. ISTEA marked a new era in transportation planning, outlining for the first time measures designed to foster a national transportation policy that transcended traditional modal issues, such as highway construction and transit subsidies, to focus on intermodal considerations

and address broader public policy concerns of economic efficiency and environmental quality. Specifically, the ISTEA policy statement declared:

> It is the policy of the United States to develop a National Intermodal Transportation System that is economically efficient and environmentally sound, provides the foundation for the Nation to compete in the global economy, and will move people and goods in an energy efficient manner.

To meet these new goals, ISTEA authorized the establishment of several new programs. For example, the Congestion Mitigation and Air Quality (CMAQ) program provided earmarked funding for major urban areas that had not attained the National Ambient Air Quality Standards. Another program provided funds specifically for enhancements to transportation projects, such as bicycle and pedestrian facilities, landscaping, and public amenities. Still another program funded research, development, and implementation of intelligent transportation systems (ITS) that use computers and information technology to improve transport capacity and safety.

The provisions in ISTEA that may have initiated the greatest change were those that called for the development of state and regional transportation plans and set forth land use and environmental factors to be considered in those plans. ISTEA assigned to MPOs lead responsibility for the regional transportation plans. State transportation agencies were to take the lead for key facilities (Interstates and a few others), as well as for plans and projects for those portions of the state outside of the major metropolitan areas. The state agencies were thus to work in partnership with the MPOs within the metropolitan areas.

ISTEA designated the U.S. Department of Transportation (DOT) as lead agency for defining national research goals and for serving as the coordinating body for transportation research for all modes. DOT was also charged with conducting an inventory of its own research activities and with developing a strategic framework for transportation research.

Need for a Long-Term Strategy

In September 1996, the U.S. General Accounting Office (GAO) conducted a review of DOT's surface transportation research program to ascertain the status of transportation research prior to the reauthorization of ISTEA (GAO 1996). GAO concluded that DOT's surface transportation research program was lacking in three principal areas:

- From fiscal year 1992 through fiscal year 1996, DOT had received a total of $2.9 billion in federal funding for surface transportation research. The vast majority of this funding had been allocated to highway-related research. Specifically, DOT had allocated $2.1 billion of the total research funding received to the Federal Highway Administration (FHWA), which in turn had allocated nearly half of those funds to the ITS program.
- GAO concluded that DOT had not succeeded in developing a strategic, integrated, or focused approach to surface transportation research as directed by ISTEA. Rather, the needs and activities of the individual modes were still governing DOT's research initiatives, and little attention was being paid to the total surface transportation system.
- GAO noted that DOT was conducting very little long-term or high-risk surface transportation research. Unless the focus of DOT's transportation research program were shifted, GAO cautioned, the transportation community would remain unprepared to fully address the goals espoused in ISTEA.

A targeted, long-term research strategy was clearly needed. The conclusion of the GAO report was that the investment in surface transportation research had been largely inadequate and to date had not reflected the significance of the issues involved. This situation persists today. Research on transportation and the environment is especially underfunded, with the environmental share of transportation research being a mere fraction of the total invested. In fiscal year 2000, DOT allocated less than $10 million of its $400 million annual research and development budget to addressing the environmental effects of transportation. If a long-term research strategy were formulated and sufficiently funded, it could provide a foundation for the development of solutions to some of today's most pressing problems while allowing policymakers to prepare for the future.

Development of a Transportation–Environment Research Agenda

The authors of the Transportation Equity Act for the 21st Century (TEA-21) were cognizant of the problems encountered in the implementation of ISTEA and recognized the need to develop a secure foundation for transportation–environment research. Thus as noted, the act called for the formation of the

Advisory Board to develop a research agenda that would guide the work of research institutions and establish the integrated research framework originally envisioned by the authors of ISTEA.

The Advisory Board identified six critical areas for the focus of its research agenda:

1. Human health,
2. Ecology and natural systems,
3. Environmental and social justice,
4. Emerging technologies,
5. Land use, and
6. Planning and performance measures.

The basis for selection of these six areas was the knowledge and collective expertise of the Advisory Board members, input received from federal agency representatives during board meetings, and the proceedings of a workshop held in September 2000 to solicit input on research priorities from experts within both the transportation and environment communities (see Appendix A for a summary of the workshop proceedings). Each of the six focus areas represents an obvious intersection point between transportation and the environment and typifies the inherent trade-offs involved. It should be noted that the Advisory Board did not attempt to provide a comprehensive list of topics for research, but rather aimed to identify research areas in which troublesome gaps in knowledge exist and further investment in research would pay off, significantly advancing the ability of transportation professionals to provide transportation systems that are socially and environmentally sound, as well as efficient and economical. It should also be noted that the six research areas identified by the Advisory Board are necessarily interconnected; this report is therefore intended to be read in its entirety, and individual chapters are not meant to stand alone.

The issues and the Advisory Board's findings in the six focus areas are reviewed in turn in Chapters 2 through 7; the board's recommendations for a research agenda in each area are presented at the conclusion of the respective chapter. Brief overviews of the six chapters are provided below. Three components necessary for establishing a comprehensive long-term research strategy for the surface transportation–environment arena are outlined in Chapter 8. In Appendix A a summary of the research priorities workshop is provided, and a matrix outlining the various components of four cooperative research programs reviewed for this study is given in Appendix B.

Research Area 1: Human Health (Chapter 2)

Transportation systems can affect human health through a variety of processes, including facility construction, operations, and maintenance, as well as vehicle fueling, operations, and scrappage. Significant health effects result from air pollution emissions, including air toxics; water pollution from runoff; deposition of emissions; leaks from solid waste disposal sites; and noise exposure. However, the links between transportation activities and human health are not yet fully understood or agreed upon. Additional research is needed to substantiate the linkages between exposure to emissions and health impacts, and to understand which transportation activities may pose the greatest threat to human health and thus should be modified. Research should address modal emissions and their implications for vehicle control strategies and transportation system designs, as well as transportation emissions of air toxics, their health impacts, and their policy implications. Research also should examine the potential health impacts from transportation runoff and deposition; the health effects of transportation noise exposure; and strategies for avoidance, minimization, and reduction of these impacts. Strategies for better understanding the economic value of health improvements and for incorporating health considerations into valuation methods also should be researched.

Research Area 2: Ecology and Natural Systems (Chapter 3)

Historically, transportation's impact on the environment has been measured in terms of human health; consequently, issues such as air pollution have received considerable attention. However, little research has been performed on the impacts of these same emissions, both short and long term, on natural systems (TRB 1997). Polls indicate that Americans value a clean environment, but also desire an efficient transportation system. To fully assess the trade-offs involved, both the transportation community and the American public need to understand the impacts of transportation on the environment in both the short and long terms. For example, if key species are reduced or eliminated as a result of the impacts of a transportation project, to what extent will biodiversity be altered? This question can be answered only through long-term monitoring and evaluation of the ecosystem. Another example involves the use of plantings near highways to reduce maintenance and create aesthetically attractive roadsides. To what extent will these plantings disrupt the natural environment and the functions provided by the ecosystem? There are many

examples of transportation's impacts on the natural environment; this chapter provides broad insight into both the spatial and temporal issues associated with transportation and natural systems.

Research Area 3: Environmental and Social Justice (Chapter 4)

ISTEA and TEA-21 mandated increased public involvement and renewed attention to the economic, social, environmental, and energy effects of transportation decisions. Chapter 4 examines issues of equity in transportation, including the distribution of social, economic, and environmental impacts and related issues of environmental justice. Research is needed to understand differences in mobility, access, travel behavior, and travel preferences across socioeconomic groups; to develop improved planning approaches that better reflect and respond to community needs; to improve evaluation methods for examining the incidence of benefits and costs; to examine the differential impacts of current methods of finance and explore alternatives; and to understand the socioeconomic implications of emerging land development patterns and new transportation technologies. Research is also needed to develop innovative applications of technology that would improve the equity of the transport system in a cost-effective manner, and to devise improved methods for community involvement, collaborative planning, and conflict resolution.

Research Area 4: Emerging Technologies (Chapter 5)

In the not-too-distant future, the transportation industry is expected to incorporate two largely new sets of technologies: (*a*) propulsion technologies and fuels that will change the energy, pollution, and noise characteristics of vehicles; and (*b*) information, communication, and control technologies that will change how vehicles are used. The way these paths may unfold and how public policy may influence their direction to achieve enhanced environmental quality are two critical research questions. Research is needed on pathways for the transition to environmentally benign fuels and vehicles for passengers and freight; on user response to and demand for new technologies that could offer improved environmental performance; on possible applications of ITS technologies for environmental benefit; on policy instruments that would encourage the development of beneficial new technologies in a cost-effective manner and would respond to the impacts of new technologies as they gained market

share; and on institutional arrangements, including public–private partnerships for the research, development, and introduction of new transportation technologies and systems.

Research Area 5: Land Use (Chapter 6)

During the past three decades, both land consumption and vehicle-miles traveled have grown more rapidly than population in metropolitan areas across the United States. Empirical studies suggest that transportation investments have contributed to these trends, but many other factors, including housing policies, school quality, and consumer preferences, are also involved. (Deakin 1990). In response to concerns about sprawl, policymakers are implementing growth management and transportation initiatives, but the effects of these initiatives remain to be assessed. Focused, coordinated, and expanded research is needed on these topics, including the impacts of transportation investments on location decisions and land use; the costs and benefits of current development patterns and their transportation implications; the effects of the built environment on people's willingness to walk, drive, or take public transportation; and the roles of public policy and institutional arrangements in current and prospective land use and transportation choices. Research is also needed to develop improved data, methods, and processes for considering land use, transportation, and the environment in an integrated, systematic fashion.

Research Area 6: Planning and Performance Measures (Chapter 7)

ISTEA and TEA-21 call for transportation planners to meet needs for transportation mobility in a manner that supports broader societal goals of economic competitiveness, social equity, and environmental sustainability. To accomplish this, transportation planners must develop a better understanding of travel needs and preferences, as well as a better set of planning methods for system analysis, forecasting, and decision making. Expanded research is needed on consumer choice processes and travel and activity patterns for both local and long-distance trips and both passenger and freight transportation; on the social, environmental, and economic benefits and costs of various transport options; on tools for measuring and forecasting complex transportation decisions for all modes and users; on performance measures and policy analysis approaches that can be used to gauge how well various strategies will accomplish desired

outcomes; and on methods for better linking public involvement, including citizens and private-sector interests, in the transportation planning and evaluation processes.

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Abbreviations

DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
EIA	Energy Information Administration
FHWA	Federal Highway Administration
GAO	General Accounting Office
TRB	Transportation Research Board

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2

Research Area 1

HUMAN HEALTH

Through the use, manufacture, maintenance, and scrappage of vehicles (including passenger cars, trucks, buses and railcars) and the maintenance of the infrastructure they use, the transportation system creates significant harmful effects on human health. Surface transportation is linked to human health (both mortality and morbidity) through vehicle emissions; road dust; degradation of drinking and stream water by road runoff from substances in vehicles, deicing chemicals, or other substances; exposure to toxic contaminants through vehicle and battery scrappage (either directly or through contamination of ground or surface water); and engine and tire noise.[1] The effects of these emissions, pollutants, and wastes on health occur at different spatial scales. Carbon monoxide (CO) emissions, for instance, are generally of concern at the local level; the same is true for larger particulate emissions, which tend to settle out quickly. Finer particles and ambient ozone, on the other

[1] Transportation is directly linked to health through the effects of vehicle crashes. However, these important health and safety issues, including those related to releases of chemical and other hazardous wastes from spills, lie outside the scope of the Advisory Board's deliberations and this report. Also excluded are some of the less significant links of health to pollution from the transportation vehicle life cycle, including the extraction, manufacturing, storage, delivery, and transportation of fuels, and the manufacturing and repair of vehicles. For instance, the automobile repair industry contributes to the hazardous wastes generated in the United States; these wastes include antifreeze, solvents, brake fluids, and linings. Also excluded is the effect of urban form on temperature through the "heat island effect" (McMichael et al. 1996). Transportation infrastructure may contribute directly to this effect via roadways, but the greater effects are seen with urban forms that remove trees and other green spaces. Finally, the Advisory Board recognized the importance of, but excluded, the effect of substituting motorized transport use for bicycling and walking on exercise and fitness levels, with the attendant effect on health and longevity (Hillman 1997).

hand, can travel for hundreds of miles or more, so that pollution in one state can affect the health of people in many other states and even other countries. While the ground-level emissions from mobile transportation sources tend to be less of a problem with regard to long-range transport relative to stationary sources with tall stacks, they are still significant. And some transport emissions, such as carbon dioxide (CO_2), have global effects (EPA 2001a).

Responsibility for research on transportation, pollution control, and human health is divided among several agencies, and while the surface transportation community may have an interest in every linkage between transportation emissions and health, some are more directly within its purview than others. As a result, gaps in research sometimes develop. Research on transportation and air quality offers a case in point. Under the Clean Air Act, the Environmental Protection Agency (EPA) is responsible primarily for estimating emissions from mobile, area, and stationary sources, linking emissions to concentrations of air pollutants, and linking the resulting air quality to human health. The agency places particular emphasis on documenting the emissions from transportation sources and seeking transportation policies and measures to reduce pollution. Little of EPA's work, however, has addressed the broader question of how current transportation programs affect human health, or how they could be redesigned to avoid or reduce pollution. The Federal Highway Administration (FHWA) takes an active interest in EPA's research and sponsors its own studies on how to meet the requirements of the Clean Air Act. In particular, FHWA is responsible for ensuring that local transportation plans conform to the Clean Air Act. However, neither FHWA nor any other transportation agency conducts research on the health effects of its programs on a regular basis. Thus although both agencies have focused attention on transportation and air quality for several decades, significant research gaps exist.

In this chapter, the Advisory Board proposes a research agenda to address these gaps. This agenda encompasses epidemiological topics of particular significance to surface transportation, as well as research issues related to estimation of the economic health benefits of reducing transportation-related emissions. Also, because health effects and the monetary value of those effects figure prominently in cost/benefit and cost-effectiveness analyses of environmental and transportation regulations, these issues are included in the recommended agenda.

The consequences of transportation for human health are not straightforward, and extensive research is needed, in some cases to substantiate the linkages and in other cases to establish the direct and indirect links. Much of the problem is due to a lack of sufficient data. Determining which transportation activities

pose the greatest threat to human health as a result of environmental impacts and which should be modified is critically important. There is also a need to achieve the greatest possible reduction in risk for the costs incurred; thus the relationship between risk reduction and cost is an important research topic as well.

The specific linkages between surface transportation and human health are described in some detail in the next section. The discussion focuses primarily on air pollution, from which most health effects of surface transportation are believed to occur. Some attention is also paid to water pollution, solid wastes, and noise. Water pollution and noise are both addressed further in the discussion of ecology and natural systems in Chapter 3.

Surface Transportation and Human Health

Air Pollution

Fuel burning due to transportation activities, whether under congested or uncongested conditions, has the potential to increase the risk of death from respiratory and cardiovascular disease; raise the risk of developing certain chronic diseases [including cancer (Pope et al. 2002); chronic bronchitis; and, according to very recent evidence, asthma (McConnell et al. 2002)]; aggravate various existing chronic conditions; and lead to acute cardiopulmonary symptoms, such as cough, a runny nose, and other signs of a cold (Key 1998; Liao et al. 1999; Tolbert et al. 2000). Burning gasoline still leads to significant emissions of volatile organic compounds (VOCs) (some of which are carcinogenic), CO, nitrogen oxide (NO_x), and particulate matter, although each of these pollutants has been heavily regulated under the Clean Air Act by means of emission standards, mandated inspection and maintenance programs, and fuel quality standards. Moreover, because of the large amount of gasoline burned in the United States, even the very small amounts of sulfur present in gasoline can lead to significant emissions of sulfur dioxide (SO_2). (Lead, however, has been virtually eliminated from gasoline.) Burning of diesel fuel (primarily by trucks in the United States) emits NO_x, SO_2, and fine particulates (under 1 micron in diameter), some of which are carcinogenic (EPA 2000). In addition, mobile source air toxics from the combustion of gas and diesel fuel pose potential human health risks.[2] Air toxics are

[2] Mobile source air toxics include the aggregate emissions of acetaldehyde, benzene, 1,3-butadiene, formaldehyde, and polycyclic organic matter (POM). Sources of mobile toxics include cars, trucks, trains, and marine vessels.

not regulated under the National Ambient Air Quality Standards, but are still subject to regulations specified in the Clean Air Act Amendments of 1990. Moreover, in 2001 EPA set new performance standards for gasoline, requiring that refiners maintain their average 1998–2000 performance levels for air toxics. It is estimated that mobile source air toxics may account for 21 to 42 percent of urban air toxics (EPA 1998a; EPA 1998b; HEI 1999).

Efforts to reduce emissions from fuels have consisted primarily of the use of fuel additives, which generate a whole new set of potential health concerns. For example, methyl tert-butyl ether (MTBE), an oxygenate added to gasoline to reduce CO emissions, may be associated with headache, nausea, and sensory irritation in sensitive individuals, and has also been linked to neurotoxic effects and cancer in animals at high exposure levels (HEI 1996). Similarly, the health effects of the cerium-based diesel fuel additive Eolys, which has been used to reduce particulate emissions, have yet to be evaluated quantitatively, though the additive is thought potentially to target the lungs or lymph nodes at high exposure levels (HEI 2001). Alternative fuels (such as ethanol) emit their own signature suite of pollutants, including formaldehyde.[3]

The following discussion of the effects of mobile sources of air pollutants on health begins with a review of the emissions and concentrations of the various air pollutants. The health effects of these pollutants are then examined, followed by a brief discussion of approaches for determining the monetary benefits of mitigating those effects. Each of these linkages is explored in great detail in EPA's regulatory impact analyses of its ambient air quality standards and in both the prospective and retrospective analyses of the costs and benefits of the Clean Air Act and its 1990 amendments (EPA 1997a; EPA 1997b; EPA 1999a).

Emissions

Emissions of automotive air pollutants vary according to many factors, such as the following:

- VOC emissions vary with the Reid vapor pressure of the fuel and the air and engine temperature. VOC emissions also result from certain high-speed accelerations, as well as from fuel leaks and spills and from evaporation.

[3] The Clean Air Act requires areas to meet concentration standards for both gaseous and particulate pollutants. The gaseous pollutants include SO_2; NO_x; and ozone, which comes from emissions of VOCs. The particulate pollutants include lead; PM_{10} (particulates with a diameter of 10 microns or less); and very recently, $PM_{2.5}$ (particulates with a diameter of 2.5 microns or less).

- CO emissions tend to move with VOC tailpipe emissions over many operating conditions; that is, both VOC and CO emissions are high when engines are cold and speeds are low.
- NO_x emissions vary with the heat of the engine. Overall NO_x emissions have a U-shaped relationship with speed: they are high at low speeds as the vehicle accelerates, fall as the vehicle gains speed, and then rise again at higher speeds.
- SO_2 emissions are directly related to the sulfur content of the fuel.
- Road dust varies with the dryness of the pavement and the number and speed of vehicles on the roadway, as well as with certain pavement designs.

In addition to these so-called "conventional pollutants," motor vehicles emit CO_2, a greenhouse gas, proportional to the amount of fuel burned; indeed, motor vehicles are estimated to be responsible for approximately 30 percent of all U.S. emissions of CO_2 (EIA 2001). Global warming attributed to greenhouse gases has been linked to a variety of health effects, some positive (due to warmer temperatures in colder climates), many more negative (due to warmer temperatures in warmer climates), and some exotic (due to the increased range of mosquito populations). In addition, vehicle air conditioners leak chlorofluorocarbons (CFCs), a critical element in the destruction of the ozone layer, which is linked in turn to higher rates of melanoma. This problem is being mitigated over time by the phase-out of production of the most potent CFCs both in the United States and worldwide in accordance with multilateral agreements under the Montreal Protocol.

While policy discussion has focused historically on the long-term health effects of global warming, research has indicated that reductions in mobile source greenhouse gas emissions—provided these reductions are based on lowered fossil-fuel combustion—may provide immediate health benefits. In a study of four major cities, Cifuentes et al. (2001) found that adoption of greenhouse gas mitigation technologies can significantly reduce ambient particulate matter (PM) and ozone concentrations, thereby leading to large reductions in premature mortality, chronic bronchitis, and restricted activity days.

The polluting role of on-road mobile sources is captured by EPA's emission estimates for such sources. As an example, during the period 1989–1998, emissions of NO_x from these sources increased by 1 percent, whereas emissions

of the other key pollutants fell[4] [SO_2 by 50 percent, PM_{10} (particulates of 10 microns or less in diameter) and VOCs by 25 percent]—and this in spite of large increases in vehicle-miles traveled. Change in the composition of the vehicle fleet appears to have played a major role in the latter improvements, as newer vehicles meeting tighter emission standards gradually replaced older vehicles. In their study of PM emissions from light-duty gas and diesel vehicles, Cadle et al. (1999) estimate that 26.8 percent of total PM_{10} mass recorded in the study was from cars dated 1986–1990, and that only 3.8 percent of the total observed PM_{10} was from cars and trucks dated 1991–1996.[5]

Concentrations

In the atmosphere, the conventional pollutants disperse according to atmospheric conditions and their own properties (reactivity, weight, particle size). Some of the pollutants transform, often in highly nonlinear processes. For instance, SO_2 converts to sulfates (a fine particulate) in the presence of ammonia. NO_2 also converts to nitrates (a fine particulate as well) in the presence of ammonia, but the ammonia reacts preferentially with the SO_2; thus, reductions in SO_2 can lead to increases in nitrates. Similarly, VOCs and NO_x react to form ozone in the presence of sunlight. Depending on atmospheric and emission conditions, however, an area may be NO_x- or VOC-limited, meaning that reductions in the nonlimiting pollutant will not affect ozone concentrations. Also, NO_x emissions into an existing ozone-rich atmosphere will "scavenge" (i.e., reduce the concentration of) ozone. An important point to note with respect to transportation is that ozone concentrations evidence a strong association with daytime hours because of their dependence on sunlight; emissions of ozone precursors at night will not create much ozone, but will be available for downwind ozone formation in the morning. Also important for transportation, ozone and fine particulates travel long distances, so emissions in one location can affect human health in downwind locations even 1,000 miles away (TRB 1995).

With regard to trends in air quality and emissions, EPA estimates that as of 2000, 121 million people nationwide lived in nonattainment areas with pollution levels above at least one of the National Ambient Air Quality Standards (set to be protective of health). Yet EPA analysis reveals much improvement.

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[4] It should be noted that data are not available for this time period for fine particulates ($PM_{2.5}$), a particulate size of greater concern from a public health standpoint.

[5] The sample sizes of the two groups were 22 and 20, respectively.

About 85 percent of areas had downward trends in concentrations of one or more of the criteria pollutants (ozone, particulates, NO_x, SO_2, CO, and lead), while only about 10 percent had upward trends. Most of the areas with upward trends had air quality that significantly exceeded the air quality standards, while the rest reflected a lack of compliance with the new (not yet implemented) 8-hour ozone standard. Still, NO_x and ozone levels had fallen only 11 and 10 percent, respectively, overall. At the same time, some cities had experienced remarkable gains. From 1991 to 2000 in Los Angeles, the area with the most severe air pollution in the nation, the number of days for which the air quality index indicated unhealthy air fell from 168 to 48; days on which there were unhealthy levels of ozone declined from 126 to 45.

While monitoring for air quality changes is a principal means of demonstrating how well an area is doing in meeting the National Ambient Air Quality Standards, linking monitored changes in concentrations to mobile source emissions is not a simple matter. Complex air quality models are used to make "source attributions," relating emissions from various source types and source locations to concentration changes in particular receptor locations (EPA 2001b). Key issues with these models include data quality and representativeness, both of which affect the statistical validity and associated error of the models; for photochemical models, representation of the underlying chemistry of pollutant formation and dissipation is also an issue.[6]

Health Effects

In addressing the linkage between motor vehicle emissions and human health, research and discussion have focused primarily on PM and ozone. PM exposure is considered an important risk factor for cardiopulmonary disease and mortality and is associated with other health endpoints, such as chronic bronchitis. Pope and Dockery (1999) review the epidemiology of PM effects. Other studies have addressed the effects of both acute exposure and chronic exposure to PM, though the former studies are more prevalent because of the availability of daily time-series datasets. These studies, such as Dockery et al. (1993) and Samet et al. (2000b), typically have suggested an increase in the daily mortality rate ranging from less than 0.5 percent to as high as 1.5 percent per 10 $\mu g/m^3$ of PM_{10}. Chronic mortality studies, such as Pope et al.

[6] Advisory Board members acknowledge that they lack the expertise required to evaluate the detailed chemical equations of certain air quality models in any depth.

(1995), have suggested a mortality response of 3 percent or greater per 10 μg/m^3. Pope and Dockery (1999) note that these studies identify complementary effects, and suggest that the implications of chronic exposure may be more important from a public health standpoint. Chronic exposure increases the risk of chronic respiratory disease and of cardiorespiratory mortality, while acute exposure is believed to cause mortality by exacerbating existing cardiovascular and pulmonary disease, thus increasing the number of individuals in the population who die from complications related to such diseases.

While the relationship between PM and health has generally been accepted, there are large uncertainties about the relative potency of particulates by size and composition (NRC 2001). Health-based standards originally were set for total suspended particulates, but this was changed to PM_{10}; in 1997 EPA promulgated standards for $PM_{2.5}$ as well.[7] It has been suggested that particles of smaller size may be more potent because they can be breathed more deeply into the lungs (Pope et al. 1995). With regard to composition, epidemiological studies have been most robust in linking PM_{10} to health outcomes (Pope and Dockery 1992), but some very influential studies have shown a linkage to $PM_{2.5}$, and within this size category to sulfates (Wilson and Suh 1997). A number of studies have evaluated the effects of more than one size category. Krewski et al. (2000), in a reanalysis of work by Pope et al. (1995), finds that $PM_{2.5}$ has a significant association with chronic mortality, while $PM_{2.5–15}$ does not. Some acute mortality studies (Fairley 1999; Ostro et al. 2000) have reported similar findings. On the other hand, Lippmann et al. (2000) suggest comparable effects of PM_{10}, $PM_{2.5}$, and $PM_{2.5–10}$. While few studies have addressed the influence of PM_{10} on health from an epidemiological perspective, a recent study by Wichmann et al. (2000) finds that $PM_{2.5}$ and PM_{10} are similarly yet independently associated with daily mortality levels.

Within these different size classifications of PM, there is additional uncertainty about the relative toxicity of different particle types. One difficulty with pinpointing the potency of pollutants is that statistical results are often sensitive to the types of pollutants included in the analyses. In particular, some recent research (Spix et al. 1998) shows that SO_2 concentrations can overshadow

[7] PM_{10} is thought to consist primarily of crustal particles generated by agriculture, traffic, construction, or similar sources, as well as some naturally generated particles. $PM_{2.5}$ consists largely of particles from fuel combustion by motor vehicles or from power generation, as well as fine crustal particles from road dust and soils (Laden et al. 2000).

particulate effects, potentially leading to an underestimation of the potency of particulate effects in certain cases. Recent research by Laden et al. (2000) attempts to link source-specific particle types within $PM_{2.5}$ to mortality. The results suggest that particles from mobile and coal combustion sources are associated with increased mortality, while crustal particles are not. Given the finding of Cadle et al. (1999) that the majority of PM mass from vehicle emissions is $PM_{2.5}$, the finding of Laden et al. (2000) appears to be consistent with the notion of $PM_{2.5}$ as more potent than larger particulate matter.[8] Also of particular interest in Laden et al. is the finding that particles from mobile sources have a mortality effect about three times that of particles from coal combustion sources.

An additional source of uncertainty is the actual level of exposure to PM and other pollutants from vehicle emissions. Epidemiological studies typically measure ambient concentrations at monitoring stations within a locality and use these measurements as a proxy for actual exposure. The potential measurement error introduced by such an assumption has been cited as a major limitation of these studies (Samet et al. 2000a). Samet et al. note that individuals spend a small percentage of their time outside, making personal exposure levels highly dependent on the ability of pollutants to penetrate indoor spaces and on the quality of indoor air. It is perhaps even more difficult to estimate the percentage of an individual's total level of exposure to air toxics that is due to vehicle emissions, which surely varies with distance from roads and traffic density, among other factors.

However, some estimates of actual exposure exist. Cohen and Nikula (1999) cite estimates from Cass and Gray (1995) and EPA (1993) that human populations in the general urban environment are likely to be exposed to average annual concentrations of diesel exhaust of 1 to 10 $\mu g/m^3$. EPA (1999b) provides annual average exposure projections for benzene and diesel PM for a variety of locations and policy scenarios, ranging from approximately 0.25 to 0.83 $\mu g/m^3$ and 0.24 to 0.40 $\mu g/m^3$, respectively, for 2007. In-vehicle exposures, however, may be substantially higher. In their study of pollution concentrations inside vehicles on Sacramento and Los Angeles roadways, Rodes et al. (1998) find in-vehicle concentrations of benzene and PM_{10} ranging from 3 to 15 $\mu g/m^3$ and 20 to 40 $\mu g/m^3$, respectively, in Sacramento, and 10 to 22 $\mu g/m^3$ and 35 to 105 $\mu g/m^3$, respectively, in Los Angeles. Interestingly, pollutant levels in vehicles traveling in a carpool

[8] Cadle et al. (1999) found that within their study sample, PM mass from gasoline and smoking/diesel vehicles comprised 91 percent and 98 percent $PM_{2.5}$, respectively.

lane were generally significantly lower than those in the righthand, slower lanes. In addition, roadway type, freeway congestion level, and time of day were shown to have some influence on in-vehicle pollutant levels.

Ozone has been the other pollutant of interest in research and policy discussion, though there is less of a consensus in the literature regarding the mortality effects of ozone than is the case for particulate matter. In their review of ozone mortality studies, Thurston and Ito (1999) suggest about a 0.3 percent increase in the risk of premature mortality for a 10-$\mu g/m^3$ increase in daily 1-hour maximum ozone. Touloumi et al. (1997) also find an association between 1-hour maximum ozone levels and daily deaths. However, Samet et al. (2000b) report an association between ozone concentrations and mortality in the summer, when ozone concentrations are at their highest, but not over the full year. In his review of the existing literature, Schwartz (1997) finds no compelling evidence of a mortality effect.

A primary reason for disagreement in the literature is the complications that arise in modeling ozone effects. Thurston and Ito (1999) note that because ozone concentrations are highly correlated with temperature, studies that fail to control adequately for weather are likely to misrepresent the relationship between ozone and mortality. Research has also linked ozone exposure to reduced lung function, aggravation of preexisting respiratory ailments, and hospital admissions and emergency room visits linked to respiratory causes (Thurston and Ito 1999).

Because of the difference in molecular weight between ozone and fine particulates, it is not straightforward to compare the potency of these two substances on the basis of such measures as the percentage change in mortality risk per $\mu g/m^3$ change in pollution concentration. Based on elasticities computed from various epidemiological studies (where the elasticity is the percentage change in mortality risk per average percentage change in pollution concentration across the study sample), acute PM_{10}-related mortality appears to be about four to five times more potent than that related to ozone.[9]

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[9] To estimate these elasticities, the percent change in mortality rate per 1 $\mu g/m^3$ (the relative risk coefficient minus 1) taken from the literature was divided by the percent change in baseline concentration, using an average or central concentration value from the study as a baseline. Elasticities were calculated on the basis of the parameters of Samet et al. (2000b) because of the high quality of this study and because both ozone and particulate concentrations are represented in the same model. For acute mortality from particulates, the relative risk estimate is 1.005 for an increase of approximately 38 percent in the mean concentration in the study, for an estimated elasticity of 0.013. For ozone, the relative risk estimate is 1.0013 for an increase of approximately 43 percent in the central concentration in the study, for an elasticity of 0.003.

Mobile source air toxics pose the third major health concern associated with vehicular emissions. EPA has estimated that mobile sources of air toxics account for as much as half of all cancers attributed to outdoor sources of air toxics (EPA 1994). A particular concern is benzene, a known carcinogen that is a component of gasoline. Acetaldehyde, 1,3-butadiene, and formaldehyde are also "reasonably anticipated" carcinogens under the National Toxicology Program's classification system (HEI 1999). Uncertainties in estimating both the actual human exposure to these pollutants and the magnitude of the carcinogenic risk to humans are currently too great to allow for a meaningful assessment of the potential impact of reducing emissions of air toxics (HEI 1996).

Sensitive populations were identified in the process of setting the National Ambient Air Quality Standards under the Clean Air Act. These subgroups, identified through clinical, field, and epidemiological studies of the health effects of the six criteria pollutants, include children, the elderly, those with cardiopulmonary diseases, and pregnant women. Air pollution aggravates existing pathologies among these groups (Key 1998) while also affecting those with underdeveloped or vulnerable immune systems. Woodruff et al. (1997) found a relative increase in mortality risk for infants from PM_{10} exposure similar to that estimated for adults by Pope et al. (1995), though over a shorter time frame of exposure, suggesting that infants face a greater risk from exposure than adults (Pope and Dockery 1999). Cohen and Nikula (1999) describe three studies that examined the association between exposure to vehicular air pollution and respiratory health in children. Brunekreef et al. (1997) and de Hartog et al. (1997) both found evidence of an inverse relationship between indices of pulmonary function and truck-traffic density and/or black smoke concentration in schools. Similarly, van Vliet et al. (1997) found that both truck-traffic density and in-school concentrations of black smoke were positively associated with prevalence of reported respiratory symptoms. Finally, a role for socioeconomic factors in determining risk from air pollution has been suggested. For example, in their reanalysis of the work of Pope et al. (1995), Krewski et al. (2000) found evidence of an inverse relationship between mortality risk from PM exposure and education.

Monetary Benefits

Private and public preferences for reducing negative health outcomes are important to the extent that certain pollutants are more likely than others to

affect particular groups or types of health outcomes (e.g., mortality, hospital admissions, colds). Individuals make trade-offs in everyday living that reveal how much they care about reducing health risks versus meeting other needs or wants, such as spending their incomes elsewhere or arriving on time at a meeting (e.g., by driving faster than they would otherwise).

These preferences have been captured with two types of indexes—quality-adjusted life-years (QALYs) and disability-adjusted life-year (DALYs)—and with monetary values. The life-years approach involves totaling life-years saved as a result of various policies and adding this figure to years with quality-of-life improvements, thereby capturing reduced morbidity. The monetary valuation approach entails converting preferences for reducing mortality and morbidity risks to monetary measures. Both approaches rest on a variety of strong assumptions (with the QALY/DALY assumptions being more restrictive about preferences) and have significant limitations. Research is ongoing to improve these approaches and determine the advantages and disadvantages of each. The life-years approach is widely used in the health care system and has been employed in rulemakings, particularly by the Food and Drug Administration. The monetary approach is used in cost/benefit analysis and by many federal and state agencies, most notably EPA and the U.S. Department of Transportation (DOT).

Water Pollution

In the three decades since passage of the Clean Water Act, vast improvements have been made in the United States and worldwide in cleaning up water resources and preventing future pollution. Cleanup of point (or stationary) sources accounts for most of these advances; little progress has been made on reducing non–point source pollution, including the road and parking lot runoff, airport runway runoff, and railroad runoff associated with transportation.

Studies have shown that increased traffic volume in watersheds increases pollutant loads (Benfield et al. 1999). Routine vehicle operations involve leakage of brake fluid, antifreeze compounds, lubricating oil, engine oil, grease, and gasoline onto the highway surface, which can lead to the contamination of surface water and groundwater, as can the washing of fine particles from tires and road surfaces into water supplies. Routine vehicle maintenance also can result in water contamination, despite regulatory efforts to limit such contamination. Moreover, routine activities such as road repair, deicing, right-of-

way maintenance,[10] and the transport of hazardous materials pose a significant risk of polluting water resources.

People become subject to negative health effects of water pollution by drinking contaminated water (either surface or groundwater), swimming in or otherwise contacting contaminated water, or eating fish or other organisms that have come in contact with contamination or have bioaccumulated contamination in their tissues. Of particular concern is acid deposition to soil and water (as well as to forests; see Chapter 3) from emissions of SO_2 and NO_x due to burning of gasoline and diesel fuel. Such deposition leaches out aluminum, mercury, and other substances in soils, which, through runoff, can bioaccumulate in fish. In addition, there is speculation that high eutrophication levels (caused by excessive nitrification of estuaries, lakes, and streams through nitrate deposition) can trigger Pfiesteria outbreaks.

Upon discovering fish contamination, authorities may issue fish consumption advisories (FCAs) to limit the exposure of recreational fisherman and fish consumers. Direct health effects may occur until the elevated levels of pollution in fish are discovered and as a result of violations (knowingly or not) of the FCA. Economic losses to recreational and commercial fisheries (and consumers) may also result from an FCA. Such losses, while not themselves health effects, are the result of trying to limit human exposure to toxicants. None of the above linkages are well understood.

Solid Wastes

Transportation is a major generator of solid wastes through the disposal of vehicles and parts as well as construction materials. Human health effects from solid waste can occur through the release of toxic substances from scrapped vehicles or parts of vehicles. Although an active battery recycling market exists, exposure to acid or lead from batteries is a possible concern, as is exposure to heavy metals that exist in small but growing amounts in vehicle electronics. Two additional concerns are with oil from scrapped parts and vehicles and with used tires. Oil is regularly recycled through market mechanisms; however, some oil may leach into groundwater or end up in surface water. Used tires are increasingly being recycled in the United States for use in a variety of products,

[10] Most departments of transportation maintain the rights-of-way for roadways, railroads, and mass transit lines through the use of petrochemical pesticides, herbicides, and insecticides. These toxic chemicals leach into groundwater or are washed into surface water during precipitation events.

as well as to fuel industrial processes and generate electricity, yet they are still frequently discarded. There are three potential health problems associated with these tires: pollution from tire fires, pollution from the use of tires as fuel (in boilers not environmentally suited to their burning), and the contribution of tire piles to the propagation of mosquito-borne diseases. The concern with tire fires is primarily with the particulates they emit, which, as noted above, are related to excess mortality; little is known about the frequency and toxicity of such fires, however. Inappropriate use of tires as fuel is not thought to be a problem in the United States, but is a problem in Mexico near the U.S. border (Blackman et al. 2001). Finally, tires provide an excellent habitat for mosquitoes. The extent of this problem in the United States is unknown, although Blackman et al. (2001) found it to be negligible in Juarez, Mexico, where large tire piles exist.

Noise

Noise pollution—defined as any form of unwanted or unhealthy sound (FHWA 1995)—has been studied extensively with respect to air transportation, and research also has addressed the noise effects of highways and transit (TRB 1987; TRB 1990; Balachandran 1992; Wyse 1994). Studies have shown that some of the most pervasive sources of noise, in both rural and urban environments, are those associated with transportation (FHWA 1995). Noise pollution is understood to have a variety of effects on humans, in addition to the obvious direct effects of annoyance and interference with hearing (Gottlob 1985; Green 1987). For example, noise has been shown to have both auditory and nonauditory adverse physiological effects (Kryter 1994), and some studies indicate linkages between noise and hypertension (Fay 1991; Kryter 1994).

In the absence of interventions, growth in surface transportation activities is likely to increase both overall noise levels and population exposure to noise (TRB 1990; Fleming et al. 2000). Strategies to address the problem include redesign of vehicles to reduce noise from engines and tires; redesign of pavements to reduce noise production; location and design of transportation infrastructure to avoid or minimize noise transmission; installation of barriers or other devices to deflect noise away from populations; and design and retrofitting of buildings and outdoor areas to reduce indoor noise exposure, mask noise, or cancel out noise (TRB 1987; TRB 1990). The relative effectiveness of these strategies, their public acceptability, and their efficacy (in terms of noise reduction and overall effects on human health) remain topics for additional

research (OECD 1991; Job 1991; Balachandran 1992; Lansdell and Cameron 1998; TRB 1998).

Recommendations

FHWA, EPA, and other government agencies have taken on the task of developing research agendas related to surface transportation and human health. In the following recommendations, the Advisory Board proposes research that cuts across the concerns of transportation, environmental, and health agencies and is aimed at the development of a stronger understanding of fundamental processes as well as policy linkages.

Recommendation 1-1.
Develop a better understanding of "modal" emissions.[11]

While knowledge about the linkage between emissions and human health impacts is increasing, a better understanding is still needed of how the release of emissions is altered as a result of congestion and travel behavior. Until quite recently, the standard data on emissions were developed for an average vehicle speed and then adjusted by a function for higher or lower average speed. Emissions of the major gasoline-vehicle pollutants (VOCs, CO, and NO_x) are highly sensitive to acceleration, deceleration, and other driving modes. Given this sensitivity, information on "modal" emissions is needed to understand how emissions respond to changes in congestion or in travel behavior that affect driving modes. While research has been conducted on this topic, much more needs to be known before the effects of policy on emissions can be estimated reliably. This need extends to alternative-fuel vehicles (including those with ethanol additives); hybrid and electric vehicles (for which attention also should be given to emissions from power plants for battery charging); and, in the future, vehicles running on fuel cells (with consideration of upstream emissions). This need also extends to increasing the numbers and types of vehicles tested to generate emission estimates.

[11] The repository of accepted information about emissions from mobile sources is embodied in EPA's MOBILE model, which is required for use in developing State Implementation Plans to meet the National Ambient Air Quality Standards. This model has a number of major limitations, both in its goals and in its information base, which represent research needs.

Recommendation 1-2.
Extend understanding of vehicle emissions to include toxic pollutants.

Understanding of overall PM and VOC emissions has been the objective of considerable research, with the caveat about modal emissions noted earlier. However, better, more detailed characterizations of these vehicle emissions are needed in light of the increasing attention being paid to the VOCs in gasoline and the various fine particulates in diesel fuel, as well as the growing awareness of mobile source air toxics in general as possible carcinogens and contributors to a variety of respiratory ailments, immune and nervous system disorders, and birth defects.

Recommendation 1-3.
Improve the performance and implementation of air quality models.

The development of improved air quality models is critically important for appropriate assessment of the effects of mobile sources of pollutant emissions on human health, as it is through these models that one can trace changes in concentrations at given receptors back to changes in emission source locations and types. Until recently, the effects on ozone of VOCs and NO_x emissions and the effects on particulates of NO_x and SO_x emissions were modeled separately. More recent efforts have focused on the development of models that integrate the air chemistry for producing ozone and particulate species (such as sulfates and nitrates). These models are just beginning to be implemented, and significant validation, testing, and application will be needed before policymakers will trust their output. An additional concern is the data inputs to the models concerning background VOC and ammonia concentrations. Until such models are in the mainstream and the data underlying them are viewed as credible, the contribution of mobile sources to air quality cannot be assessed reliably.

Recommendation 1-4.
Improve the breadth of understanding of the toxicity of mobile source air pollution.

Mobile source emissions comprise several pollutants whose health effects are not well understood. Little research has been done, for example, on the actual human cancer risk from mobile source air toxics at current exposure levels. Likewise, understanding of the potential health risks of fuel additives such as

MTBE at low exposure levels must be augmented, particularly as the use of additives becomes more prevalent and the additives themselves more varied. While the use of additives reduces emissions and thus the health effects of more conventional pollutants, a better understanding of any potential risk trade-offs is necessary.

Finally, road dust entrained by mobile sources has been found to contribute up to 60 to 70 percent of the inventory of total suspended particulates from mobile sources. Little is known, however, about the effect of exposure to road dust on mortality or morbidity risks. A better understanding of these risks is needed so that strategies for reducing road dust can be devised and prioritized.

Recommendation 1-5.
Improve understanding of the relative potency of various air pollutants.

Although EPA recently promulgated the world's first standard for fine particulates (particles with a diameter of less than 2.5 microns), uncertainties exist about the toxicity of various particle types and sizes. Until this uncertainty is reduced, the risk remains that resources will be wasted on controlling pollutants that have little or no effect on public health, while the effects of other pollutants may be underestimated. A good example of this point is nitrates, which are formed from NO_x emissions, water vapor, and ammonia. None of the key epidemiological studies relied upon by EPA in its rulemakings provides information about the effect of nitrate exposure on health. Yet nitrates are routinely assumed to be as potent an agent of mortality risk as the average $PM_{2.5}$ particle. If this assumption were to prove incorrect and nitrates turned out to be far less potent, the rationale for controlling NO_x would be significantly weakened; if, on the other hand, nitrates were shown to be more potent, different strategies might have to be introduced. Research on this topic is sorely needed. At the same time, NO_x emissions have been shown to scavenge ozone, meaning that reductions in NO_x would, at times and in certain locations, lead to higher, not lower ozone concentrations. Also, few studies have found an effect of ozone or NO_x on mortality risk, and there is still no consensus on the effect of ozone on mortality risk. Generally, effects found are of an order of magnitude lower than those found for sulfates and $PM_{2.5}$. Research is needed to establish and rank the potency of various pollutants.

In addition, mobile sources emit a complex mixture of pollutants, making it extremely difficult to establish a direct causal linkage between emission controls (particularly driving reductions or fuel switching) and health benefits.

A better understanding is needed of the synergistic and antagonistic relationships between pollutants and their effects on human health.

Special concern: Particulate matter measured by mass. EPA's newly promulgated standard for fine particulates is stated in terms of the weight of the particles in the air, i.e., $\mu g/m^3$. However, an emerging school of thought supports measuring particles by the number of particles per volume of air, as well as by mass. Specifically, it has been asserted that the particle surface area to which the lung is exposed probably is more important for determining health effects than the mass of the particles (Key 1998). Additional research is clearly needed in this area.

Recommendation 1-6.
Improve understanding of risks to sensitive populations.

Further investigation is needed of the environmental and genetic risk factors for respiratory and pulmonary disease and the interaction between these factors. Current data and research findings suggest that an exposure–response relationship exists between high levels of air pollution and aggravated conditions among vulnerable populations. More research is needed to determine the disease-specific conditions involved, the conditions of exposure that are most important, and the long-term implications of these findings. Research on the adverse effects of transportation-related exposures for vehicle occupants, travelers on congested highways, residents and workers in buildings near heavily traveled streets, and other vulnerable groups is particularly important for planners and decision makers, who will need to devise appropriate ways to avoid, minimize, or mitigate those effects.

Recommendation 1-7.
Improve understanding of preferences for improved health.

Not all health effects resulting from air pollution are of equal importance. One criterion for allocating scarce research dollars should be to determine those health effects deemed most important by the public. Research has focused on estimating these preferences across health outcomes in terms of people's willingness to pay for health improvements. However, the context and populations involved in these economic studies may have been inappropriate for generalizing such preferences, particularly preferences for reductions in mortality risk associated with air pollution. Addressing the preferences of at-risk

populations—including the elderly and the infirm—should be a major social science research priority.[12] Research should also address parental preferences concerning children's health, including avoidance of problems that arise from fetal exposure, and how such preferences are affected by latency, dread, involuntary exposure, and other features of the air pollution context. Research should be directed as well at describing preferences through the life-years (QALY) approach and at contrasting this approach with the monetary valuation approach.

Recommendation 1-8.
Improve understanding of the relationships between transportation activities and human health with regard to pollution of water bodies and solid waste disposal.

A comprehensive accounting is needed of the many pathways by which surface transportation activities affect human health through contact with polluted water or contaminated fish or through linkages with solid waste from vehicle or parts scrappage. Greater understanding is also needed of the social and economic consequences of attempts to limit such contact, for example, through fish consumption advisories or the creation of more comprehensive recycling markets.

Recommendation 1-9.
Improve cost-effectiveness, cost/benefit analysis.

Information on emissions, air quality, health effects, and valuation is most valuable when used to choose approaches and policies for controlling pollution. To help make these choices, policymakers need information relating the costs of various approaches and policies to the anticipated benefits—either in physical or QALY/DALY terms (which implies a cost-effectiveness analysis) or in monetary terms (which implies cost/benefit analysis). Research is needed on methods for assessing the economic costs of alternative approaches and policies and for combining them appropriately with physical or monetary measures of benefits. This need is particularly acute in light of the new regulatory concern for fine particulates and the need to assess as effectiveness measures not just emission reductions, but also (because they have common precursor

[12] Research on this topic should also consider the effects of such factors as income, education, employment status, race/ethnicity, sex, and age on revealed and expressed preferences.

emissions) reductions in concentrations of both ozone and fine particulates combined. As regulations directed at transportation emissions may affect differentially the various phases of the transportation system, including the production of vehicles and their scrappage, as well as the mix of vehicles in use and the amount they are driven, research methods are needed for capturing these effects across the vehicle life cycle.

Special concern: Technological improvements. Technological improvements in transportation must be evaluated and their costs and benefits fully characterized in terms of their impacts on human health. For example, the fuel additive MTBE was introduced as a technological advance for improving air quality, but also adversely impacts water quality and thus poses potential risks to human health through both inhalation and ingestion. In the past, technological improvements designed to improve air quality have also exacerbated noise pollution. The tightening of standards for vehicle emissions of VOCs, NO_x, and CO and for the sulfur content of diesel fuel and gasoline—as well as the penetration of reduced emissions vehicles required by federal law and regulation as well as alternative-fuel vehicles—will diminish the air quality problems associated with these pollutants. But as new fuels and forms of transport emerge, so, too, will new types of pollution problems. Research efforts should outpace these major changes in transportation technology. More research is needed to understand the potential human health impacts of transportation technologies prior to their full implementation.

Special concern: Regulatory constraints. Conformity requirements in the Clean Air Act were intended to incorporate air quality considerations into transportation planning. In the process, significant requirements were placed on the transportation community not only to meet demands for reduced congestion, but also to achieve and maintain clean air goals. Some of these burdens are tied to the procedural aspects of the conformity process, others are associated with the state implementation plan process, and others are the inevitable result of tensions between the congestion and air quality goals. Research is needed to identify mechanisms for reducing these burdens and for developing constructive and cooperative ties between the agencies responsible for transportation planning and for maintaining air quality. Conduct of this research may necessitate closer linkages between air quality and transportation models.

Another regulatory issue arises because of growing understanding of the long-range transport of important pollutants, such as ozone and fine particulates. Both of these pollutants may travel across half the continent, and long-range transport is an issue for mobile as well as stationary sources. The Clean Air Act

was designed primarily under the premise that localities make their own messes and thus are responsible for cleaning them up. Understanding of long-range transport has challenged that assumption and called into question the appropriateness of making the locality (the air basin) the centerpiece of the regulatory strategy. This issue affects the locus of control of transportation emissions through transportation control measures and other, nonfederal approaches.

Recommendation 1-10.

Conduct further research on the singular and cumulative impacts of transportation-related noise.

Further studies are needed to provide data that can be used to measure the singular and cumulative impacts of transportation-related noise separately—focusing on noise annoyance, noise exposure, and the interaction between the two.

References

Abbreviations

EIA	Energy Information Administration
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
HEI	Health Effects Institute
NRC	National Research Council
OECD	Organization for Economic Cooperation and Development
TRB	Transportation Research Board

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3

Research Area 2

ECOLOGY AND NATURAL SYSTEMS

A 4-million-mile public road network carrying 200 million vehicles covers about 1 percent of the United States—equal to the size of South Carolina. A recent article published in *Conservation Biology* presenting the first calculation of the ecological effects of this road system suggests that roughly one-fifth of the total U.S. land surface is directly affected (Forman 2000).

The extent of what is unknown about the ecological effects of transportation is even more surprising. For example, no one has calculated how many streams, lakes, and wells are polluted by chemicals from roads, airport runways, and railroads, or how many species are potentially endangered because of roadkills and habitat changes. While traffic noise by highways may prove bothersome, little is known about whether it has serious negative effects on numerous native animals. Nor is it known how often the many nonnative plants along roadsides and railroads invade nearby ranchlands, farmlands, and nature reserves. In addition, research remains scarce on how well road-crossing structures for wildlife are working, as well as on the influence of road systems on habitat fragmentation and the ecology of landscapes. And compared with roads, still less is known about the ecological effects of railroads.

The current road network was essentially built prior to the first Earth Day in 1970, long before the explosion in environmental knowledge represented by modern ecology. The numbers of vehicles, vehicle-miles traveled (VMT), and traffic jams have continued to increase, along with resultant air pollutants, traffic noise, water-transported chemicals, barriers to wildlife crossing, and pressure for additions to the road network. Therefore, it is no

surprise that the cumulative damage to nature due to surface transportation continues to expand and permeate the land. Today, then, the environmental effects of the road system are extensive and growing (as illustrated in Box 3-1), yet they are barely recognized by most people and poorly understood by the scientific community.

The ecosystem services provided to humankind include drinking water, fishing, hunting, nature appreciation, swimming, aesthetics, inspiration, flood control, and more. Indeed, society demands, votes for, funds, and treasures these services. Fortunately, nature is resilient. Although the degradation is substantial, much can be done to mitigate the damage to groundwater, biodiversity, soil surfaces, native vegetation, streams, lakes, fish, and wildlife populations caused by surface transportation.

Major issues loom on the horizon, however. As noted earlier, the American population is expected to grow by another 60 million people in the next 25 years. Where the expanded population will decide to live and the resulting changes in land use are linked directly to changes in the transportation system. Similarly, it is important to estimate how many more vehicles and how much traffic will appear on the road network, as well as which roads will likely be widened and where new roads will emerge. These considerations lead to the further critical questions of how much land will be consumed for development and how many natural systems will be significantly altered or damaged by roads.

A window of opportunity now exists. The key step in exploiting this opportunity is to catalyze and integrate research on transportation and natural systems. New research methods, including displays and models for analyzing geographic information, tracking emissions of pollutants, performing DNA analyses of wildlife, and assessing road/rail-crossing mitigation designs, are beginning to offer major new insights. Research should lead to valuable results. For example, research on alternative road/rail-side designs and road/rail-crossing structures should lead to less habitat fragmentation and more-natural wildlife movement. Studies on chemicals and sediments associated with roads, culverts, airport runways, railroads, and bridges can be expected to result in more native fish populations in streams. And research on the transport of fine particles and dust from vehicle use should help produce clearer lake water and more naturally functioning ecosystems. In view of today's massive road network and vehicle fleet, such restorations of nature will not return the land to a pretransportation state. However, implementation of research results should lead to improvements in natural systems across the road network, as well as

Box 3-1

What Nature Is Like Near a Busy Highway

Consider taking a leisurely stroll or nature walk along the edge of a woods by a busy two-lane highway. The noise level quickly eliminates leisurely from your mind, especially if, say, every 20th vehicle or so is a truck. Underfoot an abundance of objects appears that could have been recycled. If you briefly emerge at the roadside, speeding vehicles evoke a new sense: danger. Drivers stare and occasionally reach for their cell phones. Busy roads and people outdoors seem incompatible.

So you move back into the woods' edge to look more closely. Many of the native forest birds seem to be missing; apparently it is too noisy for them, even quite a distance into the forest. Indeed, few other forest vertebrates—mammals, frogs, turtles, snakes—tend to be around; this must be a road-avoidance zone for them, too. If you had ventured to walk along the roadside, you might have seen roadkilled animals, though carcasses do not last long in areas populated by roadkill scavengers. The combination of a road-avoidance zone and a roadkill strip makes you suddenly realize what a barrier the busy highway is, dividing large natural populations into small ones that could be prone to extinction. Moreover, wildlife movement corridors that connect distant patches across the landscape may be severed. You wonder if this is an inadvertent collective assault on biodiversity.

Unlike the adjoining forest interior, the forest edge is commonly full of generalist "weedy" plants, some being nonnative exotics and all persisting because of the open environment of the frequently mowed roadside. The roadside vegetation growing on earth that was homogenized and smoothed during road construction appears monotonous, largely devoid of its natural heterogeneity and richness. Grasses and exotic plants tend to be abundant at the expense of native wildflowers. Straight open roadside ditches carry warmed-up water, alternating with pulses of rainwater, into a narrow wooded stream that lost its valuable curves during road construction. An array of invisible chemicals has blanketed the roadside and penetrates the forest; heavy metals such as zinc and cadmium, nitrogen oxides, hydrocarbons, herbicides,

(continued)

Box 3-1 *(continued)* **WHAT NATURE IS LIKE NEAR A BUSY HIGHWAY**

and road salt are typical. Entering the streams, wetlands, and groundwater around you, they inhibit all kinds of natural processes and are toxic to countless species.

What is it like next to a busy road? There is no place for a neighborhood walk, or a path in a park, or even a nature reserve. Here nature is both severed and impoverished. With a well-used 4-million-mile infrastructure, U.S. transportation faces a unique challenge: to reconnect nature. Targeted research undertaken now could bring us notably closer to meeting this challenge.

reestablishment and protection of near-natural conditions in areas especially important to society.

It must be recognized that the application of research results poses a formidable challenge because of dispersed data, unclear relationships between transportation and natural-resource bodies, and inertia. Nonetheless, high-quality targeted research precedes effective applications, and therefore is an immediate priority. As in the examples just given, applications based on research should produce visible results quickly, whereas if the research is not done, problems will persist, and effective applications will be delayed.

SURFACE TRANSPORTATION AND NATURAL SYSTEMS

As discussed earlier, although surface transportation includes rail corridors and managed waterways with barge transport, the focus here is on road systems. Four major groups of issues highlight the close linkage between road transportation and natural systems. These issues, together with a summary of the state of knowledge on each, are described below.

Biodiversity and Wildlife

Headlines such as "Roadkill Causes Crash," "Wildlife Corridor Severed," "Amphibian Tunnels Work," and "Rare Plant and Butterfly Discovered in Roadside" increasingly reflect the importance of this subject to society.

Roads and traffic are often mentioned in discussions of endangered species, impacts on stream fish, and the spread of exotic species. In essence, transportation's effects on biodiversity and wildlife are a primary reason why, in state after state, the public raises questions about the environmental impacts of roads and vehicles (Conover et al. 1995; *Natuur Over Wegen* 1995; Evink et al. 1999; Harper-Lowe 1999). Calls for new solutions also are increasingly heard from environmental scientists, the transportation community, and decision makers.

Only two aspects of biodiversity and wildlife associated with surface transportation are well documented: common roadside plants and animal roadkill (Bennett 1999; Fahrig et al. 1995; Romin and Bissonette 1996; Harper-Lore 1999). Many aspects remain as little-explored frontiers: rare plants; habitat heterogeneity related to construction, mowing, maintenance, and management regimes; exotic species invading from roadsides to surrounding lands; the barrier effect on wildlife movement (Fahrig et al. 1995); optimal designs of road-crossing structures for animals (Clevenger and Waltho 2000); roadside microclimate altering adjacent woods; effects of traffic noise on populations (Reijnen et al. 1996); road-avoidance zones of different animals (Rost and Bailey 1979); and designs that can reduce disturbance effects. Because the road system is so extensive, biodiversity and wildlife movement near roads are an enormously important research challenge for the nation. [Similarly, the ecological effects of rail and barge transportation are little known (Nelson et al. 2001)].

Water and Aquatic Ecosystems

Transportation facilities are a defining feature of the hydrologic system of numerous landscapes. Roads crisscross streams, rivers, and wetlands on the land surface, as well as underground lakes in the form of groundwater and aquifers. Drainage patterns are commonly blocked and altered. Thus, because of the need to control water on and around a road, road systems normally have a distinctive defined set of hydrologic conditions. Furthermore, roads typically are the places along streams and rivers where human use and the environment interact most intensively. These interactions may be benign or damaging. Highway runoff can deliver a wide range of contaminants from road surfaces to receiving streams and other bodies of water (GKY and Associates 2001). In fact, to control water on and around the roadway, highway designs usually reflect an attempt to accelerate water flows away from the

road. The result is that natural hydrologic regimes in the surroundings are altered by highway construction, and aquatic ecosystems are regularly shocked by large flushes of water and contaminant loading (Nelson et al. 2001). As a consequence, the overall environmental quality of aquatic systems suffers.

An extensive literature exists on the overall characteristics and composition of water running off of highways. These studies confirm that the wide range of human-produced materials that reach the road surface and roadside, together with spills of diverse materials, contribute heavily to contamination of highway runoff. In contrast, the effects of highway runoff on receiving streams and lakes are less well understood. Contaminants are funneled through road drainage systems to aquatic ecosystems. Some of the direct effects of this runoff on certain plant and animal species have been identified, but most contaminant–species interactions remain unknown. Perhaps more important, the direct effects of highway runoff on patterns and processes of aquatic ecosystems are poorly understood. One major constraint has been that ecosystems typically encompass both the highway and the surrounding landscape. The effects of highway runoff have been difficult to separate from those due to changing land use, permitted pollutant discharges, and natural change that may occur in the absence of a road. Furthermore, placing limits on the assessment of effects transportation systems on the environment is difficult. Separating the direct effects of the road/highway and its design from the numerous broader effects of a road, such as providing access to a new or remote area, remains a research challenge.

Ecological Effects of Air Pollutants

Transportation systems are the path for moving sources of air pollutants (see Chapter 2). Engines combusting fuel produce pollutant emissions, and the passage of vehicles generates dust and suspensions that carry pollutants away from the transportation corridor. Thus an array of pollutants consistent with the traffic volume, type, and, to a lesser extent, road surface emanate from road corridors. These pollutants have numerous effects on the environment—some short term, such as a smog alert, and others long term, such as climate change. At a local scale, wind carries an assortment of materials from roads and vehicles onto roadsides, as well as adjoining lands and communities. Dead foliage from herbicides and road salt catch the eye. Most dust and heavy metals tend to be carried short distances from the road surface. However, materials

such as sulfur dioxide, carbon dioxide, hydrocarbons, nitrogen oxide, and perhaps fine particulates may spread over a larger surrounding area and produce significant ecological effects (TRB 1997; Angold 1997; IPCC 2001). At a regional scale, ozone and nitrogen oxide sometimes accumulate in the lower atmosphere at levels sufficient to alter plants and natural communities. Globally, the greenhouse gas carbon dioxide (plus aerosol-particulate matter) is associated with climate change, which is expected to lead to a range of major ecological alterations at all scales from local to global. Some of these alterations will not only affect natural systems, but also have significant effects on the ecology of infectious disease.

Much is known about the production of pollutants from the internal combustion engine, as well as their aerial transport, destinations, and breakdown. For example, we understand the mechanisms of smog formation and can trace certain pollutants enormous distances around the globe. In contrast, the ecological effects of these airborne pollutants are much less well understood. For instance, dust and fine particles reaching Lake Tahoe and the Great Lakes are believed to be a significant cause of eutrophication, yet little is directly known about the role of road systems—adjacent, nearby, or distant—in this phenomenon. The effects of air pollutants both on terrestrial and aquatic ecosystems and on key plant and animal species need to be studied.

The ecological effects of certain locally airborne pollutants, such as salt, herbicides, and some heavy metals, are well understood relative to those of many other pollutants (TRB 1997; IPCC 2001). As a key greenhouse gas, for example, carbon dioxide is actively studied, but its ecological impacts, though assumed to be large, are uncertain. At the regional scale, ozone, sulfur dioxide, and nitrogen oxide damage certain crop plants and forest trees, but the effects on biodiversity in natural communities remain relatively obscure (Winner 1994). Similarly at the local level, studies have often focused on the relative tolerance of species to road and vehicle pollutants, instead of on the pollutants' effects on food chains or natural communities. Research appears to be scarce as well on the effects of particulates on wildlife populations, and on the ecological effects of hydrocarbons and certain heavy metals.

Landscape Ecology of Transportation Systems

Landscape ecology is a rapidly developing body of knowledge and research that represents a relatively new, highly useful, and far-reaching dimension for consideration in transportation planning and activity. Landscape ecology

(including the related areas of conservation biology and watershed science) provides principles and models that directly address habitat fragmentation, arrangements of green patches, wildlife corridors for foraging–dispersal–migration, groundwater and surface-water flow paths, effects of small populations in enclosed polygons, remote-area impacts due to human access, sources and sinks in the landscape, changing spatial patterns over time, and ecologically optimum spatial models (Forman 1995; Reed et al. 1996; Turner et al. 2001), all of which can be related to transportation networks. Focusing precisely at the scale of road systems, this approach integrates the science of ecology with spatial pattern, process, and change at the whole-landscape, or human, scale. Integrating road systems with these principles, patterns, processes, and models represents a key collaborative opportunity for engineers, ecologists, and planners (Findlay and Houlahan 1996; Canters 1997; Evink et al. 1999). The results of such collaboration should have notable application in transportation planning, evaluation of transportation projects, and overall environmental stewardship. Most important, the results should become visible on the road system and on the land.

Although transportation systems and ecological flows across landscapes operate at the same spatial scale, the two subjects have just begun to be linked (Canters 1997; TRB 1997; Evink et al. 1999). Scattered studies and research done for other purposes point to a promising frontier. Ecologists' rigorous spatial models and analyses of landscapes now need to incorporate road systems (Forman 1995; Reed et al. 1996; Turner et al. 2001). The workings of the major ecological flows and movements across the landscape should be integrated with traffic flows on road networks. Effectively incorporating principles and models of landscape ecology into transportation planning and project evaluation and meshing ecological solutions with other societal goals, such as recreation and reintegration of bisected communities, represent important research opportunities. The development of models for landscape effects near roads is a promising area for collaboration among engineers, ecologists, and planners, but will require research and testing (Forman and Alexander 1998; Forman 2000).

Recommendations

The recommendations presented below fall into the four areas discussed in the previous section. These four research foci differ markedly from the existing

research priorities and programs in transportation. While they represent largely new initiatives, the proposed work would build on strong foundations in transportation research in such areas as hydrology, sediment flow, roadside vegetation management, roadkills, traffic flows, and pollutant emissions. Funding agencies and sources both inside and outside the transportation field have shown little interest in supporting the proposed research; thus very little research is being done in most of these areas. Successful research on the topics outlined below will require expertise from both within and outside the transportation community. Thus research funding mechanisms will be required that can attract researchers from other key disciplines to collaboration with the transportation community. The results produced will then provide a sound basis for effective planning, policy, and implementation.

Biodiversity and Wildlife

Recommendation 2-1.
Expand research and thinking on the uses for and vegetation of transportation corridors in the United States.

Roadsides in the United States cover an area equal to 100,000 football fields for every state,[1] and on intensively used land, railroad rights-of-way are often refuges for rare native plants. With few ecological benefits provided, these areas represent an enormous societal resource warranting creative thinking and careful research. Roadsides today are designed primarily for the safety of vehicles that run off the road, with little attention to other values important to society, such as visibility for wildlife, absorption of some toxic chemicals, harboring of rare plants, and aesthetics. Currently, much is known about the types of roadside plants and vegetation and the relative abundance of native and exotic (nonnative) plants present in these areas (Harper-Lore 1999). On the other hand, only a partial picture emerges for rare plants at roadsides, the ecological effects of mowing, and the effects of vehicle- and road-generated chemicals.

Many important roadside-related questions remain unanswered. For example, which spatial and temporal controls are ecologically best for native plants, butterflies, birds, and whole communities (*Natuur Over Wegen* 1995,

[1] This assumes that about 1 percent of the U.S. land area is road right-of-way (TRB 1997), perhaps half of that is roadside, and a football field averages approximately 1 hectare.

Forman and Alexander 1998)? What wildlife species should and should not be encouraged by increasing food and/or cover in roadside areas? How can bridges, signs, and other road structures be designed to increase the populations of desirable species? What are the main sources for colonization of roadside exotic species, and how often do exotics spread along roadsides (Harper-Lore 1999)? Which chemical substances from vehicles and roads affect roadside vegetation and animals (FHWA 1996)? How much absorption and breakdown of chemicals occurs at roadsides, and would this increase if there were more woody vegetation and wetland? Finally, how can roadsides be designed to educate neighbors and travelers ecologically?

Recommendation 2-2.
Expand research efforts aimed at understanding wildlife movement near corridors, roadkill rates, and road-barrier effects and at developing efficient mitigation designs for road crossing by animals.

Although crashing into a large animal with a motorized vehicle may involve damage, human injury, or death (Conover et al. 1995; Romin and Bissonette 1996), roadkills overall appear to be a minor problem ecologically. Most animals simply reproduce at a rate that outpaces the losses. The exceptions include flagship species, such as the Florida panther and key deer, and some other state-level endangered species that probably suffer significant roadkill rates. Perhaps equally important are the many wildlife species whose foraging, dispersal, or migration movements are blocked by roads. These disruptions in natural movement patterns doubtless reverberate widely, affecting the nature of both natural ecosystems and production lands.

Certainly wildlife road-crossing structures capture the public's imagination (Evink et al. 1999; Clevenger and Waltho 2000). Humble salamander tunnels, "tunnels for toads," and "tunnels of love" for tiny mountain mammals serve to catalyze aficionados and draw ongoing media attention. Examples include some 30 Florida underpasses that have successfully provided groundwater to Everglades National Park, reduced the roadkill mortality of the threatened Florida panther, restored corridor connectivity for black bear populations, and been used by a wide range of other terrestrial fauna. The impressive wildlife overpasses in Canada's Banff National Park and in several European nations (with antecedents in New Jersey and Utah) are treasured by the respective national publics. A significant information base exists on the numbers of roadkill, and possible ways of reducing roadkill rates have been the subject of considerable

study (Romin and Bissonette 1996). A limited amount of research is also available on the road as a barrier to movement, including the frequencies of attempted and successful crossing by various animals.

Striking research gaps in knowledge also exist, however. For example, how does the arrangement of the surrounding landscape, including wildlife movement corridors, affect where different species tend to cross roads (Evink et al. 1999)? How does road and roadside design affect crossing location? Which species have the highest and lowest road kill rates? And what tunnel, underpass, and overpass designs are most effective and affordable for road crossing by which species (Clevenger and Waltho 2000)?

Recommendation 2-3.
Catalyze research on the effects of corridors and traffic on adjoining land, including traffic disturbance and the spread of invasive species.

People dislike the noise from busy highways, as evidenced by the noise barriers frequently used to separate busy roadways from residential communities. Not surprisingly, other vertebrates, such as birds, also appear to be sensitive to traffic noise (Reijnen et al. 1996). Recent research suggests that traditional avian habitat near roadsides is diminishing as a result of excessive noise levels produced by busy highways, which must have a large cumulative effect across America. Indeed, a similar avoidance zone has been noted for certain mammals, amphibians, and reptiles (Rost and Bailey 1979, Fahrig et al. 1995). Thus the evidence indicates that nature reserves and busy highways are incompatible. Indeed, the effect of roads on endangered species may often be tied to this avoidance zone.

More familiar is the concern with exotic species (Harper-Lore 1999). Ranchers fight range-weed invasions. Farmers spray herbicides and other pesticides against competitors and pest invaders. Park and wildlife refuge managers battle exotics threatening their prime lands. And nature conservationists decry the invaders that threaten the natural functioning of native ecosystems. Roadsides tend to be laden with exotic species, suggesting transportation as the source.

None of the above topics has been well researched. Some information is available on the avoidance zones near highways, where native mammals, amphibians, and reptiles tend to be at low density (Rost and Bailey 1979). Few, though more detailed, analogous studies are available on avian communities (Reijnen et al. 1996). The published literature on microclimate around roads

appears to be limited, though the basic principles are generally clear. These research gaps are surprising because of the potential importance of the issues involved. Research is needed to determine whether the population size and species diversity of birds within hundreds of feet, even miles, of busy roads have been sharply decreased by traffic disturbance, especially noise (Reijnen et al. 1996, Forman 2000). The effect of traffic volume on species' habitats near lightly traveled roads should also be examined. More research should be conducted as well on which endangered or threatened species are affected by roads and what solutions are best for long-term protection of such species (Evink et al. 1999, Forman and Alexander 1998).

Water and Aquatic Ecosystems

Recommendation 2-4.
Conduct further research on means of restoring natural hydrologic and sediment flows and distributions in the vicinity of roads.

Because roads interact with hydrology in many ways, developing a better understanding of the interactions between roads and hydrologic systems, along with faunal connectivity, is important. These linkages are both critical and conspicuous to society in affecting streams and their channelization/restoration, natural water tables and aquifers, wetland drainage and mitigation, peak flows and floods, stream and river migration, and other natural floodplain processes. In each case, water quantity and quality are linked. For example, road drainage that changes stream flows alters both the physical form and the habitat of the stream channel, as well as the water quality conditions within the channel, and may have a direct impact on faunal movement.

Because hydrologic conditions around corridors are the result of transportation-system design processes, the major patterns of road hydrology are well documented. It is generally clear, for example, how highway hydrology interacts with the hydrologic system of the landscape, as well as how basic geomorphic processes relate changing hydrology to changing channel form. In addition, the principles of erosion and sediment transport appear to be clear. How highway runoff might be modified to mitigate road–hydrology impacts remains a challenge, however, because that goal can be attained only through a better understanding of the specific effects of changing hydrology on aquatic ecosystems. Thus the effects of varying highway runoff levels on the stability of channels or the functioning of wetlands cannot be predicted. Likewise, the

deposition patterns of roadway-generated sediment in streams, rivers, and lakes warrants further study because of the array of ecological effects produced. Although awareness of watershed processes and management has increased in recent years, transportation systems, for the most part, still are evaluated separately from those processes. To build a foundation for mitigating the impacts of transportation systems on watersheds, a better understanding is needed of how road hydrology can be designed to meet the objectives of watershed management programs, which are increasingly focused on maintenance and restoration of environmental quality. Research on water and sediment distributions and flows that link the road corridor to the surrounding land will be key in this regard. Research should also be conducted on the various methodologies for handling and treating highway stormwater quantity and quality to prevent downstream effects.

Recommendation 2-5.

Expand research on transportation's effects on water quality, aquatic ecosystems, and fish in various bodies of water and on ecologically effective solutions.

Major and visible effects—such as shoreline alteration, reduced connection to adjacent upland, sediment filling-in, eutrophication, reduced oxygen levels, and altered fish populations—are attributable to roads altering coastal, lake, reservoir, pond, and vernal-pool ecosystems. Similarly, stream and river water quality is significantly altered by roads, as illustrated by bridge effects, eroded sediments, turbidity, reduced diversity of stream habitats, warm water from roadside ditches, movement of chemical substances, truncated food webs, and altered fish populations (FHWA 1996; Findlay and Houlahan 1996; Evink et al. 1999). However, a broader view of the cumulative impacts is critical.

Transportation systems provide a major mechanism for dispersing human influences across the landscape. This dispersion begins with single pathways, expands to networks, and culminates in increasing release of contaminants and corresponding environmental damage around the networks. The cumulative effects of transportation systems on water quality, considering all points of corridor–waterway interaction, must be recognized. Such a cumulative-effects analysis would go beyond simple toxicity determinations or parameter-specific regulation to examine the effects, both small and large, of water quality change over expansive spatial and temporal scales, focusing in particular on the functioning of aquatic ecosystems.

An extensive literature on the hydrology of transportation systems includes the effects of roads on water and of water on roads. The contaminants in highway runoff have also been widely characterized, though much remains poorly known. For example, the specific ecosystem effects of highway runoff and their relative contribution to overall environmental quality in receiving waters remain elusory. The situation is complicated by the fact that some effects of highway runoff are site-specific, while others are general; moreover, runoff may exacerbate problems created by other activities in watersheds. Although general consequences may sometimes be predicted, the information available on the aquatic effects of roads often is inadequate to support effective planning. For example, although contaminant loading can be estimated, regulatory authorities often require site-specific studies, which seldom follow a uniform protocol that would permit extrapolation to other sites. Research on certain aquatic–ecosystem processes operating over decades and centuries, as is the case with road systems, also would enhance extrapolation for planning. Thus both the state of knowledge and transportation planning would be advanced by conducting broader analyses of cumulative effects instead of the narrower analysis of transportation-related effects.

Ecological Effects of Air Pollutants

Recommendation 2-6.

Support, expand, and initiate research on the ecological effects of air pollutants from roads and vehicles at the roadside, neighborhood, regional, and global levels.

Climate change is predicted to vastly alter major areas of the United States. New rainfall and temperature conditions not taken into account in initial road designs will have to be considered by transportation engineers and planners if unplanned-for failures of road components are to be avoided. At the same time, transportation is a major source of carbon dioxide, a leading greenhouse gas linked to global climate change (TRB 1997; IPCC 2001). The ecological ramifications of climate change include inundation and movement of coastlines far inland; greater climate variability; and rearrangement of soil erosion–deposition patterns, flood zones, water bodies, agricultural crops, livestock lands, and vegetation types. Regional ozone pollution in the lower atmosphere may also inhibit plants and vegetation (TRB 1997). In addition, nitrogen oxides may alter the soil, plants, and vegetation. Usually on a more local scale,

many road- and vehicle-related materials are carried and deposited by wind, producing ecological effects; these pollutants include herbicides, road salt, dust, nitrogen oxides, and heavy metals (Angold 1997). Developing solutions that can both support viable future transportation and reduce the ecological effects of air pollutants is extremely important.

There is an extensive literature on vehicle emissions and atmospheric pollutant levels, as well as a growing literature on contaminants associated with roadways. A limited amount of information has accumulated on ecological damage associated with pollutants close to roadways. Perhaps most is known about the ecological effects of salt, herbicides, sulfur dioxide, and some heavy metals. At least some useful ecological information is probably available on the remaining air pollutants. The fate of pollutants and the underlying processes involved are incompletely understood, however. Global climate models agree that major environmental changes are probable, but the amount, timing, and spatial distribution of those changes remain the subject of much disagreement. For effective transportation planning, research is needed on the ecological effects of pollution at both regional and local scales, as well as on measures that can be used to control the sources of pollutants.

In contrast with the high-profile subjects of greenhouse gases and aerosol particulates, climate change and ecological effects remain poorly understood (TRB 1997; IPCC 2001). Much of the research on ozone has centered on plants of economic value and on forest growth (Winner 1994; TRB 1997), whereas little is known about the effects of ozone on natural-community patterns. Despite large amounts of nitrogen being deposited on land and ecosystems from nitrogen oxide, the resulting effects, especially near highways, require study. Much of the research on airborne dust, salt, and herbicides focuses on the relative tolerance of different species, rather than on understanding effects on nat grasslands, deserts, and arctic areas also warrant study. Moreover, some heavy metals are not well understood in ecological terms, while others warrant further study with regard to toxic and food-chain effects. After all, if the size and density of fine particles is important to human health, wildlife populations are undoubtedly affected as well, and these impacts require study. Furthermore, little appears to be known about the ecological impact of hydrocarbons. Finally, while the effects of sulfur dioxide on vegetation located near point sources, as opposed to those located near highways, are relatively well known, significant questions remain about carbon monoxide, PCBs, and other pollutants. In short, for all of the transportation-generated pollutants, major knowledge gaps exist in

the timing, distance, amount, and interaction of effects on plants, animals, and ecosystems.

Landscape Ecology of Road Systems

Recommendation 2-7.
Develop road-network models and approaches for reducing habitat fragmentation, population extinction, wildlife-corridor, and remote-area impacts.

Road systems link human communities together and provide access to landscape and regional resources. However, the same networks slice the land and nature into pieces. Large mammal populations, fire, floods, and other important ecological characteristics are sensitive to road density (e.g., number of road-miles per square mile) (Findlay and Houlahan 1996, Forman and Alexander 1998). Yet the form of road systems, less well explored, is doubtless a better ecological predictor and basis for planning. Habitat fragmentation is widely cited as a major cause of declining biodiversity (Reed et al. 1996; Canters 1997). Road systems may play a role when a population is reduced and genetic inbreeding thus increases, with both processes heightening the risk of local extinction (Reh and Seiz 1990; Fahrig et al. 1995). Road networks also disrupt nature's networks of green patches and corridors across the landscape, while remote roads built to provide human access result in disturbance to natural populations and communities.

A fair amount of information on the effects of road density on large mammals exists, although not on many other ecological aspects (Forman and Alexander 1998; Evink et al. 1999). Moreover, a limited but useful literature is available on the human impacts in remote areas and on the disruption of wildlife corridors. Some information developed in other fields may be useful for developing models of alternative road-network forms. Some information is available on reducing habitat fragmentation. However, little is known about small populations or genetic inbreeding leading to extinction relative to road networks (Reh and Seiz 1990), though the theory has been reasonably well developed in other domains.

Existing knowledge gaps in this area are significant. Issues that need to be examined include which road and roadside designs are crossed most successfully by animals and therefore serve to reduce habitat fragmentation (Romin and Bissonette 1996); which temporarily closed or permanently removed roads in a network best reduce human-access impacts in remote areas or produce the

greatest ecological gain; which network designs best concentrate or distribute traffic disturbance impacts (e.g., how different road networks alter natural ecosystems and biological diversity by affecting fire frequency, size, and control); and what ecological form is best for a road network in a forestry landscape or, alternatively, in a rapidly developing exurban fringe area where roads are to be built (Reed et al. 1996; Findlay and Houlahan 1996).

Recommendation 2-8.

Foster collaborative landscape-wide environmental analyses by engineers, ecologists, and planners, with an emphasis on combining ecological solutions with other societal objectives.

Landscape ecology integrates traditional ecology with spatial patterns at the landscape or regional scale, precisely the scale of road systems (Forman 1995, TRB 1997). If transportation planners incorporated landscape ecology in the planning process for both improvements and additions, many useful insights might be anticipated (*Natuur Over Wegen* 1995; Canters 1997; Evink 1999). For instance, promising solutions should emerge to address ecological flows and movements across the landscape, including wildlife routes for foraging, dispersal, and migration; groundwater and surface-water flows; sediment and chemical sources, routes, and sinks; and sources and sinks for air-transported materials. In effect, how natural systems in the landscape work and how they interact with the road system would be elucidated. Further benefits would include an understanding of landscape spatial patterns, their linkage to the road system, and their changes over time, as well as ecological spatial models with and without the road system. The principles and models thus derived would aid in targeting restoration actions for a road system built largely in another era. Engineers and ecologists also would find much common ground in the environmental stewardship of transportation.

While transportation primarily provides safe and efficient transport, its secondary goals include maintaining ecological systems, public health, viable communities, and more (see Chapter 1). The basic infrastructure is in place. Thus, opportune times to accomplish goals related to natural systems are during maintenance, redesign, and upgrading of projects (*Natuur Over Wegen* 1995, FHWA 1996). Combining ecological and other public goals in the same project is an additional gain and—based on good research—should become the norm.

A scattering of useful studies appears to exist on using landscape-wide analysis to repair ecological damage, evaluate transportation projects, and

mesh ecological and other societal objectives. A road-effect-zone model has been proposed and tested (Forman and Alexander 1998; Forman 2000). When a road or bridge is enlarged, an opportunity exists to enhance wildlife crossings, create recreational paths, and reconnect a community bisected by the road. Systematic interdisciplinary research is needed to fully capitalize on this highly promising area.

Recommendation 2-9.
Stimulate research on understanding public preferences for improvements in natural systems of both short- and long-term significance to society.

Both transportation and natural systems serve and generate support in society. Natural-resource economists seek monetary valuations of natural systems or components thereof. For instance, what are people willing to pay for a clean aquifer, an endangered species, or a distant wildlife refuge? Broadly speaking, values underlying public support can be divided into "use values" (e.g., a clean aquifer for drinking water) and "existence values" (e.g., the simple existence of an unseen wildlife refuge). Native foods and medicinal plants and vegetation along streams provide direct services to society. Their value is often less difficult to estimate, and tends to be lower, than existence values such as those of natural ecosystems for aesthetics or inspiration.

Research linking these issues to transportation is scarce. Yet to set planning and policy priorities for addressing the diverse dimensions of natural systems, it is important to consider people's preferences and consequent public support when allocating scarce resource dollars. The research challenge includes not only understanding the attitudes of different groups of people, but also determining what is included in the valuation and developing the best methodologies for conducting the valuation. For example, the closing of a forestry road that borders a fragile pond and favorite fishing spot could be valuated on the basis of accessibility, or accessibility plus the fishing equipment used and the store where it would be bought. Furthermore, some implementation actions, such as restoring a trout population or planting shrub cover for deer, provide a short-term ecological gain. Others provide a long-term sustainable value for society, such as altering land uses to prevent eroded sediment from filling a key reservoir or planting trees far from a road for future harvest. Such long-term values, so important for planning and policy, may deserve but not receive strong public support.

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Abbreviations

FHWA	Federal Highway Administration
IPCC	Intergovernmental Panel on Climate Change
TRB	Transportation Research Board

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Research Area 3

ENVIRONMENTAL AND SOCIAL JUSTICE

Concerns about the community impacts of transportation projects have been voiced since the 1950s and 1960s, when community leaders first challenged proposals to build freeways through inner-city, minority neighborhoods and commercial districts.[1] Citizens opposed to freeways in the 1960s and 1970s used a variety of methods—from demonstrations, to political action, to litigation—to slow or stop freeway construction through urban neighborhoods (Lupo et al. 1971; Colcord 1974; Dittmar 1996). Following passage of the National Environmental Policy Act (NEPA) in 1969, the anticipated environmental effects of government-funded projects had to be documented and mitigation measures proposed. Citizen groups questioned many of these reports, in particular for their adequacy in documenting community impacts. NEPA and civil rights statutes were both used to challenge transportation projects that appeared to have disproportionate negative consequences for the poor, people of color, and the politically disenfranchised (National Commission on Urban Problems 1969; Baldassare 1997).

[1] One early freeway controversy occurred in Boston in the 1950s, when the Central Artery was proposed to be routed through the site of the Chinese Merchants Association building, a recently completed symbol of community pride in Boston's Chinatown. The controversy was resolved by placing the road in a tunnel, avoiding the building. During this period, however, most urban analysts and journalists were favorably inclined toward freeways. Two notable exceptions were Lewis Mumford and Daniel Patrick Moynihan, who warned that freeways would likely disrupt the urban fabric.

In successive highway bills in the 1960s and 1970s, Congress responded to community concerns regarding transportation impacts by expanding citizen participation and requiring increasingly detailed analyses of social, economic, and environmental effects. Reflecting legislative mandates, a National Cooperative Highway Research Program (NCHRP) project in 1975 set forth basic approaches for "highway agencies that were . . . evolving into transportation agencies . . . [and] asked to consider a broader range of possible direct and indirect social, environmental, and economic effects in all aspects of their decision-making" (Manheim et al. 1975). Three key findings of this research informed the proposed approaches: (*a*) "social, economic, and environmental considerations" in transportation planning are important because "inevitable conflicts among competing interests" must be resolved; (*b*) "social equity must be explicitly recognized and taken into account in transportation decision-making"; and (*c*) "different groups of people can be expected to have different interests and different priorities." The report presents a proposed new approach to transportation planning and decision making that relies on ongoing community involvement; considers a wide range of alternatives; and produces information on social, economic, and environmental impacts in ways that clarify their magnitude and incidence.

Almost two decades later, Congress renewed the call for consideration of social, economic, and environmental effects in transportation planning and decision making for both highways and transit with passage of the Intermodal Surface Transportation Efficiency Act (ISTEA),[2] a call that was reiterated in the Transportation Equity Act for the 21st Century (TEA-21). Today, earlier recommendations regarding social equity and environment are being revisited not only by transportation professionals, researchers, and policymakers, but also by the affected population groups. Their common task is to establish a more equitable transportation system characterized by choice in mode, high-quality access, and equity in spending for operations and infrastructure.

[2] ISTEA listed social, economic, and environmental factors to be considered in both state and metropolitan transportation planning. In addition, the act declared that the national transportation system should include "significant improvements in public transportation necessary to achieve national goals for improved air quality, energy conservation, international competitiveness, and mobility for elderly persons, persons with disabilities, and economically disadvantaged persons in urban and rural areas . . ." (ISTEA declaration of policy).

Surface Transportation and Environmental and Social Justice

The concept of "community impact" has broadened during the past 30 years. In the 1960s and 1970s, impact studies focused primarily on the direct effects of highways and transit investments on economic development and community vitality, on regional levels of transportation system–generated air pollution, and on corridor noise levels. Today, attention is equally devoted to such issues as the effects of transportation investments on metropolitan patterns of growth and decline, neighborhood quality, the comparative accessibility of jobs and other important activities, the impacts of transportation noise and air pollution on different population groups, and differentials in per capita spending for transit. Increasingly recognized as well are the varying transportation needs and interests of men and women, children and adults, the elderly, and those with differing physical or mental abilities.

Civil rights have become a prominent consideration in transportation,[3] as has the related notion of environmental justice.[4] Though first used in connec-

[3] Title VI of the Civil Rights Act of 1964 has two provisions, known by their U.S. Code designations as Sections 601 and 602. Section 601 bars racial and ethnic discrimination in any federally funded program. Section 602 authorizes federal agencies to promulgate rules and regulations implementing section 601. The Department of Transportation's (DOT's) regulations explicitly prohibit actions that result in a disparate impact upon minorities. According to 40 Code of Federal Regulations (CFR) 7.35 (b) and (c), "(b) A recipient shall not use criteria or methods of administering its program which have the effect of subjecting individuals to discrimination because of their race, color, national origin, or sex, or have the effect of defeating or substantially impairing accomplishment of the objectives of the program with respect to individuals of a particular race, color, national origin, or sex. (c) A recipient shall not choose a site or location of a facility that has the purpose or effect of excluding individuals from, denying them the benefits of, or subjecting them to discrimination under any program to which this Part applies on the grounds of race, color, or national origin or sex; or with the purpose or effect of defeating or substantially impairing the accomplishment of the objectives of this subpart." Administrations within DOT have promulgated regulations for their own specific programs. For example, the Federal Highway Administration has promulgated regulations pursuant to Title VI that require state agencies to conduct annual reviews to ensure compliance, require state highway agencies to develop procedures for the collection of statistical data on participants in and beneficiaries of state highway programs, develop Title VI information for dissemination to the public (and, where appropriate, in languages other than English), and establish procedures to identify and eliminate discrimination.

[4] Work in the 1980s indicating that low-income and minority communities disproportionately housed toxic waste disposal sites led to a series of organized citizen actions that has come to be known as the environmental justice movement. In 1991, advocates adopted "Principles of Environmental Justice" (1991), which have since been widely disseminated. Executive Order 12898, promulgated in 1994 to further the implementation of Title VI civil rights provisions, is commonly

tion with toxic waste sites, the term "environmental justice" commonly refers today to the equitable distribution of both negative and positive impacts across racial, ethnic, and income groups (with environment being broadly defined to include social, economic, and ecological effects). Environmental justice advocates, along with others supporting community reinvestment, have focused their attention on the distribution of transportation benefits and costs and have begun to seek transportation investments that will increase social equity, improve access and mobility among disadvantaged populations, and help improve the quality of life in low-income and minority neighborhoods.

This increased emphasis on the incidence and distribution of costs and benefits is generating new demands on the transportation planning process. Methods that can be used to disaggregate impact information and display effects on different communities and socioeconomic groups are increasingly needed in place of, or as complements to, existing methods and measures. Both metropolitan planning organizations and community groups have been trying out new techniques of data collection and analysis that provide information by neighborhood and city, race and ethnicity, sex and age. At the same time, community members not only are seeking additional information about transportation investments and their impacts, but also want to bring about substantive changes in transportation policies, programs, and projects. In some cases, recognizing the value of transportation research and analysis in achieving these objectives, they have sought to reproduce and test current transportation models and evaluation measures on their own, and have conducted original research that has resulted in important findings (see, e.g., Almanza and Alvarez 1995; Grimshaw 1995; Mann and the Planning Strategy Center 1996).

In this chapter some of the key findings emerging from studies of transportation equity and the distribution of transportation impacts are reviewed,

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known as the Executive Order on Environmental Justice. It called for federal agencies to develop environmental justice strategies that (*a*) promote enforcement of health and environmental statutes in low-income and minority areas; (*b*) "ensure greater public participation"; (*c*) improve research and data collection; and (*d*) "identify differential patterns of consumption of natural resources among minority populations and low-income populations." In response to Executive Order 12898, in April 1997 DOT issued an order that provides guidelines for Title VI compliance. Programs that may disparately affect racial and ethnic groups are permissible only if they can be justified by a "substantial need for the program" and if the alternatives would have "other adverse social, economic, environmental or human health impacts that are more severe" or if they would involve higher costs "of extraordinary magnitude." The Order explicitly prohibits judicial review, and states that its purpose is simply to regulate the functioning of the executive branch, not to establish substantive rights. Shortly thereafter, the various federal agencies that comprise DOT began to advance internal policies reflecting these principles.

and recommendations for an initial program of research in this area are presented. In keeping with the dual charge of the Advisory Board, both environmental and planning issues are examined. Throughout this chapter, people of color are often referred to, as is typical in the literature, as belonging to "minority communities." The terms "lower-income" and "economically disadvantaged" are used interchangeably to describe those in the bottom one-quarter of the U.S. income scale. Demographic data show that people of color typically account for more than 50 percent of this income group, and many are also women, children, or elderly (U.S. Bureau of the Census 1999). A high percentage of this group lives in poverty; indeed, despite economic gains in the 1990s among much of the U.S. population, reports of deprivation and inability to purchase food, health care, and clothing are as widespread now as in past decades (Pew Research Center for the People and the Press 1991).

The natural and built environments and the quality of life in a community are inextricably linked to the distribution of transportation system impacts and the social equity of transportation policies and programs. Research carried out during the last decade has only begun to reveal the varied travel needs of different population groups, and to identify planning processes and substantive solutions that can address long-standing concerns about transportation equity and disparate impacts. A decade after the passage of ISTEA, there remains a compelling need for better methods of planning, evaluation, community involvement, and decision making to ensure that environmental and social justice goals are achieved. Some of the fundamental research questions related to transportation, environmental justice, and social equity that must be addressed if those goals are to be met are explored in the remainder of this chapter.

Differences in Mobility, Access, and Travel Behavior

A growing body of research conducted at the national level or for particular regions has identified significant differences in mobility, access, and travel behavior across racial and ethnic groups (Myers 1997; Zmud and Arce 2001; Polzin et al. 1999), across age groups (Myers 1997; Burkhardt and McGavock 1999), and by sex (McGuckin and Murakami 1999; Mallett and McGuckin 2000; Spain 1997). The research suggests, among other things, that minorities are more likely than whites to use transit (Polzin et al. 1999); that women drive more than men, mainly because they shoulder greater responsibilities for home work and children's transportation (Rosenbloom and Burns 1993);

and that older people are driving more at more advanced ages than they did in the past, resulting in an increased number of accidents among this age group despite the widespread adoption of coping mechanisms (Rosenbloom 1988.)

While this research has provided important evidence on the differing travel behavior and transportation needs of specific population groups, it has done so in a very limited way. In particular, the available studies have not always controlled for other possible explanatory factors, most notably income. Nor has most of the research examined changes in travel behavior over time or accounted for likely changes in behavior under varying conditions of transportation supply and cost. In addition, very little work has examined the policy implications of observed differences in behavior, especially with regard to variations among racial and ethnic groups. There is a large body of work on the transportation needs of the disabled (e.g., Rosenbloom 1981; Rosenbloom 1994); a modest but growing body of work on the needs and concerns of the able-bodied elderly (e.g., Rosenbloom 2001); and a growing but very recent body of work on the travel concerns of current and former welfare clients (e.g., Blumenberg et al. 1998; Chapple 2000). But relatively little work to date has focused on how well various transportation strategies address the observed needs of children, of women versus men, of poor people who have not received public assistance, or of different racial and ethnic groups.

Alternative policy instruments and their differential consequences for costs and affordability have also been explored only briefly. Compared with other important consumer goods such as food, housing, and public utilities, relatively little work has been done relative to transportation to set standards for affordability or to examine how affordability is affected by different policy instruments. Thus while it is understood that low-income households pay a higher share of their income for transportation (and most other necessities) than do more affluent households, there is no equivalent in transportation policy to Section 8 housing subsidies or food stamps.[5]

A limited amount of research has been conducted on the impact of transit fares on low-income groups (e.g., Cervero 1984). Very little work has been done on whether and how a lack of income constrains travel and activity

[5] According to the Consumer Expenditure Survey, households with incomes between $12,000 and $25,000 spend 27 cents of every dollar on transportation; for those with incomes below $12,000, the share is 37 cents of every dollar. This compares with less than 18 cents on the dollar for the average household.

choices for travelers of either sex or any age or ethnic group. There has been some research on the socioeconomic effects of alternative taxation methods (e.g., Cameron 1994; Wachs 2001) and pricing strategies (e.g., Deakin et al. 1996), but relatively little work on how broader investment choices, such as highway versus transit investments, affect different racial, ethnic, or income groups or how such choices affect women versus men.

The Concept of Environmental and Social Justice

Civil rights and environmental justice have been the impetus for a number of challenges to transportation programs and projects in recent years, including cases concerning the provision of transit service and the siting of highways. Some of these conflicts have resulted in litigation.[6] Underlying these controversies are concerns not only about the adverse effects of transportation projects on different population groups, but also about the fairness of the decision-making processes involved. While a recent court decision may reduce litigation over alleged disparate impacts of transportation projects,[7] transportation professionals and community leaders continue to seek ways of ensuring the fairness of the planning process and the equity of the resulting plans and investment programs. Research on equity, or justice, is particularly relevant to today's and tomorrow's transportation planning and decision-making processes.

According to one definition, justice means having a basis in fact and following established rules and procedures to produce an impartial result. Impartiality, or the absence of prejudice or favoritism, was Cardozo's definition of fairness and justice under the law (Cardozo 1948). Yet long-standing tradition

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[6] See, e.g., *The New River Valley Greens, et al. v. U.S. Department of Transportation.* T1996 U.S. District LEXIS 16547, Civil Action No. 95-1203-R (U.S. District Court, W. Dist. of VA), *affirmed* 1997 U.S. App. LEXIS 32166; 46 ERC (BNA) 1155 (4th Cir. 1997); *Coalition of Concerned Citizens Against I-670 v. Damian,* 608 F.Supp. 110, 127 (S.D. Ohio 1984).; *Tolbert v. Ohio Department of Transportation,* 992 F. Supp. 951, 953-56 (N.D. Ohio 1998); *Labor/Community Strategy Center, et al. v. Los Angeles Metropolitan Transportation Authority,* 263 F.3d 1041; 2001 U.S. App. LEXIS 19410; *New York Urban League, Inc. v. Metropolitan Transportation Authority,* 905 F.Supp. 1266 (S.D.N.Y. 1995), *Community for a Better North Philadelphia v. SEPTA,* 1990 WL 121177 (E.D.Pa. 1990).

[7] In the recent decision of *Alexander v. Sandoval,* 532 U.S. 275, No. 99-1908 (April 24, 2001), the U.S. Supreme Court ruled 5 to 4 that private individuals cannot bring a lawsuit to enforce regulations promulgated under Section 602. The case does not affect aggrieved parties' rights to appeal for relief to administrative agencies such as the Federal Highway Administration and the Federal Transit Administration.

supports the idea that justice does not always mean treating everyone in the same way. For example, the law considers context, evaluating the circumstances in interpreting the facts. In addition, in Anglo-American jurisprudence, equity developed as a formal body of doctrines and rules of procedure designed to supplement, and if necessary override, common law and statutes to protect substantive, fundamental rights of individuals. The law of equity addresses those circumstances in which the "ordinary" rules, applied in a blind or narrowly rigid fashion, would produce a result that violates the notion of justice in another sense: that a just result is a good one. Today both the law of equity and the rules of administrative procedure directing how government should operate recognize that due process may require varying rules and approaches to reflect acknowledged differences in circumstances (Deakin 1999).

Rawlsian conceptions of justice offer a still broader notion of equity. Rawls based his theory of justice as fairness on two principles: the first dictates equality in the assignment of rights and duties; the second holds that social and economic inequalities are just only if they result in compensating benefits for everyone, and in particular for the least-advantaged members of society (Rawls 1971). The idea that justice necessitates an examination of the distribution of gains and losses and sometimes requires compensatory action has been a powerful one for planners (Davidoff 1975; Krumholz and Forester 1990), and work on the distributional consequences of public policies has provided an important factual basis for reforms.

Research and policy studies have demonstrated that discrimination has occurred in the provision of public services, from the paving of streets and installation of sewers to the delivery of quality education (see, e.g., Ratner 1968; Inman and Rubenfeld 1979; Haar and Fessler 1986; Gillette 1987). Researchers have also sought to address unfairness in the allocation of public burdens, from the routing of highways through inner-city neighborhoods to the siting of landfills, incinerators, and hazardous waste disposal sites (Lazarus 1993; Been 1993). The latter studies have consistently shown that neighborhoods having these locally undesirable but regionally necessary facilities tend to be poorer and to house a higher percentage of minorities than other neighborhoods. It is less clear, however, whether this result is due to discriminatory siting practices or to other forces that lead minorities and the poor to settle in impacted areas—such as racial and ethnic discrimination; a shortage of affordable housing; and constraints on the availability of jobs, transportation, and services (Been 1993). Because appropriate remedies depend on the causes of a problem, research is needed to better understand infrastructure siting

processes, household location decisions, and other factors that lead to disproportionate impacts (Bowen 2001; Foreman 1998; Dobson 1998; Gelobter 1992). Research is needed not only for new projects, but also for situations in which adverse community impacts already exist (Bowen 2001). This research could augment current studies that use available data on demographics, travel patterns, ridership, and impacts to show the incidence of impacts (see, e.g., Camacho 1998; Faber 1998).

Box 4-1 describes a number of environmental justice actions taken by transportation advocacy groups in lower-income and minority communities. While in some instances the advocacy groups opposed particular government programs or projects, in each case the groups proposed other approaches that in their view involved preferable social, economic, and environmental consequences. Many of the advocacy groups specifically linked transportation improvements with additional measures that would produce a cleaner environment and expanded economic opportunities (e.g., investments in revitalization of community retail areas, park cleanup).

A review of these and other community actions leads to the following conclusions:

- Transportation is a major issue for low-income and minority communities, tied to the quality of daily life and economic well-being.
- Despite federal legislation during the last decade mandating public input into transportation planning and development in low-income and minority communities, many are dissatisfied with the processes used for this purpose.
- Low-income populations and communities of color are increasingly challenging the equity of transportation agency policies for the funding and operation of public transportation systems.
- Organizations representing low-income groups and communities of color increasingly are carrying out their own analyses of transportation issues. They are developing research techniques, models, and data collection methodologies that can be used to develop alternative transportation policies and spending scenarios for comparison with those promulgated by local transportation agencies.

Equity of Transportation Costs and Funding

As the cases in Box 4-1 illustrate, during the past few years community members in several large U.S. metropolitan areas have taken action to address inequities

Box 4-1

Transportation and Environmental Justice: Some Recent Examples

The **Clean Buses for Boston Coalition** movement began in the lower-income South Boston/Roxbury area to combat what the communities considered to be inequities in transit service. The motivation for the movement was public health statistics showing a disturbing increase in asthma among younger children and young adults in the area. Community leaders began to research the causes of the asthma problem and found a linkage to diesel emissions. Because diesel buses tended to idle for extended periods at street corners in the neighborhood, the assistance of the Massachusetts Bay Transit Authority was solicited. The coalition also conducted research, collected data, and made recommendations for alternatively fueled buses and changes in operating procedures.

In Austin, Texas, predominately low-income Hispanic communities headed by **PODER** have been fighting for equal financing of public transportation systems for their residents. Members, who include academics and researchers, have developed models for analyzing improvements in basic transit services. In addition, the community has developed a public monitoring system that tracks transportation decisions, policies, and recommendations.

The **Labor/Community Strategy Center Bus Riders Union,** representing several hundred thousand riders in East and South Central Los Angeles, argued against diverting transit funds from bus services to light rail and urged the Los Angeles Metropolitan Transit Authority (MTA) to instead upgrade the buses and keep them running at an affordable cost. The MTA had been spending 30 percent of its funding on buses and 70 percent on light rail, while the buses carried almost 94 percent of total transit customers. About 80 percent of the bus riders were people of color.

In Harlem, the **NYC Environmental Justice Association** has taken steps to get the New York Transit Authority and the New York metropolitan planning organization to change their policies on siting transportation infrastructure facilities, such as bus maintenance depots, in communities of color.

(continued)

Box 4-1 *(continued)* **TRANSPORTATION AND ENVIRONMENTAL JUSTICE: SOME RECENT EXAMPLES**

Using a geographic information system (GIS), the investigators found six transit diesel facilities in a 7.4-square-mile area near playgrounds and schools, and more were planned. No other area of the city showed a similar pattern of transit facility operations.

Chicago community activists teamed with organizations such as the Center for Neighborhood Technology to gather GIS and economic data showing how light rail improvements would benefit both the city and communities of color economically while costing less than abandoning the lines altogether. The Campaign for Better Transit brought low-income Chicago residents and those from the Gold Coast together after providing research findings indicating how bus line closures would cause disruption to both communities.

Sources: Almanza and Alvarez (1995); Grimshaw (1995); Garcia (2000); Mann and the Planning Strategy Center (1996). Case study summaries taken from expert panelist participants at the Title VI/EJ Expert Panel Forum, sponsored by the Federal Transit Administration and convened by Planners Collaborative and Alternatives for Community and Environment, Roxbury, Mass., June 6, 2001.

in transportation costs (particularly fares), services, and funding. Transportation investment disparities have also been identified in rural and suburban areas where low-income populations reside (Dittmar and Chen 1995). Case studies of funding disparities have shown, for example, that heavily used bus services in low-income communities and communities of color were cut back or had to rely on old, poorly maintained equipment, while new investments with high levels of amenity were provided in wealthier suburban areas (Wypijewski 2000; Mann and the Planning Strategy Center 1996). A few cases also documented the community coalitions that successfully changed these conditions (Grimshaw 1995).

While these cases expose the problems and sometimes describe successful remedies, few of the available studies document how the disparities came to exist—whether they were exceptions or commonplace, the result of policy decisions or unintentional. Nor do the studies document how corrective

actions were developed or explain whether the actions taken addressed only the particular situation or led to more general and permanent policy reforms. In short, the available cases rarely provide enough detail to allow generalizations to be made about their causes, effects, and cures. And for the most part, the cases lack sufficient specificity for their solutions to be easily adopted by others who may be facing similar situations.

As noted earlier, transportation research has shown that minorities and low-income households are more dependent on public transport than is the U.S. population as a whole, although this effect declines with income and, for immigrants, with length of time in the United States (Polzin et al. 1999; Myers 1997). Because so many people of color and minority and low-income individuals are transit users, the relatively low level of funding available for transit can have significant mobility implications, as well as environmental and social justice consequences. Research on alternative methods for financing transit and for improving service to make it more attractive to a wide range of users should address these issues by including an explicit analysis of the distribution of benefits and costs according to income, race, and ethnicity.

Many low-income workers are dependent on automobiles for much of their transport, in many cases using older vehicles.[8] The costs of automobile ownership and operation are affected by public policies in myriad ways, many of which are devised to meet environmental objectives. These policies in turn have impacts that vary with household income, but for the most part, the distributional consequences are not well understood. Studies have examined the equity effects of parking pricing policies, safety and emission standards, vehicle scrappage programs, and insurance costs, among other factors (see, e.g., Deakin et al. 1996; Cameron 1994; Dill 1998). But most of the studies are for a single state or region, often California, and in many instances the researchers were able to investigate only a few broad income levels and not the full range of socioeconomic issues of interest. A wider range of investigation is warranted.

[8] Congress noted in TEA-21 that fewer than 6 percent of those on welfare owned an automobile, and a General Accounting Office (1998) report cites a 1997 U.S. Department of Health and Human Services study showing that for those 6 percent, the average reported value of their vehicle was $620. While the majority of low-income households have never received welfare or faced its restrictions on automobile ownership, they, too, tend to have fewer cars than their more affluent counterparts, and the vehicles they own are of relatively low value.

Policies regarding street maintenance and traffic operations also are issues in many economically disadvantaged communities. Maintenance disparities have been documented by some researchers along with policies that tend to produce or exacerbate these disparities (Bullard et al. 2000a; Bullard et al. 2000b; Wilner 2000). Adverse consequences of these disparities can include neighborhood exposure to higher levels of noise, as well as reduced safety and more wear and tear on vehicles traversing poorly maintained roads.

The high traffic levels often present in low-income and minority communities also can be detrimental to the quality of the community environment, resulting in increased noise and congestion, reduced comfort and convenience for pedestrians, and reduced levels of neighborhood and community cohesion (Appleyard 1980). Here, too, policies on traffic management, especially those that call for resident finance of data collection or remediation, can result in disparate availability of remedial actions (see, e.g., Weinstein and Deakin 1999). While there is general agreement that funding mechanisms (e.g., reliance on abutter assessments and property taxes for local transportation improvements) often produce such disparities, generally by reflecting or magnifying underlying income differences, little work has been done to identify alternative methods of transportation finance that would be more equitable.

Equity Impacts of New Technology

Intelligent transportation systems and other technological advances are becoming important strategies for many state and local transportation officials. Transportation technology can result in cleaner, safer, more reliable, more convenient, and more efficient transportation (see also Chapter 5). An important equity issue is that many of these new technologies are or will be available only to those who can afford to invest in them and can learn to use them. For example, those who have a home computer and know how to use it can obtain traffic advisories and route information; those not so equipped find it much more difficult to obtain such information. A "digital divide" will exacerbate existing disparities in access and mobility (Mack 2001).

Studies of how different technology implementation pathways might affect various racial, ethnic, and income groups differentially are warranted. Research in this area could involve examining access to and use of such new transportation technologies as smart cards, electronic toll tags, and onboard and hand-held route guidance systems.

It is important to note that new technologies may offer ways to overcome or offset disparities associated with transportation. Work is already proceeding on determining how technological advances could be used to increase the equity and accessibility of transportation systems for disadvantaged populations, for example by making distance-based fees and fares practical or by providing an "invisible" discount to qualified low-income travelers (see, e.g., Bushnell 1995; Fleishman et al. 1996). More work of this sort is clearly needed.

Analysis Methods and Equity Issues

For years transportation planners have used models for forecasting travel demand and evaluating system improvements. Most of these models produce aggregate estimates of travel choices and traffic flow without regard to cultural and racial differences in opportunity and preference. Neither the sex nor the age of the traveler is considered, unless the traveler is too young to have a driver's license. Likewise, racial and ethnic differences are typically omitted from the model specification. While income enters into most standard models in relation to time (and value of time) and cost variables, the typical models use aggregate data (often zonal averages) that mask disparities in income and ability to pay (Harvey and Deakin 1993). When air quality and noise models are used, they typically are applied at the level of the corridor or region without regard to recipients' characteristics. Thus, both in specification and in application, standard models provide little information on social and economic differences.

Disaggregate travel demand models and methods such as sample enumeration and microsimulation offer significant opportunities for greatly improving transportation-related forecasts. These approaches can allow forecasts to be made for any subgroup of interest as long as the underlying data are adequate to support the analysis. To date, however, these methods have been applied in only a handful of metropolitan areas. Furthermore, the complexity of the models suggests that the level of effort required to understand and apply them may be quite high. Thus there is a need for both more testing and dissemination of models capable of disaggregate analyses, and the development of simplified sketch planning models and heuristics for evaluating the effects of transportation projects on different demographic and socioeconomic groups. These latter models and heuristics would be used as a first-cut alternative to the more complex models.

Improvements also are needed in cost/benefit analysis methods. Most of the existing methods (often based on available software) share with travel forecasting models the tendency to aggregate data in a way that masks rather than displays the incidence of impacts on various groups and interests. In addition, most cost/benefit methods omit measures that cannot easily be quantified, such as quality of life (Forkenbrock and Schweitzer 1999). While alternative approaches, including impact tableaux, cost-effectiveness analysis, and community-based rating and ranking schemes, have been available for many years, they are not frequently applied at present.

A promising method for both analyzing and displaying impact information involves using geographic information system (GIS) tools to create maps showing the location and intensity of various transportation-related effects. By using overlays of socioeconomic and demographic data, jurisdiction and neighborhood boundaries, and the like, relationships between transportation projects and their community effects can be visualized. Both beneficial aspects, such as access and mobility measures, and negative impacts, such as pollution concentrations, can be mapped. Increasingly, GIS-based methods of impact display are being used both by public agencies and community activists to examine transportation project effects. Indeed, those who represent low-income populations in transportation delivery and planning have begun to develop their own GIS tools for evaluating the next generation of transportation services (Almanza and Alvarez 1995; Rothman et al. 1998). Some researchers also have experimented with user-friendly, community-focused information systems and models that assist communities in matching their transportation needs with the best alternatives for meeting those needs. These models are designed to be used independently or in cooperation with transportation agency staff and policymakers (Zimmerman et al. 1997). Research is needed to examine these emerging planning methods and evaluate their efficacy.

Transportation, Sprawl, and the Distribution of Impacts

The role of transportation in shaping land use and patterns of development (urban, suburban, and rural) has emerged as a significant research topic during the last decade (see Chapter 6). From an environmental justice perspective, sprawling suburbs compete for jobs, housing, and other resources with the inner city and older suburbs, which together are home to the majority

of low-income and minority households. In turn, few suburbs are developed in a pattern that can be served successfully by transit. As the share of a metropolitan region that is transit-oriented declines, those who depend on transit for their basic mobility become vulnerable to service cuts and accessibility losses. Further, as more people depend on automobiles to meet their travel needs, costs for highway infrastructure rise and traffic impacts increase; these costs and impacts fall heavily on low-income and minority households.

Demographic analyses conducted during the last four decades indicate that a majority of the nation's metropolitan areas are divided spatially by race, ethnicity, and income (Massey and Denton 1993; Bullard 1997; Benfield et al. 1999). Research also suggests that this segregation is not solely the result of market choices or discrimination in the housing market, but also a consequence of public policies, including investments in suburban highways, preferential tax policies for home ownership, infrastructure policies favoring new construction over maintenance and rehabilitation, and government and private redlining[9] in inner-city neighborhoods (Burrington and Heart 1999; Powell 1999; Richmond 1995). The consequences of such policies warrant more research to identify their relative contributions to these urban segregation patterns.

Today, policies intended to slow or reverse the decline of inner cities and older suburbs are being tested, as discussed in detail in Chapter 6. Just as further study of sprawl is warranted, it is important for research to address the possible unintended consequences of antisprawl policies on minorities and low-income communities. One such consequence of increasing concern is "gentrification" and its possible effects on existing residents (ranging from rising costs to outright displacement) (Beauregard 1985; Anderson 1990; Smith 1996; Kennedy and Leonard 2001). The factors underlying gentrification are highly contested, and there is little certainty about the efficacy of policies being proposed to protect lower-income households (transit-oriented design, job development, affordable housing development). Policy research on suburbanization and community revitalization thus could have both transportation and environmental justice aspects.

[9] Redlining was the practice of labeling certain neighborhoods or districts high risk, making insurance expensive and loans and mortgages costly and difficult to obtain. Redlining was often based on racial and ethnic characteristics of the population, hence was discriminatory, and is now illegal.

Emerging Approaches to Public Involvement

Federal statutes mandate that state and regional planning agencies ensure public input on transportation investment and spending decisions. Most states have similar requirements. Yet many community groups are dissatisfied with the current planning processes. Public agencies hold hearings and workshops, run focus groups, conduct surveys, and respond to comments on environmental impact statements. As Arnstein (1969) notes, however, actual participation in the development, evaluation, and selection of alternatives is unusual. Innes and Booher (1999) believe the biggest obstacles to change are two institutionally entrenched models of planning: the technical bureaucratic model, which focuses on analyses and relegates citizen involvement to minor feedback, and the political influence model, which operates with the powerful players and does not welcome direct citizen involvement at all.

Certainly citizens are concerned about discrepancies between the comments and suggestions made by community members during the planning process and the way public funds are ultimately spent. Public agencies are concerned about the legitimacy of their decision processes and whether the participants in the planning process are representative of the larger public. Given the importance of outcomes as well as processes, research on public involvement and its effects on funding decisions, project design, impact assessment, and outcomes is an essential element in making transportation planning and decision making more effective.

In addition, there has been growing recognition that the sheer diversity of views requires a new approach to decision making (Schlosberg 1999). Many researchers have concluded that social justice requires a democratization of the planning and decision processes, and that this objective can often be attained through cooperative approaches (Ostrom 1990). The success of such approaches depends, however, on building individual and group capacity to participate in the process and to identify and communicate one's interests. Success also depends on developing sufficient mutual trust and other forms of social capital (including leadership) to keep the process going. The increased use of capacity-building and consensus processes in a variety of planning applications (Innes 1992; Innes 1998) is an important step toward broader participation and democracy, and hence greater social equity, in planning. Innes and Booher (1999) report that newly emerging collaborative planning processes, implemented as a loose network of communicating citizens and public and private entities, enable citizens to learn how to deliberate effec-

tively. They note that people involved in such processes come to prefer them to confrontation. A recent handbook by Susskind et al. (1999) provides examples and guidance, but specific applications for transportation need further development.

Emerging citizen coalitions in low-income and minority communities have advocated a basic theme of "back to local control," reflecting the policies of ISTEA and TEA-21. This participatory activism is particularly apparent in communities of color, where transportation is regarded as a civil right. The roles and limitations of local control are appropriate topics for study, especially because there are both supporters and critics of localism as a strategy. Innes and Gruber (2001), for example, caution that devolution can make it difficult to address regional issues and concerns.

Research also is needed to evaluate alternative models of decision making and the role of social justice coalitions. Questions to be addressed include how various groups frame the debate on environmental and social justice issues, what process is used by people and communities to interpret and express their transportation needs, and why some disengaged communities have developed the ability to organize and resolve transportation problems while others are still not empowered.

Recommendations

The following recommendations are organized into seven areas: (*a*) differences in mobility, access, and travel behavior across demographic groups; (*b*) definitions of social equity and understanding of environmental justice problems and issues; (*c*) effects of costs, funding, and finance methods; (*d*) new technologies and their impacts; (*e*) methods and processes for the evaluation of impacts and their distribution; (*f*) effects of sprawl on social equity; and (*g*) approaches to public involvement.

Recommendation 3-1.
Conduct research on variations in mobility, access, and travel behavior among different social, economic, and demographic groups.

While currently available studies offer some insights into differences in travel options and behaviors for various social, economic, and demographic groups,

much more work is needed to explore choices, constraints, and preferences more thoroughly and to understand their consequences. Research needs include, for example, documentation of changes (or stability) in various groups' behavior over time; consideration of the effects of experience, changing income, aging, and other life-cycle changes; and examination of changes in the transportation options available. The social and environmental impacts of identified differences in transportation preferences and choices should be explored as well. Cross-sectional as well as longitudinal research designs are needed, as are case studies that provide depth and richness of understanding.

Recommendation 3-2.
Develop operational definitions and indicators for environmental justice and social equity as the concepts pertain to transportation.

Working definitions and indicators of environmental justice and social equity that are widely understood and accepted remain to be developed. The process of definition will need to occur through a collaborative effort involving a range of stakeholders in meaningful discussions, and it may need to be revisited and updated from time to time. Similarly, the development of indicators for use in measuring environmental justice is likely to require research conducted through collaborative processes.

Recommendation 3-3.
Investigate the social and economic effects of current investment policies for both transit and highways, and conduct research on the equity and impacts of alternative methods of finance.

Research is needed to identify and document how current investment policies affect different groups and interests, with particular attention to minorities and the economically disadvantaged. Both detailed case studies and cross-sectional and longitudinal studies are appropriate. Findings from this research should, over the longer run, support investigations into alternative methods of finance and their comparative equity and impacts.

Policy analyses and empirical research that illuminate the causes of disparities in transportation investment are needed. Such research could examine decision-making processes, including models of decision making and "world views," that result in greater or smaller disparities, and could help identify ways to improve transportation equity and avoid, minimize, or mitigate adverse effects.

Recommendation 3-4.

Conduct research on the effectiveness and impacts of transportation technology innovations for different socioeconomic and demographic groups, particularly economically disadvantaged communities. Also examine methods for making new technologies available to diverse population groups.

Research on new technologies should be expanded to include evaluation of their accessibility to low-income and minority communities, the young, the elderly, and the disabled. Research should also address how new technologies might be used to overcome existing gaps between advantaged and disadvantaged groups and to enable communities to become better integrated into the transportation decision-making process.

Recommendation 3-5.

Develop and demonstrate methods that can be used to display the incidence of transportation project and program effects, both beneficial and adverse. Also, develop improved methods for evaluating costs and benefits when they are not evenly distributed. Include environmental and social justice impact criteria in system performance measures used in transportation planning and investment decisions.

Current evaluation methods are often too aggregate to reveal social, economic, demographic, and community-based differences in the impacts of transportation programs and projects. Low-income and minority communities have been shown to suffer disproportionate negative impacts from transportation projects. If such consequences are to be avoided in the future, better methods are needed for performing transportation forecasting and analysis, as well as for carrying out and communicating the results of program and project evaluations. The role of the public in such evaluations is an appropriate topic for research, as discussed in recommendation 3-7 below.

Research aimed at identifying performance measures that adequately reflect the distribution of transportation impacts also should be carried out. Research should be conducted as well to develop new strategies for avoiding, minimizing, and mitigating adverse impacts and disparate burdens associated with transportation programs and projects.

Innovative data analysis procedures, utilizing qualitative as well as quantitative criteria, should be further developed and refined. Methods that use GIS

and other new impact analysis and display methods should be given particular priority, since work to date indicates that these methods have considerable potential for effectively communicating analysis results to decision makers and the general public. Methods that draw on community-based knowledge and resources, such as communities' own assessments of their assets and concerns, also should be given research attention.

Recommendation 3-6.

Continue and expand studies on the comparative costs of transportation and the effects of different development patterns, particularly for economically disadvantaged communities.

Research is beginning to identify the connections among sprawl, inner-city decline, lengthy commutes, congestion, and damage to the urban and natural environments. While the work to date is revealing, it is neither comprehensive nor definitive, and more research is warranted. Research should be carried out to evaluate "smart growth" alternatives and their efficacy, as well as their effects on housing prices, environmental quality, regional and local economic development, and the well-being and satisfaction of various social and economic groups.

Recommendation 3-7.

Develop and test new methods for integrating public involvement into transportation analysis and decision making, and examine the implications of emerging citizen coalitions for environmental and social justice.

New approaches to public involvement that focus on collaboration and mutual learning, rather than on mere comment and feedback, show significant promise. Research should help elucidate the conditions under which these methods are effective, and evaluate their effectiveness in transportation planning and environmental assessment. The role of social justice organizations in transportation and environmental decision making also needs to be examined. The participatory activism displayed by social justice organizations has challenged traditional notions of transportation planning and research. Social justice coalitions are introducing their own data, analyses, cost/benefit calculations, and alternatives into transportation planning processes, creating new political dynamics and issues for transportation agencies and decision makers that are only beginning to be examined. Research is needed on planning frameworks that can accommodate

a broader spectrum of data and perspectives, as well as on improved ways to include the public in transportation analyses and evaluations.

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Abbreviations

GAO	General Accounting Office
TRB	Transportation Research Board

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5

Research Area 4

EMERGING TECHNOLOGIES

The transportation industry is arguably on the cusp of a technological revolution. In coming years, the industry will be incorporating two largely new sets of technologies that are the focus of this chapter: (*a*) propulsion technologies and fuels that will change the energy, pollution, and noise characteristics of vehicles; and (*b*) information, communication, and control technologies that will change the way vehicles are used. An important challenge is to create a policy environment that will facilitate and encourage the proliferation of these environmentally beneficial technologies (DeCicco and Delucchi 1997).

In this chapter, technology is addressed from two perspectives: as a key element of transportation systems that often leads to adverse environmental impacts, and as a source of solutions to environmental problems. The primary concern is with rapidly evolving technologies for vehicles, fuels, vehicle–highway user-support systems [i.e., intelligent transportation systems (ITS)], and telecommunications in the context of energy efficiency and supply, air quality, and climate change. A proliferation of new propulsion, fuel, information, communication, and control technologies are becoming available, promising major enhancements to the performance and environmental sustainability of transportation services and activities. The focus of this chapter is on those emerging technologies that have the largest potential environmental impacts, both negative and positive, but have not yet been fully addressed by publicly supported research and development (R&D).

Since technology is a broad category encompassing a vast array of material and knowledge sets, the aim in this chapter is not to be all-encompassing. Not addressed here, for example, are technologies for the construction and

maintenance of safe, environmentally friendly facilities; technologies and infrastructure for protecting wildlife (e.g., tunnels and road overpasses for animals); technologies that provide incremental information-based improvements in traffic and fleet management; conventional transit and railroad services and technologies; telecommunications electronics; fuel manufacture and distribution; crashworthiness and crash-avoidance technologies; and whole-vehicle design and manufacture. The Advisory Board elected not to discuss these technologies because they are adequately covered by other research programs, such as the National Cooperative Highway Research Program; because they are central to industry R&D activities; because they may have little effect on environmental quality; because they facilitate only small incremental changes; or because they are covered in other chapters (in particular, technologies to protect wildlife are covered in Chapter 3, while improved planning and decision-making tools are covered in Chapter 7). On the other hand, emerging mass information services, although not technically classified as transport technologies, are included in this chapter to the extent that they have the potential to transform the manner in which the transportation system is currently utilized. This transformation could dramatically influence transportation's impact on the environment.

Surface Transportation and Emerging Technologies

Government plays a central role in guiding the development and diffusion of environmentally beneficial technologies. It regulates emissions, energy use, and safety; provides R&D funding through various programs; and owns and manages many transport services, facilities, and activities. But rapid advances in a range of technologies can render government policies, rules, and R&D programs anachronistic, while the marketplace treats environmental attributes largely as externalities.

A role for government is necessary to ensure the wise use of technology—this despite the fact that government seldom has perfect information and is routinely lobbied by special-interest groups that may have little or no interest in environmental protection. The problem is illustrated by the unintended consequences of some government-inspired initiatives, including the federal-aid highway program, which has led to species separation; dredging by the U.S. Army Corps of Engineers, which has reduced wetlands and destroyed marine habitats; and the development of large state- and municipal-owned airports that have

expanded noise footprints. Moreover, the government's decision not to price the use of congested roads at the point of consumption has led to excessive road use, with associated pollution and noise impacts. It is important, then, that any government role regarding the use of transportation-related technologies be premised on a strong knowledge base to minimize the chances of negative environmental impacts. And given government's expanding role in overseeing the environmental effects of transportation technologies, the challenge is to ensure that the potential benefits of new transportation technologies are realized in a cost-effective manner. These benefits are direct in reducing pollution, energy use per vehicle-mile traveled (VMT), noise, and so on, but also indirect in catalyzing shifts in travel patterns to more environmentally benign travel forms.

Industry is spending billions of dollars annually on transportation-related technologies R&D (AAAS 2000), and major technological changes are about to occur—with or without government direction. A range of new and enhanced research is needed to ensure that government exploits these changes effectively and wisely. A strong, sustained research agenda can address both the opportunities and concerns presented by new technologies. The goals of this research would be as follows:

- To define and articulate an appropriate and effective role for public R&D in accelerating the development and commercialization of environmentally beneficial technologies (given that government resources are at a much smaller scale than the private investment in transportation technologies).
- To create a scientific basis for effective and wise government policy-making, investment, and regulation with respect to transportation technologies to serve the ultimate government role of environmental stewardship.
- To understand the relationship between government regulations and private-sector investments in R&D.

Grounded in such a research base, public investment in transportation-related technology R&D can fill critical gaps, leverage billions of private R&D dollars, and ensure the development of a more sustainable and healthy transportation system. The potential payoff is great. At the same time, it must be recognized that user response to technological change can be complex. The environmental balance sheet following the introduction of new technologies depends substantially on large numbers of micro decisions made by both consumers and suppliers about how to exploit the resulting new opportunities. It is important to note that those opportunities are not always

anticipated by the designers and promoters of new technologies; some are discovered or invented by consumers. A recent example is provided by consumers who offset fuel-efficiency improvements by buying more powerful vehicles and driving more miles. The aggregate effects of user responses to simultaneously introduced innovations, as well as interactions between responses, are even more difficult to anticipate. Behavioral responses to the two major technological revolutions discussed in this chapter may result in major changes in vehicle use patterns and concomitant environmental impacts.

Current Technology Context

The current situation in the United States with respect to transportation and the environment is one of both promise and concern. The largest success story is in the area of air pollution, though progress here is neither uniform nor—as population and travel patterns expand—ensured. Major reductions in vehicle emission rates have resulted mainly from technological advances in combustion efficiency, fuel reformulation, and the treatment of exhaust substances. Urban regions and major corridors have benefited from the elimination of lead in fuel and from major reductions in carbon monoxide. In addition, low-level ozone pollution is slowly improving, primarily as a result of large reductions in hydrocarbon emissions from vehicles.

The continuing challenge with regard to air pollution is to reduce the high levels of nitrogen oxides and ultra-fine particulate matter emitted by vehicles. Diesel engines, largely unnoticed by air quality regulators until the late 1980s, are responsible for a significant proportion of these two pollutants. Dramatic reductions in emission rates (per VMT) have been accomplished for carbon monoxide and hydrocarbons, but less so for nitrogen oxides. With large offsetting increases in VMT, the overall effect has been substantial net reductions in carbon monoxide and hydrocarbon emissions, but no net reduction in emissions of nitrogen oxides.[1]

[1] High nitrogen oxide levels contribute to acid precipitation and thus have interregional and international implications, as well as impacts on urban air quality. Vehicular emissions of nitrogen oxide and sulfur oxide combine with industrial sulfur emissions to acidify soils and lakes over long distances. Although a concern for more than three decades, some cumulative effects of soil acidification have only recently been proven (for example, the serious degradation of sugar maple forests in Eastern Canada). Sulfur oxide emissions are a prominent contributor to acid precipitation in most regions. Sulfur oxide emissions from diesel engines were at one time important, but sulfur levels in fuel have been reduced, resulting in a significant decrease in these emissions.

An emerging issue related to vehicles is newfound evidence of the negative health impacts of fine particulate matter (see Chapter 2). Very small particulate matter emitted from diesel engines, but also from gasoline engines, is now recognized as posing perhaps the most significant health hazard of any vehicle-related pollution. Historically, however, improvements in transport-related air pollution have been attributable largely to technology advances. New emission standards continue to be adopted, spurring the development of technologies to meet those standards. It is believed that progressively tighter standards are likely to lead to continuing improvements in the near future, ultimately resulting in near-zero air pollutant emissions from vehicles.

Other, more problematic areas in which trends are moving in the wrong direction are fuel consumption and related greenhouse gas emissions. Such emissions are continuing to increase 1 to 2 percent annually in the U.S. transportation sector (Oak Ridge National Laboratory 2000). A growing body of evidence links carbon dioxide (CO_2) and other greenhouse gas emissions to major changes in global climate and to such consequences as the flooding of human settlements and natural habitats, changes in growing seasons and water supplies for agriculture, desertification, and the introduction of tropical disease vectors into temperate regions (IPCC 2001) (see Chapters 2 and 3, respectively, for discussion of the human health and environmental impacts of greenhouse gas emissions). The contribution of the U.S. transportation system to greenhouse gas production, in particular the increasing output of CO_2, is a major concern internationally.

As noted, while the technical energy efficiency of engines continues to improve through more efficient combustion and the use of lightweight materials and improved vehicle designs, fuel consumption continues to increase as a result of the production and sale of larger and more powerful vehicles and growth in travel. Indeed, as noted earlier, both motor vehicle stock and total VMT are growing more rapidly than the nation's population. This pattern is repeated throughout the world. In other countries, however, private vehicles are, on average, substantially smaller and driven substantially less.

At present, the processes by which environment-enhancing technologies are introduced, diffused, and utilized are poorly understood, as is the role the public sector can play in guiding the commercialization of these technologies. As illustrated by the paradox cited above, rapid advances in energy and materials technologies have not automatically led to reduced fuel consumption per VMT. There is a need to refocus research on the demand for vehicles, fuels, and transportation, along with new means of reducing the environmental impacts asso-

ciated with increases in that demand. These issues are addressed below for the two categories of technology advances noted earlier: fuels and propulsion technologies, and information, communication, and control technologies.

Fuels and Propulsion Technologies

Technologies are now being developed that could further reduce pollution from internal combustion engines in the near term, and new energy-efficient hybrid-electric propulsion technologies are being introduced. More efficient fuel-cell electric technologies also appear to be imminent. Fossil fuels will continue to be available for transport uses throughout the 21st century, mainly as a result of large supplies of natural gas being discovered around the world and increasing use of unconventional sources of petroleum, such as heavy oils and tar and oil sands. Natural gas is attractive because it has lower carbon content than petroleum and is cleaner burning; it also has the advantage that it can be converted to clean-burning liquid fuels at modest cost. However, use of these fuels will increase U.S. trade imports, and after energy losses from conversion and long-distance transport are taken into account, these fuels will tend to generate greenhouse gas emissions at levels similar to those produced by petroleum fuels.

Industry is spending billions of dollars annually to develop and commercialize environmentally enhanced fuels and vehicles. A major debate is under way, however, in both public and industry circles over which vehicle technologies are most attractive, which fuels should be used, and which policy instruments are most appropriate. Policymakers today are concerned primarily with reducing air pollutant emissions from diesel engines and with improving fuel economy. Vast sums of R&D funding are directed at these goals, primarily by the automotive and energy industries, but also by government. International, national, and some state governments spend millions of dollars addressing the health effects of diesel emissions; the automotive industry spends billions on reducing emissions from both gasoline (spark ignition) and diesel (compression ignition) engines; and the oil industry is spending billions on reducing sulfur levels, reformulating petroleum fuels, and designing new processes for converting natural gas to clean transport fuels. Consequently, internal combustion engines operating on cleaner petroleum fuels will continue to dominate the automotive market for many years, with natural gas–based fuels and next-generation electric-drive propulsion technologies gradually entering the market.

It is largely accepted that the conventional internal combustion engines and drive trains of passenger and freight vehicles will eventually be replaced by electric-drive technologies; that is, vehicles will be propelled at least in part by electric motors (Box 5-1 provides a brief overview of these vehicles). Less certain is which technologies are most attractive to society, and when and how these changes will occur and what the strategy for transition will be. Related technological issues include recycling of vehicles and the design and manufacture of vehicles using lightweight materials (technologies that are not addressed in this chapter).

The overall question is how R&D, public policy, regulatory controls, and public investments can be directed so as to accelerate the development, commercialization, and use of environmentally beneficial technologies in the most cost-effective manner. What publicly funded R&D is needed, and what public and public–private R&D processes need to be put in place to ensure continuity in these public efforts? The huge size of the automotive and energy

Box 5-1

Electric-Drive Vehicles

Electric-drive vehicle technologies may be divided into four generic types:

- Pure battery electric vehicles that store wall-plug or charging-station electricity on board in batteries, ultracapacitors, and flywheels;
- Pure electric vehicles that obtain their electricity as needed from a rail, wire, or other off-board source;
- Hybrid electric vehicles that generate some or all of their electricity on board using a combustion engine; and
- Fuel-cell electric vehicles that convert chemical energy into electricity on board using a fuel-cell system.

Common to all four is an efficient and reliable electric motor that drives the wheels, the use of batteries (or other devices) to store energy captured during braking (known technically as regenerative braking), and the advantageous use of electronic technologies for a variety of vehicle control and auxiliary functions.

companies and the cyclical nature of public attention to energy issues have seriously undermined independent R&D capabilities in energy-related transport technologies. At present, major automotive companies, most of which are abandoning plans to build and market conventional-sized battery electric vehicles, are on the verge of deciding whether to make substantial investments in fuel-cell electric vehicles and are beginning to invest in hybrid electric vehicle production.

Automotive and energy companies are motivated to develop and commercialize these technologies by a variety of considerations. During the past three decades, the principal motivation for developing and introducing more environmentally benign vehicles in the United States and most other countries has been the desire for clean air and the resulting Clean Air Act regulations. The result has been an extraordinary reduction in vehicle pollutant emissions: average emissions from cars in real-world conditions declined by about 60 to 80 percent per VMT between the mid-1960s and mid-1990s (Pickrell 1999). As suggested above, continuing reductions are certain during the next decade as a result of even more stringent regulations scheduled to take effect in the next few years for both cars and trucks. These emission reductions have been the central focus of automotive research since the early 1970s. The improvements have centered on in-cylinder combustion and treatment of exhaust gases. This high level of R&D attention has generated many important side benefits, including the introduction of computer controls, first deployed to better control the mix of fuel and air entering cylinders. Other strong motivations have been reducing noise, and decreasing the costs and increasing the availability of energy. Much of the motivation for more environmentally friendly vehicles has derived from government through a mix of incentives and technology-spurring regulations.

While clean air will continue to be a strong motivation for enhancing vehicles and fuel, climate change is anticipated to play an increasingly important role. Mounting concerns about climate change are strengthening the resolve of governments and automakers to develop cleaner and more efficient vehicles. The European Union signed a voluntary agreement with automakers to reduce CO_2 emissions per VMT by 25 percent between 1995 and 2008, and Japan adopted significantly tighter fuel-economy standards in 1999 (Plotkin 2001). The United States has not increased fuel-economy standards for many years, but pressure is mounting for more stringent car and light-truck standards (currently at 27.5 and 20.7 mpg, respectively) and for abandonment of the distinctions between cars and light trucks (NRC 2001a; NRC 2001b).

Information, Communication, and Control Technologies

Innovation and change in the transport sector have tended to be slow and incremental. In part, this pattern reflects the institutional complexity of transport systems: a large proportion of transportation activities is in the public sector (e.g., building, operating, financing, and regulating facilities and vehicles); companies in a multitude of industries participate in a variety of ways; and an enormous number of individuals and companies operate vehicles. Nonetheless, system-transforming innovations have occurred that have led to dramatic advances in productivity and societal benefits. We now appear to be on the verge of another such transformation.

In the past two centuries, only a few major system innovations have transformed surface transportation. They include interurban railroads in the mid-1800s; electric urban rail, introduced a few decades later; and automobiles in the early 1900s. Railroads transformed the nature of business; electric rail changed patterns of neighborhood development and contributed to the emergence of metropolitan regions; and the automobile altered the locus and variety of human activities. By increasing the speed of travel, these innovations transformed not only transportation, but also much of society. The catalysts for these earlier transformations in transportation were (respectively) the steam engine, electric traction, and the internal combustion engine, together with the associated fuel supply infrastructures.

The next era of transformation in transportation will reflect the integration of information and communication technologies into lifestyles and modal choices. The catalyst for this era of "smart transportation" will be electronic and wireless communication systems.[2] The major thrust of research in the area of ITS has been advanced transportation management and information systems, which serve to provide a new class of information to drivers, fleet operators, and traffic managers. One of the public goals for these systems is to maximize the throughput and usage of existing roadways. The private goal is to create markets for new products and services, such as navigation devices

[2] The one notable exception to the incremental advances in this area is the aborted automated highway program, funded by the Intermodal Surface Transportation Efficiency Act with substantial industry partnerships. This program was not continued under the Transportation Equity Act for the 21st Century, largely because of weak interest by industry (due in part to liability concerns) and opposition from the environmental public-interest community, which feared accelerated urban sprawl. The automated highway R&D program was converted into the Intelligent Vehicle Initiative, a program aimed at near-term safety innovations.

and information services for drivers. Attention and resources are directed primarily at using that information to improve safety and the efficiency of travel and goods movement. Tens of billions of dollars are being invested, mainly by the private sector. The net result of these initiatives will clearly be to improve the current system. At the same time, it is important to note that, as in the past, most innovations and initiatives are aimed at enhancing existing services and patterns. However, lifestyles are also evolving. A broader vision and more systems-level initiatives would likely result in a wider choice of access to activities, services, and products, and in shifts in patterns of consumption that could generate far greater benefits through reductions in congestion and environmental impacts.

The potential for a major break from the past is highlighted by the following trends and relationships. Light-duty vehicles account for 95 percent of all person-miles of surface travel in the United States; these vehicles are typically unused 23 hours per day, and all are designed to operate with roughly the same speed performance. Since World War II, transit has progressively lost overall market share, although transit ridership has grown in absolute terms in most major urban regions.[3] Personal-vehicle occupancy rates declined until fairly recently and remain low. Vehicle ownership has steadily increased, and more than 60 percent of U.S. households own more than one private vehicle. The overall effect is unprecedented mobility and accessibility. But the situation also leads to massive consumption of resources and the generation of many adverse environmental impacts, while contributing to various social ills.

The opportunity may now exist to enhance access to goods, services, and activities while reducing the need for motorized transportation and mitigating its adverse impacts. In the past 50 years, vehicles and roads have been standardized and privately operated vehicles more widely embraced because no alternative could compete with the personal (and often single-occupant) vehicle except in specialized circumstances, such as dense downtowns. However, the widespread availability of low-cost communication and information tech-

[3] Although transit has progressively lost market share since World War II, investments in public transportation in recent decades have resulted in dramatic increases in its use in some areas. That being said, in the United States, transit still accounts for only 2 percent of all person-miles traveled in vehicles. To evaluate the effectiveness of public transportation, however, one must consider where it is provided. Only about half of the communities in the United States have public transportation systems, and even in those communities, proper evaluation of public transportation requires route-by-route comparisons of places where people have a choice between their private vehicle and public transportation.

nologies, including the Internet, may allow vehicles to be used in a far more specialized and efficient manner. This could come about directly from a better match between personal travel needs and the system of private vehicles (e.g., access to a variety of vehicle types through car sharing), or indirectly from user adaptations (discussed in the next section). However, there is no consensus on the probable size and direction of these benefits of communication and information technologies, and the distributional impacts are largely unknown.

Analogous observations about vehicle information systems can be made for the freight sector, which has led in the application of these technologies to improve logistics and exploit new forms of supply-chain management. Again, however, resulting shifts in the distribution of benefits and undesirable environmental consequences are poorly understood, notably in the area of urban trucking.

Role of Publicly Funded Research

New and improved technologies play a central role in the evolution of the transportation sector. Huge investments have been made in R&D, especially by the private sector, to enhance transportation technologies and improve their environmental performance. For example, the global automotive industry spends about $50 billion on R&D per year (5 percent of revenue) (GAO 2000); about a third of that total is spent by U.S.-based companies, with a large proportion of those expenditures going to energy and emissions research. Government-funded research is a small fraction of that amount.

New industrial R&D is increasingly being directed at hybrid and fuel-cell electric vehicles and at applications of information, communication, and control technologies. In all of these cases, rapid innovation is taking place. Rapid innovation, however, does not necessarily translate into environmental improvements, primarily because the innovations are generally introduced as technology fixes; that is, they are designed to enhance existing technologies without disrupting current patterns, investments, or lifestyles. Arguably, much greater improvements in environmental quality, resource utilization, productivity, and quality of life would be possible if these technology solutions were incorporated into *system* innovations that led to a transformation of transportation, energy, and information systems, including the market mechanisms that enable these systems to function.

In any case, government can and does play an important role through a variety of means in directing industrial R&D toward those innovations that

have larger environmental benefits and in targeting public investments to systems and services that offer the greatest benefits. The means employed include corporate tax policy, participation in public–private R&D partnerships, leveraged R&D awards, consumer tax incentives, and rules and regulations. Recent examples include R&D partnerships with the automotive and battery industries [e.g., the Partnership for a New Generation of Vehicles (PNGV), the U.S. Advanced Battery Consortium, the Intelligent Vehicle Initiative, and the Future Truck Initiative], as well as regulations regarding the safety, air and water pollution, solid waste disposal, and energy use aspects of vehicles. The market implications of these rules and incentives and the value of the R&D partnership investments easily amount to tens of billions of dollars per year.[4] Even a modest improvement in government rules and R&D strategies could generate billions of dollars per year in savings while enhancing the environment.

The Advisory Board concludes that an enhanced public R&D program is needed to generate the knowledge base required to develop a broad view of system-enhancing transportation technologies. This conclusion is supported by a number of observations on the current state of policy, knowledge, and practice:

- Government regulations and policies largely reflect a historical tendency to address problems within a narrow, single-issue framework. Some policies and regulations address air pollution, others fuel consumption, others safety, and still others congestion; few policies address several problems simultaneously. Policy conflicts sometimes result from this narrow focus, and trade-offs can be difficult to make. For example, more fuel-efficient vehicles by themselves do nothing to reduce congestion and may even support more driving by reducing operating costs; higher fuel prices may encourage conservation but reduce mobility. Policies may need to allow for a flexible technological response to satisfy multiple goals. Research could contribute to the design of policies that would be sensitive to synergies and unintended interaction effects.
- To date, air quality improvement has been achieved primarily through technology, and this has reduced motivation for behavioral changes.

[4] Reliable data do not exist. It is estimated that on average, $2000 is spent per car for safety and emissions; with about 15 million light-duty vehicles being sold each year in the United States, the expenditures are $30 billion annually. In addition, billions of dollars are spent annually on R&D partnerships.

- Improvements in energy efficiency have not been exploited in the United States to achieve greater fuel economy. The technical energy efficiency of vehicles has increased about 30 percent in 15 years, but fuel consumption rates have increased because vehicles being sold are, on average, larger and more powerful.
- New technologies such as fuel cells, information technologies, wireless communication, and advanced vehicle control technologies tend to be used first as substitutes and as a means of enhancing existing patterns and only much later as a way to transform overall patterns. This evolution can be accelerated.
- In many ways, the United States is out of step with the rest of world in terms of the size and use of vehicles. Better understanding of how this situation evolved could be a first step in developing effective policies for managing the energy and environmental policy consequences of new technologies.
- A majority of households have access to more than one vehicle and are tending to move toward ownership of specialized vehicles (and perhaps new ownership patterns and mobility services).
- The potential social benefits of information and telecommunication technologies and telesubstitution are great, but their realization will require innovative, system-level thinking and designs.

RECOMMENDATIONS

The recommendations that follow address five topics: (*a*) fuel and propulsion technologies and their impacts; (*b*) intelligent transportation technologies and their impacts; (*c*) user behavior and consumer choice and demand; (*d*) policy instruments related to evolving technologies; and (*e*) institutional arrangements for R&D. For each topic, examples of the kinds of research envisioned by the Advisory Board are given.

Recommendation 4-1.
Analyze transition pathways to environmentally beneficial fuels and vehicle propulsion technologies.

The United States is seriously considering a transition away from petroleum fuels and internal combustion engines. With intensifying calls for more environmentally

benign vehicles and fuels and rapid innovation in propulsion technologies, major changes are about to take place. Better understanding is needed of the choices and pathways of those changes. An improved knowledge of the new technologies and their impacts would inform the policy and R&D processes with respect to pollution, energy use, energy supply, and climate change.

Government and the public need to be well informed to ensure that environmental factors are adequately considered in the development, evolution, and use of vehicles and fuels. The petroleum and automotive industries are among the largest in the world, are global in their operations, and spend billions of dollars every year on product development and market research. The challenge is to complement, leverage, and influence industrial R&D, not duplicate it.

Example: Toward a hydrogen economy. It is widely believed that hydrogen will be the dominant energy carrier at some point in the future. But how will hydrogen be produced and distributed? How will it be used in vehicles? What is the desirability of introducing an interim fuel such as methanol? How should emissions and energy rules be modified and when? Are new standards and codes needed for storage tanks, pipelines, and fuel handling? Should investments for converting remote natural gas into liquids be encouraged (through basic R&D at national laboratories and universities, R&D tax incentives, and fuel quality and vehicle emission standards)? Any actions that are or are not taken can influence billions of dollars in industrial investments and can have far-reaching implications for the environmental impacts of the transportation system.

Example: Handling and distribution of alternative fuels. The recent reversal of California regulations concerning methyl tertiary butyl ether (MTBE), a chemical made from natural gas and added to gasoline to reduce air pollutant emissions, highlights the need for better scientific and policy research. MTBE is being banned in California because leakage from storage tanks has polluted groundwater, even though oil refiners had been required by regulators just a few years earlier to invest billions of dollars in MTBE's production and distribution. Every fuel has a different set of safety and environmental impacts, and more research is necessary to understand and measure the full spectrum of those impacts. Research is needed on the costs and safety implications of infrastructure for new fuels (e.g., where hydrogen fuel stations might be located and at what cost), on issues of industry competitiveness associated with introducing new fuels, and on strategies for sequestration of carbon from new fuels (e.g., from natural gas converted into hydrogen).

Example: New propulsion technology and fuels in heavy-duty vehicles. Even though medium- and heavy-duty trucks are a principal source of air pollutants (responsible for about one-third of nitrogen oxide emissions from vehicles) and greenhouse gases, they have received little scrutiny from regulators and policymakers until recently. Emission regulations and emission control technology on large diesel engines lag perhaps a decade behind those for light-duty gasoline engines. Data and knowledge about freight transport and its energy and environmental impacts are sparse. Research is needed on truck usage patterns (including idling), emissions and energy-use characteristics, policy instruments that can reduce energy use and emissions, development of infrastructure for new truck fuels, and vehicle and fuel tax policy.

Example: System-transforming transport-energy opportunities. Research is needed on new transport and energy system designs that have the potential to yield dramatic improvements in energy consumption and other environmental attributes. These might include designs incorporating not only non-fossil-based hydrogen, but also CO_2 sequestration, entirely new forms of hydrogen and electricity storage, and new energy-serving vehicle guideways. In the latter case, for instance, electricity could be supplied easily and cheaply to battery-powered vehicles along a guideway. The vehicles would have small (inexpensive) battery packs for short access and egress trips off the electrically powered guideway at either end of the line-haul portion of the trip. Other related system designs are possible, with the potential for large reductions in energy use and emissions.

Recommendation 4-2.
Design and analyze the application of intelligent transportation technologies to achieve environmental benefits.

R&D on ITS technologies is dividing into two groups. One is dominated by the transportation departments of the state and federal governments and is focused on better management of the road infrastructure. The other group involves automotive, telematics, and other information technology companies that are working to develop profitable products and services for vehicle buyers and travelers. In each case, beneficial research and product development are taking place. However, the resulting changes are of an incremental nature and may or may not have environmental benefit. For instance, providing better traffic information to drivers may smooth traffic flows but also encourage more driving.

Little effort is being devoted to investigating technology-based strategies, designs, and services—for example, use of ITS technology to facilitate the use of public transportation—with the potential to generate a transformation of transportation patterns that could greatly reduce environmental impacts. These new options and services might include smart car sharing, smart paratransit, dynamic ridesharing, and teleservices, as well as a variety of other innovative new mobility services. Currently, none of these options can compete effectively with the private motor vehicle. However, combined with each other and with other innovations, such as neighborhood cars, they could lead to a basic change in transportation patterns with attendant environmental, economic, and social benefits. The challenge of research is to determine how wireless technologies can be used to connect the various modes and services seamlessly in a way that will be attractive to consumers and service providers and yield major societal benefits. It is also important to understand that particular services and products are likely to evolve over time and may develop differently in different communities and institutional settings.

Example: Demonstrations and pilot tests of innovative transportation services. Standardized software and hardware technologies now being developed are key to the successful emergence of the above new services and products; in many cases, they are a necessary precondition. But the key challenge, again, relates to market and institutional issues, many of which are situational and specific to local settings. There is a need to experiment with means of developing effective market strategies, creating local partnerships, and educating local communities about the possibilities for innovative transportation. Demonstrations need to be launched with the idea that they are pilot tests expected to evolve into full-fledged businesses and services.

Example: Economic, financial, environmental, and social equity analyses of innovative transportation businesses, services, and products. New transportation services and businesses will usually build on partnerships and have multiple revenue streams. They may evolve within entirely new mobility companies that own and maintain passenger vehicles. These companies may spring from car rental firms, car-sharing organizations, local affinity groups, automotive companies, large business parks, or any number of other organizations. They may have links to transit operators, fleet managers, and large employers. Unfortunately, limited experience is available on which to build. A research initiative is needed to explore various economic and business models; to determine whether these models might better meet the needs of particular user groups, such as the elderly and mobility-disadvantaged; and to examine envi-

ronmental impacts. The overall effects on the amount of travel and the types of vehicles used could be great. The research would address vested interests of taxi and transit operators and the organizational behavior of prospective service providers, whether traditional businesses or wholly new types of mobility enterprises. Existing travel demand, energy, and emission models need to be extended to handle these new applications, modes of travel, and services, including delivery of packaged goods.

Recommendation 4-3.
Analyze user response to and future demand for environmentally beneficial vehicles, fuels, and mobility services.

Public policy addresses the continuing tension between the desires of the individual and the interests of society. If travel were free and involved no delay, individuals would travel more frequently. Travel, however, is not free, and many of the associated costs are not borne by the traveler. Relative to other countries, the United States has been less restrictive regarding the travel desires of its citizens. Fuel prices are relatively low, vehicles are lightly taxed, and road capacity and quality have been expanded rapidly.

To provide a better knowledge base for public policy, research is needed on the demand for and use of environmentally beneficial vehicles, fuels, and mobility services. Under what conditions and with what incentives would individuals and organizations embrace environmentally friendly products and services? What might be the anticipated and unanticipated consumer responses to different packages of innovations? What would be the aggregate consequences for the environmental balance sheet of the ready availability of such products and services on a large scale? Do we even have suitable analytical tools to address these questions?

Example: Demand for and use of new environmentally beneficial vehicles and fuels. With the proliferation of vehicles (overall, more than one per licensed driver) and the introduction of new fuels and propulsion technologies, the opportunity arises to match specialized vehicles with appropriate applications. However, U.S. vehicle users are familiar with only a narrow range of vehicle attributes. The nation's population of private automobiles and light trucks tends to be more homogeneous than those of other countries, with fewer small vehicles and almost all vehicles operating on gasoline and diesel fuel. Nonetheless, multivehicle households (about two-thirds of all U.S. households) increasingly own a mix of vehicle types, suggesting increasing specialization of use. In this

context, little is known about the demand for home recharging and refueling, the driving "feel" of electric motor propulsion, the perceived safety aspects of new fuels, the use of smaller vehicles in various settings, or the attraction of new auxiliary services made possible by on-board high-power electrical systems.

A number of other questions also arise. Are companies following the market? Under what conditions might consumers shift buying patterns toward "green" vehicles? Does the development of new technologies, even without mass commercialization, lead to a restructuring of demand patterns? How might more environmentally benign vehicle technologies be introduced to the marketplace? How might the market be segmented differently? What is the role for social marketing? What additional research is needed to understand the demand for new attributes unfamiliar to consumers, especially those associated with fewer environmental impacts?

Example: Demand for and use of new packages of communication, ITS, and vehicle technologies. Many of the above research priorities for vehicles and fuels also apply to new modes of transport and mobility services now being created, including smart car sharing, smart paratransit, and dynamic ride-sharing; they apply as well to information services that can permit the spatial and temporal reorganization of activities, notably work and shopping. Under what conditions will individuals and organizations pay for and use new mobility and information service packages? To what extent will purely electronic services complement or replace physical movement? People are already using telecommunications spontaneously to become more mobile and more flexible. In the work domain, this trend appears to have influenced travel behavior more than organized telecommuting, but will the penetration of flexible work become more substantial if it is coupled with smart car sharing and other innovations? In any case, patterns of travel and access could be transformed in ways that would lead to radically different life and work styles. A particular case of interest is the role of integrated transportation and information services in meeting the mobility needs of the growing elderly segment of the population; for this segment, these services may also be packaged with housing. What will be the effect of these technologies on total travel, and what will be the energy and environmental impacts? Again, would environmental benefits be greater if governments actively promoted these transformations?

Example: New methods for estimating demand and simulating adoption paths. In addition to research on the demand for environmentally beneficial vehicles, fuels, and mobility services, research is needed on methods for estimating the penetration of these technologies and alternative paths for their adoption.

Conventional models and other methods of projecting private-vehicle and travel demand are likely to be increasingly less helpful in answering these complex questions about emerging technologies, individually or in combination.

The challenge is to estimate a sufficiently broad set of interacting outcomes in a future that may, in some respects, be unfamiliar. Most survey methods that address stated preferences for particular attributes of new products and services do not provide stable results except for questions that are highly limited in scope and frame. Research is needed on how to improve the design of simulations of consumer responses, such as those used for conducting some premarket surveys of new vehicle types or for exploring responses to unusual circumstances, such as fuel shortages. The focus of these methods should be on understanding decision processes as much as on forecasting outcomes. Understanding demand for technologically advanced packages of mobility, access, and information services will also require new urban modeling tools that can take into account interactions with land use (as discussed in Chapter 6).

Recommendation 4-4.
Develop policy instruments to encourage environmentally beneficial vehicles, fuels, and mobility services.

To a large extent, public policy is predicated on previous and current circumstances—environmental, political, economic, and technological. The advent of new system-transforming technologies means that many of the central premises of existing policies and policy instruments may no longer be relevant or appropriate. For example, emission and fuel economy standards are based on the use of internal combustion engines and petroleum fuels. Road standards and traffic rules are premised on all vehicles using all roads. Road financing is based on vehicles consuming petroleum fuels roughly in proportion to their use. Rules limiting jitney services are grounded in the ubiquity and effectiveness of conventional bus and rail services. All of these fundamental understandings and conditions are likely to become anachronistic with the introduction of new fuels and propulsion technologies and the widespread availability of inexpensive wireless communications. And new understandings of environmental threats—largely with respect to climate change and particulate matter—necessitate even further overhaul of policy instruments. New policy research is also needed on how to maximize environmental and social justice benefits, with explicit attention to opportunities and problems created by new technologies (see also Chapter 4).

Example: Reform of policy instruments for reducing energy and environmental impacts of technologies. Today's policy instruments are rapidly becoming anachronistic and inefficient and have a distorting effect on innovation, new technology, and fuel investments. What type of policy structure might be used to reduce greenhouse gas emissions from transportation? Might it replace or be added to the existing air quality regulatory structure? How might emissions trading be employed to reduce greenhouse gases? What is the role of voluntary instruments? How might policy instruments be crafted to integrate behavioral and technological strategies? What are the potential advantages and problems associated with introducing passive vehicle monitoring, such as onboard diagnostics linked to a pollution pricing system? How can instruments be devised that would allow for trade-offs between different goals (such as diesel's lower greenhouse gas emissions but higher particulate emissions)? How should fuel taxes evolve given that they are now calculated on a volumetric basis and provide most of the funding for U.S. roads? As vehicles become more energy-efficient and use different fuels with differing units of measurement, energy characteristics, and greenhouse gas emissions (from the vehicle and upstream), the current fuel tax system becomes not just inadequate, but grossly distorted. And beyond this empirical research is a need for fundamental social science research on associated political processes and public attitudes.

Example: An equitable regulatory environment for emerging transportation systems. Minimal research has been devoted to analyzing the policy implications of new transportation system configurations. The more specialized nature of future fuels and vehicles, coupled with the potential to reduce the transaction costs for intermodal travel (with low-cost information and communication technologies), creates the opportunity to link vehicles to applications in a more efficient and socially and environmentally desirable manner. Instead of buying and using conventional-sized personal vehicles for all trips, travelers could choose readily available alternatives, for example, shared-lease arrangements (e.g., for an everyday vehicle for exclusive use, plus an allotment of time on a vehicle with a larger carrying capacity or some other attribute, such as four-wheel drive); shared-use vehicles; smart paratransit services that would promptly pick one up at home or elsewhere; and small neighborhood vehicles powered by batteries. All of these concepts require policy research on regulatory structures that would maximize the associated environmental and social justice benefits, with due regard for the opportunities and problems created by enabling technologies, such as electronic toll collection, integrated smart cards for parking, and vehicle positioning technology. Research is also needed with respect to standards and codes,

insurance requirements, and taxi and jitney regulation, as well as the best ways to address safety concerns, such as the operating limits of neighborhood vehicles.

Example: Conception of environmental life-cycle policy approaches. Over time, efforts to reduce environmental degradation have shifted toward prevention through better product design and more efficient use of resources. In the future, the emphasis is likely to proceed one step further toward the use of materials and resources that are fully regenerative, rather than depletive, and that are fully biodegradable or reusable (McDonough and Braungart 1998; Hawken et al. 2000). Research is needed to determine what role government can play in encouraging new and existing companies to design and produce transport technologies that are more environmentally sustainable. A knowledge base needs to be developed to better understand the opportunities, costs, and benefits involved. Possibilities range from the use of more recyclable and less toxic materials to technologies that leave a smaller environmental footprint. A strategy needs to be developed for determining the types of products and companies that merit support, the nature of that support, and the economic and environmental benefits of those investments.

Recommendation 4-5.
Design an independent institutional arrangement for transportation technology R&D.

Technology development is principally an industrial activity. However, transport technologies have large environmental externalities and major societal impacts, and many transport facilities and services are owned, managed, or regulated by government. The public sector plays an important role in encouraging the development of technologies that are more environmentally and societally beneficial. The R&D resources of industry, especially in the automotive, energy, and information technology sectors, dwarf those of government. The challenge is to devise a cohesive public-sector R&D strategy that can leverage and stimulate industrial investments in environmentally beneficial technologies, and provide a knowledge base for designing and implementing efficient and effective public policy regarding transportation technologies. A stable and independent institutional arrangement is needed to oversee public R&D investments associated with transport-related technologies and to ensure the continuity of the knowledge base.

Example: R&D on vehicles and fuels. Considerable government funds are invested in cutting-edge research aimed at developing cleaner-burning and

more efficient vehicles and fuels (as well as increasing the global competitiveness of domestic companies). In recent years in the United States, much of this R&D has been conducted under the rubric of PNGV. Substantial R&D funds are also spent in this area by the military and under various other programs. Historically, little of this research has been directed through the Department of Transportation (DOT), even though DOT administers fuel economy standards. Better R&D strategies and more effective R&D programs are needed in the area of vehicles and fuels. The question of what strategies and R&D activities would be most effective needs to be considered, as well as what relative priority should be given to safety, greenhouse gas emissions, particulate matter and other pollutants, acid precipitation, basic science research, and the role of Original Equipment Manufacturers (OEM).

Example: Improving the effectiveness of public R&D and public–private R&D partnerships. Challenges and problems increasingly cut across many institutional jurisdictions, political and national borders, and disciplines. More and more transportation and energy companies are mounting joint R&D ventures, within and across industries. What is the most appropriate and effective role for public R&D?

Public–private research partnerships for transport technologies launched in the 1990s include PNGV, the U.S. Advanced Battery Consortium, the Intelligent Vehicle Initiative, and the Future Truck Initiative. While PNGV is often cited as a model (Chapman 1998), and a series of National Research Council reports have evaluated its progress, no evaluation has been performed of the overall benefits of the program or of its effectiveness and efficiency in meeting the goal of developing affordable advanced technology (Sperling 2001; NRC 2001b).

From the public-sector perspective, a better understanding is needed of the opportunities and challenges presented by partnerships between federal agencies, and even more so by those among federal agencies, universities, state and local governments, small companies, other countries, energy companies, and automaker OEMs. Intra- and interindustry partnerships (for instance, between automakers and major suppliers to develop new technologies, and between automakers and oil companies to develop new fuels), are becoming more common and also need to be understood. Such research should thus be aimed at evaluating the *processes* of partnership. It should shed light on the types of companies and partnerships that are most likely to bring environmentally beneficial products to market and help identify the best methods for leveraging public R&D funds.

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Abbreviations

AAAS	American Association for the Advancement of Science
IPCC	Intergovernmental Panel on Climate Change
NRC	National Research Council
GAO	General Accounting Office

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6

Research Area 5

LAND USE

Research on transportation and the environment has only recently begun to explore in any significant depth the complex relationships among land development patterns, transportation investments, travel behavior, and consequent environmental impacts.[1] Decision makers and practitioners have little knowledge about, for example, the role the built environment may be playing in causing Americans on a per capita basis to drive more and to transport goods farther each year, as has been the pattern for several decades. Transportation professionals need to know more about other factors, in addition to land use, that have contributed to today's travel patterns and that interact with land use in sometimes subtle ways to influence travel choices. Decision makers and practitioners also know very little about the reverse—how driving habits and related factors affect land use and community life. In general, a better understanding is needed of the complex forces that shape land development and subsequent community form so

[1] Several recent publications provide detailed reviews of the literature on transportation, land use, urban design, and growth patterns. For example, the National Transit Institute's *Coordinating Transportation and Land Use Course Manual* provides a detailed discussion of transit-oriented development studies (NTI 2000); Handy (1997) reviews research on travel behavior and urban design; Burchell et al. (1998) summarize findings on sprawl and its relation to infrastructure needs; and Burchell et al. (2002) analyze sprawl, its costs and benefits, its relation to infrastructure, and its personal and social effects. A study by Kuzmyak et al. (forthcoming) for the Transit Cooperative Research Program will provide a summary of literature on traveler responses to land use and site design. These publications also note substantial gaps in the research to date and identify research needs, ranging from more systematic and longer-term analyses of trends and more comprehensive case studies to the development of better policy tools and evaluation methods.

that decision makers and the public can evaluate alternative policy and investment strategies for the future.

These are immensely challenging topics, in part because the causal relationships involved are two-way: land use has profound impacts on transportation, and transportation has profound influences on land use. Figure 6-1 illustrates this relationship. The land use–transportation relationship is depicted as two closed-loop systems that exert influence over each other. Simply put, the development of land for a particular use can generate new trips, thereby influencing demand and ultimately the need for new transportation facilities. Conversely, improvements to transportation systems have the ability to influence accessibility to existing activity centers, thereby improving land values and influencing location decisions and development patterns (Meyer and Miller 2000). Improving the knowledge base on these subjects is critical because—through the marketplace, public policy, or, more likely, a combination of the two—Americans will be making decisions about how to accommodate a likely 50 percent increase in population during the next half-century. These 140 million new residents will need mobility to access homes, schools, shops, workplaces, and recreation. Where and

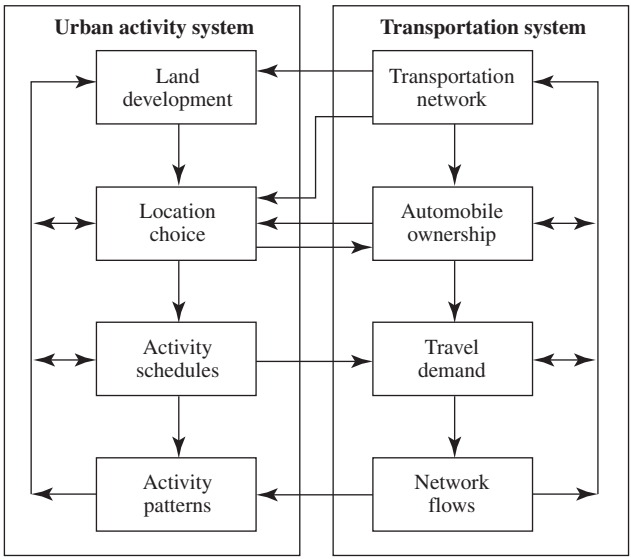

FIGURE 6-1 Urban activity (including land development) and transportation systems interaction. (Source: Meyer and Miller 2000, Figure 3.7, p. 130.)

how this expected growth is distributed on the landscape is likely to have major implications for surface transportation, as well as for the landscape itself. The transportation community needs better information on ways to handle this growing population that better account for, respond to, and, where possible, avoid transportation-related environmental impacts.

Surface Transportation and Land Use

Metropolitan areas in the United States expanded at rates from 2 to as many as 20 times faster than population growth during the second half of the 20th century (see Tables 6-1 and 6-2). Expansive land development has come to rural areas and small towns as well. According to the Department of Agriculture, in the 1990s Americans converted open space to developed land at a rate of 2.2 million acres per year or 251 acres per hour—a rate of conversion 50 percent greater than that of the 1980s[2] (USDA 2000). The land most affected by the extent and pace of expansive development is that closest to existing cities and towns—the farms and open space that Americans often care most about. Development on the metropolitan fringe typically is low-density, scattered, and automobile-dependent. Some of the longest commutes in metropolitan regions are made by residents who live at the metropolitan edge. Not only are citizens and their leaders questioning the transportation impacts of such development, but they are also concerned about the effects of sprawling land development on ecosystems, farmland, scenic and historic resources, and Americans' senses of place and community (see also Chapters 3 and 4). Citizens are concerned, too, about the economic and social consequences of prevailing development patterns, both for new communities with new fiscal burdens and for older communities left behind as investment and employment opportunities flow outward[3] (Orfield 2002; Burchell et al.

[2] A comparison of the midpoint of the more recent period surveyed by the U.S. Department of Agriculture, 1995, with the midpoint of the earlier period, 1987, indicates that nationwide traffic volume increased 25 percent, from 1.92 trillion to 2.4 trillion vehicle-miles traveled per year (FHWA 1996a). During that same period, the U.S. resident population grew only 8.5 percent, from 242.3 million to 262.8 million (U.S. Bureau of the Census 2000).

[3] For a sampling of opinion data, see, e.g., Princeton Survey Research Associates (2000) (finding that 18 percent of Americans mention issues related to development, sprawl, traffic, and roads as "the most important problem facing the community where you live," tying that cluster of issues with crime and violence as the most mentioned categories, above education and the economy); Janes (1999) (finding that 68 percent of state and local policy makers believe that concern

TABLE 6-1

GROWTH IN POPULATION AND LAND CONSUMPTION, 1950-1990

Urbanized Area	Population Growth, 1950–1990 (%)	Developed Land Growth, 1950–1990 (%)	Ratio of Area Growth to Population Growth
Pittsburgh, Pa.	9.50	206.30	21.72
Buffalo, N.Y.	6.60	132.50	20.08
Milwaukee, Wis.	47.90	402.00	8.39
Boston, Mass.	24.30	158.30	6.51
Philadelphia, Pa.	44.50	273.10	6.14
St. Louis, Mo.	39.00	219.30	5.62
Cleveland, Ohio	21.20	112.00	5.28
Cincinnati, Ohio	49.10	250.70	5.11
Kansas City, Mo.	82.70	411.40	4.97
Detroit, Mich.	34.30	164.50	4.80
Baltimore, Md.	62.70	290.10	4.63
New York, N.Y.	30.50	136.80	4.49
Norfolk, Va.	243.60	971.00	3.99
Chicago, Ill.	38.00	123.90	3.26
Minneapolis–St. Paul, Minn.	110.70	360.20	3.25
Atlanta, Ga.	325.40	972.60	2.99
Washington, D.C.	161.30	430.90	2.67
34 metropolitan areas with population > 1 million	92.40	245.20	2.65

Source: Meyer and Miller (2000).

over livable communities is growing, naming traffic congestion, urban sprawl, and housing development as three of the top four "most serious issues" facing their communities); National Association of Local Government Environmental Professionals (1999) ("In recent years, more and more business leaders have come to realize that sprawl can be bad for their bottom lines and economic competitiveness . . . Business leaders whom NALGEP interviewed overwhelmingly cited the impact of sprawl on quality of life as the primary concern . . ."); American Planning Association (2000); Smart Growth America (2000); American Farmland Trust (2001); and National Association of Realtors (2001).

TABLE 6-2

GROWTH IN POPULATION AND LAND CONSUMPTION, 1982–1996

Urbanized Area	Population Growth, 1982–1996 (%)	Developed Land Growth, 1982–1996 (%)	Ratio of Area Growth to Population Growth
Detroit, Mich.	–1.1	19.6	–
Rochester, N.Y.	–3.1	15.5	–
Buffalo–Niagara Falls, N.Y.	0.0	52.0	–
Pittsburgh, Pa.	6.6	39.0	5.9
Harrisburg, Pa.	14.5	72.0	5.0
Boston, Mass.	5.6	26.9	4.8
Chicago, Ill.–Northwestern Ind.	10.9	44.2	4.1
Cleveland, Ohio	6.3	23.8	3.8
New York–Northeastern N.J.	2.9	10.1	3.4
St. Louis, Mo.–Ill.	9.2	30.8	3.3
Baltimore, Md.	26.2	64.4	2.5
Nashville, Tenn.	25.0	53.9	2.2
Tucson, Ariz.	42.2	86.7	2.1
Las Vegas, Nev.	138.9	243.8	1.8
Los Angeles, Calif.	23.4	22.7	1.0
Houston, Tex.	27.5	9.8	0.4
Avg. of 70 U.S. metropolitan regions	20.2	28.8	1.43

Source: Meyer and Miller (2000). Calculated on the basis of data from Texas Transportation Institute (1998). Developed land growth as represented by urbanized area in census data.

2002). The cumulative effect of individual development decisions is that development continues to occur in a dispersed pattern, for reasons that are not fully understood but that include a range of individual preferences, market forces, and public policies.

At the same time that metropolitan areas have been expanding, the amount of driving in personal cars and light trucks (mainly minivans, sport utility vehi-

cles, and pickup trucks) has also grown substantially. As with developed land area, driving has grown at a significantly faster rate than population. For the 5 years 1996 through 2000, driving grew at an average rate of more than 2 percent per year, ranging from a 3.1 percent increase in 1997 to no increase in 2000, a year of higher fuel prices and a dampened economy.[4] Although the relationships of association and causation between the two trends are complex and only partly understood, their implications are significant for the future of community development, transportation planning, transportation system efficiency, and environmental quality.

Environmental Problems Associated with the Land Use–Transportation Connection

Understanding how metropolitan growth and travel trends are related—how land use and other factors, including national and local policies and investment decisions, influence travel behavior—will be fundamental to the choices American society must make as the country's population and economy grow in the 21st century. What is apparent now is that, whatever the causes, the absolute and per capita growth in vehicle travel has been associated (either directly or indirectly) with the expansion of metropolitan areas and with a number of environmental problems.

Tailpipe Emissions

While improved emissions technology has resulted in cleaner air in many parts of the country, transportation in the United States still contributes some 450 million metric tons annually of carbon dioxide, a major greenhouse gas, to the atmosphere (see Chapter 2). This figure represents about 32 percent of total U.S. carbon emissions, and the amount is growing rapidly. Carbon emissions from transportation are increasing at a 20 percent faster rate than overall

[4] The number of miles driven nationally remained essentially the same from 1999 to 2000. While it is possible that this leveling will be sustained, nothing in the previous 4 years or the past three decades indicates that the drop-off represents a trend. In 1999, miles driven increased 2.5 percent, the same rate of growth observed in 1998 and close to the average annual rate for the 1990s as a whole. The reasons why 2000 was different have yet to be fully explored. Lower rates of driving associated with the energy shortages of the late 1970s and early 1980s were short-lived. If the leveling is sustained, research will be needed to explain why and to indicate ways of taking maximum advantage of the trend for transportation efficiency and the environment.

emissions from all sources.[5] In addition, as discussed in Chapter 2, cars and other highway vehicles constitute a continuing major source of air pollutants that are harmful to human health, including carbon monoxide, volatile organic compounds, nitrogen oxides, diesel soot, and a number of carcinogenic and toxic chemicals.[6]

A publication of the U.S. Environmental Protection Agency (EPA) summarizes the situation and suggests that the rising trend in emissions from transportation sources is due in substantial part to urban sprawl and changes in land use:

> Despite considerable progress, the overall goal of clean and healthy air continues to elude much of the country. Unhealthy air pollution levels still plague virtually every major city in the United States. This is largely because development and urban sprawl have created new pollution sources and have contributed to a doubling of vehicle travel since 1970. (EPA 1994)

Government analysts are concerned that current trends in vehicle trips and miles driven, even with continuing incremental improvements in emission control systems, threaten to reverse recent national improvements in air quality by causing increases in total emissions of not just carbon dioxide, but also other pollutants (including sulfur dioxide and particulates) (EPA 2001a; EPA 2001b; FHWA n.d.; EPA 1993). Nitrogen oxide emissions are of particular concern. Despite improvements in the emission performance of individual vehicles, total nitrogen oxide emissions from highway vehicles rose

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[5] Changes in the world's climatic patterns due to the greenhouse effect have already been detected by consensus among international scientists, and the eventual damage to human health and ecosystems is predicted to be widespread and serious. As of this writing, it is unclear what the ultimate American response will be to international agreements negotiated in Rio de Janeiro and Kyoto on containing greenhouse gas emissions or whether new agreements will be negotiated. Under any scenario, however, it will be difficult to meet national obligations if emissions from the transportation sector continue to rise so dramatically.

[6] Although air is getting cleaner in many areas of the country as a result of better emissions technology, highway vehicles still emit some 60 million tons of carbon monoxide per year, about 62 percent of the nation's total inventory of that pollutant. Cars and other highway vehicles still emit some 7 million tons per year (almost 26 percent) of total volatile organic compounds and 8 million tons per year (about 32 percent) of total nitrogen oxides. Volatile organic compounds and nitrogen oxides are both precursors of ozone smog. Motor vehicles also continue to emit as much as 50 percent of the country's carcinogenic and toxic air pollutants, such as benzene and formaldehyde. And heavy vehicles, particularly diesel-powered buses and freight trucks, constitute a significant source of soot and other unhealthy fine particles.

some 2.1 percent from the mid-1980s to the mid-1990s. Although there was some leveling in the latter part of the 1990s, Department of Transportation analysts predict that nitrogen oxide emissions from highway vehicles will grow between now and 2015 in metropolitan areas that experience continued traffic growth unless tighter vehicle controls than those currently scheduled are adopted (FHWA 1996b, 19; DOT 1995, 12).

Infrastructure-Related Impacts

Transportation decision makers have frequently responded to the increasing volume of automobile travel by building more roads. The mileage of public roads and streets in the United States grew steadily after 1900 to nearly 4 million miles in 1999 (BTS 2000, 6, Table 1-4). Nationwide, roads now occupy 11.1 million acres, an area equal in geographic size to the states of Maryland and Delaware combined. Parking lots are estimated to occupy an additional 1.2 to 1.9 million acres (EPA 2001a; EPA 2001b). Private infrastructure has grown as well: analysts report that in the 1990s more space was devoted to parking than people in typical new suburban workplaces, providing as much as 1,400 square feet of parking, usually in surface lots, for every 1,000 square feet of office space (Downs 1992). As discussed in Chapter 3, transportation-related pavement is a major source of runoff water pollution in many watersheds.[7] Highways also fragment wildlife habitats and significantly alter previously pristine areas. In addition, it is becoming increasingly clear that new highway capacity can itself induce additional travel and land development, which in turn can necessitate still more roadway space and other infrastructure, although the extent and workings of this dynamic are still largely to be determined, and more research is needed before any definitive conclusions can be drawn (Noland and Lem 2002).

Social and Economic Impacts

Although the focus of this report is on the environment, it bears mention that the impacts of traffic and land development go further. With growth in driving

[7] Non-point-source pollution remains the nation's most serious water-quality problem. Although agriculture's unfortunate grip on first place as a contributor to non-point-source pollution nationally is not threatened, the impact of pavement on urban and suburban watersheds is immense.

has come increased congestion.[8] Today 70 percent of peak-hour travel on urban Interstate highways occurs on congested roads operating at more than 80 percent of capacity. Researchers have estimated the annual cost to the American economy of lost productivity from congestion-related delays to be $78 billion in 1999. At current rates of population growth and urban expansion, public agencies lack sufficient fiscal resources to keep pace with congestion and Americans' increasing propensity to travel by automobile through the construction of expensive new highway lanes, even if the provision of more roadway space were to constitute an adequate response.

Growth in traffic and land development has substantial impacts on communities in addition to congestion. As investment follows transportation facilities to the fringe of metropolitan regions, existing communities in central cities and traditional towns can suffer declining jobs and opportunities. This pattern can have serious consequences for populations left behind, including a disproportionate number of low-income neighborhoods (see Chapter 4).

Dispersed and low-density land development also requires increased expenditure of scarce economic resources for additional infrastructure beyond that related to transportation, such as schools, sidewalks, crosswalks, public safety, water, sewer, natural gas, electric power, telecommunications, and other utility lines. Some have estimated that the infrastructure needed to serve low-density development costs 9 to 12 percent more per capita than that required for more compact land use (Burchell et al. 2002). Moreover, service routes for mail and parcel delivery, police, and fire and ambulance units may become longer and less efficient.

Current State of Knowledge

Researchers have studied the causes of growth in automobile and truck travel and the relationships of that growth to urban and regional development patterns. However, most of the work has been conducted on a limited scale and scope; there has been little or no coordination of the research. Researchers have evaluated cases of local transportation and land development policies,

[8] While the average commute to work has increased in length, so has the travel time to work, but at a slower rate. Between 1983 and 1995, commuting trips grew 37 percent longer in miles, while travel time increased 14 percent. Reasons cited for the disparity include decentralization of metropolitan areas, greater flexibility in work hours, and increasing use of single-occupant vehicles.

but have used such widely different variables and definitions that comparisons across studies are not always possible. A number of studies have examined correlations between travel and land development patterns, but have not controlled for such variables as household income, household size, automobile ownership, and age of household members, leaving the findings subject to interpretation. Research has also been limited by a lack of data or a lack of resources to assemble available data from local sources. Other than in a few regions, the subject has not been a major focus of government or other institutional activity.

Despite these shortcomings, it is generally accepted that travel is substantially affected by land use and urban development patterns; that federal, state, and local government policies significantly affect both travel and land use choices; and that current trends have significant adverse consequences for air and water pollution, emissions of greenhouse gases, natural ecosystems, and the American landscape (Giuliano 1995; Garrison and Deakin 1991). Questions remain concerning the magnitude of the effects, the relative contribution of transportation policies to travel and development choices, the role of current public policy in steering these choices and outcomes, and alternative policy instruments that might be considered. In many cases, the findings of current research suggest where future study should be directed.

Effects of Development Patterns on Travel Behavior

Much of the research undertaken to date has focused on the relationships between the density of residential neighborhoods and household travel behavior. Some of this research has been performed by environmental organizations, in cooperation with the federally chartered mortgage institution Fannie Mae and other federal agencies, to investigate the impact of neighborhood characteristics on transportation spending patterns.[9] Related research on household density, neighborhood characteristics, and travel behavior has been scattered among a number of institutions. For example, such research has been conducted in the private sector at the Urban Land Institute and at a number of academic institutions, and summarized in presentations at meetings of the Transportation Research Board.[10] International research on the subject includes

[9] See, e.g., Holtzclaw et al. (2002); Holtzclaw (1994).
[10] See, e.g., Ewing and Cervero (2001).

that sponsored by the World Bank, as well as that conducted by the Organisation for Economic Cooperation and Development and the European Council of Ministers of Transport.[11]

The overall body of work on density and travel, notwithstanding differences in methodologies and variations in specific results, is generally consistent in its findings: as population and employment density decline, as occurs with expansive land development, travel distances lengthen, vehicle trips and usage increase, and transit usage and walking decline. Indeed, these associations have been demonstrated in research dating as far back as 1963 (Handy 1997).

An extensive 1998 review of the literature on the costs of sprawling land development performed for the Transit Cooperative Research Program found support for all of these conclusions. With respect to growing vehicle-miles traveled (VMT), the review led to the following conclusion:

> Three factors have contributed about equally to the growth in VMT—changing demographics, growing dependence on the automobile, and longer travel distances. Thus, sprawl, which creates the longer travel distances and increased dependence on the automobile, is a major source of increased vehicle use. (Burchell et al. 1998)

The review also revealed support in the literature for the proposition that sprawling land use reduces the cost-efficiency and effectiveness of transit service as compared with more compact development, and causes households to spend higher proportions of their income for personal transportation. Moreover, travel in sprawling areas generates higher social costs. Findings on the effects of sprawl on total travel times were mixed.

Researchers have investigated a number of other factors in addition to land use density that contribute to travel patterns. One important category of such factors encompasses the effects of other neighborhood characteristics, such as the extent to which jobs, housing, and other activities are mixed or separated from each other in development parcels; the presence or absence of pedestrian amenities; and proximity to central business districts and transit stations (see, for example, Frank and Pivo 1994; Cervero 1996; Ewing and Cervero 2001; Dunphy and Fisher 1996). Most of the studies addressing these factors

[11] For explication of the existing research on relationships between urban form, including neighborhood density, and transportation behavior, see, e.g., EPA (2001b); EPA (2001a, 15–21); Burchell et al. (1998, 6–72, 159–175).

are small, and there are wide variations among the results. Nevertheless, the available evidence indicates that these factors also are relevant to the number of driving trips made and the distances driven.

Other Factors Relevant to Land Use and Travel

In addition to research on the effects of development patterns on travel, several scattered lines of inquiry are addressing other factors that may be relevant to land use, travel, or both. One such factor is government policies that may have the ancillary effect of causing or contributing to low-density development patterns. These policies include, for example, zoning regulations; state and federal tax policies; subsidies for sewage treatment facilities; and even implementation of state or federal regulatory statutes, such as the Clean Air and Clean Water Acts. There is little existing research on these subjects. The same can be said for research on how highways and public transit facilities affect development patterns and communities, although the issue has been examined both in histories (e.g., Warner 1962; Jackson 1985) and in a long but sparse series of empirical case analyses (e.g., for transit, Spengler 1930; Boyce et al. 1972; Gannon and Dear 1972; Webber 1976, Knight and Trygg 1977; Landis and Loutzenheiser 1995; Weinberger 2001; for highways, U.S. Congress 1961; Payne-Maxie and Blayney-Dyett 1980; Forkenbrock et al. 1990; Boarnet 1995; Hansen et al. 1993).

Research is even more widely scattered and piecemeal on other potentially relevant phenomena, such as the effect on travel of such factors and trends as changing demographic characteristics, shifts in consumer and household opportunities and preferences, changes in the organization and location of workplaces, and shifts in shopping habits (Kitamura 1988; Kitamura et al. 1994; Redmond and Mokhtarian 2001; Ferrell and Deakin 2001). Knowing more about such factors is essential to understanding the true impacts of land use.

Sparse research has also been undertaken to test a number of claims about the positive transportation-related impacts of expansive land use. The 1998 literature review noted above (Burchell et al. 1998) and a more recent study on sprawl by the same authors (Burchell et al. 2002) cite a number of these claims, including shorter commuting times (if not distances), reduced congestion, lower governmental costs (because transit is claimed to require greater subsidy than driving), and travel efficiency. These reviews reveal that the work to date on these claims has failed to produce a consensus. Yet these claimed benefits are highly relevant to the attractiveness and likely success of attempts

to affect travel behavior through alternative forms of land development, and need to be understood.

Ultimately, a critical goal of scientific inquiry into the relationships between land use and transportation must be improving the ability of decision makers, practitioners, and the public to evaluate the likely effects of different policy and investment choices on travel behavior and communities. New, technologically advanced tools, such as geographic information systems and other forms of visual imaging, are becoming available to assist in these efforts. In some applications, technology for forecasting land use patterns and integrating land use and transportation models is improving as well. The substantial LUTRAQ (land use, transportation, and air quality) effort undertaken in Portland, Oregon, in the 1990s and the ongoing SMARTRAQ (Strategies for Metropolitan Atlanta's Regional Transportation and Air Quality) research initiative in Atlanta illustrate how these tools can be applied (1000 Friends of Oregon 1997). The need to strengthen existing tools and models for assessing land use and transportation has been documented at recent conferences of modeling experts (Shunk 1995).

Lack of Research Coordination

One of the most challenging obstacles to advancing understanding of the relationships between transportation and land use is that there is no central repository, coordinating body, or effective cataloging operation to which one can turn to locate salient data and evidence and assess relevant studies.

Looking only at the federal government, for example, no agency or institution is in charge of tracking and assembling land use–transportation information, to say nothing of communicating such information to potential users and the public. Instead, there are numerous independently conceived and managed studies scattered among separate institutions, including the Department of Housing and Urban Development, the Federal Highway Administration, the Federal Transit Administration, the Environmental Protection Agency, the Department of Agriculture, the Department of Energy, Fannie Mae, and others. These institutions rarely coordinate closely with each other; in fact, they frequently lack sufficient internal coordination. This fragmentation is also apparent in the scattered undertakings among the 50 states, various real estate development interests, environmental organizations, transportation service providers, universities and other research institutions, trade associations, and private corporations.

Benefits of Increased and More Focused Research

A better understanding of the interactions among land use, public and private transportation infrastructure, and travel behavior could have profound economic and environmental benefits by helping states, localities, and their federal partners allocate both public and private resources more wisely. Better-informed decisions about the consequences of alternative development and transportation investment scenarios could help reduce public expenditures and private costs and generate potentially large reductions in air emissions and other pollution from transportation, while avoiding unnecessary impacts on the landscape.

Although many of the problems associated with transportation and development patterns (e.g., increasing congestion, loss of open space due to urban sprawl) are evident to most Americans, the solutions are far less obvious. A commitment to better, expanded, and more systematic research on these issues could aid in finding ways to meet the access and mobility needs of America's citizens while reversing, or at least limiting the growth of, travel and development patterns that have significant environmental impacts.

Recommendations

Recommendation 5-1.
Expand and focus research on the impacts of development patterns and characteristics on travel behavior.

Existing research indicates that neighborhood density, mix of uses, pedestrian amenities, and related characteristics may have significant impacts on travel behavior. The research suggests that encouraging different development patterns could play a significant role in helping to reduce infrastructure needs and limit growth in the number of vehicle trips made and miles driven, thereby playing a role in reducing environmental impacts as well. If the land use and mobility needs of a growing population and economy are to be met, it is critical that this research be intensified and expanded. Examples of useful future research in this area are presented below.

Example: Expanded geographic scope. To date, study of the influence of neighborhood form on travel has been geographically limited. For example, the research on travel expenditures and urban form being conducted by nonprofit environmental organizations in cooperation with Fannie Mae is currently

limited to three major U.S. cities; other research has been even more limited, to specific neighborhoods or developments. Additional studies should extend this type of inquiry to other cities, including smaller ones, and to nonmetropolitan areas as well. The research should be coordinated so that comparisons can be made across cases. Comparison of the results for different communities could both enhance understanding of the dynamics of the land use–transportation relationship and suggest different approaches for encouraging greater travel efficiency that may be appropriate to particular areas.

In addition, Americans drive cars and trucks nearly twice as much as do Europeans per capita, and more than twice as much as do the Japanese[12] (FHWA 1998, Section VI). Neighborhood density and related factors could perhaps explain this difference, but so might fuel or automobile prices, or differences in policy or culture. It would be useful to expand and refine current knowledge of the extent to which the associations with neighborhood characteristics found in American cities also apply in European and Asian cities—for example, whether differences in household income levels have similar impacts in different countries. If the general tendencies are the same throughout the world, the findings might assist in other lines of inquiry, such as the extent to which gasoline and automobile price differences affect travel behavior.

Example: Refinements in methodology. Research is needed to improve on the current methodology used to study the impacts of development patterns on travel behavior. For example, studies of urban design and its relation to travel behavior have typically relied on available data that may be too aggregate to capture all relevant effects. Future research might assess more precise characteristics of neighborhoods and locations, as well as various aspects of driving, walking, use of public transit, and other transportation behavior. The relative significance of other variables known to affect travel behavior, such as household size and income, could be tested more completely as well. An additional important line of inquiry is better understanding of the shape of the curve of the relationship between neighborhood density and driving: At what points of increased density do we reap the most benefit in terms of reduced driving?

[12] It is important to include both cars and trucks in any international comparison, because many data sources classify minivans and sport utility vehicles as trucks. In 1997, the United States, with a population of 276 million, recorded nearly 4 trillion km of car and truck travel. France and the United Kingdom, each with a population of 59 million, recorded some 470 billion and 434 billion km, respectively. Japan, with a population of 127 million, recorded 731 billion km.

Also needed is a better understanding of causality rather than mere correlation between neighborhood characteristics and travel. Given that a host of factors affect travel decisions and behavior, to what extent can trends and differences among locations be properly attributed to neighborhood characteristics instead of, for example, differences in income or household demographics? For instance, research shows that denser neighborhoods are associated with less travel, but how much of that effect might be explained by lower incomes, lower automobile ownership levels, and smaller household sizes that are often found in denser neighborhoods? Also, how much does travel behavior reflect urban form and travel opportunities versus personal and household characteristics? How important are transportation characteristics in housing location choices? Do people's preferences for driving, taking transit, walking, and so on remain largely the same regardless of their location and the options offered? Or do those who move from more compact to more dispersed areas end up driving more and owning more cars? If behavior changes, how long does it take for the adjustment to occur? Are the results the same if the direction is reversed; that is, as people move from dispersed areas to compact neighborhoods, do they immediately begin driving less?

Finally, although it is likely that future research will confirm and refine the current understanding that development patterns play a significant role in influencing how much Americans travel and by what means, it is probable that other factors are significant and help explain rising rates of vehicle use. These factors might include, for instance, economic growth, rising personal incomes, new living options made possible by communications technology, entry of multiple household members into the workforce, and continued relatively low fuel prices, among others. To understand the true influence of land development patterns on travel behavior, it will be necessary to identify and assess the impact of these other factors as well (see also Chapter 7).

Example: Study of impacts on public transit. Another important linkage among land use, urban design, and travel behavior is the relationship between land use and public transit usage. Although transit still represents a small portion of total trips made nationwide, it represents a major and growing share in many places (APTA 2001; STPP 2001). Indeed, recent years have seen striking increases that reverse decades of declining ridership, and many public transit systems are now struggling to keep up with demand. One special focus of research on the relationship of neighborhood and location characteristics to travel behavior should be the impacts on transit usage, along with other factors affecting transit ridership, such as the comfort, safety, and

convenience of transit systems. Transportation planners and decision makers need to identify those combinations of factors most conducive to transit usage.

Example: Commercial locations and concerns. Much of the quantitative work to date relates to differences in travel behavior associated with various characteristics of residential locations—the typical origins of trips. Intuitively, however, it appears plausible that such characteristics as density, transit access, and pedestrian amenities could make a difference on the destination side as well. Indeed, the impacts might vary with particular types of commercial locations, such as workplaces, shopping areas, and service providers. Future research could explore these potential influences.

Some intriguing corollary questions concerning commercial locations also need to be explored more fully than in the past. The most recent comprehensive study of the impact of commercial development on travel is a Transportation Research Board study on travel characteristics of large-scale suburban activity centers (Hooper 1989). There is a need to update this study. For example, do suburban campus-style offices generate more or less travel than more compact or centralized alternatives, and is there any difference in travel time? Do regional malls and other suburban shopping centers generate different patterns of travel from those associated with traditional downtown areas? Does the concentration of jobs in a single location (a downtown) correlate with reduced or increased travel and travel times, and if so, to what extent? To what degree are differences in the distribution of high-paid versus low-paid (or professional versus industrial) jobs responsible for these effects? If a region has multiple centers or one center with subcenters, does this lead to more or less efficiency than having one large center? How much does the provision of parking, either paid or free, affect these results? What is the price elasticity connecting parking fees with the propensity to drive to work?

Moreover, nearly all of the existing research on these subjects is related exclusively to personal transportation. But one might hypothesize that areas with certain density and proximity characteristics are associated with reductions in trips and mileage for package delivery and other freight transportation as well, because the distances from retailer to distributor and from distributor to final recipient, for example, are smaller. An alternative hypothesis would be that freight transportation has a very different set of controlling variables from personal transportation and does not vary with urban design characteristics. These and related hypotheses should be tested.

Recommendation 5-2.
Continue and expand research on the impacts of transportation facilities.

Another important category of research encompasses the impacts of highway, transit, walking, and bicycling facilities on travel behavior, as well as on land use and the community.

Example: Transportation facilities and travel behavior. The body of evidence from the United States and elsewhere supports the notion of "induced demand": that the demand curve for travel is like that for other goods and services and that, at least under some conditions, the construction or expansion of highway lane capacity will lead to more driving, not just make a preexisting amount of driving more efficient by relieving traffic congestion (Hansen et al. 1993; Cervero 1991; Boarnet 1995). Knowing the extent to which this supposition is true can help in making a more accurate determination of the long-range efficiency of transportation investments (see also Chapter 7). Moreover, while a helpful body of international research on the subject is available, it has not been applied extensively in American transportation planning. Thus there is also a need for better linkages between research on this subject in other countries and the United States.

Transportation professionals and decision makers need to have a better understanding of a range of factors relevant to behavioral responses to added capacity (induced travel), as well as to congestion. What conditions must be present for induced travel to occur? What role is played by land development induced or facilitated by highway construction? To what extent is induced traffic a cause of increasing regional travel volume? And given that added lane capacity may also produce at least short-term benefits, how does induced traffic affect the cost–benefit analysis of highways in particular situations? As metropolitan highway networks become more congested, it is also important to understand better how people and businesses adapt over time. Do they move farther out, relocate to more transit-accessible locations, move to less congested communities, or otherwise internalize the added costs of congestion?

Such research should not be limited to the impacts of highways. What happens when system providers add public transit access or capacity? What conditions must be present for the level of transit demand to be changed by facilities and investments? To what extent do transit facilities affect regional rates of driving? What effect do additional bicycle and pedestrian facilities have on transportation behavior, including rates of driving?

Example: Transportation facilities and land use, development, and community. Decision makers, practitioners, and the public need to know more about how transportation facilities affect land development, not just how development affects transportation. For example, it is evident from observation that the opening of new freeways is often followed by the construction of commercial facilities near exits. Is it reasonable to hypothesize that highway construction induces expansive land development? If so, can the development impacts be predicted? What is the geographic zone of influence of roadways and intersections in affecting development? How do these factors interact with changes in land prices due to improved access to influence development? To what extent, if any, does induced development play a role in the amount of and changes in overall regional vehicle use? (See Meyer and Miller 2000; Forkenbrock et al. 2001.)

There is also inadequate research on the influence of public transit facilities, especially fixed-rail transit construction, on property development near stations. Most of the research done on this subject examines residential property; only a few studies have addressed commercial property as well (Weinberger 2001). In addition, most of the available research has taken a very short-term perspective; more research concerning effects over a 25- or 50-year time horizon would be helpful. Research is also needed to examine the overall impacts (beyond those related to transportation per se) of transit stations and facilities on communities, and how those impacts vary with different types of communities and transit-facility designs.

Another important category of inquiry is the effects of transportation facilities on the social environment of communities as places to live, work, and play (see Chapters 4 and 7). What effects do highways have when they bisect existing communities and when they detour traffic around communities? Moreover, just as some communities are beginning to dismantle unpopular public housing projects, some are deciding not to repair or replace freeways, as was the case following the last major San Francisco earthquakes. How has the decommissioning of highways affected surrounding communities and travel behavior?

Roadway design has also become an important topic in many communities. Efforts are under way to reconsider design standards for major roads; these efforts include federal and state initiatives to develop context-sensitive designs. However, the concern that standard designs are often not sufficiently sensitive to impacts on place and community extends across the entire range of facilities, including regional and local arterials, collectors, and residential streets. Research should address the impacts (including but not limited to land use) of various design types on different kinds of rural areas, suburban communities, and urban

neighborhoods. Can an adequate template for context-sensitive design be developed? What are the impacts of alternative street designs on the affected neighborhoods, districts, and corridors and their inhabitants, and on transportation system performance? What effects do different forms of highway access management have on communities, development patterns, and related travel?

Finally, many municipalities have begun to implement measures designed to further community cohesion and safety, as well as to encourage walking and bicycling. Examples include traffic-calming measures, enhanced pedestrian crossings, shaded sidewalks, and dedicated bicycle lanes, among others. The transportation community needs to learn more about the effects of these measures on both travel patterns and affected neighborhoods and communities.

Example: Agency evaluation of impacts. The National Environmental Policy Act and many state laws require that the environmental impacts of major actions, including significant new transportation facilities, be evaluated prior to implementation. It is important that decision makers and other reviewers of impact statements understand not just the immediate impacts of a proposed facility (e.g., the loss of a particular wetland supplanted by a new roadway), but also the secondary and cumulative impacts, including the likely effects of the facility on travel behavior and land development. Research is needed to address emerging knowledge on these subjects and provide information and understanding that can serve as a basis for best practices.

Recommendation 5-3.
Conduct and expand research on the causes and benefits of current development patterns.

Evidence suggests that expansive land development and so-called "leapfrog" development that skips over undeveloped land are associated with increased motor vehicle use per capita. Such development patterns also cause or are associated with a wide range of additional environmental and social impacts (Burchell et al. 2002). In opinion polls, Americans register increasing concern about these impacts, as well as growing interest in and preference for alternatives.[13] But there is little question that, despite the problems associated with low-density development and citizens' expressed concerns about concomitant impacts, such development remains the dominant pattern of land use in the

[13] See, e.g., Smart Growth America (2000, 1–7).

United States. Thus there is an apparent dissonance between what people say they would like to experience with respect to community and their actual behavior. Given the emerging national interest in smart growth and other alternatives to sprawling development, researchers need to identify and understand the factors that contribute to dispersed growth patterns so these factors can be addressed to the extent possible. Research in this area might focus on two important categories of forces driving sprawl, as described below.

Example: Personal benefits and preferences associated with housing and business location. It has long been held, largely on the basis of anecdotal evidence, that residents and businesses have been choosing outer-suburban locations to escape problems that plague central cities, and now inner suburbs as well. These problems include a real or perceived greater risk of crime; unaffordable housing; expensive land prices; and, especially for families, inferior public school systems. There are also those who contend, with some empirical justification, that racism has caused white flight to the suburbs.[14] In addition, residents and businesses are increasingly choosing outer-suburban locations simply to be closer to each other or to find a quieter environment (Burchell et al. 1998). Dispersed development patterns may also be caused or influenced by Americans' patterns of time management, which are shifting because of emerging technology (see Chapter 5).

As noted earlier, some perceived benefits of suburban sprawl, such as shorter commuting times and reduced traffic congestion, are related directly to transportation. Others relate to the environment, such as the larger yards and personal open space available in some outlying developments, as well as real or perceived greater access to public and private open space beyond the metropolitan edge or on land passed over by leapfrog development. In many cases, residents who perceive their local environment to be threatened by any new development, regardless of how well designed, resist changing an expansively developed community to one that is more supportive of transportation efficiency. At the same time, higher inner-city housing values and the rapid sale of new residential offerings in more urban locations, as well as in more compactly designed new suburban developments, suggest that demand for urban and denser suburban locations remains high.

Government officials and other interested parties need to understand the extent to which these and other consumer preferences drive location decisions

[14] See, e.g., Powell (2000); Brookings Institution (2000).

and which of these factors are most important. Developers and land use planners need to learn whether the attributes preferred by residents and businesses can be provided in communities and developments with different urban designs. For businesses, it is especially important that the convenience of access to various markets (workers, clients, users) be among the attributes studied.

Example: Public policy influences. A range of public policies appears to be important in influencing the shape and location of development. Examples include zoning and building codes that once made sense (such as those mandating large lot sizes or separation of residential and commercial uses), but that now often limit market-based decisions that could support the building of developments more conducive to walking and transit. A related topic is local governments' frequently apparent preference for revenue-generating commercial developments and opposition to developments (particularly those with affordable housing) that require expensive government services, such as schools. Some observers have also expressed concern that interpretation of certain federal regulatory statutes, such as the Clean Air and Clean Water Acts, may unintentionally contribute to dispersed development. Research is needed to investigate such claims.

A number of related questions need to be explored. For example, how do federal, state, and local tax policies, including special policies for particular developments, influence development decisions? To what extent do competitive tactics among different municipalities—for instance, offering subsidies, free infrastructure, and tax breaks to attract businesses—lead to some forms of development? To what extent do state and federal assistance programs for infrastructure, such as roads, schools, and water treatment, provide incentives for choosing dispersed rather than central or compact suburban locations? And what impact does the location of government facilities themselves, such as courthouses, post offices, and agency offices, have on local development patterns? Participants in location decisions need to learn more about which of these factors have been most influential in shaping the built landscape and how shifts in policy are most likely to produce different results.

Recommendation 5-4.
Assess and compare alternative transportation and land use strategies.

Closely related to causes of vehicle use and expansive land development are questions concerning how different transportation and land use strategies will most likely affect travel patterns (see Chapter 7). Many communities are

interested, for example, in obviating the high cost of building new highway capacity to free resources for maintenance of the existing system; many are also struggling to overcome increasing traffic congestion. In addition, finding effective methods for educating the public on the connections between land use and transportation is critical.

Example: Effectiveness of strategies. Because of the complexity, difficulty, and cost of modeling long-run changes in land use and travel behavior given different transportation investment scenarios, many metropolitan areas do not use very sophisticated techniques to analyze land use as part of the transportation planning process by incorporating the interaction over time among new facilities, subsequent land development patterns, and altered travel behavior. A striking exception is the LUTRAQ study in Portland, Oregon, which involved extensive evaluation over several years. A somewhat more developed body of international research has also been undertaken, although its applicability to the U.S. context is uncertain (see, e.g., Mackett 1985 and Wegener 1987).

Efforts such as LUTRAQ and SMARTRAQ that involve simultaneously evaluating land use and transportation scenarios need to be applied elsewhere and made simpler for communities with limited resources. In addition, a broad range of research should be undertaken at multiple sites across the United States to determine what effects different strategies have on travel behavior and which approaches are most effective in reducing pollution and other environmental impacts. Available options might include the following: transit-oriented development and other land use strategies, such as those discussed earlier; ride-share strategies, including increased use of paratransit services; road pricing; improvements to public transit systems; park-and-ride lots or structures at transit stations; and other market-oriented or regulatory techniques. All of these options should be explored.

Research should also address the effectiveness of, and problems associated with, policy measures being developed and applied across the country to shape land development in a more environmentally benign manner. These measures include, for example, urban growth boundaries (such as those pioneered in Oregon), limits on infrastructure spending in locations less desirable for development (such as those being applied in Maryland), land conservation measures (such as conservation easements and programs for the purchase of development rights), financial incentives to homebuyers in smart-growth locations (such as the location-efficient mortgage), direct acquisition of lands that should be protected from development, tax policies, the imposition of local impact fees and exactions, and special zoning in areas targeted for development.

American communities are increasingly employing variations on and combinations of these growth-management techniques, all of which have potentially significant implications for transportation investment needs and travel choices. A portion of the research agenda should be directed to studying the impacts and effectiveness of all the available strategies, and identifying those aspects and combinations that are most effective, as well as the social and economic conditions and institutional and policy frameworks most supportive of particular approaches. Studies might also be undertaken to compare and improve our understanding of the current differences in land use and travel behavior among communities with widely divergent characteristics, such as Portland, Houston, Phoenix, and Boston. In addition to investigation at the community level, analysts should compare the likely effects of alternative policy and investment scenarios at the state and federal levels.

Example: Development and refinement of models for assessing strategies. In investigating the above questions, researchers will frequently need to develop better methodologies that are sensitive enough to predict the likely outcomes of alternative policy choices. Such new models might encompass many variations. One example is the development of a better method for assessing the economic attractiveness of alternative scenarios comprising different combinations of transportation investment and management decisions and land use planning and development patterns. Transportation is one of the largest categories of public expenditure, yet there is not a valid and accepted methodology for comparing, within a given geographic sector of a metropolitan region, the economics of roadway investments versus different sorts of transit expansions and land use strategies in a way that accounts correctly for the likely effects of development patterns on travel behavior.

The performance of integrated land use–transportation models also should be examined to determine what refinements to the models are needed. For example, forecasts of the LUTRAQ model could be evaluated and their prediction accuracy assessed. With each passing year, more data become available to illuminate how accurate that model has been in predicting travel behavior and what refinements might be appropriate. Other applications of integrated transportation land use models might similarly be evaluated.

Transportation professionals are hampered by the fact that current models used to predict travel behavior do not deal well, if at all, with walking and bicycling and with short trips in general. Since many land use and community design strategies are aimed at encouraging walking and cycling and reducing trip lengths, this is a major shortcoming. Models should be developed that are

capable of accurately evaluating the potential substitution of walking trips for motorized travel under different land use scenarios. Some current research suggests that the effects of transit facilities and walking on travel patterns may be more extensive and subtler than is allowed for by current models.

Using existing research as a starting point and developing additional methodologies, researchers and planners might attempt to create a template that could be used by a region to satisfy its accessibility and mobility needs at minimum cost. The objective of such a template would be to determine optimum investments in highway capacity and transit expansion for any given land use pattern, while taking into account economic incentives for development that is more compact. A tool that would aid in least-cost planning could have immense practical benefits in supporting what are now mainly informal and underinformed evaluative processes. (Additional issues with respect to planning methods are discussed in Chapter 7.)

Example: Models for regional cooperation. Changes in federal transportation law—the most important of these being the Intermodal Surface Transportation Efficiency Act and its successor, the Transportation Equity Act for the 21st Century—have made a difference in encouraging states, municipalities, and metropolitan regions to work together in planning a region's major transportation investments (at least those that receive federal funds). This change is important because regional economies and travel patterns predominate in today's highly mobile and interconnected world. Residents and businesses seldom remain within their own jurisdictional borders as they go about their daily business. Yet many metropolitan regions have yet to achieve the level of cooperation anticipated by Congress in federal transportation legislation. For example, concerns are frequently raised about the adequacy of representation of different jurisdictions and constituencies within metropolitan planning organizations.

One of the most significant challenges to be met is the coordination of transportation and land use planning (see also Chapter 7). Ideally, it is desirable to plan the two together because of the extent to which they influence each other. While some incremental progress has been made in regional transportation thinking, minimal progress has been achieved with regard to regional decision making for land use, which remains the near-exclusive domain of the smallest units of government in most locations. The difficulties posed by this dynamic can be immense given the sheer number of government units that can be involved in a given region. Metropolitan Chicago, for example, has been estimated (though the reported estimates vary) to comprise some 267 municipalities and counties

and some 1,250 "governments" of one sort or another, including various school and service districts and regional authorities. All of these entities can have impacts on land use patterns and, by extension, on the transportation system. Such jurisdictional fragmentation can make regional coordination of transportation and land use virtually impossible.

Portland (Oregon), Minneapolis–St. Paul, and Atlanta are among the metropolitan regions that are attempting to overcome this challenge with new regional institutions. Other arrangements are being developed in various locales around the country, with wide variation among strategies and methods. As regions gain experience with coordination mechanisms, it is important that these undertakings be monitored and assessed, and that further study be undertaken to ascertain which mechanisms hold the most promise in furthering the ability of regions to consider land use and transportation together rather than separately. Both evaluation research and exploration of new forms of cooperative planning would be important.

Recommendation 5-5.
Translate research findings into accessible tools for practitioners and citizens.

As noted earlier in this chapter, research on the interactions between land development patterns and transportation has been piecemeal and scattered with respect to both substance and geography. The field comprises a rather bewildering array of disconnected literature and undertakings that even experts find difficult to identify, assemble, and apply. And nowhere is the bewilderment felt more acutely than at the state and local levels, where transportation planners and engineers, along with elected officials and their citizen constituents, must make sense of policy options. Practitioners and citizens need new tools that can make this body of evolving information more accessible and easy to use. Such accessibility can take many forms—from the development of so-called "sketch" models that can reveal quickly and broadly the likely impacts of alternative development scenarios, to sophisticated new visual applications using geographic information system technology, to traditional best-practices manuals (see Chapter 7). Development of such tools is an essential component of any meaningful research agenda on transportation and land use.

In making this complex body of research more accessible, some attention needs to be paid to the dissemination of data on overall land development and transportation trends and patterns. Currently, a lack of standards and uniform

practices in collecting and reporting these data limits their availability and usefulness. In fact, more research should be conducted on means of assessing and improving upon current methods for measuring land use characteristics and patterns. Special emphasis should be placed on techniques that use computer imagery and other visual media.

At the same time, there is a need to improve education and training among transportation professionals so that state departments of transportation and other public agencies will have enhanced expertise on these often rapidly developing issues. There is a particular need for urban planners and other land management professionals to help coordinate transportation and land use planning at the state level.

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Abbreviations

APTA	American Public Transportation Association
BTS	Bureau of Transportation Statistics
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
NTI	National Transit Institute
STPP	Surface Transportation Policy Project
USDA	U.S. Department of Agriculture

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7

Research Area 6

PLANNING AND PERFORMANCE MEASURES

The planning and decision-making processes surrounding surface transportation in the United States will have to address serious challenges in the 21st century as a result of the nation's continuing demographic growth and changing makeup, global trade and environmental issues, and rapidly changing technology and travel behavior (Burwell 2000; Tate-Glass et al. 1999). While these challenges are great in themselves, they are compounded by arguably inadequate planning and decision-making methods and tools. Methods and tools that address contemporary concerns regarding environmental protection and enhancement, sustainability, economic impacts, efficient goods movement, community quality of life, customer satisfaction, and the performance of an oversaturated highway system are few and far between. Moreover, a strong case can be made that the methods and tools available to planners for understanding travel and economic behavior lag behind current issues by at least a generation. Likewise, the methods and tools used by engineering and environmental professionals for integrating environmental considerations into various aspects of transportation decision making are quite rudimentary, having originated in the major highway construction era of the 1950s and 1960s (Marshment 1999). [The cooperative venture of the U.S. Department of Transportation and the Environmental Protection Agency to develop TRANSIMS (the Transportation Analysis and Simulation System) is a notable exception.] In addition, consideration of the various modes—highways, transit, trucking, shipping, rail freight, and so on—as an integrated system is uncommon, making it difficult to foster efficient investment policies (Pedersen 1999; Neumann 2000).

This foundation promises treacherous footing in addressing the growing concerns cited above.

The situation is exacerbated by the fact that, as discussed in previous chapters, public-sector decision-making processes demonstrate spotty and often inadequate integration of transportation, land use, economic development, and environmental considerations. Additionally, most private-sector transportation decisions are made in isolation from the public-sector planning process. When public–private partnerships are sought, considerable difficulty is encountered in harmonizing the short time frame and site-specific nature of private-sector investment decisions with the long time frame and community-wide nature of public-sector investments.

Surface Transportation and the Planning Process

The environmental significance of transportation planning and decision-making processes lies in the fact that transportation facilities, services, and usage directly affect community cohesion, human health, ecosystem health, global energy consumption, and climate change. Moreover, transportation is an arena of American life in which market forces are significantly constrained by public policy. Individuals and businesses make rational transportation decisions based on the choices available. However, the private sector has a limited role in contributing to a range of consumer options. In contrast with retail trade, for example, firms have an extremely limited ability to enter major portions of the transportation market (siting and building of highways, transit systems, and intermodal facilities). Major elements of transportation supply and pricing are defined by public policy and public agency decisions. Yet the effectiveness of these public agency decisions that form the framework for consumer and business travel practices is typically compromised by a limited understanding of underlying complex travel behavior and by frequent disconnects between real-world issues and institutional decision processes.

The major, dominating influence of public policy on the effectiveness of the transportation system raises the stakes with regard to the effectiveness of the planning and decision-making processes. Decisions made by individuals and businesses may be far from optimal in a system in which a largely monopolistic supply of transportation infrastructure is inadequate, inflexible, inappropriate, or over- or underpriced.

Current State of Knowledge

The effectiveness of current transportation planning and decision-making methods and tools is limited by the fact that they are based in engineering principles, facility standards, and an emphasis on mobility defined as travel time and cost. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, reinforced by the 1998 Transportation Equity Act for the 21st Century (TEA-21), provided a strong impetus to move transportation planning and decision-making practices toward a more holistic approach. In response to ISTEA, TEA-21, the Clean Air Act Amendments of 1990, and similar legislated initiatives, the nation's transportation planning community has worked hard, with varying success, to make the transition from using engineering standards as the basis for their efforts. The new criteria for evaluation are multidimensional, and include access to jobs and other personal and economic needs; availability of alternative modes; community quality of life; environmental protection and enhancement; freight and intermodal concerns; social equity and environmental justice; and service quality, reliability, and flexibility. Frequently, however, metropolitan planning organizations and state departments of transportation find themselves adapting existing methods and technical tools to explore new issues. Too often, planners and other interested parties become frustrated with the inadequacy of these old methods and tools for dealing with current problems.

With regard to the current state of transportation planning knowledge, there is a reasonable understanding of travel behavior at the broadest level, and there are specific techniques available for modeling discrete events and measuring limited impacts. The dynamics of travel demand are apparent at an aggregate level, but not at a detailed level: planners may be competent at creating models to estimate the total number of trips emanating from a subarea, for example, but cannot describe why a particular household chooses to drive a teenaged child a third of a mile for soccer practice even though sidewalks are available. Without understanding the underlying activities, preferences, and travel options of householders and businesses, planners are left with the challenge of using aggregate models to estimate the subtleties of complex, emerging travel behavior. Evening, weekend, and nonwork travel models and trip-chaining models are underrepresented (Winters 1999).

Aggregate person-trip models are also being adapted across the nation in an attempt to reflect commercial and freight travel behavior. Unfortunately, limited understanding among the transportation planning community of the dynamics of the manufacturing, distribution, retailing, and freight transportation sectors

challenges the effectiveness of these freight modeling efforts. Too often, the adaptation of long-standing aggregate models to meet current challenges conjures the image of someone using a cannon to hit a moving target on a rifle range: the tool was not designed for the application and is too cumbersome and imprecise to be effectively adapted.

Similarly, while detailed highway network models are able to simulate the dynamic interactions among vehicles under varying circumstances on a highway, planners are not yet able to determine how frequently such circumstances will occur, nor can they point confidently to effective operational practices that can address problem circumstances. Institutional arrangements frequently separate those individuals responsible for operating the highway and transit systems from those planning the systems, further limiting the effectiveness and responsiveness of the institutions.

Vast experience lies behind models used to estimate the amount of user time and cost savings that will result immediately upon completion of a highway improvement, but there is little information about how the complex decision processes of individuals and businesses will respond to those savings over time. How much new traffic will the highway system see a month or a year after the improvement? What is the nature of this new travel? Does it reflect new economic or social opportunities that travelers previously were discouraged from pursuing, or diversion from a less efficient mode or means of achieving the desired objective?

Current understanding of the precise nature of the various interactions described above is poor, and few methods and tools are available to allow planners and other decision makers to incorporate these interactions into evaluation or decision making. Coupled with decision processes that are disjointed between the public and private sectors, between planning and project design, between construction and operations, between land use and transportation, and among various levels of government, the current knowledge base is too weak for addressing the critical transportation planning issues of the 21st century. Such fundamental questions as how an oversaturated highway system behaves and how the presence of an oversaturated system influences other personal and business decision processes cannot be answered reliably at present. Yet such questions are central to effective transportation decision making.

The level of interest in advancing the state of the art and the state of the practice in transportation planning and decision making is quite high, however. As a result, effective research will find a receptive audience and can be expected to produce rapid changes in planning and decision-making practice.

New methods and tools will be gratefully received by practitioners. A successful planning and decision-making research program will produce modern methods and tools that will give practitioners greater ability to meet ever-increasing demands and expectations.

The transportation community and many others readily acknowledge the inadequacy of current planning and decision-making methods and tools and of the underlying knowledge of specific behavioral interactions. Reflecting this concern, the Transportation Research Board (TRB) convened two conferences in 1999 on the subject of Refocusing Transportation Planning for the 21st Century. The conferences, which continued a 40-year tradition of meeting on a recurring basis to assess the transportation planning process, produced more than 100 research statements to help address the issues involved (Annex 7-1 lists these statements). The list reflects awareness of the significant need for research and development on new transportation planning techniques and institutional arrangements.

Despite acknowledgment of the inadequacy of current processes, the conferences offered grounds for optimism. Through federal participation, major metropolitan transportation decisions are now among the most open, participatory public decision processes in the nation. The transportation program has, through federal transportation law and planning requirements, directly empowered local elected officials, established an intergovernmental policy forum, facilitated a structured technical process, and encouraged outreach to other stakeholders. Current cooperative research programs, such as the National Cooperative Highway Research Program and the Transit Cooperative Research Program, have a structured agenda and oversight, thereby increasing knowledge on a continuing basis. However, the pace of investigation, the development of methods and tools, and the refinement of institutions are slow and unsatisfactory to many stakeholders. Given both the large role of public agency decisions in establishing the transportation framework for the nation and the interest of such institutions in seeking improved knowledge, the benefits of better-informed planning and decision-making processes will be substantial—commensurate with the scale of the U.S. transportation system, whose usage is measured in the trillions of dollars and tens of billions of person-hours per year.

Research Needs

A large number of recent reports have identified research requirements for the transportation planning and decision-making processes. These include the

proceedings of the Refocusing Transportation Planning for the 21st Century conferences; the Federal Highway Administration's *Strategic Plan for Environmental Research, 1998–2003;* the National Science and Technology Council's 1999 *National Research Agenda for Transportation and Sustainable Communities;* background materials for TRB's October 2000 Conference on Performance Measures; *Transportation Research Circular 469: Environmental Research Needs in Transportation*; the proceedings of the July 2000 National Conference on Transportation and the Environment for the 21st Century; and other materials, such as the numerous "millennium papers" prepared by TRB committees.

In addition to research problem statements, the Refocusing Transportation Planning conferences produced documentation identifying a number of cross-cutting challenges that will be faced by practitioners in the first decade of the 21st century:

- Developing a customer- and user-based planning process;
- Linking planning to the political decision process;
- Creating a vision for the community and defining the role of transportation in achieving that vision;
- Understanding the current and future movement of freight;
- Addressing the unsatisfactory nature of current technical processes, including models;
- Exploring the role and impact of technology in the transportation arena;
- Relating land use and transportation;
- Resolving questions about the adequacy of existing institutions and relationships;
- Ensuring professional development for those in the transportation field;
- Linking transportation planning to other program-area processes; and
- Encouraging the consideration of certain transportation solutions or outcomes.

These cross-cutting challenges underscore the growing recognition that improvement of the methods and tools to be used in meeting tomorrow's transportation planning challenges is a critical need.

Previous efforts have gone a long way toward articulating research needs for transportation planning. Meyer (2000) has suggested a framework for transportation planning research for which "a logical starting point is the identification of enabling research, that is, those issues, societal trends, and

needs for knowledge that lead to subsequent research on the planning process and the tools that are used in this process." Figure 7-1 depicts Meyer's conceptual approach. Research would flow from basic (enabling) research to the development of tools, then to creation or refinement of decision-making processes, and finally to methods of institutionalizing the new approaches.

With respect to transportation planning, performance measurement, and institutional issues, the research program recommended below can be grouped more simply and the contributions of other work incorporated more effectively by combining the bottom two levels of the pyramid into a basic research category labeled "More Effective Understanding of Travel Dynamics." The top two levels of the pyramid can likewise be combined into a single applied research category labeled "Effective Techniques and Responsive Institutions." The recommendations that follow are grouped in these two categories. In some cases, these recommendations generalize those made in earlier chapters to address the transportation planning context. In the interest of brevity, however, recommendations covered in depth elsewhere in this report, such as those pertaining to land use and transportation, are excluded here.

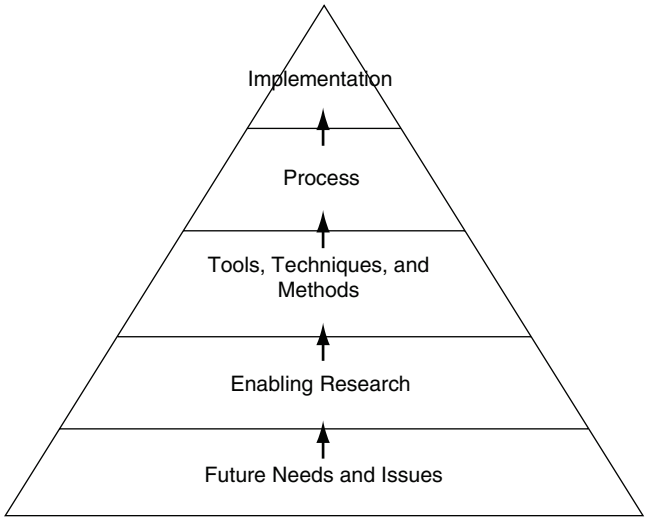

FIGURE 7-1 Conceptual framework for transportation planning. (Source: Meyer 2000.)

Recommendations

More Effective Understanding of Travel Dynamics

The foundational research required for effective transportation planning and decision making must focus on understanding travel dynamics. No methods, tools, techniques, or institutions can succeed if developed without this information. The breadth of the need for basic travel research is great.

Recommendation 6-1.
Develop a more effective understanding of the perceptions and priorities of the transportation system's customers (users and taxpayers).

The importance to customers of travel time brevity (the traditional goal of transportation plans) as compared with, for example, travel time reliability, requires further research. Apparent paradoxes in customer attitudes must be identified and reconciled. Questions about the value the public assigns to such attributes as the availability of an alternative mode also require research. States and municipalities are spending considerable financial resources on quality-of-life improvements (such as streetscaping) on the one hand and on major highway investments on the other without reliable information about customer expectations or desires. Better methods are needed to address this subject.

Recommendation 6-2.
Develop a more effective understanding of the nature of personal travel, as well as associated trends and decision processes.

There is a need for serious exploration of personal travel behavior, structured according to underlying needs and desires, activities, resources, and constraints. While much work is being done in the international arena on this subject, the work is still largely in the exploratory stage, and the results have not reached the mainstream of the transportation planning community. Research in this area needs to address questions about why a particular travel event (a trip from point A to point B at a specific time by a particular mode along a given route) occurs, instead of merely accounting for the occurrence of the event. Such analysis must also be performed for each sector of society, giving special consideration to unique population groups. Information for decisions

related to travel demand can no longer be based on aggregated data for all travelers at a specific zone or subarea level. The research proposed here would provide a behavioral basis for examining the effects of further technological advances on travel patterns.

Special concern: Changing demographics and unique population groups. The aggregate transportation planning approaches used by most transportation agencies are particularly ineffective in interacting with the increasingly diverse and complex population of the United States. In the real world, traditional suburban workers commuting to the central city in the morning have been replaced to a great extent by entrepreneurial immigrants; single parents shuttling between day care and work; families executing lengthy, complex trip chains on Saturday afternoons; elderly individuals maintaining part-time employment (and perhaps also different residences in the summer and winter); and teenagers traveling long distances to spend time at the mall (Pisarski 1996). Innovative research is needed to identify the travel practices and choice processes of different market segments, given that the travel behavior of one segment may have little in common with that of another. Research is also needed to understand the correlation between changing economic patterns (e.g., changes in the location of economic activity, changes in wealth distribution) and travel behavior. Populations that are difficult to survey (such as recent immigrants, non-English-speaking residents, migrant workers and other transients, and individuals with low levels of literacy) require particular research attention. Research is also needed to determine the appropriate demographic parameters with which to explain particular travel choices.

Further, there is a need to examine the likely shift in travel by purpose, vehicle occupancy, and time of day caused by the expected increase in the average age of the U.S. population. It is possible that an older population base in 2030 with a smaller percentage of residents in the workforce and more leisure time may make more daily trips but fewer peak-hour trips per capita than does today's population base. If so, planning processes must adjust to these changing circumstances.

Special concern: Effects of technological advances on travel behavior. Telecommuting, Internet shopping, and similar shifts in economic practices may lead to significant changes in the nature, amount, and time of day of travel demand. Planners struggle to address such issues as the likely extent of substitution of electronic communication for personal travel. A 5 percent increase in the penetration of telecommuting into the workplace or electronic shopping

into the retail arena could be safely overlooked in system investment policies; in contrast, a 40 percent penetration would call for a radical reconsideration of policies. Future rush-hour traffic forecasts continue to exert a heavy influence on the design of highway facilities, and near-term capital decisions are being made across the nation without a reasonable understanding of likely future shifts in travel behavior.

Recommendation 6-3.
Develop a more effective understanding of the nature of commercial travel and the freight industry, as well as associated trends and decision processes.

During the past 10 years, states and metropolitan planning organizations have sought to include private-sector stakeholders from the freight community more fully in the planning process. Unfortunately, the combination of the public sector's traditional emphasis on personal travel and the private sector's reticence to share proprietary data makes it difficult to incorporate freight dynamics into planning decisions. Research is needed to identify the appropriate means of obtaining effective information about commercial traffic and its dynamics without compromising firms' competitive positions. This research is essential to the ability of the United States to compete in a global economy while enhancing the environment and protecting other core values. Free-trade agreements and other burgeoning aspects of international freight have raised policy questions regarding the appropriate priorities in using scarce public resources for costly, location- and mode-specific freight and intermodal investments. Answers to questions about the expected functional longevity of major infrastructure investments cannot be obtained without a better understanding of the risks involved. At present, knowledge on this subject is scarce (Neumann 2000).

Special concern: E-commerce and e-freight. E-commerce and just-in-time delivery of both manufacturing components and consumer products are generating significant changes in the nature and amount of long-distance freight traffic and local-delivery traffic. Research is required to understand this aspect of commercial traffic so that further changes resulting from the maturing of e-commerce can be anticipated and factored into the planning process. The economic impacts of e-commerce and e-freight must also be analyzed and related to current travel patterns and behaviors.

Recommendation 6-4.
Develop a more effective understanding of the role of transportation services and facilities in the economy.

Many if not most transportation investments in the United States are justified to some extent on the basis of their anticipated economic benefit. Whether this benefit is expected to accrue to society primarily through decreased travel time or through removal of barriers to access, economic impact is central. Further research is required to produce a more meaningful understanding of these relationships and methods for better incorporation into transportation decision processes. Once a location is served with a basic level of accessibility, what further contribution to economic health does the next level of improvements offer? Does traffic congestion cost a community its economic well-being, or is it a sign of economic vitality?

Recommendation 6-5.
Develop a more effective understanding of the role of transportation services and facilities in the culture and social fabric of the United States.

Research is needed on the effect of the transportation system on individuals' sense of self-worth, civic pride, and personal aspirations. Community impacts of transportation, such as neighborhood integration or disintegration, improved or diminished sense of place, and connectivity to the regional community, are also generally not well understood, but they are critical areas of knowledge in a holistic decision-making process. Note that this recommended research overlaps with the critical research recommendations presented in Chapter 6 regarding the causal relationships between transportation investments and land use patterns and between community design and travel choices.

Effective Techniques and Responsive Institutions

Improved understanding of the nature and dynamics of personal and commercial travel and the impacts of the transportation system on communities and the environment will be useful only if there are techniques available to apply the knowledge, as well as institutions ready to use those techniques. The following recommendations address this need.

Recommendation 6-6.
Develop techniques for identifying community aspirations and crafting community and regional visions related to transportation planning.

There is a great need for transportation planning practices that can effectively engage disparate elements of a community and produce a vision for the community's future that is both desirable and achievable. Research is required to identify techniques for public outreach, methods for assessing public preferences, and approaches to consensus building, and to determine which market research techniques (e.g., polling) have the most credibility with elected officials.

Special concern: Underrepresented population groups. Efforts to articulate a community vision can focus too easily on the attitudes and perceptions of community leaders, business representatives, advocacy groups, and community activists. Research is required on effective methods for engaging populations that are not predisposed to participate in such activities. Such research should examine, for example, the effectiveness of polling and various survey techniques (Pedersen 1999).

Recommendation 6-7.
Develop tools that incorporate the complex dynamics of travel behavior.

Improved understanding of travel dynamics is useful if it can be incorporated into the tools used by planners and decision makers. TRANSIMS is one effort in this direction. This model provides a micro simulation of all individual travelers on a metropolitanwide network, and is designed to produce more accurate and more sensitive travel forecasts by integrating six modules: population synthesis, activity-based travel demand generation, intermodal trip planning, traffic microsimulation, emissions/air quality analysis, and a feedback selector. However, the true utility of this complex model cannot be realized until its mechanics are tested, and behavioral relationships (the why's of travel behavior and location decisions) are incorporated and validated against observed behavior.

TRANSIMS is not the only initiative requiring research support in this area. Numerous independent research efforts are required to identify the most effective tools for addressing specific policy or technical questions. As noted in Chapter 6, explanatory models that incorporate the relationships between transportation actions (location and quality of facilities and services) and land use are needed. Too often the lack of a good understanding of these relation-

ships causes transportation professionals to treat settlement patterns and development trends as factors exogenous to the transportation system.

Special concern: Data needs. Complex behavioral relationships and comprehensive models require large and reliable datasets. Research is required on data collection methods that can meet the demands of new models and emerging issues while remaining timely and affordable (Tate-Glass et al. 1999). Journey-to-work data from the long form of the decennial U.S. Census will be replaced during the next decade by data from the continuous American Community Survey. Research is required to understand the reliability of these data and to develop methods for their use in transportation planning. At the same time, the coming years will be marked by rapid advances in the use of Global Positioning System devices, electronic transponders, satellite imagery, and other remote methods of gathering travel information. Research is needed to identify the extent to which technology can be used to supplement or replace costly surveys and other data collection methods.

It should be noted that few of the research recommendations presented in this chapter can be pursued effectively without a process for obtaining and interpreting large amounts of data. Greater use of available technology is perhaps the most promising avenue for meeting the long-standing need for more robust datasets.

Recommendation 6-8.
Develop tools that can be used to estimate the impacts of transportation-related public policy and decisions on comprehensive measures of performance.

Performance measurement is a technique for assessing the degree to which current transportation systems and usage match community aspirations, as well as the ability of available policy, investment, and operational options to help achieve those aspirations. Defined in this manner, transportation system performance extends far beyond traditional measures of travel time and cost, ranging from effects on economic vitality to levels of customer satisfaction (Pedersen 1999). Issues such as transportation's effects on human health, ecosystem health, global energy consumption, climate change, and the ability to respond to unforeseen conditions must be incorporated into evaluation tools. While some measures may not lend themselves to quantification, research must still identify ways of ensuring equitable consideration of such measures in decision-making processes.

Special concern: "Back-casting." Back-casting is an approach that has been applied to good effect in Europe but not used widely in the United States. Once a vision of a desired future in a metropolitan area or local community has been defined, the approach is used to determine what actions are required to achieve that vision. This approach differs from the traditional focus of models, which attempt to predict the impacts of anticipated growth and change, including a defined set of transportation investments and related policies. Research into best practices for back-casting could be of particular benefit for strategic planning and policy development efforts.

Special concern: Travel safety. While travel safety research is generally not within the environmental arena addressed in this report, methods for integrating a variety of safety initiatives more adequately into the planning process are essential. Research is required to understand complex safety-related interactions among facility design, site and community design, driver demographics, experience and education, and law enforcement, and to incorporate these interactions into planning and design tools, thus moving current practice away from a simple focus on accident countermeasures.

Special concern: Sustainability and growth. In the realm of transportation system performance, one of the greatest demands from both within and outside the transportation planning community is for assessment of the sustainability of planned transportation and land use arrangements. There is a need for methods and tools that can be used to test alternative visions and public policies against the ability of a metropolitan area or community to maintain its systems over time. Research regarding the impacts of transportation policy and investments on environmental protection and enhancement, energy consumption, land consumption, economic health, and affordability must be translated into tools available for use at the front lines of transportation decision making (Burwell 2000). The need for this particular facet of performance measurement is compounded by the fact that the United States will have to accommodate the activities of tens of millions of additional residents in the coming years. Metropolitan areas such as Atlanta and Dallas–Fort Worth continue to absorb population growth in excess of 10,000 residents per month. These rapidly growing areas have a tremendous need for tools that can be used to assess the long-term sustainability of current practices.

Special concern: Distribution of impacts. There is a need for performance evaluation techniques that acknowledge the often differing impacts of the transportation system (both positive and negative) on various segments of the

population. Federal civil rights laws require that federal transportation programs distribute impacts equitably. Tools are needed to both clarify the types of differential impacts and estimate their scale (Kennedy 2000).

Special concern: Policy-level tools. There is a need for quick-response, order-of-magnitude tools in addition to TRANSIMS and comparably detailed forecasting and analysis models. Often, policy questions are amenable to techniques that focus on scale (Are there enough people to support the investment?) and that use transferable parameters (How will incident-related delay increase as freeway traffic volumes increase?). The availability of sketch tools would allow timely responses to policy questions without requiring full-scale operation of TRANSIMS or other detailed network models. Availability of sketch tools would expand the scope of issues that can be addressed by smaller planning staffs.

Special concern: Multimodal performance measures. The current emphasis on performance-based planning has highlighted several key areas requiring improvement. One such area is the development of multimodal performance measures and methods. This is an area in which research to date has been inadequate and that will require additional research and resources if planners are to be expected to make truly multimodal decisions.

Recommendation 6-9.
Develop techniques and ensure institutional arrangements that support integrated, performance-based planning and decision making.

Improved evaluation methods and tools must be accompanied by improved decision processes, particularly when public–private partnerships are sought. To achieve improved decision processes in turn requires research into methods of articulating critical choices and communicating performance comparisons to decision makers and the public. Undeniably, the more sophisticated and comprehensive a technical process becomes, the more opaque it becomes, and the more difficult it is to apply the process in accommodating the often short time frame and site-specific nature of private-sector investment decisions. Moreover, the nation does not want key public decisions to rest on the products of "black-box" technical tools. Rather, the goal in a representative form of government is to craft public policy through elected officials on the basis of both sound technical information and open access by all concerned. Simultaneously maintaining the comprehensiveness and transparency of technical processes to allow informed and intelligent debate about policy choices,

as well as making the processes more responsive to private-sector decision making, is one of the greatest research challenges facing the transportation planning community.

Special concern: Effective institutional arrangements. Decision-making institutions must be capable of meeting the challenge of an integrated process such as that described above. At a minimum, this capability requires capacity building at both the policy and technical levels of transportation agencies, planning organizations, and state and local governments. It may also require investigation of the barriers to effective coordination between transportation decisions and land development (Marshment 1999), along with exploration of means of streamlining the current transportation decision-making process to allow for a multitude of decision makers without generating fragmentation and gridlock. New or modified institutions may be needed.

Special concern: Incorporating customer preferences and priorities. A related concern is that of increasing the role of identified customer preferences and priorities in the decision-making process. To this end, planners and decision makers need guidance in interpreting public attitudes. Failure to address this issue could lead to an overreliance on technical information regarding travel behavior, external impacts, and the like in the decision-making process. Research that can be of assistance in approaching the matter of dispute resolution is also needed.

Special concern: Integrating transportation, land use, and environmental decision making. Of particular concern is the need for research on methods of better integrating transportation, land use, and environmental decision making. Improved integration would significantly enhance the time- and cost-efficiency of decision making by weeding out unworkable and undesirable alternatives early in the planning process. Integration would also allow a shift from environmental impact assessment to environmental protection and enhancement, and from transportation problem solving to comprehensive community planning. The required research must focus as much or more on institutions as on techniques. It must examine the contribution of institutional barriers to the current lack of integration and suggest structural changes that can eliminate the most significant barriers.

Special concern: Climate change and transportation planning and decision making. Weather patterns in recent years have been characterized by unusual ambient air temperatures, as well as greater frequency and severity of flooding, drought, tropical storms, and hurricanes. These weather patterns have put considerable stress on affected transportation facilities and

services. If climate change due to greenhouse gas emissions causes such weather patterns to become more frequent and widespread, significant impacts on the transportation system will result. These impacts will be experienced in three categories:

- *Emergency preparation and response*—Transportation facility siting and design are based on engineering principles incorporating climatological expectations (e.g., 100-year flood plains, historic frost depths, prevailing wind patterns). The transportation system has not been crafted to withstand the demands of unexpected weather events. Severe storms, flooding, and unprecedented extremes in temperature or precipitation can produce circumstances beyond the design characteristics of the transportation system. As a result, the life expectancy of facilities may be shortened, and weather-related failures (e.g., road washouts, frost heaves and heat buckling, bridge failures) may exceed historical frequencies. Moreover, emergency planning for evacuation may need to be extended to areas beyond those typically exposed to weather-related disasters.
- *Lasting changes*—Measurable changes in sea levels can drastically alter the nature and location of coastal areas, as well as inland waterways. Given the strong proximate relationship between water bodies and human development (i.e., development is close to water for transportation, power, drinking water, and recreation), changes in coastlines and waterways will cause significant damage to developed areas and transportation facilities. Lasting changes to sea levels would necessitate redesign and reconstruction of many major transportation facilities, including affected ports, airports, major highways, and rail facilities—at considerable expense.
- *Actions to influence greenhouse gas emissions*—Transportation is currently highly reliant on combustion processes that generate carbon dioxide (see Chapter 2). If concerns about climate change become part of the planning agenda, transportation planners will be expected to produce reliable estimates of the effectiveness of available public actions in reducing carbon dioxide emissions. Few of the transportation planning tools available today address fuel use, let alone carbon dioxide emissions, or account for changes in travel behavior or in vehicle technology and fuels that might be considered in planning to reduce the impacts of climate change (see Chapter 5). The current need for investment in the development of reliable transportation planning tools and decision-making techniques is heightened by the significant role that may be played by such tools and techniques in the future.

Special concern: Development of environmental information and environmental management methods and tools for efficiently integrating environmental protection and enhancement into transportation planning and decision making. In view of the extremely complex and technical nature of transportation planning, decision making, and environmental management, there is a need to develop methods and tools that are easy to understand and use. These methods and tools must be integrated, as must the processes they support.

Special concern: Transportation financing. At the broadest level, transportation decision making must be more closely related to the formulation of public policy regarding the collection and allocation of public revenues. Of significant concern within the transportation community is the need for research on new options—such as value pricing—for generating revenue to provide and maintain transportation services. This concern also reflects a need for research on the potential impacts of dampened travel growth and increased vehicle fuel-efficiency on the adequacy of revenues based on fuel consumption. Both technical information and understanding of public preferences are important objectives of research aimed at identifying the appropriate mix of user-based and general tax revenue sources. Further, research is required to help clarify the priority of transportation funding within the universe of financial demands on government.

Recommendation 6-10.
Develop methods and institutional structures for integrating transportation planning, programming, design, and operation.

Beyond integration of decision-making processes across disciplines, improvement is needed in the institutional arrangements and practices within the transportation discipline. Too frequently there is a disconnect between system plans and the prioritization of projects for funding, while design and environmental impact assessment processes discount decisions made earlier in the planning process regarding scale and purpose. Commonly, the operation of transit services (route design, service scheduling, and fare policy) and of highways (incident detection and response, information system management, computer signal control) have little structured interaction with the planning and programming processes. Research on new institutional structures and on ways of improving the interaction of operational management with system planning and programming is a critical research need.

Special concern: Traditional orientation to capital projects. A particular challenge is to find workable approaches that can help transportation institutions transition from a traditional focus on capital projects to a more integrated approach that involves exploring both capital and operational actions for achieving stated goals. The urgency of this challenge is related to the nation's demand for accommodation of increasing levels of economic activity and limited support for expansion of transportation infrastructure.

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Annex 7-1

Transportation Planning Research Statements from Conferences on Refocusing Transportation Planning for the 21st Century

More than 100 research statements pertaining to the transportation planning process were provided by participants in the two conferences on Refocusing Transportation Planning for the 21st Century held in 1999. The specific statements cover the majority of the research needs identified in this chapter. The list below is arranged according to the cross-cutting issues identified by the conference participants. Because of the strong influence of planning practitioners at the conferences, a majority of the research statements reflect a desire to identify and disseminate improved practices. The suggested research topics and the estimated cost for addressing each topic (in thousands of dollars) are listed below. Where a range of costs was offered in the conference report, the value presented here is the low end of the range. If no cost was estimated by the authors of the research statement, the cost column is left blank (–). The total cost of the identified research items exceeds $60 million.

A More Robust Planning Process

Identifying emerging 21st-century user needs driving demand for transportation services	200
Extent to which transportation investments result in economic development and growth	450
Future trends and expected changes in goods movement	200
Barriers to intermodal freight	150
Overcoming institutional barriers to multimodalism	150
Role of planning in improving the reliability of transportation system performance	200
Effect of system reliability on freight-sector planning and decisions	200
Comparative benefits of investments in management, operations, system preservation, and capacity expansion	500
Institutional issues associated with addressing maintenance and operation (M&O) in the planning process	200

How congestion-pricing projects could redistribute financing responsibility for transportation improvements	150
Understanding the linkages between transportation systems and sustainable communities: evaluating alternative plans and policies	200
Consideration of environmental factors in transportation planning	750
Identifying and communicating the purpose of and need for transportation projects	250
Integration of transportation corridor and land use planning	300
Defining and analyzing disparate impacts in the context of environmental justice	350
Methods and techniques for better identifying transportation issues of disadvantaged populations and costs associated with providing potentially different transportation services to these populations	350
How to examine the equity of benefits and disbenefits in the planning process	150
Understanding the travel characteristics of welfare recipients and low-income individuals	200
Planning for effective coordination of nonemergency transportation services	200
Systemwide approaches to planning for safety	250
Creative approaches to transportation planning	150
Identifying transportation planning needs of the future	250
Applying new information technology to improve the transportation planning process	300
Integrating new environmental concerns into the transportation planning process	350
Survey of international best practices in planning processes and implementation	250
Resource and energy consumption and sustainable transportation	200
Using performance data generated by intelligent transportation systems (ITS) in the planning process	200

Developing a Customer- and User-Based Planning Process

Identifying what basic research is needed to develop customer-related planning and to create a vision for the community	–
User's guide to the transportation planning process	60
Promoting effective public involvement in the greatest transportation challenges	250
Tools for fostering stakeholder collaboration and dispute resolution in transportation planning	180
Public involvement and customer interaction in analysis for transportation decisions	250
Cultural sensitivities and communication with diverse populations	75
Measuring the effectiveness of Internet tools for soliciting public involvement	50
Tools for assessing the effectiveness of public-involvement processes	250
Institutional barriers to integrating public involvement into transportation planning	200
Incorporating visioning into the transportation planning process	100

Aligning Planning Processes, Decision-Making Institutions, and the Political Process to Meet 21st-Century Challenges

Measuring the impact of transportation systems decisions in terms that matter to decision makers and the public	300
Effectively defining and communicating investment trade-offs and choices for decision makers	200
Closing the gap between regional planning and positions taken by decision makers and the public	500
Improving the linkage between decision making and accountability through performance audits and program assessments	250
Aligning the planning process with faster-paced political change and participatory democracy	200
Reinventing transportation planning	250

Documenting for elected officials the importance of M&O investments to the performance of the overall transportation system	350
Forty years of regional plans: critical review of lessons learned	500
Administrative reform by states, metropolitan planning organizations, and transit agencies: integrating environmental and economic factors into business and investment decisions	300
New cooperative relationships for planning, design, construction, operation, and management	200
Changing institutional capacity of planning organizations: benchmarking progress	500
New or reformed political institutions: Is there a better way to make planning decisions?	1,000

Understanding the Current and Future Movement of Freight

Understanding the freight industry: trends and future characteristics	250
Integrating freight needs into regional land use planning	200
Strategic measurement for evaluating and assessing the impacts of freight-related projects	2,000
Identifying freight forecasting guidelines and methods	100
Impact of technology on the way commodities are purchased and delivered	250
Land use and circulation implications of express package-delivery services	50
Intermodal terminal capacity and access	100

Unsatisfactory Nature of Technical Processes, Including Models

Socioeconomic research program for metropolitan and nonmetropolitan areas	250 + 150/year
Techniques for equity analysis in metropolitan transportation planning	120
Enabling research program on travel behavior	25,000

Development of guidelines for collecting impact and performance data	400
System operation considerations in planning models	900
Integration of current travel demand forecasting procedures with dynamic assignment models	500
M&O performance indicators	120
Multimodal evaluation	200
Methods for assessing public preferences and incorporating them into transportation decision making	150
Development of a holistic ecosystem evaluation tool	840
Tools for assessing the impacts of neighborhood-scale projects	180
Sensitivity analysis and error assessment in travel demand forecasting models	450
Comparison of forecast and actual travel trends	400
Integrating significant and emerging emission-factor elements with travel demand models	1,080
Techniques for improving communication with community groups and the general public	250
Package of quick-response planning tools for small communities	120
Time-use research to support a new generation of travel and activity models	300
Induced travel and mode substitution as reactions to transportation improvements	400
Interactions between telecommunications and travel	900
Statewide planning model	240
Development of procedures and tools for investing in transportation assets to improve the overall transportation system	5,000
Strategic data research: transportation equity	250

Role and Impact of Technology on Transportation

Technology and organizations: learning from other industries	400
Bringing transportation planning alive: use of advanced technologies to enhance the interactivity of the transportation decision-making process	300
Using ITS data to enhance the transportation planning process	250

Evaluation of benefits provided by information technology to transportation system operations	500
Reexamination of transportation planning assumptions that may have become outdated as a result of technological advances	500
Technology scanning 2025	150 every 3–5 years
Best-practice survey methods for capturing impacts of information technology on transport activity	425
Applying technology to improve performance measurement for transportation systems	400

Land Use and Transportation

Land use and the transportation planning process: evaluation of existing land use tools applied in transportation decision making, and development of improved tools for use by decision makers in demonstrating the effects of managed growth	100
Transportation strategies for successful redevelopment of established areas	525+
Analytical methods using geographic information systems to evaluate potential transportation and land use impacts on new land development, redevelopment, and rural community development	–
Considering environmental and land use issues and community values in the transportation planning process	–
Techniques to increase multimodal accessibility in suburban communities	150
Flexible approaches to parking development	–
Linking metropolitan travel growth and sprawl	100
Integration of corridor and local land use planning	300
Best practices in metropolitan land use planning and regulation	500
Impacts of new community and neighborhood designs on household travel behavior	1,000

Professional Development

Professional development in transportation planning	150

Linkages to Other Programs and Outcomes

Development of a national shared-knowledge network for social and environmental aspects of transportation planning	350
Information sharing among planning processes	495
Rural participation in transportation decision making	400
Determining and planning for the impacts of tourism on transportation infrastructure	100
Analysis of network connectivity for bicycling and walking	400
Revisiting vision in the planning process	425

8

ESTABLISHMENT OF A LONG-TERM RESEARCH STRATEGY

In 1996, the General Accounting Office recommended the development of a long-term research strategy for surface transportation (GAO 1996). In 1998, in the Transportation Equity Act for the 21st Century, Congress called for the establishment of a surface transportation environmental cooperative research program, along with the development of a national research agenda on transportation, energy, and the environment. Congress recognized that a research program with a targeted national agenda is critically needed to help transportation decision makers effectively provide for mobility while simultaneously protecting and enhancing the environment.

In the preceding chapters, the Advisory Board has outlined a proposed agenda for the cooperative research program called for by Congress. The work to be carried out under the program encompasses further developing the research agenda and updating it from year to year; sponsoring and coordinating the research itself; and fostering increased coordination, cooperation, and communication among research entities as part of a long-term national research strategy on transportation and the environment.

Research can be used to identify new policies and approaches for resolving, mitigating, and managing adverse environmental impacts resulting from transportation, as well as for enhancing the environment and contributing to public health and community integrity. For example, research could be conducted to refine the current sketchy understanding of the impact of the expansion of transportation facilities on travel behavior, enabling policymakers to predict associated land use changes more accurately. As another example, additional research could lead to better definition of the relationship between

roadway width and wildlife habitat fragmentation, thereby assisting transportation planners in protecting and reestablishing wildlife migratory routes.

Current research on transportation and the environment is making valuable contributions, but its ultimate impact is limited because of low levels of funding, inadequate coordination across research entities, and the short-term focus that characterizes most of the work done to date. The Advisory Board has concluded that there is a pressing need for a new strategy for transportation environmental research. This strategy is necessary to (*a*) fill gaps in the existing research programs of the multiple agencies with interests in transportation, energy, and the environment; (*b*) extend the scope of research to system-level and long-term issues as well as short-term needs; (*c*) ensure that all related research initiatives are coordinated; (*d*) provide for broad dissemination of research findings; and (*e*) present research findings in forms and formats that are easily accessible to transportation professionals and policymakers. Absent such a strategy, a fragmented, primarily short-term approach to research will persist without a strong relationship to transportation investment policies and operating practices (GAO 1996).

A long-term, coordinated research strategy with sufficient funding is the only way of adequately preparing transportation policymakers to confront the substantial challenges of an increasing population and expanding economy. In this chapter components of a national research agenda for a proposed surface transportation environmental cooperative research program are outlined; the characteristics of successful cooperative research programs are detailed; and mechanisms for funding and implementing the proposed program, as well as fostering increased cooperation and coordination between the surface transportation community and other research entities, are examined.

National Research Agenda for a Surface Transportation Environmental Cooperative Research Program

The first step in formulating a long-term research strategy for transportation and the environment is to develop a national research agenda that responds to current and anticipated problems and policy choices. That first step has been taken in the previous chapters of this report, in which problems and policy choices have been outlined and six key areas in which targeted research is needed have been identified:

- Human health,
- Ecology and natural systems,
- Environmental and social justice,
- Emerging technologies,
- Land use, and
- Planning and performance measures.

As noted earlier in the report, these six areas were chosen because they represent the points of intersection between transportation and the human and natural environments. While research is being conducted in each of these areas, important gaps exist. Without new research in each of the six areas, decision makers will lack important information needed to make sound decisions on transportation and the environment.

A new surface transportation environmental cooperative research program is needed to ensure that the national research agenda on these critical issues is implemented. This would be accomplished under the program proposed herein in two ways: in some cases, the program would serve as the sponsoring organization for research, while in others the program would serve as the coordinating body for research carried out by others.

Typically, cooperative research programs are formed for two primary reasons. The first is to leverage financial and other resources, as is the case with the National Cooperative Highway Research Program (NCHRP). For example, NCHRP was formed by state departments of transportation (DOTs) for the express purpose of pooling funds to conduct research of common value. State DOTs realized that many of the problems that were occurring in one state were also occurring in many others. Pooling funds for research to solve these problems instead of duplicating efforts enables the state DOTs not only to carry out more research than would be possible on an individual state basis, but also to conduct this research in a more cost-effective manner.

The second primary reason for forming cooperative research programs is to resolve political stalemates and scientific debates. In other words, when tough political choices are made more difficult by scientific uncertainty or conflict, forming a cooperative research program can be the key to producing credible research results that are accepted by multiple parties. For example, the Health Effects Institute (HEI) was formed in 1980 to produce research necessary for resolving disputes between the automotive industry and the Environmental Protection Agency (EPA) regarding the health effects attributable to vehicle emissions. By thus bringing EPA and the automotive manufacturers

together, it was possible to reach agreement on the questions that needed to be researched and the methodologies to be employed. Interpretations of the results may still vary, but underlying conflicts over basic data have been resolved. Essentially, the primary benefit of such cooperative research programs is the ability to conduct research in a manner that is both transparent to and accepted by all relevant parties.

Today, transportation policy choices have become more polarized than necessary because interested parties hold different positions on the likely answers to important but unresolved scientific questions. For example, what combination of transit and automobile-oriented investments will best provide for population growth while minimizing environmental harm? Do noise barriers produce more benefit or harm to wildlife near highways? Will denser land use configurations lead to decreased automobile dependency? Does transportation influence land use, or is the converse true? Can travel behavior be significantly altered if the right incentives are provided? What are the right incentives? The list of questions currently unanswered ranges from the complex to the relatively simple. Unfortunately, in the areas in which research has been conducted, definitive results have remained elusive. The primary reasons for this are that the research generated is often narrowly scoped, frequently because funding is limited; there is not always agreement on the scientific interpretations, the conclusions, or even the fundamental methodology used to conduct the research; and new forums for discussion of the findings and their interpretations and implications have emerged. Further, research findings are often narrowly disseminated, so that they are known within academe but not the broader community of professionals, or are known in the state where the work was conducted but not elsewhere. If a surface transportation environmental cooperative research program were established, all parties representing contending perspectives could be brought together to define the research questions, review the research methodology, and jointly interpret the findings, thereby increasing the likelihood of acceptance of the results.

Characteristics of a Successful Cooperative Research Program

Cooperative research programs must have certain characteristics to succeed. These characteristics, listed below, are designed to instill a basic level of trust

and confidence in the integrity of the research process, which is just as important as the research that is produced (Deen and Harder 1999):

- A clearly articulated mission from which a strategic focus and research priorities can be ascertained;
- An institutional structure that provides for complete scientific independence from outside influences;
- A credible and openly competitive process for soliciting and evaluating research proposals based on merit review;
- A rigorous standard for evaluating research products;
- A mechanism for widely disseminating research findings and for involving a wide array of stakeholders; and
- An ability to obtain competent staff and to secure a stable funding source.

The Advisory Board reviewed the organizational structures of four leading cooperative research programs: HEI,[1] EPA's Science to Achieve Results Program (STAR),[2] NCHRP, and the Transit Cooperative Research Program (TCRP).[3] Summaries of these programs are included in Appendix B. On the basis of this review, the following specific program elements appear to be most important for success:

- *Core partners*—entities that should contribute to the overall governance of the program, the primary customers and recipients of the research products.[4] Three categories of core partners should be considered when forming a surface transportation environmental cooperative research program: public entities, the private sector, and nongovernmental/nonprofit organizations.
- *Institutional arrangement*—establishment of the research program in a setting that provides for independence and credibility. A partnership between industry and the public sector enhances a cooperative research program's ability to create a cohesive, integrated research environment and should offer the added attraction of securing private investments while

[1] See www.healtheffects.org.
[2] See es.epa.gov/ncerqa/ncqwelc.html.
[3] Interviews were conducted with Chris Jenks, Senior Program Manager, TCRP; Ronald McCready, Senior Program Manager, NCHRP; Peter Preuss, EPA, Manager of the STAR program; and Robert Reilly, Transportation Research Board, Division Director and Manager of NCHRP and TCRP.
[4] For purposes of this report, core partners are classified as sponsors, a separate and distinct category from stakeholders.

establishing a firewall of independence around the program. Representatives from nongovernmental organizations can form the third leg of the partnership, thereby differentiating the model from that of HEI.[5]

- *Strategic focus*—program direction, as established by the core partners and stakeholders of the program and guided by the national research agenda. To ensure that all core partners and relevant stakeholders are in agreement on the priorities of the cooperative research program, a mechanism is needed for formulating, articulating, and periodically updating the program's strategic focus areas. HEI and STAR, for example, develop multiyear strategic plans.
- *Solicitation and evaluation of research proposals*—the ability to exercise vital quality control mechanisms through open competition and merit review. Establishing clear criteria aids in the selection of the most appropriate research projects, thereby ensuring a selection process that is transparent, fair, and subject to open competition. HEI, STAR, NCHRP, and TCRP all use clear selection criteria in addition to insisting that the selected research projects undergo external merit review. Although the merit review processes differ among the four programs, each incorporates the fundamental elements of both external and internal merit review, as well as open competition.
- *Evaluation of research*—peer review and other approaches designed to ensure the validity and credibility of both the research and the operating functions of the cooperative research program. In addition to evaluating specific research projects upon completion, periodic programmatic evaluations can serve to increase confidence in the operations of the program (NRC 1999) and may be important when a significant number of end users/customers/stakeholders are to be satisfied.
- *Dissemination of research*—mechanisms for effectively disseminating research findings. Too often, the research process ends with the publication of findings. Unless research programs make a concerted effort to inform other researchers and research institutions, practicing professionals, decision makers, and the general populace about those findings, a system of fragmented, uncoordinated research initiatives will persist.

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[5] The primary drawback associated with creating a new institution is the customary lag time between the creation of a new entity and its full implementation. This problem can be solved by either establishing the cooperative research program in an existing independent, nonprofit entity with appropriate capabilities for managing such a program, or by simply incorporating the lag time into the initial strategic planning stage and communicating clear expectations to all involved in the partnership.

- *Funding*—stable funding that enables support of long-term basic and applied research (see below).
- *Competency and availability of staff*—the ability to attract and retain highly skilled and independent staff. Next to stable and sufficient funding, the support of competent staff is the most crucial element in achieving a successful program. If the program is to avail itself of the best and most experienced representatives of the multiple disciplines needed for the research efforts, long-term stable arrangements and flexible contracting processes must be offered with established and emerging institutions that can demonstrate the ability to assemble appropriate teams and complete the tasks assigned. The staffs and institutions involved must also be shielded from political interests and undue influence from key stakeholders and core partners; that is, they must be granted full independence so they can apply the highest standards of scientific rigor to their work (NRC 1999).
- *Stakeholder involvement/communication*—mechanisms for providing for meaningful stakeholder involvement in the selection, evaluation, and coordination of the research.[6] To maintain stakeholder confidence, the process for determining research priorities, selecting and structuring studies, and reviewing the final research products must be clearly understood and readily transparent. All four of the research programs reviewed share common features for actively soliciting stakeholder involvement. Stakeholders are invited to participate in the formulation of the program's strategic plan and strategic focus areas, to submit research proposals, to participate in merit reviews of the research proposals, to participate in workshops at which ongoing research is presented, and to participate in peer reviews of the research products. They are also apprised of the research findings and recommendations.

In summary, the structure and characteristics of a cooperative research program designed to improve the quality and credibility of research in the surface transportation arena should have the following elements:

- Core partners
  - Public partners
  - Private partners
  - Nonprofits

[6] For purposes of this report, stakeholders are defined as all entities, excluding core partners, who demonstrate an interest in the work of the cooperative research program or are fundamental to the successful completion of the program's work.

- Board of directors
  - Formed by core partners
  - Solicits stakeholder input
  - Develops strategic focus
  - Manages priority setting
- Proposal solicitation
  - Request for proposals
  - Open competition
  - Merit review—project selection criteria
  - Stakeholder involvement
- Evaluation of research proposals
  - Expert peer review
  - Publication of final report with reviewers' comments
- Dissemination of research results
  - Set-aside funds for distribution of reports
  - Internet, professional databases, libraries, and so forth
  - One-page summaries of reports for the nonscientific community
  - Presentations of research at workshops
- Periodic program evaluation (measures of success)
- Stakeholder involvement
  - Strategic plan
  - Open solicitation of research proposals
  - Merit review of research proposals
  - Research presentations at workshops
  - Peer review of final research
  - Dissemination of research reports

FUNDING

Adequate and stable funding must be available for the proposed program on a multiyear basis to support administrative, contracting, and sponsorship activities, including the ability to enter into partnerships with other public and private entities; to support long-term research, both basic and applied; and to sponsor workshops and demonstrations of implementation.

Congress first established a continuing commitment to transportation research beyond the budget of the then Bureau of Public Roads of the Department of Agriculture through the Hayden-Cartwright Act of 1934, enabling the

states to use federal transportation funds for surveys, planning, and engineering investigations in support of future highway improvements (FHWA 1976). The scope of this commitment was subsequently expanded to encompass broader planning and research activities. In these early years, the development of fundamental science and engineering knowledge to support transportation improvements and operations was essential.

The Federal-Aid Highway Act of 1962 (Public Law 87-866) first enabled the states to pool funds collaboratively to further research interests. NCHRP was established to conduct research in acute problem areas that affected highway planning, design, construction, operation, and maintenance nationwide. In 1991, the Intermodal Surface Transportation Efficiency Act increased funding for planning and research to 2 percent of the funding for certain federal-aid highway program categories and required that at least 25 percent of those funds (now known as State Planning and Research Funds) be spent for research. These funds, along with limited direct apportionments to DOT, remain the principal source of transportation research support today.

With passage of the National Environmental Policy Act of 1969, transportation agencies were given broader responsibilities and required to coordinate with environmental organizations. However, no funding commensurate with such responsibilities was ever identified. Nor was any mechanism created to further collaborative approaches rather than regulatory research initiatives. While transportation-derived funding remains one of the largest sources of investment in many environmental research areas, most of the activity associated with this funding is tied directly to individual transportation projects instead of to the development of knowledge that would assist in enhancing the overall condition of the environment. Also, little research into the effects of past projects and current operations is undertaken, the focus being primarily on new endeavors.

Because transportation–environment research has been underfunded during the past 30 years, a significant investment is now needed to address both the backlog of issues requiring attention and the issues that continue to arise. Current programs are not designed to address the full range of pressing research needs in surface transportation and the environment. HEI focuses on only one such issue—the health effects of air pollution. NCHRP and TCRP focus on their respective surface transportation modes, and while the scope of both programs includes topics in planning, economics, and environmental protection, program resources are devoted each year primarily to modal concerns. NCHRP research dollars are used mainly for the design and

construction of highway structures and pavements, and on issues related to safety and operations; TCRP focuses on transit concerns. In contrast, the transportation–environment research agenda proposed in this report would address all surface transportation modes (highways, transit, and rail) and would cover the full range of environmental impacts, with research spanning the six priority areas identified above. Both research addressing short-term needs and longer-term efforts aimed at uncovering fundamental relationships and devising basic new approaches to transportation and the environment would be funded.

While a precise budgetary estimate has not been developed, it is the judgment of the Advisory Board that full implementation of the agenda proposed in this report would necessitate a multiyear investment of well over a $100 million. In reviewing the NCHRP, TCRP, and HEI programs, the Advisory Board ascertained that the minimum operating budget of each was $8 million. The multiyear investment envisioned for the proposed transportation–environment research agenda would be an important complement to these other expenditures. Indeed, by developing new knowledge and helping to put that knowledge into practice, a focused, coordinated investment in transportation–environment research would enhance the efficacy of these existing programs.[7]

A large-scale research program requires a careful startup phase and review of success before a sustainable and effective annual level of research activity can be determined. Thus it is prudent to anticipate that full implementation of the proposed program should and will be phased in over several years. However, there is little reason for growth of the program to be constrained by a lack of funding. At current federal funding levels, as little as 0.05 percent of annual authorizations of certain federal-aid program categories produces approximately $150 million. While a precise annual budgetary estimate for the eventual surface transportation cooperative research program cannot be established until after the startup phase, it is the Advisory Board's opinion that the budget will not exceed such a small fraction of the overall federal transportation program. A national commitment of this scale would not pose a significant financial challenge to the federal transportation program, and given the importance of the environmental issues at stake in the proposed research program, could be expected to produce benefits many times as large.

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[7] The transportation–environment research agenda also would complement the proposed Future Strategic Highway Research Program, which includes proposals for applied, short-term work on planning and the environment as one of its components (see TRB 2001).

Implementation

The Advisory Board envisions that representatives from appropriate federal government agencies would establish a relationship with an independent entity capable of implementing and managing a national surface transportation environmental cooperative research program having the characteristics of a successful program outlined above. The implementing organization would be directed to report the program's activities each year to the appropriate federal agency representatives and to Congress.

Increased Cooperation, Coordination, and Communication

The proposed surface transportation environmental cooperative research program could serve as a coordinating body for many entities involved in such research. Such entities might include federal agencies conducting environmental and transportation research, universities, the private sector, nongovernmental organizations, state transportation and environmental agencies, international bodies, and other research institutions. Specifically, the program could be tasked with (*a*) annually surveying the research being conducted in the area both domestically and internationally; (*b*) providing specific recommendations for enhancing coordination, eliminating duplication, and identifying research gaps and priorities, with particular attention to long-term research needs; (*c*) enabling and supporting ongoing information sharing and collaborative debate; (*d*) sponsoring demonstrations and operational tests of promising research findings in cooperation with other parties; (*e*) soliciting stakeholder input to the management and evaluation of the program; and (*f*) fostering further education and capacity building in both research and professional practice.

References

Abbreviations

FHWA	Federal Highway Administration
GAO	General Accounting Office

NRC	National Research Council
TRB	Transportation Research Board

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Appendix A

RESEARCH PRIORITIES WORKSHOP: SUMMARY REPORT

On September 26–27, 2000, in Washington, D.C., the Surface Transportation Environmental Cooperative Research Program Advisory Board (Advisory Board) convened a broad spectrum of transportation and environmental professionals for a focused 2-day workshop designed to identify future research priorities for the surface transportation community. Prior to the "Research Priorities Workshop," the Advisory Board members identified six critical research areas and outlined three pertinent questions for each area. Panelists and audience members were invited to respond to these questions. The critical research areas were selected on the basis of the Advisory Board's mission to produce a national research agenda of energy, environment, and planning research for the surface transportation community.

Critical Research Areas

The six critical research areas selected for discussion during the Research Priorities Workshop were as follows:

- *Human health,* as defined by transportation's impact on the environment and the potential adverse effects on human health related to, for example, air quality, water quality, and safety;
- *Ecosystem health,* specifically, transportation's impact on the environment and the resulting health of the ecosystem;

- *Climate change,* namely the effects of patterns of demand on fuel consumption and greenhouse gas emissions, and the role for alternative fuels, new vehicles, and other strategies;
- *Land use and the built environment,* focusing on the relationship between patterns of growth and land consumption and surface transportation;
- *Design and management of research programs,* soliciting recommendations for how to effectively structure a research program that will address the intersection between the environment and transportation; and
- *Institutions, governance, and capacity-building.* The Advisory Board queried participants during this segment of the workshop to consider how research can be structured to best aid agencies and institutions that develop and deliver surface transportation.

Each panelist and invited workshop participant was requested to respond to the following three questions, tailored to the individual critical research areas:

- What should be the priority for future research in the area of human health?
- What organizational arrangements may be needed to meet these new priorities?
- What areas in human health research are currently underresearched or inadequately addressed via traditional research programs?

Mission of the Surface Transportation Environmental Cooperative Research Program Advisory Board

> (c) ADVISORY BOARD.—
> ESTABLISHMENT.—In consultation with the Secretary of Energy, the Administrator of the Environmental Protection Agency, and the heads of other appropriate Federal departments and agencies, the Secretary shall establish an advisory board to recommend environmental and energy conservation research, technology, and technology transfer activities related to surface transportation. [Transportation Equity Act for the 21st Century (TEA-21), Sec. 5107]

On the basis of the legislative mandate contained in TEA-21, the Federal Highway Administration (FHWA) contracted with the Transportation Research Board (TRB) to create the Advisory Board. The National Research Council

appointed a group of preeminent experts to the Advisory Board and placed them under the leadership of Elizabeth Deakin in 1999. Members of the Advisory Board represent a broad spectrum of the transportation and environmental communities, including academia, state departments of transportation, state environmental protection agencies, metropolitan planning organizations (MPOs), transit organizations, environmental groups, and industry.

The Advisory Board is formally charged with recommending a national agenda of energy, environment, and planning research for the surface transportation community. It should be noted that the Advisory Board members determined that in order to recommend a viable agenda for environment and energy conservation research related to surface transportation, the concept of "planning" would have to be integrated into the agenda. It remains the contention of the Advisory Board members that unless environmental and energy conservation concerns are factored into the transportation planning process, the secondary and cumulative effects of system-level transportation decisions on larger-scale environmental systems will continue to remain insufficiently addressed in the early stages of the transportation planning process. The Advisory Board's emphasis in the planning area specifically focuses on the overlap between planning processes and environmental issues and focuses on theme areas such as land use and transportation, distributional impacts, and the creation of an integrated, user-oriented, systems approach to transportation and the environment.

The Advisory Board members also believe that the identification of research priorities will only be a productive exercise if existing research programs are structured to implement the new priorities. Therefore, the Advisory Board members identified institutions and institutional structures along with the design and management of research programs as two of the six critical research areas. In its final report the Advisory Board intends to outline a national research agenda, which will be accompanied by recommendations for structuring and managing research programs and institutions.

Research and Technology Partnership Forum

The Research and Technology Partnership Forum was created by FHWA, TRB, and the American Association of State Highway and Transportation Officials to promote an awareness of research and technology activities in the surface transportation arena and to create more efficient and effective partnerships. TRB is serving as the "secretariat" for the Forum. The Forum is composed of

five working groups: safety, infrastructure renewal, policy analysis and system monitoring, operations and mobility, and environment and planning. As the Advisory Board's scope of work overlaps with the mission of the environment and planning workgroup, namely to create a national agenda for environment and planning research, it was agreed by all pertinent parties that the Advisory Board would assume the responsibilities for that workgroup. Therefore, the Research Priorities Workshop was created for two purposes. First, the workshop served as an efficient means for the Advisory Board to gather broad input from transportation and environmental professionals regarding the appropriate research priorities for surface transportation. The input received will serve as a foundation to the Advisory Board's report scheduled for completion in October 2001, outlining a national agenda for anticipated use by Congress, federal agencies, and other pertinent stakeholders in establishing environmental, energy, and planning research priorities. Second, the workshop served as a forum for promoting the goals of the Research and Technology Partnership Forum. During the workshop the Advisory Board solicited and received input from individuals representing the following organizations and constituencies: FHWA, EPA, the Department of Housing and Urban Development, the National Environmental Respiratory Center, the Health Effects Institute, the American Lands Alliance, the Institute for Ecosystem Studies, the American Council for an Energy-Efficient Economy, Oak Ridge National Laboratory, Sky Trust International, People in Defense of Earth Resources, Natural Resources Defense Council, Arcadia Land Company, Honda Motor Company, Defenders of Wildlife, and various academics and university research centers. A list of participants is provided in Appendix B.

Structure of Workshop Summary

The Advisory Board determined that a summary highlighting the key points associated with each critical research area would be a more productive and beneficial tool for both the Advisory Board and for other interested parties. Therefore, transcripts or summaries of each presenter's dialogue will not be given in the summary.

Human Health Panel

Presenters: Dr. Joe Mauderly, National Environmental Respiratory Center; Dr. Patricia Waller, formerly Director of the University of Michigan Trans-

portation Research Institute; Dr. Jane Warren, Director of Science, Health Effects Institute.

Summary: "The continued evolution of the national transportation infrastructure and the strategic planning, technological developments, and regulatory decisions shaping this evolution will be driven in significant part by health concerns" according to Dr. Joe Mauderly. Therefore, the ability to properly assess transportation's impact on human health and to accurately evaluate alternative transportation proposals in their proper context becomes critical. The issue of whether current research methodologies and programs are currently being designed and managed to accomplish this goal was a focal point for discussion. A key theme emerging from this dialogue centered on the need to integrate research into a systems management approach. Both Dr. Mauderly and Dr. Warren provided examples in their presentations illustrating the need to shift the current research paradigm of examining and evaluating the effects of individual air pollutants on human health to a paradigm in which all sources contributing to a particular health burden are considered. Presenters and participants acknowledged that, to date, research on pollutant mixtures has been largely underfunded and avoided because of the inherent complexity of the task. The issue of risk and the need to reconcile the total risk with the total health burden was also identified as requiring further consideration under a national research agenda.

The second key theme that emerged from the workshop discussion was the overall concept of community and connectivity. Dr. Waller eloquently made the case for broadening the Advisory Board's working definition of human health (i.e., air quality, water quality, and safety) to encompass both community health and social well-being along with individual quality-of-life indicators. The issue of tracking human incapacity rates resulting from transportation-related causes was an area cited as an example of a quality-of-life issue requiring additional research along with access issues for the elderly, the poor, and the traditionally disenfranchised communities.

Considering transportation as an integral component of a larger system appeared to resonate with the majority of participants and presenters. When asked how to shift the current research culture to one of an integrated, collaborative system, presenters and participants suggested that a concerted effort should be made to expand the network of traditional transportation partners. The transportation community needs to consider the impacts of transportation on the global community and to develop institutions and structures that are capable of factoring and filtering the needs of different cultures, regulatory structures, and decision-making processes.

Ecosystem Health Panel

Presenters: Dr. John Bissonette, Utah State University; Dr. Gene Likens, Institute of Ecosystem Studies; Dr. Faith Campbell, American Lands Alliance; Daniel Smith, University of Florida.

Summary: According to Dr. Gene Likens, "The health of an ecosystem is based on its structure and function, and how these change with time and in response to natural and anthropogenic impacts." The presenters during this session began their presentations by briefly outlining the most pervasive ecological impacts, both direct and indirect, of transportation systems.[1] First, the construction of roadways may disrupt natural hydrologic flowpaths and increase erosion, air pollution, and surface water runoff. Second, roadways may also facilitate the rapid spread of invasive species and contribute to increased wildlife mortality rates through wildlife–automobile collisions. Third, roadways can serve as effective barriers to wildlife movement, altering natural migratory patterns; this in turn may result in habitat fragmentation, whereby certain species become at risk for genetic isolation.

The list of ecological impacts is wide-ranging. While the presenters were not charged with enumerating or elaborating on specific ecological impacts associated with transportation, they effectively conveyed an overarching theme of the need to incorporate ecological considerations into the transportation planning and maintenance processes. Many of the presenters and participants concurred, and echoed the need to focus future research efforts on the various intersection points between transportation systems and habitat networks.

Presenters and participants also acknowledged that a considerable number of studies have already been conducted and documented regarding the ecological effects of transportation. To date, however, substantial progress has not been made in monitoring long-term ecosystem responses to anthropogenic stressors, nor has there been a concerted effort to comprehensively assess certain ecological impacts on a countrywide, continentwide, or even statewide basis. For example, while large animal mortality rates frequently receive considerable attention, no comprehensive databases have been established to track these rates on a countrywide basis. Even more important, many of the presenters and participants articulated the need to develop databases that would provide for experimental manipulations on a systems level, such as measuring the

[1] The discussion primarily centered on the impacts associated with roads and roadside ecological issues.

impacts of various deicing agents on aquatic and terrestrial ecosystems, or quantifying the effects of highway infrastructure on ecosystem integrity. The concept of collecting data and conducting systemwide analysis emerged as the second primary theme of the session.

Climate Change/Sustainable Transportation Panel

Presenters: Dr. John DeCicco, The American Council for an Energy-Efficient Economy; Dr. David Greene, Oak Ridge National Laboratory; Rafe Pomerance, Sky Trust International.

Summary: Water vapor, carbon dioxide (CO_2), ozone, methane, nitrous oxide, and chlorofluorocarbons constitute the primary "greenhouse gases," all of which are naturally occurring and are essential to regulating the atmospheric temperature. Since 1990, total U.S. greenhouse gas emissions have risen by 11.1 percent.[2] The primary greenhouse gas emitted as a result of human activities is CO_2; fossil fuel combustion constitutes the largest source of CO_2 and is the leading source of overall greenhouse gas emissions in the United States. While scientists and other professionals agree that concentrations of CO_2 in the atmosphere have increased, significant disagreement persists concerning the resulting impact on the atmosphere. Several panelists and workshop participants, therefore, concluded that a fundamental step toward rectifying the global climate change problem is to clearly delineate the issue, the potential impacts, and the necessary solutions before, for example, seeking customer acceptance of new vehicular technologies. Discussion also centered on the need to research various aspects of social marketing and market penetration in order to close the gap between the supply and the demand for "greener" products. In addition, transportation professionals must be informed of the potential impacts of global climate change on the nation's transportation infrastructure so they can anticipate needed changes.

The majority of presenters and panelists agreed on the need for conducting further research to comprehensively evaluate the existing array of strategies for reducing greenhouse gas emissions, emphasizing economic and social costs, secondary benefits, and societal acceptance. It was noted that strategies should be researched and evaluated in light of their ability to hold society "harmless." The issue of using alternative fuels as a strategy for reducing greenhouse gas

[2] Year of measurement 1997; baseline of 1990.

emissions received considerable attention. Some participants asserted that research on alternative fuels should be curtailed until a corresponding infrastructure is established; in particular, mass-market sales of such fuels may not occur as long as alternative-fuel vehicles are restricted to niche markets.

In conclusion, the overarching theme expressed during this session was the need to incorporate social marketing research into existing and future programs designed to explore reduction strategies for greenhouse gas emissions. The technical strategies necessary for accomplishing emissions reductions are fairly well understood and incorporated into traditional research programs; the next step will be to connect these technologies to broader societal goals. Several participants recommended the formation of new institutions that would link global and local initiatives; incorporate the activities of government, industry, and nongovernmental organizations; and have the forethought and capability to create "value" for sustainable technologies and systems.

Land Use/Built Environment Panel

Presenters: Susan Wachter, Department of Housing and Urban Development; Susana Almanza, People in Defense of Earth Resources; Dr. David Goldstein, Natural Resources Defense Council; Dr. Susan Handy, University of Texas at Austin; Christopher Leinberger, Arcadia Land Company.

Summary: Dr. Handy began the discussion by grouping transportation and land use research into two primary categories: (*a*) the influence of transportation investments on land use and (*b*) the influence of land use patterns on travel behavior. While both categories have been extensively researched, additional questions remain concerning causal relationships and the role public policies can and will play vis-à-vis other factors. The linkage between transportation and land use, according to Dr. Handy, needs to be assessed at both the macro and micro levels and in both the short and the long term. Christopher Leinberger concurred with Dr. Handy, observing that to date research conducted on land use has not been very effective since it has not addressed long-term land use problems or focused on changing public attitudes. Land use research needs to take a 20-year perspective. Dr. Wachter noted that between 2000 and 2025, jobs and capacity in the United States will grow by 25 percent, and 50 percent of the current built environment will be replaced. Where this development occurs will affect many environmental and societal issues. Susana Almanza also commented that long-term research is needed to realistically

determine future land uses that will be compatible with the unique cultural and behavioral characteristics of all affected communities. For example, research should be conducted to assess which communities will benefit from land use decisions and which communities will be left behind or negatively affected.

According to Dr. Goldstein, future long-term transportation research should also explore the impacts of location efficiency and the development of least cost planning templates for transportation investments. For example, long-term research in these areas could explore the potential directions of causality, such as the extent to which the ability to access transit leads to higher density, and what is the actual price elasticity for gasoline, holding other variables constant.

The key theme that emerged from the panelists' presentations was the need to connect research to both current and future policy decisions. Workshop participants and panelists expressed a need to close the gap between research and current practice. To close this gap and to work within funding constraints, Dr. Handy suggested that the following questions be considered when prioritizing research needs:

- What research has been done and to what end? Some of the questions have been largely answered; for others, much research has been conducted, but few answers have been generated; and for the remainder, very little is known.
- What is the relative importance of the remaining questions, and what makes a question important? One criterion is the frequency with which the question is asked. Another is the implications of the answer—what difference it will make in decisions about transportation and land use policy.

Design and Management of Research Programs

Presenters: Dr. Ray Chamberlain, former Vice President of the American Trucking Associations, former Executive Director of the Colorado Department of Transportation; Dr. Randy Erickson, formerly Technical Director, 3M Traffic Control Materials Division; Dr. William C. Harris, President and Executive Director, Columbia University's Biosphere 2 Center.

Summary: All three presenters were asked to provide their recommendations for successfully designing and managing research programs. Several key factors for success emerged from the discussion. First, the institutions that house the research programs must provide the requisite administrative support, that is, the space, equipment, and staff time needed to implement the research program

effectively for an extended time. Second, a support system must be created within the institution to provide for the encouragement and motivation of staff, appropriate peer reviews, and a positive work environment for scientists. Third, vision statements and clear expectations for the research programs must be developed and communicated to both internal and external customers. Finally, all three presenters strongly advocated that discretionary funding be provided to research scientists, arguing that the scientists must have the flexibility to conduct research that is not necessarily linked to customer-driven needs.

The primary barrier to effectively designing and managing research programs identified by the presenters centered on funding. The presenters noted that to accomplish timely research, secure funding sources must be identified. It was also noted that frequently many research projects require multiple sources of funding and that oftentimes these sources may not be working on the same time schedules, leaving the coordination of funding to the research institution—which may not be equipped to serve as the "banker." Several presenters also noted that research institutions must secure sufficient funding to attract top researchers and to complete complex research projects.

When asked to provide recommendations for establishing or redesigning existing research programs to more fully address the intersection between transportation and the environment, several of the presenters commented that it would be a mistake to refocus existing programs. Rather, they suggested that the Advisory Board recommend the formation of a new program utilizing new funding sources. The concept of research centers, modeled after the National Science Foundation centers, was recommended. Many presenters and workshop participants noted that researchers and transportation policymakers must do a better job communicating to citizens the need for transportation research. People must be motivated to solve problems and work with a team approach. New research programs must be cognizant of this need when soliciting funding. Finally, any new research program that is developed must have champions associated with its establishment.

Institutions, Governance, and Capacity-Building Panel

Presenters: Alex Taft, Executive Director, Association of Metropolitan Planning Organizations; Carole Whiteside, President, Great Valley Center.

Summary: Alex Taft began his presentation by outlining the need to establish a National Cooperative Metropolitan Planning Organization Research

Program (NCMPORP). The primary need for such an organization, according to Mr. Taft, stems from the fact that after Congress increased the role of MPOs in TEA-21, MPOs were viewed by many constituencies as the venue for multimodal planning and transportation/land use planning. Mr. Taft also noted that MPOs are increasingly becoming the avenue for local citizen groups and environmental interests to address their transportation-related equity issues and environmental concerns.

While no clear consensus was reached concerning the formation of NCMPORP, both panelists and several workshop participants concurred with the need to develop an approach or system whereby solutions to transportation planning issues are truly multimodal in scope. In other words, the current practice of "stovepiping" research or decision-making processes by modes or planning functions needs to be rectified.

Carole Whiteside provided a synopsis of the problems facing the Great Valley Region of California and in so doing identified several critical questions facing the structure and functioning of institutions. What methods can be used to increase the collaboration of a multitude of jurisdictions and independent local governments, particularly as commute corridors and transit routes are extended beyond traditional boundaries and in many directions at once? What are the potentially useful models of government? What will the process be for governing interjurisdictional and interregional projects?

While none of the workshop participants had an obvious answer to these questions, most concurred with the concept that the "bigger picture" in transportation needs to be articulated by policymakers and understood by the general public. For example, all too often, policymakers and planners are focused on and concerned with only one piece of a much larger regional project. Therefore, the range of impacts and alternatives associated with a particular project are oftentimes not identified or assessed from a systems-level perspective prior to the decision-making process. Many participants also commented that existing models are not scaled or scoped to identify the full range of alternatives hindering the "bigger picture" approach.

The concluding sentiment and overarching theme of this session appeared to center on the concept of connectivity. While new institutions and new analytical tools may be warranted, it was the view of many that the current problems associated with the environment–transportation interface will not be solved until the public feels a connection to the issue and demands a solution. In other words, regional cooperation may not emerge until the public forces the political will.

Appendix B

MATRIX OF COOPERATIVE RESEARCH PROGRAMS

Program	Core Partners	Strategic Focus	Solicitation and Evaluation of Research Proposals	Evaluation of Research Product
Health Effects Institute (HEI)	Automotive industry and U.S. Environmental Protection Agency (EPA)	Priorities are guided by a 5-year strategic plan. Plan is reviewed and updated annually	The Research Committee identifies program areas and openly solicits proposals. Proposals are reviewed for scientific quality and overall integration into the research program. Board of Directors reviews recommended proposals for procedure, independence, and quality of the selection process	The Health Review Committee evaluates all HEI-funded studies on the basis of scientific quality and the study's contribution to unresolved scientific questions. Each draft final report is peer-reviewed by scientists with appropriate technical expertise

EPA's Science to Achieve Results program (STAR)	EPA. Partnerships are formed with other agencies for particular projects	Strategic plan establishes priorities for research and development using a risk-based process	Competition for Request for Applications (RFAs) is announced through the *Federal Register,* the Internet, universities, and so forth. RFAs are awarded after an external peer review and an internal relevancy review (merit review)	No evaluation of final research product
National Cooperative Highway Research Program (NCHRP)	State departments of transportation, Transportation Research Board (TRB), and American Association of State Highway and Transportation Officials (AASHTO)	Priorities are set on an annual basis by the primary customers of the program—state departments of transportation	Problem statements are solicited from individual states and AASHTO standing committees. Problem statements are selected by a merit-based review. Research proposals are selected for funding on the basis of an expert panel review	No formal evaluation of final research product. If panel review committees are not satisfied with the work of the researcher, the final report will not be published
Transit Cooperative Research Program (TCRP)	TRB, American Public Transportation	Priorities are set on an annual basis by the pri-	Problem statements are openly solicited and are	No formal evaluation of final research product. If panel

(continued)

Program	Core Partners	Strategic Focus	Solicitation and Evaluation of Research Proposals	Evaluation of Research Product
	Association (APTA), Federal Transit Administration	mary customers of the program—transit operators	selected on the basis of a merit-based review. Research proposals are selected for funding on the basis of an expert panel review	review committees are not satisfied with the work of the researcher, the final report will not be published

Program	Research Dissemination	Funding Sources	Competence and Independence of Staff	Stakeholder Involvement
HEI	Research reports are distributed to EPA, industry sponsors, the scientific community, public interest groups, and appropriate libraries. A one-page statement is written for nonscientists	EPA and the automotive industry	HEI employs a small, highly skilled technical staff. A firewall is established between staff serving as liaisons to the Research Committee (proposal selection) and staff serving as liaisons to the	HEI's Board of Directors consists of public and private figures in science and policy. HEI routinely consults with interested parties on the development of the HEI strategic plan and in determining

	summarizing the key findings of the report		Review Committee (project evaluation)	research priorities. Stakeholders also have the opportunity to attend annual workshops, where research results are presented
STAR	Final reports are distributed via the National Technical Information Service and the EPA website. Summaries of reports are provided in both scientific and nonscientific formats	EPA's Office of Research and Development (ORD) contributes about $110 million; federal partners contribute about $20 million	Through ORD's intramural and technical support program, ORD scientists are assigned to areas of highest risk/priority. A firewall is established between staff who administer the independent peer review and staff who write or select RFAs	The STAR program follows the federal guidelines for public comment and involvement. In addition, stakeholders are invited to workshops to hear updates on research in progress. Finally, stakeholder participation is solicited in the writing of RFAs when STAR forms a partnership with a private entity

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Program	Research Dissemination	Funding Sources	Competence and Independence of Staff	Stakeholder Involvement
NCHRP	Final reports are published and distributed via the TRB website, and copies of the reports are mailed to the program subscribers	State departments of transportation. The program is voluntarily funded from a percentage of the federal-aid highway funds of the state departments of transportation. These funds are projected for several years, providing a consistent funding base	NCHRP hires staff experienced in the areas of research undertaken by the program. No firewall is established between staff selecting and administering the program	The AASHTO Standing Committee on Research determines the priorities for the program. The Federal Highway Administration is provided an opportunity to propose projects. Expert panels are selected to conduct merit reviews of the problem statements
TCRP	Funding is set aside for TCRP to contract with APTA to distribute and market research reports	Funding is specifically earmarked for TCRP through the appropriation process. Funding has not kept pace with inflation and has recently been subject to earmarks	TCRP hires staff experienced in the areas of research undertaken by the program. No firewall is established between staff selecting and administering the program	The Transit Development Corporation's Board of Directors serves as the Board of Directors for TCRP. Expert panels are selected to conduct merit reviews of the problem statements

STUDY COMMITTEE BIOGRAPHICAL INFORMATION

Elizabeth Deakin, *Chair,* is Director of the University of California Transportation Center and a professor in the Department of City and Regional Planning at the University of California at Berkeley. She also holds faculty appointments in the Energy and Resources Group and in the Master of Urban Design Program at Berkeley. She received S.B. and S.M. degrees in political science and civil engineering/transportation from Massachusetts Institute of Technology and a law degree from Boston College Law School. Her areas of expertise include transportation planning and policy, land use planning and administration, and environmental policy. She has authored or coauthored more than 150 journal articles and technical reports as well as a book and six book chapters. She served as Chair of the Transportation Research Board (TRB) Committee on Transportation and Land Development from 1992 to 1998. She is the California Senate's appointee to the state's Vehicle Inspection Maintenance Review Committee and has served on a number of local government commissions. She currently sits on the board of three nonprofit environmental organizations.

F. Kaid Benfield is an environmental attorney and director of transportation and smart growth policy for the Natural Resources Defense Council (NRDC) in Washington, D.C. He has also served the organization as director of its land program, director of its forestry and agriculture projects, and legal affairs coordinator. Before coming to NRDC, he worked at the U.S. Department of Justice and in private legal practice. He is a graduate of Emory University and Georgetown University Law Center and the author of numerous publications related to environmental law and policy, including the books *Solving Sprawl* (with Jutka Terris and

Nancy Vorsanger) and *Once There Were Greenfields* (with Mathew D. Raimi and Donald D. T. Chen). He is a member of several steering committees and boards relating to transportation and smart growth.

Kenneth J. Button is currently Professor of Public Policy at George Mason University. He received a B.A. in economics from the University of East Anglia, an M.A. in economics from the University of Leeds, and a Ph.D. in economics from Loughborough University. He has been elected a Fellow of the Institute of Logistics and Transport, Fellow of the Institution of Highways and Transportation, and Fellow of the Chartered Institute of Transport. His areas of expertise include transport economics, travel demand modeling, environmental economics, and international transport policy. He has authored or coauthored more than 80 books and hundreds of articles and papers pertaining to various aspects of transportation policy. Currently, he is the Editor-in-Chief for *Transportation Research D, Transportation and Environment,* and the *Journal of Air Transport Management.* He serves on numerous committees and in 1996 cochaired the European Science Foundation/National Science Foundation Joint Initiative on Transport Research.

Judith M. Espinosa is the director of the Alliance for Transportation Research Institute at the University of New Mexico. She received a B.A. in nursing from the University of New Mexico; a master's degree in public health administration from the University of California, Los Angeles; and a doctor of jurisprudence from the University of New Mexico. She was recently nominated by President Clinton and confirmed by the U.S. Senate to serve as a Trustee on the Morris K. Udall Foundation for Scholarship and Excellence in National Environmental Policy, and she chairs the Good Neighbor Environmental Board, a federal advisory committee on U.S.–Mexico environmental and infrastructure issues. She served for 4 years as New Mexico's Secretary of Environment and for 2 years as its Secretary of Transportation. She currently is a member of the following boards: the National Wildlife Federation, the Environmental Leadership Program, the Surface Transportation Policy Project, the Energy Foundation, and the Clean Air Action Corporation. She has written several articles on transportation and the environment.

Richard T. T. Forman is Professor of Advanced Environmental Studies in Landscape Ecology at Harvard University. He received a B.S. from Haverford College, a Ph.D. from the University of Pennsylvania, an honorary A.M. from Harvard University, an honorary doctor of humane letters from

Miami University, and an honorary doctor of science from Florida International University. His interests and research include the principles of landscape and regional ecology, forest ecology, the spatial meshing of nature and people, and the ecology of road systems. He has authored numerous articles, and his books include *Landscape Ecology Principles in Landscape Architecture and Land Use Planning* and the award-winning *Land Mosaics: The Ecology of Landscapes and Regions*. He has served as President of the Torrey Botanical Society and as Vice President of the Ecological Society of America. In 1992 he was named Distinguished Landscape Ecologist, and he has received medals and awards in eight countries. He is the lead author of a forthcoming book, *Road Ecology: Science and Solutions*.

Fred Hansen is the General Manager of the Tri-County Metropolitan Transportation District of Oregon (Tri-Met). He assumed this position in 1998. Previously he served for 4 years as the Deputy Administrator for the U.S. Environmental Protection Agency (EPA) in Washington, D.C., where he managed EPA's day-to-day operations and was involved in all major policy issues. Before joining EPA, Hansen directed the Oregon Department of Environmental Quality for more than 10 years. He also served as Oregon's Deputy State Treasurer as well as in previous positions in Washington, D.C., where he worked as Executive Officer of the Peace Corps and Chief of Staff to a member of Congress from Oregon. He received a bachelor's degree from the University of Oregon (Phi Beta Kappa) and a master's degree from McMaster University, and he completed a year of doctoral work at The Johns Hopkins University.

Edwin E. Herricks is Professor of Environmental Biology in the Department of Civil Engineering at the University of Illinois at Urbana-Champaign. He received a B.A. in biology and English from the University of Kansas, an M.S. in engineering from The Johns Hopkins University, and a Ph.D. in biology from Virginia Polytechnic Institute and State University. His areas of expertise include aquatic ecology, biomonitoring, and stream ecosystem management, and he has broad experience in the identification, assessment, and restoration of the adverse effects of man's activities on streams, rivers, lakes, and their watersheds. Recent research has focused on stormwater toxicity, stream restoration, climate change impact, and environmental management systems integration. He has authored or coauthored three books; his most recent book, *Stormwater Runoff in Receiving Streams: Impact, Monitoring, Management,* was published in 1995. He has authored more than 140 articles and reports. He has recently served on National

Research Council (NRC) panels addressing river navigation and nuclear waste issues, and he is presently a member of the Panel on Methods and Techniques of Corps of Engineers Project Analysis. Herricks is an advisor to local, state, and federal agencies and has participated in educational and management programs in the United Kingdom, Yugoslavia, France, Germany, Japan, and Taiwan.

Wayne W. Kober has more than 28 years of multimodal transportation and environmental management experience for both the public and private sectors. He has a B.S. degree in environmental resource management from Penn State University. He is nationally recognized as an innovative leader in the field of transportation project development and environmental management. His broad span of experience at successfully integrating environmental analysis, agency/public involvement, and context-sensitive design aspects into a systematic decision-making process has enabled him to play a prominent role in advancing Pennsylvania's multimodal transportation improvement programs. In addition, he has worked at the regional and national levels in leading the development of environmental streamlining and stewardship legislation, policies, and practices. He is in private practice and currently serves as a Senior Transportation and Environmental Management Specialist for the American Association of State Highway and Transportation Officials (AASHTO).

Alan J. Krupnick is Senior Fellow at Resources for the Future and Director of its Quality of the Environment Division. He received his Ph.D. in economics from the University of Maryland. His research interests include the analysis of environmental issues, with a particular focus on air pollution, cost–benefit analysis, and the design of environmental policies, including their intersection with transportation policies. He recently cochaired a federal advisory committee that provided counsel to EPA on implementing its new ozone and particulate standards. In 1994 Dr. Krupnick served as a senior staff economist for environment and natural resources on the President's Council of Economic Advisers. He served on TRB's Committee for a Review of the Highway Cost Allocation Study and its Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program, and he is currently a member of NRC's Committee on Research and Peer Review in EPA.

Martin Lee-Gosselin is currently Professor of Planning at Laval University, Quebec, Canada. He received a Ph.D. in urban, technological, and environmental planning from the University of Michigan, as well as master's

and bachelor's degrees in interdisciplinary fields from Michigan State University and the University of Bristol, England. He specializes in survey and analysis methods to investigate travel behavior both as it exists now and in response to future changes in policy or the availability of alternative fuel, vehicle, and telecommunications technologies. He is the principal investigator of a major network research program, involving seven Canadian universities, on the behavioral foundations of integrated land use, transport, and environmental impact models. Before joining Laval in 1990, he was a SERC Visiting Research Fellow at London and Oxford Universities. He spent 20 years in university research, state government, and the private sector, including 7 as Research Director for the Office of the Secretary of State of Michigan. He has served on various international bodies for the Organization for Economic Cooperation and Development, the World Health Organization, and the European Community; on the Japanese institute IATSS; on five TRB committees; and on the Board of the International Association for Travel Behaviour Research. He has coedited several books, including *Understanding Travel Behaviour in an Era of Change* (1997) with Peter Stopher, and has published numerous articles on the travel behavior, energy, environmental, and safety aspects of transportation.

Ysela Llort is the State Transportation Planner for the Florida Department of Transportation. In this capacity, she oversees the statewide and systems planning function for the Department of Transportation. Among her primary responsibilities are executive level policy formulation and interpretation, as well as working with the numerous transportation partners, including metropolitan planning organizations, to obtain consensus on needs and priorities for the state. Prior to her work with the Florida Department of Transportation, Ms. Llort served 9 years with the Virginia Department of Transportation as Assistant District Engineer for Planning and Operations in Northern Virginia, adjacent to Washington, D.C. Ms. Llort is a graduate of Duke University, where she earned a degree in economics; she holds master's degrees from Clemson University in both city and regional planning and transportation engineering.

C. Ian MacGillivray is Director of the Engineering Division for the Iowa Department of Transportation. He is responsible for the department's traffic and transportation safety programs along with general coordination and management of research, technology transfer, and the department's engineering staff/process development programs. He served as the Director of the Planning and Research Division from 1977 to 1993. Mr. MacGillivray

received a bachelor of science degree in civil engineering from the University of Alberta and a master of science degree in civil engineering from Purdue University. He currently serves on the AASHTO Standing Committee on Research; chairs the National Cooperative Highway Research Program's (NCHRP) Project Panel 20-05: Synthesis of Information Related to Highway Problems; serves as Vice Chair of AASHTO's Special Committee on International Activity Coordination; and serves on various other TRB, AASHTO, and NCHRP committees.

Jane T. Nishida has been Maryland's Secretary of the Environment since 1995. She received a B.A. in international relations from Lewis and Clark College and a doctor of jurisprudence degree from Georgetown University Law Center. She currently serves on the following committees: Governor's Council on the Chesapeake Bay, Governor's Pesticide Council, Lead Hazard Advisory Committee, State Soil Conservation Committee, Northeast Ozone Transport Commission, Smart Growth and Neighborhood Conservation Subcabinet, Western Maryland Economic Development Task Force, and the World Trade Center Institute. She also chairs the Smart Growth Task Force of the Environmental Council of the States.

John P. Poorman has been the Staff Director of the Capital District Transportation Committee (CDTC) since 1981. CDTC is the designated metropolitan planning organization for the four counties containing the Albany-Schenectady-Troy, New York, urbanized area. In recent years, CDTC has been recognized nationally for work in transportation and land use integration, public involvement in decision making, and the development of effective transportation system performance measures for planning and programming. Mr. Poorman received a B.A. in economics from Haverford College and an M.S. in transportation from Northwestern University. Since 1984 he has been a member of the adjunct faculty of the State University of New York at Albany's graduate Urban and Regional Planning Program. He also serves as Chairman of the New York State Association of Metropolitan Planning Organization Directors and as a Member of TRB's Executive Committee (1999–2002). In 1996 he was a recipient of an Environmental Fellowship from the German Marshall Fund of the United States.

Catherine L. Ross recently became the Director of the Greater Georgia Regional Transportation Authority. Previously, she was the Associate Vice President for Academic Affairs, Co-Director of the Transportation Research and Education Center, and Professor of the Graduate City Planning Program

at the Georgia Institute of Technology. She received an undergraduate degree from Kent State University and master's and Ph.D. degrees in regional planning from Cornell University. Her areas of expertise include planning theory and policy analysis, transportation planning, impact assessment, disaster planning, urban revitalization, environmental planning, and public participation. She has written numerous articles and research reports on various aspects of transportation planning. She is a member of the TRB Executive Committee, the Urban Land Institute, the Urban Affairs Association, the American Planning Association, the Planners Network, the Association of Collegiate Schools of Planning, the Sigma Xi, the National Scientific Research Society, the Women's Transportation Seminar, and the Conference of Minority Transportation Officials.

Daniel Sperling is Professor of Civil and Environmental Engineering and Environmental Studies and founding Director of the Institute for Transportation Studies (ITS-Davis) at the University of California, Davis. He received a B.S. in systems analysis/urban planning from Cornell University and M.S. and Ph.D. degrees, both in transportation engineering, from the University of California, Berkeley. His areas of expertise include alternative transportation fuels and the deployment of rail transit and intercity bus transit services. He has authored or coauthored more than 100 technical papers and 5 books in the last 14 years on advanced transportation technologies and energy and environmental aspects of transportation, and he was a principal contributor to a 1993 Organization for Economic Cooperation and Development book on alternative fuels and a 1994 International Agency book on electric vehicles. His most recent book, *Future Drive: Electric Vehicles and Sustainable Transportation,* was published in 1995. He was the founding chair of TRB's Committee on Alternative Transportation Fuels and serves on nine advisory committees for environmentally oriented research organizations and activities.

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