Fifth Edition

Traffic & Highway Engineering

Nicholas J. Garber   Lester A. Hoel

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Nicholas J. Garber
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University of Virginia

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This book is dedicated to our wives,
Ada and Unni
and to our daughters,
Alison, Elaine, and Valerie
and
Julie, Lisa, and Sonja
With appreciation for the support, help, and encouragement that we received during the years that were devoted to writing this textbook.

Contents

Preface

PURPOSE IN WRITING AND REVISING THIS TEXTBOOK

The purpose of *Traffic and Highway Engineering,* Fifth Edition, is to serve as a resource textbook for students in engineering programs where courses in transportation, highway, or traffic engineering are offered. In most cases, these courses are usually taught in the third or fourth year but may also be covered at the graduate level.

Another purpose of this book is to serve as a reference for transportation engineers who are in practice or are preparing for a professional engineering examination.

The initial motivation for writing this textbook, which was first published in 1988, was many years of teaching highway and traffic engineering using textbooks that were primarily descriptive and lacked examples that illustrated the concepts presented. We also noted that none were comprehensive in dealing with all aspects of the subject and that some were written with transportation engineering titles but lacked specific focus. We also saw the need to demonstrate the challenges of the field and to explain the solid quantitative foundations that underlie the practice of transportation engineering. We wanted to select a mode that is ubiquitous and of worldwide application and one that students had contact with on a daily basis. Accordingly, we decided to focus on motor vehicle transportation and the highways that are an essential partner for this mode to exist. Our experience and instincts proved correct as the book became known and widely used.

The objectives of this textbook are: (1) To be a contemporary and complete text in highway and traffic engineering that can be used both at the undergraduate and at the graduate level for courses that emphasize highway and traffic engineering topics and (2) To serve as a reference for engineers in the highway and traffic field and as a study guide for use in preparing for the professional engineering license exam, review courses, and preparation for graduate comprehensive exams in transportation engineering.

The Fourth Edition of this textbook was published in 2009 and in the ensuing years there have been significant changes to the highway transportation literature that mandated a major revision. Professors from transportation programs at twenty-one major universities reviewed various editions of the book and their comments and suggestions have been incorporated into the Fifth Edition.

The book is appropriate for a transportation curriculum or as an introductory transportation course because it provides an opportunity to present material that is not only useful to engineering students who may pursue careers in or related to transportation engineering, but is also interesting and challenging to those who intend to work in other areas. Furthermore, this book can serve as a reference for practicing transportation engineers and for use by students in graduate courses. Thus, the textbook provides a way for students to get into the area of transportation engineering, develop a feel for what it is about, and thereby experience the challenges of the profession

MAJOR ORGANIZING FEATURES OF THE TEXT

The scope of transportation engineering is broad and covers many modes and disciplines. Accordingly, several approaches have been used to introduce this topic to students.

One approach is to cover all transportation modes-air, highway, pipeline, public, rail, and water, presented in an overview course. This approach ensures comprehensive coverage but tends to be superficial with uneven coverage of some modes and can be lacking in depth.

A second approach is to present the subject of transportation by generic elements, such as vehicle and guideway characteristics, capacity analysis, planning, design, safety, human factors, administration, finance, system models, information technology, operations, and so forth. This approach is appealing because each of the modes is considered within a common context and the similarities between various modes are emphasized. Our textbook, *Transportation Infrastructure Engineering: A Multi-Modal Integration,* is based on this concept.

A third approach is to select a single mode and cover the relevant disciplines to provide a comprehensive treatment focused on that mode. Our book follows this approached by emphasizing the subject of traffic and highway engineering, which is a major area within civil engineering. It is a topic that appeals to students because they can relate directly to problems created by motor vehicle travel and is useful to professionals employed by federal, state and local agencies as well as private consulting and construction organizations.

Each chapter presents material that will help students understand the basis for transportation, its importance, and the extent to which transportation pervades our daily lives. The text also provides information about the basic areas in which transportation engineers work: traffic operations and management, planning, design, construction, and maintenance. Thus, this book has been categorized into five parts

- Part 1: Introduction to the profession, its history, systems, and organizations
- Part 2: Traffic Operations
- Part 3: Transportation Planning
- Part 4: Location, Geometrics, and Drainage
- Part 5: Materials and Pavements.

The topical division of the book organizes the material so that it may be used in one or more separate courses.

For a single course in transportation engineering, which is usually offered in the third year where the emphasis is on traffic and highway aspects, we recommend that material from Parts 1, 2, and 3 (Chapters 1-13) be covered.

For a course in highway engineering, where the emphasis is on highway location, design, materials, and pavements, we recommend that material from Parts 2, 4, and 5 (Chapters 3 and 14-21) be used.

A single introductory course in transportation facilities design could include Chapters 1, 2, 3, 14, 15, 16, 19, and 21.

The book also is appropriate for use in a two-semester sequence in transportation engineering in which traffic engineering and planning (Chapters 3-13) would be covered in the first course, and highway design (Chapters 14-21) would be covered in the second course.

The principal features of this textbook are:

- Comprehensive treatment of the subject.
- Extensive use of figures and tables.
- Numbering of subsections for easy reference.
- Completed examples in each chapter that illustrate the concepts presented.
- Representative homework problems at the end of each chapter
- References and additional readings at the end of each chapter

CHANGES TO THE NEW EDITION

In addition to responding to reviewer comments on the Fourth Edition and updating each chapter, substantial changes were made in several chapters due to the availability of new editions of the following professional publications:

- *A Policy on Geometric Design of Highways and Streets,* 6th Edition, 2011, American Association of State Highway and Transportation Officials.
- *HCM 2010 Highway Capacity Manual,* Transportation Research Board
- *Highway Safety Manual,* 1st edition, American Association of State Highway and Transportation Officials, Washington, D.C., 2010.
- *Manual on Uniform Traffic Control Devices (MUTCD),* 2009 Edition, U.S. Department of Transportation, Federal Highway Administration
- *Roadway Design Guide,* 4th Edition 2011, American Association of Highway and Transportation
- *Transportation Planning Handbook,* 3rd Edition, Institute of Transportation Engineers

New Learning Objectives have been added for each chapter, and the Problem Sets have been thoroughly revised and updated to match the new content in the book.

ANCILLARIES TO ACCOMPANY THE TEXT

An Instructor's Solutions Manual is provided with each problem completely solved. All figures and tables in the text are provided as PowerPoint slides. Also LectureBuilder PowerPoint slides are provided for all equations and examples so that instructors may easily and quickly build their own lectures. A digital version of the ISM and both sets of PPT slides are available for instructors through registration at www.cengagebrain.com

MINDTAP ONLINE COURSE AND READER

In addition to the print version, this textbook will also be available online through MindTap, a personalized learning program. Students who purchase the MindTap version will have access to the book's MindTap Reader and will be able to complete homework and assessment material online, through their desktop, laptop, or iPad. If your class is using a Learning Management System (such as Blackboard, Moodle, or Angel) for tracking course content, assignments, and grading, you can seamlessly access the MindTap suite of content and assessments for this course.

In MindTap, instructors can:

- Personalize the Learning Path to match the course syllabus by rearranging content, hiding sections, or appending original material to the textbook content
- Connect a Learning Management System portal to the online course and Reader
- Customize online assessments and assignments
- Track student progress and comprehension with the Progress app
- Promote student engagement through interactivity and exercises

Additionally, students can listen to the text through ReadSpeaker, take notes and highlight content for easy reference, and check their understanding of the material.

ACKNOWLEDGMENTS

The success of our textbook has been a source of great satisfaction, because we believe that it has contributed to the better understanding of highway transportation in all its dimensions. We wish to thank our colleagues and their students for selecting this book for use in transportation courses taught in colleges and universities throughout the United States and abroad and for the many suggestions received during the preparation of all five editions.

The authors are indebted to many individuals who assisted in reviewing various chapters and drafts of the original manuscript and succeeding editions. We especially wish to thank the following individuals for their helpful comments and suggestions:

Maher Alghazzawi, Edward Beimborn, Rakim Benekohal, David Boyce, Stephen Brich, Chase Buchannan, Bernard Carlson, Christian Davis, Michael Demetsky, Brian Diefenderfer, Stacey Diefenderfer, Conrad Dudek, Lily Elefteriadou, Thomas Freeman, Ron Gallagher, Per Garder, Alan Gesford, Richard Gunther, Jiwan Gupta, Jerome Hall, Kathleen Hancock, Marvin Hilton, Jotin Khisty, Lydia Kostyniak, Michael Kyte, Feng-Bor Lin, Qun Liu, Yuan Lu, Tom Maze, Catherine McGhee, Kenneth McGhee, Richard McGinnis, Carl Monismith, Thomas Nelson, Ken O'Connell, Jack Page, Emelinda Parentela, Brian Park, Mofreh Saleh, Mitsuru Saito, Anthony Saka, Gerald Seeley, Robert Smith, Hamid Soleymani, James Stoner, Ed Sullivan, James Taylor, Egons Tons, Erol Tutumluer, Joseph Vidunas, Joseph Wattleworth, Peter Weiss, W James Wilde, F. Andrew Wolfe, Hugh Woo, Lewis Woodsen, Robert Wortman, Shaw Yu, Yihua Ziong and Michael Zmuda.

In the preparation of the Fifth Edition and earlier editions as well, we received reviews, comments and suggestions on individual chapters from several of our colleagues who have special expertise in the topics covered. We are most grateful for their willingness to devote this effort and for their help in validating and augmenting these chapters. They are: Richard Boaz, Michael Fontaine, Arkopal Goswami, Winston Lung, John Miller, Adel Sadek and Rod Turochy.

We also received a significant number of helpful comments from the reviewers of the fourth edition. We wish to thank them for their insightful comments and helpful suggestions many of which have been incorporated into this book. They are: Montasir Abbas, Virginia Tech, Mashrur Chowdhury, Clemson University, Shauna Hallmark, Iowa State University, David S. Hurwitz, Oregon State University, Wesley Marshall, University of

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The many organizations cited herein that permitted us to include material from their publications deserve special mention because, without their support, our book would not have been a reality. We also wish to thank our editor Hilda Gowans, for her help and guidance in the preparation of this edition, and Rose Kernan of RPK Editorial Services for her Production skills.

Nicholas J. Garber
Lester A. Hoel

About the Authors

Nicholas J. Garber is the Henry L. Kinnier Emeritus Professor of Civil Engineering at the University of Virginia and served as chairman of the Department from 1996 to 2002. Before joining the University of Virginia, Dr. Garber was Professor of Civil Engineering in the faculty of Engineering of the University of Sierra Leone, where he was also the Dean of the faculty of Engineering. He taught at the State University of New York at Buffalo, where he played an important role in the development of the graduate program in Transportation Engineering. Dr. Garber worked as a Design Engineer for consulting engineering firms in London between 1961 and 1964 and as an Area Engineer and Assistant Resident Engineer in Sierra Leone between 1964 and 1967.

Dr. Garber received the degree of Bachelor of Science (B.S.) in Civil Engineering from the University of London and the Masters (M.S.) and Doctoral (Ph.D.) degrees from Carnegie-Mellon University.

Dr. Garber's research is in the areas of Traffic Operations and Highway Safety. He has been the principal investigator for many federal-, state-, and private-agency-sponsored research projects. He is the author of over 120 refereed publications and reports. He is a co-author of the textbook *Transportation Infrastructure Engineering: A Multi-Modal Integration,* Thomson/Nelson, 2007.

Dr. Garber served as a member of the Executive Committee of the Transportation Research Board (TRB) and served for many years as chair of the TRB Committee on Traffic Safety in Maintenance and Construction Operations, currently the Committee on Work Zone Traffic Control. He has served as a member of several TRB Policy Studies on speed management, size and weight of large trucks, transportation of hazardous materials, and research priorities and coordination in highway infrastructure and operations safety. He also served as a member of the TRB Oversight Committee for the Strategic Highway Research Program II (SHRP II). Dr. Garber also has served as a member of several other national committees of the American Society of Civil Engineers (ASCE) and The Institute of Transportation Engineers (ITE). He also served as a member of the Editorial Board of the ASCE *Journal of Transportation Engineering*.

Dr. Garber is a member of the National Academy of Engineering. He is a recipient of many awards, including the TRB D. Grant Mickle Award, the ITE Edmund R. Ricker Transportation Safety Award, and the American Roads and Transportation Builders (ARTBA) S. S. Steinberg Outstanding Educator Award. He is listed in *Who's Who* in Science and Engineering and *Who's Who* in the world.

Dr. Garber is a Distinguished member of the American Society of Civil Engineers, a Fellow of the Institute of Transportation Engineers, a Fellow of the Institution of Civil Engineers of the United Kingdom, a member of the American Society for Engineering Education, and a member of Chi Epsilon.

Lester A. Hoel is the L. A. Lacy Distinguished Professor of Engineering Emeritus, at the University of Virginia. He held the Hamilton Professorship in Civil Engineering from 1974 to 1999. From 1974 to 1989 he was Chairman of the Department of Civil Engineering and from 2002 to 2009 was Director of the Center for Transportation Studies. Previously, he was Professor of Civil Engineering and Associate Director, Transportation Research Institute at Carnegie-Mellon University. He has been a registered professional engineer in California, Pennsylvania, and Virginia. His degrees are: BCE from the City College of New York, MCE from the Polytechnic Institute of New York, and the Doctorate in Engineering from the University of California at Berkeley.

Dr. Hoel's area of expertise is the management, planning, and design of surface transportation infrastructure with emphasis on highway and transit systems. He is an author of over 150 publications and was co-editor (with G.E. Gray) of the textbook *Public Transportation,* and co-author (with N.J. Garber and A.W. Sadek) of the textbook *Transportation Infrastructure Engineering: A Multi-Modal* Integration and Lead Editor of the Textbook, Intermodal Transportation: Moving Freight in A Global Economy.

Dr. Hoel is a member of the National Academy of Engineering, a Distinguished Member of the American Society of Civil Engineers, a Fellow of the Institute of Transportation Engineers, a member of the American Society for Engineering Education and the Norwegian Academy of Technical Sciences. As a student, he was elected to the national honor societies Chi Epsilon, Tau Beta Pi, and Sigma Xi. He was a member of the Executive Committee of the Transportation Research Board (TRB) from 1981 to 1989 and from 1995 to 2004 and served as its Chairman in 1986. He was an ex-officio member of the National Research Council (NRC) Governing Board of the National Academies and the Transportation Research Board Division Chairman for NRC Oversight from 1995 to 2004. In that capacity, he was responsible for oversight of the NRC review process for all TRB policy studies produced during that period. He served as the Chairman of two congressionally mandated policy studies. He also has served on TRB technical committees and NCHRP/TCRP panels. He was a member of the TRB Transit Research Analysis Committee, whose purpose is to advise the Federal Transit Administration on its research program, and was a member of the National Research Council Report Review Committee, in which he oversees the review process for policy studies prepared by the National Research Council of the National Academies.

He is a recipient of the American Society of Civil Engineers' Huber Research Prize, the Transportation Research Board Pyke Johnson Award, the Highway Users Federation Stanley Gustafson Leadership Award, the TRB W.N. Carey, Jr. Distinguished Service Award, the ASCE Frank Masters Transportation Engineering Award, the ASCE James Laurie Prize, the Virginia Society of Professional Engineers Service Award, the Institute of Transportation Engineers' Wilbur Smith Distinguished Educator Award, the American Road and Transportation Builders S. S. Steinberg Outstanding Educator Award, and the Council of University Transportation Centers Distinguished Professor Award. He is listed in *Who's Who in America* and *Who's Who in the World*. He resides in Saint Helena, California.

Dr. Hoel has served as president of the Council of University Transportation Centers and on the ASCE accreditation board for engineering and technology. He was chairman of the Board of Regents of the Eno Transportation Foundation Leadership Center and served on its Board of Advisors. He is Senior Editor of the *Journal of Transportation of the Institute of Transportation Engineers* and has served on the editorial boards of transportation journals, including *Transportation Research, Journal of Advanced Transportation, Journal of Socio-Economic Planning Sciences, Journal of Specialized Transportation, Computer-Aided Civil and Infrastructure Engineering,* and *Urban Resources*.

P A R T 1

Introduction

Transportation is essential for a nation's development and growth. In both the public and private sector, opportunities for engineering careers in transportation are exciting and rewarding. Elements are constantly being added to the world's highway, rail, airport, and mass transit systems, and new techniques are being applied for operating and maintaining the systems safely and economically. Many organizations and agencies exist to plan, design, build, operate, and maintain the nation's transportation system.

CHAPTER 1

The Profession of Transportation

For as long as the human race has existed, transportation has played a significant role by facilitating trade, commerce, conquest, and social interaction while consuming a considerable portion of time and resources. The primary need for transportation has been economic, involving personal travel in search of food or work and travel for the exchange of goods and commodities; in addition, travel has been spurred by exploration, a quest for personal fulfillment, and the desire to improve a society or a nation. The movement of people and goods, which is the basis of transportation, always has been undertaken to accomplish these basic objectives or tasks, which require transfer from one location to another. For example, a farmer must transport produce to market, a doctor must see a patient in the office or in the hospital, and a salesperson must visit clients located throughout a territory. Every day, millions of people leave their homes and travel to a workplace—be it a factory, office, classroom, or distant city.

CHAPTER OBJECTIVES:

- Explain the importance of transportation in a modern and developed society.
- Become familiar with the critical issues in transportation.
- Understand how transportation technology has evolved over time.
- Discuss the principal technical areas and employment opportunities in transportation and highway engineering.
- Identify and discuss the challenges faced by transportation engineers in the twenty-first century.

1.1 IMPORTANCE OF TRANSPORTATION

Tapping natural resources and markets and maintaining a competitive edge over other regions and nations are linked closely to the quality of the transportation system. The speed, cost, and capacity of available transportation have a significant impact on the economic vitality of an area and the ability to make maximum use of its natural resources. Examination of most developed and industrialized societies indicates that they have been noted for high-quality transportation systems and services. Nations with well-developed maritime systems (such as the British Empire in the 1900s) once ruled vast colonies located around the globe. In more modern times, countries with advanced transportation systems—such as the United States, Canada, and countries in Asia and Europe—are leaders in industry and commerce. Without the ability to transport manufactured goods and raw materials and without technical know-how, a country is unable to maximize the comparative advantage it may have in the form of natural or human resources. Countries that lack an abundance of natural resources rely heavily on transportation in order to import raw materials and export manufactured products.

1.1.1 Transportation and Economic Growth

Good transportation, in and of itself, will not assure success in the marketplace, as the availability of transportation is a necessary but insufficient condition for economic growth. However, the absence of supportive transportation services will serve to limit or hinder the potential for a nation or region to achieve its economic potential. Thus, if a society expects to develop and grow, it must have a strong internal transportation system consisting of good roads, rail systems, as well as excellent linkages to the rest of the world by sea and air. Transportation demand is a byproduct derived from the needs and desires of people to travel or to transfer their goods from one place to another. Transportation is a necessary condition for human interaction and economic competitiveness.

The availability of transportation facilities can strongly influence the growth and development of a region or nation. Good transportation permits the specialization of industry or commerce, reduces costs for raw materials or manufactured goods, and increases competition between regions, thus resulting in reduced prices and greater choices for the consumer. Transportation is also a necessary element of government services, such as delivering mail, providing national defense, and assisting U.S. territories. Throughout history, transportation systems (such as those that existed in the Roman Empire and those that now exist in the United States) were developed and built to ensure economic development and efficient mobilization in the event of national emergencies.

1.1.2 Social Costs and Benefits of Transportation

The improvement of a region's economic position by virtue of improved transportation does not come without costs. Building vast transportation systems requires enormous resources of energy, material, and land. In major cities, transportation can consume as much as half of all the land area. An aerial view of any major metropolis will reveal vast acreage used for railroad terminals, airports, parking lots, and freeways. Transportation has other negative effects as well. Travel is not without danger; every mode of transportation brings to mind some major disaster—be it the sinking of the *Titanic,* the explosion of the zeppelin *Hindenburg,* the infrequent but dramatic passenger air crashes, and frequent highway crashes. In addition, transportation can create noise, spoil the natural beauty of an area, change the environment, pollute air and water, and consume energy resources.

Society has indicated a willingness to accept some risk and changes to the natural environment in order to gain the advantages that result from constructing new transportation systems. Society also values many social benefits brought about by good transportation. Providing medical and other services to rural areas and enabling people to socialize who live some distance apart are just two examples of the benefits that transportation provides.

A major task for the modern transportation engineer is to balance society's need for reasonably safe and efficient transportation with the costs involved. Thus, the most efficient and cost-effective system is created while assuring that the environment is not compromised or destroyed. In carrying out this task, the transportation engineer must work closely with the public and elected officials and needs to be aware of modern engineering practices to ensure that the highest quality transportation systems are built consistent with available funds and accepted social policy.

1.1.3 Transportation in the United States

Is transportation very important? Why should you study the subject and perhaps consider transportation as a professional career? Many "gee whiz" statistics can be cited to convince the reader that transportation is vital to a nation, but before we do so, consider how transportation impacts people's daily lives.

Perusal of a local or national newspaper will inevitably produce one or more articles on transportation. The story might involve a traffic fatality, a road construction project, the price of gasoline, trends in purchases of motor vehicles, traffic enforcement and road conditions, new laws (such as cell phone use while driving), motor vehicle license requirements, neighborhood protests regarding road widening or extensions, proposals to increase road user fees or gasoline taxes to pay for maintenance and construction projects, the need for public transit services, or the debate over "sprawl" versus "smart growth." The enormity of transportation can be demonstrated by calculating the amount of land consumed for transportation facilities, such as sidewalks, parking lots, roads, driveways, shoulders, and bike paths, which in some cases can exceed 50 percent of the land area.

The examples cited suggest that transportation issues are largely perceived at local and state levels where people live. Mayors and governors are elected based on their promises to improve transportation without raising taxes. At the national level, transportation does not reach the "top 10" concerns, and transportation is rarely mentioned in a presidential address or national debate. At this level, issues of defense, health care, immigration, voting rights, taxes, and international relations take center stage. While many Americans probably know the name of the Secretary of State or Defense, few could answer the question, "Who is the Secretary of Transportation?"

The Executive Committee of the Transportation Research Board of the National Academies periodically develops a list of "critical issues" in transportation, which are posted on the committee's Web site. Among the issues identified are the following: (1) congestion; (2) emergency preparedness, response, and mitigation, such as vulnerability to terrorist strikes and natural disasters; (3) energy, environment, and climate change; (4) finance and equity; (5) safety; (6) twentieth-century institutions mismatched to twenty-first-century missions; and (7) human and intellectual capital as reflected in the inadequate investment in innovation. Each issue suggests the importance of transportation and the priorities of concern to the transportation professional community.

The importance of transportation in the United States can also be illustrated by citing statistics that demonstrate its national and worldwide influence. For example, data furnished by agencies such as the Bureau of Transportation Statistics of the U.S. Department of Transportation, the Federal Highway Administration, and the U.S. Bureau of Labor Statistics provide major indices, such as the following: approximately 18 percent of U.S. household expenditure is related to transportation. Regarding energy consumption, transportation accounts for about 28 to 29 percent of total energy consumption in the United States, of which approximately 95 percent of the energy utilized for propelling transport vehicles is derived from petroleum products. The extent of U.S. travel is summarized as by the almost 90 percent of the driving age population in the United States that possess a license to operate a motor vehicle and the 12,000 to 15,000 miles per person travelled annually in the United States during the past decade. Transportation infrastructure is vast; for example, in the United States there are almost 4 million miles of paved roadway, of which 754,000 miles are used for intercity travel and 46,800 miles are interstate highways. In addition, there are approximately 140,000 miles of freight railroads, 5300 public use airports, 26,000 miles of navigable channels, and 360,000 miles of oil and gas pipelines. These statistics demonstrate that transportation will continue to play a key role in the economy even as it shifts from manufacturing to a focus on services, which is the largest and fastest growing sector in the U.S. economy.

1.2 TRANSPORTATION HISTORY

The story of transportation in the United States has been the subject of many books; the story covers a 300-year period and includes the development of many modes of transportation. Among the principal topics are travel by foot and horseback, automobile and truck travel, development of roads and highways, the building of canals and inland waterways, expansion of the West, construction of railroads, the use of public transportation (such as bus and metro systems in cities), and the development of air transportation. A summary of the historical highlights of transportation development is shown in Table 1.1.

1.2.1 An Overview of U.S. Transportation History

In its formative years, the United States was primarily rural, with a population of about 4 million in the late 1700s. Only about 200,000 people, or 5 percent of the population, lived in cities; the remainder inhabited rural areas and small communities. That pattern remained until the early 1900s. During the twentieth century, the urban population continued to increase such that at present over 75 percent of the U.S. population lives in urban or suburban areas. Large cities have been declining in population, and increases have occurred in suburban and rural areas. These changes have a significant impact on the need for highway transportation.

Early Road Building and Planning

During the eighteenth century, travel was by horseback or in animal-drawn vehicles on dirt roads. As the nation expanded westward, roads were built to accommodate the settlers. In 1794, the Lancaster Turnpike, the first toll road, was built to connect the Pennsylvania cities of Lancaster and Philadelphia. The nineteenth century brought further expansion of U.S. territorial boundaries, and the population increased from 3 million to 76 million. Transportation continued to expand with the nation. The remainder of the nineteenth century saw considerable activity, particularly in canal and railroad building.

The Canal Boom

An era of canal construction began in the 1820s when the Erie Canal was completed in 1825 and other inland waterways were constructed. Beginning in the 1830s, this efficient

Table 1.1 Significant Events in Transportation History

1794: First toll road, the Lancaster Turnpike, is completed.

1807: Robert Fulton demonstrates a steamboat on the Hudson River. Within several years, steamboats are operating along the East Coast, on the Great Lakes, and on many major rivers.

1808: Secretary of Treasury Albert Gallatin recommends a federal transportation plan to Congress, but it is not adopted.

1825: Erie Canal is completed.

1830: Operations begin on Baltimore and Ohio Railroad, first railroad constructed for general transportation purposes.

1838: Steamship service on the Atlantic Ocean begins.

1857: First passenger elevator in the United States begins operation, presaging high-density urban development.

1865: First successful petroleum pipeline is laid between a producing field and a railroad terminal point in western Pennsylvania.

1866: Bicycles are introduced in the United States.

1869: Completion of first transcontinental railroad.

1887: First daily railroad service from coast to coast.

1888: Frank Sprague introduces the first regular electric streetcar service in Richmond, Va.

1903: The Wright brothers fly first airplane 120 ft at Kitty Hawk, N.C.

1914: Panama Canal opens for traffic.

1915–18: Inland waters and U.S. merchant fleet play prominent roles in World War I freight movement.

1916: Interurban electric-rail mileage reaches a peak of 15,580 mi.

1919: U.S. Navy and Coast Guard crew cross the Atlantic in a flying boat.

1927: Charles Lindbergh flies solo from New York to Paris.

1956: Construction of the 42,500-mile Interstate and Defense Highway System begins.

1959: St. Lawrence Seaway is completed, opening the nation's fourth seacoast.

1961: Manned spaceflight begins.

1967: U.S. Department of Transportation is established.

1969: Men land on moon and return.

1972: San Francisco's Bay Area Rapid Transit System is completed.

1981: Space shuttle *Columbia* orbits and lands safely.

1991: The Interstate highway system is essentially complete.

1992: Intelligent transportation systems (ITS) usher in a new era of research and development in transportation.

1995: A 161,000-mile National Highway System (NHS) is approved.

1998: Electric vehicles are introduced as an alternative to internal combustion engines.

2000: A new millennium ushers in a transportation–information technology revolution.

2005: Energy-efficient autos as hybrid vehicles gain in popularity and ethanol production increases.

2011: Global warming and climate change become an emerging issue in planning, design, and emergency preparedness aspects of highway transportation.

means of transporting goods was replaced by the railroads, which were being developed at the same time. By 1840, the number of miles of canals and railroads was approximately equal (3200 mi), but railroads, which could be constructed almost anywhere in this vast, undeveloped land at a much lower cost, superseded canals as a form of intercity transportation. Thus, after a short-lived period of intense activity, the era of canal construction came to an end.

The Railroad Era

The railroad was the emerging mode of transportation during the second half of the nineteenth century, as railway lines were spanning the entire continent. Railroads dominated intercity passenger and freight transportation from the late 1800s to the early 1920s. Railroad passenger transportation enjoyed a resurgence during World War II but has steadily declined since then, owing to the competitiveness of the automobile. Freight rail was consolidated and remains viable. Railroad mileage reached its peak of about 265,000 miles by 1915.

Transportation in Cities

Each decade has seen continuous population growth within cities, and with it, the demand for improvements in urban transportation systems. Urban transportation began with horse-drawn carriages on city streets; these later traveled on steel tracks. They were succeeded by cable cars, electric streetcars, underground electrified railroads, and bus transportation. City travel by public transit has been replaced largely by the use of automobiles on urban highways, although rail rapid transit and light rail systems have been built in many large and medium-sized cities since the 1970s.

The Automobile and Interstate Highways

The invention and development of the automobile created a revolution in transportation in the United States during the twentieth century. No facet of American life has been untouched by this invention; the automobile (together with the airplane) has changed the way we travel within and between cities. Only four automobiles were produced in 1895. By 1901, there were 8000 registered vehicles, and by 1910, there were over 450,000 cars and trucks. Between 1900 and 1910, 50,000 miles of surfaced roads were constructed, but major highway-building programs did not begin in earnest until the late 1920s. By 1920, more people traveled by private automobile than by rail transportation. By 1930, 23 million passenger cars and 3 million trucks were registered. In 1956, Congress authorized a 42,500-mile interstate highway network, which is now completed.

The Birth of Aviation

Aviation was in its infancy at the beginning of the twentieth century with the Wright brothers' first flight, which took place in 1903. Both World Wars I and II were catalysts in the development of air transportation. The carrying of mail by air provided a reason for government support of this new industry. Commercial airline passenger service began to grow, and by the mid-1930s, coast-to-coast service was available. After World War II, the expansion of air transportation was phenomenal. The technological breakthroughs that developed during the war (coupled with the training of pilots) created a new industry that replaced both ocean-going steamships and passenger railroads.

1.2.2 Evolution of America's Highways

To commemorate the 200th anniversary of the signing of the Declaration of Independence in 1776, the Federal Highway Administration published a landmark commemorative volume titled *America's Highways* that described the evolution of the federal government's involvement in roads, which culminated with the establishment of the U.S. Bureau of Public Roads and its successor, the Federal Highway Administration. The book follows the major milestones in highway transportation, beginning with the colonial period and early settlement, when roads were unpaved and nearly impassable, with few bridges to span streams and rivers, and horse paths were unsuited for wheeled vehicles. It concludes with the growth of motor vehicle transportation in the twentieth century and its impact on highway transportation. The following sections summarize this evolutionary journey.

Turnpikes and Canals

In the eighteenth and nineteenth centuries, surface transportation improvements were focused on improving both roads and inland waterways, as together they comprised the internal network of transportation for a new nation led by its first president, George Washington, who had been elected in 1789. Federal interest and support for "internal improvements" was limited, as these functions were seen as the purview of states. The earliest attempt by a state government to develop a plan to build roads and canals was in Pennsylvania, when the legislature authorized private companies to build and maintain roads and canals and collect tolls that would cover costs and yield a profit for its investors—a practice still prevalent in the nineteenth and early twentieth centuries. (This method of financing was rejected for the U.S. Interstate Highway System, but recent trends have been moving toward this earlier financing model as states are turning to the private sector for "partners" to own, build, and maintain state highways.)

In 1791, the Philadelphia and Lancaster Turnpike Road Company was formed, having been granted a charter to build a 62-mile highway that would include a 20-ft hard surface and a 50-ft right-of-way with grades not to exceed 7 percent. The road, designed by the well-known Scottish road builder John Loudon McAdam, was completed in three years and served the travel needs of horse-drawn coaches and freight-carrying wagons. The road served as a model for similar toll roads constructed in East Coast states connecting cities and towns. The Lancaster "Pike" was so named because the toll gate was similar to a pivoted lancer's pike. It proved to be a success, yielding up to a 15 percent annual return on investment. It was later extended across the state to Pittsburgh.

Spurred on by the success of the Philadelphia and Lancaster Road, a "turnpike building frenzy" ensued with construction in Connecticut, New York, Maryland, and Virginia. By 1850, thousands of miles of turnpikes were in existence. Not many were as successful as the Lancaster Pike, and eventually there were failures due to low traffic demand and competition from canals and railroads. (Similar experiences were noted in the twentieth century, when many toll roads went bankrupt due to competition from free roads and other modes.)

The 1800s were a dark period for roads because other modes were dominant and vehicle technology had not changed since the time of the Roman Empire. Accordingly, animal and wind power continued to be the means of propulsion. Since the United States had an extensive system of rivers and lakes, it was logical that water navigation was a priority, and the building of canals would be a natural enhancement. Then in 1830, the "iron horse" appeared on the scene, and for the next 100 years, the railroad would dominate. Railroads initially appeared in Europe and were horse drawn. They, too, were regarded as "public highways" and had little to offer other than serving as short extensions from quarries to rivers as roads and canals were already in place.

The most extensive and successful of all canal projects was the Erie Canal, a 363-mile connection between the Hudson River in New York and Lake Erie, Pennsylvania. Construction began in 1817 and was completed in 1825. It had a trapezoidal cross section 40 ft wide at the top and 28 ft at the bottom, and it had a uniform depth of 4 ft. The canal ascended and descended a height of 675 ft through 83 separate locks. Eighteen aqueducts spanned rivers, and numerous bridges connected roads on opposite sides of the canal. Since the profession of civil engineering had yet to be established, this project became known as the first school of civil engineering in the United States. The canal was profitable, which convinced other states to undertake similar projects. However, most were not "money-makers" for their investors, and eventually canals became largely extinct.

A National Plan and a National Road

In the eighteenth and nineteenth centuries, sources of revenue for highways and canals included tolls, state and local taxes, and donated labor, while the federal government played a small (albeit important) role. The first act of Congress to support road building occurred in 1796. This authorized Colonel Ebenezer Zane (1741–1811) to build a 320-mile post road (called Zane's Trace) through the northwest territory (now Ohio) between Wheeling, Virginia (which became West Virginia in 1863) and Limestone (now Maysville), Kentucky. The road was primitive, following Native American trails, but it was to serve as a mail route and later was widened for wagon travel. It became part of the National Road in 1825. The federal government did not pay for the road but permitted Colonel Zane to purchase selected tracts of land where the road crossed three major rivers. Unfortunately, this small beginning of federal involvement in early road development was to have little influence on future events.

During the administration of President Thomas Jefferson (1801–1809), two events of major significance occurred that had an impact on road and canal building. The first was the completion of the Gallatin Report on internal improvements, and the second was the authorization of the Cumberland Road.

Secretary of the Treasury Albert Gallatin, at the request of the U.S. Senate, prepared the first national transportation inventory in 1807. The report, titled *Roads, Canals, Harbors and Rivers,* was submitted to Congress on April 4, 1808. The document contained a detailed program of "internal improvements" intended to increase the wealth of this undeveloped nation, as had occurred in France and England. The proposed 10-year program contained projects totaling $20 million and was to be financed by the federal government. This bold plan was fiercely debated in Congress but was not completed in time to be acted upon by President Jefferson. Rather, the bill reached the desk of President James Madison (1809–1817), who vetoed it on the grounds that direct federal support for internal improvements was unconstitutional as these matters were to be dealt with by the states. Gallatin earlier had proposed that the states use a portion of federal land sales for building roads, and some states did adopt this funding mechanism.

The Cumberland Road (later known as the National Road) is the first example of federal aid for a major road project in the United States. On March 29,1806, President Thomas Jefferson signed a bill authorizing the construction of a 125-mile road from Cumberland, Maryland, to Wheeling, Virginia, on the Ohio River. Road construction began in 1811, and the project was completed in 1818. In 1820, Congress appropriated additional funds to extend the road to the banks of the Mississippi River. Appropriations continued until 1838, and construction ceased in 1840 at Vandalia, Illinois. The National Road, now about 750 miles in length, was poised to open the western territories for settlement. However, this was not to be, because the federal government ceded the road to those states through which it traversed, and soon after, railroads were constructed—further sealing the National Road's fate.

The Demise of Federal Support for Roads

Another blow for federal support for road building was struck by President Andrew Jackson (1829–1837), who vetoed a bill that would have allowed the Secretary of the Treasury to purchase $150,000 in shares to help build a 65-mile turnpike from Maysville to Louisville in Kentucky. His veto was based on the continuing belief by U.S. presidents that since "internal improvements" were not specified in the Constitution as a federal responsibility, he could not sign the bill. Jackson's decision effectively ended attempts to secure federal funds for roads. The Maysville Turnpike was eventually completed with the support of state and private funds and was used as a mail route by the government.

In subsequent years, with the exception of the National Road, the responsibility for building toll roads fell to the states and private investors. Military roads were built during this period, most of them in the territories, and consisted primarily of clearings for wagon wheels. The total mileage of military roads was about 21,000, and they often served as the sole routes available to settlers moving westward. Following the Civil War (1860–1865), there was a reversal in federal policy that provided significant support to a new and emerging technology that would open the West to development and span the continent. The railroad era was about to begin.

Steamboats and Railroads

A "golden age" of transportation was to emerge in the nineteenth century, thanks to the genius of James Watt (1736–1819), a Scottish inventor and engineer who, with his partner Matthew Bolton (1728–1809), perfected and produced the steam engine. Steam engines originally were used to pump water from tin and copper mines and for spinning and weaving. Later, they were adapted to propel marine vessels and steam locomotives. The introduction of the first successful steamboat in 1807 is credited to Robert Fulton (1765–1815), who, with his partner Robert Livingston (1746–1813), used a 20-horsepower Watt and Bolton steam engine to propel a 133-ft-long passenger vessel. The *Clermont* (Figure 1.1) left New York City for Albany, New York, on a 150-mile journey up the Hudson River and arrived safely after 30 hours. This demonstration proved the viability of steamboat travel on rivers and lakes, and thus steamboats became instrumental in opening the West for settlement during the first half of the nineteenth century. By 1859, 2000 steamboats plied the Mississippi and its tributaries. The federal government subsidized inland waterway transportation, primarily

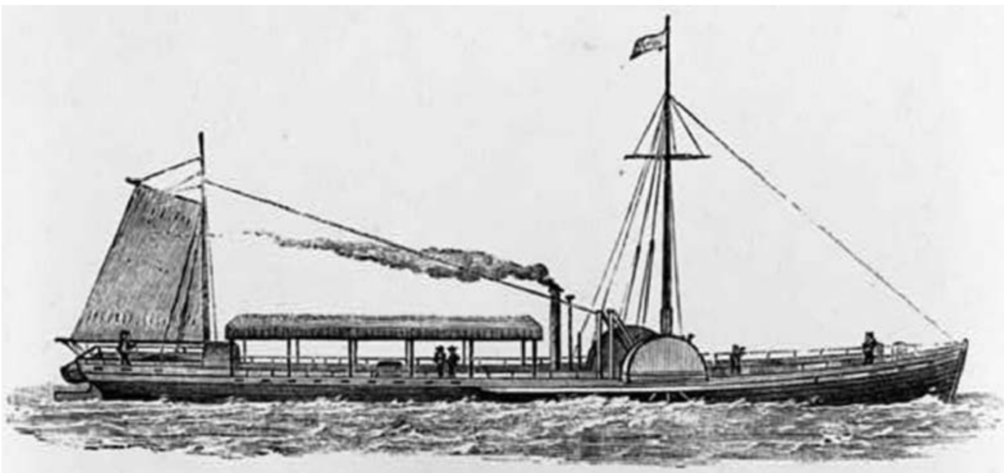

Figure 1.1 The *Clermont*—1807

SOURCE: Courtesy of the Library of Congress, LC-USZ62-110382 on the Ohio and Mississippi Rivers, the Great Lakes, and coastal ports. However, by 1850, it was increasingly clear that the railroad was the dominant mode compared to waterways and turnpikes because it was faster, cheaper, and more adaptable.

During the 10 years prior to the Civil War, railroad construction was widespread, with entrepreneurs and financiers seeking to gain fortunes while meeting a growing demand for rail connections between towns, villages, lakes, and seaports. To encourage railroad expansion westward, the federal government provided land grants to railroads totaling over 3.7 million acres. Rail lines were built without a system-wide plan, and the result was a plethora of unconnected short lines with varying track gauges. Later, many of these lines would form the basis for a system-wide network connecting major cities, all with a common track gauge of 4 ft 8.5 in. At the time of the Civil War, two-thirds of all railroad mileage was in the Northern states—an advantage that proved increasingly significant as the war progressed. After hostilities ended, railroads expanded rapidly (Figure 1.2), paralleling rivers and canals and heading inland and westward. Fierce competition ensued between steam packet ships and the railroads in a brutal and unregulated environment

Figure 1.2 Workmen Repairing Railroad Track—1895

SOURCE: Jackson, William Henry, 1843–1942. World's Transportation Commission photograph collection, Library of Congress, LC-W7-637 leading to the demise of waterways for moving freight and the dominance of railroads for moving freight and passengers. Additional land grants totaling 36.5 million acres were given to 50 railroads to encourage expansion westward. Eventually, four transcontinental railroads were completed (the first in 1869), with all liberally subsidized by generous federal land grants. This frenzy of railroad construction during the last half of the nineteenth century had produced approximately 260,000 miles of railroad track as the nation entered the twentieth century.

The Automobile and Resurgence of Highways

Highway transportation remained primitive and unchanged during the nineteenth century, as railroads dominated the landscape. Long-distance freight and stagecoach companies had been driven out of business, and toll road revenues continued to decline. Even though this "dark age" of roads seemed to be unending, over 1.5 million miles of rural roads were built—most composed of natural soil or stones that could be muddy in rainy seasons and dusty in dry ones. Rural roads were paid for and maintained by local citizens through property taxes, land donations, and donated labor. In cities and towns, the transportation situation was considerably better, as streets were paved with granite blocks, and public transit was introduced by 1880. Electric or cable streetcars (Figure 1.3) were common by the turn of the century.

The introduction of bicycles in the United States occurred as early as 1817. Bicycle transportation did not become practical for the general public until the introduction of a "safety bicycle," which used two wheels of equal size and pneumatic tires. Bicycle riding became a popular pastime, and many "wheel clubs" were formed followed by a national organization called the League of American Wheelmen. This organization is still in existence as the League of American Bicyclists, and reflects a persistent and increasing demand for improved bicycle facilities. (Figure 1.4.)

To their dismay, the new bicycle owners were soon to discover that a ride into the country was nearly impossible to complete due to the poor quality of roads, many of which were rutted, uneven, and lacked bridge links over streams and rivers. Thus was formed the first "highway lobby" seeking to influence the building of "good roads." A Good Roads Association was formed in 1891 in Missouri, with similar organizations to follow in other states. Ironically, an ally in this movement were the railroads themselves, whose representatives believed that if roads were improved, access to rail stations would be easier, thus increasing their market. Rail cars were outfitted with exhibits to demonstrate the benefits of "good roads" and how they should be built. These trains traveled throughout the nation, stopping at cities, towns, and villages and convincing citizens and politicians alike that it was time for the nation to begin investing in roads. Thus, "good road" trains roamed the nation proclaiming the benefits of a transport mode that by the end of the twentieth century would contribute to rail travel's own demise.

The introduction of a successful and practical gasoline-powered vehicle was the result of inventions by Gottlieb Daimler in 1885 and Karl Benz in 1886 and sparked a fury of innovation that culminated in a vehicle design that could be mass produced. The Ford Model T transformed the automobile market from that of a "rich man's toy" to "everyman's transport." The Ford Motor Company, led by Henry Ford, began to mass-produce cars selling for $950, and production of this model (available in all colors as long as they were black) totaled 15.5 million by the time production ceased in 1927 (Figure 1.5). Not to be outdone, other manufacturers followed suit, and an orgy of auto building began such that by 1921 there were 10.5 million registered vehicles in the United States.

Figure 1.3 Cable Car in Tacoma, Washington—1906

SOURCE: Courtesy of the Library of Congress, LC-USZ6-173

The next 50 years would witness a transformation in highways, from largely unpaved rural roads to an impressive network of rural and urban highways, despite an economic depression (1929–1939) and World War II (1941–1945). However, along with the mobility offered by automobiles (and later trucks) came traffic congestion, traffic fatalities, and diminished environmental quality. In 1956, highway construction entered a new era with the authorization of a 42,500-mile National Interstate Highway System, which when completed at the end of the twentieth century would total 47,800 miles and change the way people lived and traveled. Thus, the highway revolution (which began with the

Figure 1.4 Bicycling on the Golden Gate Bridge

SOURCE: Moreno Novello/Shutterstock.com

invention of the internal combustion engine in 1885 and its mass production in 1908) coupled with the introduction of "heavier than air" flight in 1903 dominated travel and reduced the role of rail and water transportation.

Looking ahead, can we expect that things will remain as they have in the past or will history be the prologue for future changes in transportation?

1.3 TRANSPORTATION EMPLOYMENT

Employment opportunities in transportation exist in the United States as well as in many other countries throughout the world. The principal areas of this field are logistics and supply-chain management, vehicle design and manufacture, provision of services related to transportation, and planning, design, construction, operations, and management of the infrastructure required if vehicles are to function as intended.

1.3.1 Logistics and Supply-Chain Management

The physical-distribution aspect of transportation, known as business logistics or physical-distribution management, is concerned with the movement and storage of freight between the primary source of raw materials and the location of the finished manufactured product. Logistics is the process of planning, implementing, and controlling the efficient and effective flow and storage of goods, services, and related information from origination

Figure 1.5 Parked Automobiles—1920

SOURCE: Library of Congress, Prints & Photographs Division, Theodor Horydczak Collection, LC-H823-V01-004

to consumption as required by the customer. An expansion of the logistics concept is called supply-chain management: a process that coordinates the product, information, and cash flows to maximize consumption satisfaction and minimize organization costs.

1.3.2 Vehicle Design and Transportation Services

Vehicle design and manufacture is a major industry in the United States and involves the application of mechanical, electrical, and aerospace engineering skills as well as those of technically trained mechanics and workers in other trades.

The service sector provides jobs for vehicle drivers, maintenance people, flight attendants, train conductors, and other necessary support personnel. Other professionals, such as lawyers, economists, social scientists, and ecologists, also work in the transportation fields when their skills are required to draft legislation, to facilitate right-of-way acquisition, or to study and measure the impacts of transportation on the economy, society, and the environment.

1.3.3 Transportation Infrastructure Services

Although a transportation system requires many skills and provides a wide variety of job opportunities, the primary opportunities for civil engineers are in the area of transportation infrastructure. A transportation engineer is the professional who is concerned with the planning, design, construction, operations, and management of a transportation system (Figure 1.6). Transportation professionals must make critical decisions about the system that will affect the thousands of people who use it. The work depends on the results of experience and research and is challenging and ever changing as new needs emerge and new technologies replace those of the past. The challenge of the transportation engineering profession is to assist society in selecting the appropriate transportation system consistent with society's economic development, resources, and goals, and to construct and manage the system in a safe and efficient manner. It is the engineer's responsibility to ensure that the system functions efficiently from an economic point of view, and that it meets external requirements concerning energy, air quality, safety, congestion, noise, and land use.

1.3.4 Specialties within Transportation Infrastructure Engineering

Transportation engineers are typically employed by the agency responsible for building and maintaining a transportation system, including federal, state, or local government, railroads, or transit authorities. They also work for consulting firms that help carry out the planning and engineering tasks for these organizations. During the past century, transportation engineers have been employed to build the nation's railroads, the interstate highway system, and rapid transit systems in major cities, airports, and turnpikes. Each decade has seen a new national need for improved transportation services.

In the twenty-first century, there will be increased emphasis on rehabilitating the highway system, including its surfaces and bridges, as well as on devising a means to ensure improved safety and utilization of the existing system through traffic control, information technology, and systems management. Highway construction will be required, particularly in suburban areas. Building of roads, highways, airports, and transit systems is likely to accelerate in less-developed countries, and the transportation engineer will be called on to furnish the services necessary to plan, design, build, and operate highway systems throughout the world. Each of the specialties within the transportation infrastructure engineering field is described next.

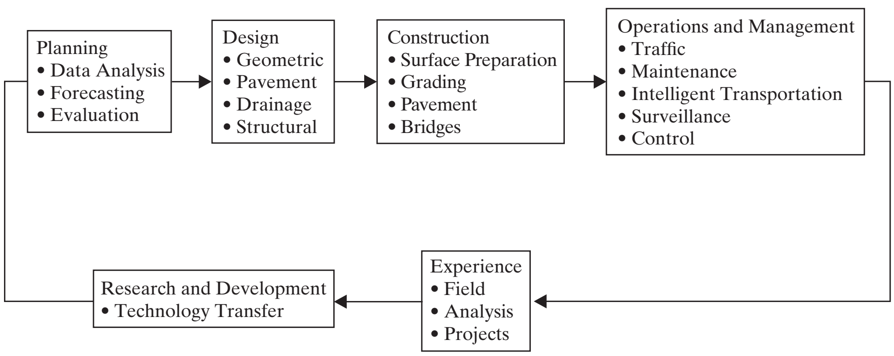

Figure 1.6 The Profession of Transportation Engineering

Transportation Planning

Transportation planning deals with the selection of projects for design and construction. The transportation planner begins by defining the problem, gathering and analyzing data, and evaluating various alternative solutions. Also involved in the process are forecasts of future traffic; estimates of the impact of the facility on land use, the environment, and the community; and determination of the benefits and costs that will result if the project is built. The transportation planner investigates the physical feasibility of a project and makes comparisons among various alternatives to determine which one will accomplish the task at the lowest cost—consistent with other criteria and constraints.

A transportation planner must be familiar with engineering economics and other means of evaluating alternative systems; be knowledgeable in statistics and data-gathering techniques, as well as in computer applications for data analysis and travel forecasting; and be able to communicate with the public and policy makers.

Transportation Infrastructure Design

Transportation design involves the specification of all features of the transportation system to assure that it will function smoothly, efficiently, and in accord with physical laws of nature. The design process results in a set of detailed plans that can be used for estimating the facility costs and for carrying out its construction. For highway design, the process involves the selection of dimensions for all geometrical features, such as the longitudinal profile, vertical curves and elevations, the highway cross section, pavement widths, shoulders, rights-of-way, drainage ditches, and fencing. The design processes also include the pavement and structural requirements for base courses and the concrete or asphalt surface material. Highway design also includes bridges and drainage structures as well as provision for traffic control devices, roadside rest areas, and landscaping. The highway designer must be proficient in civil engineering subjects (such as soil mechanics, hydraulics, land surveying, pavement design, and structural design) and is concerned primarily with the geometric layout of the road, its cross section, paving materials, roadway thickness, and traffic-control devices. Special appurtenances (such as highway bridges and drainage structures) are usually designed by specialists in these areas.

Highway Construction

Highway construction involves all aspects of the building process, beginning with clearing of the native soil, preparation of the surface, placement of the pavement material, and preparation of the final roadway for use by traffic. Highways initially were built with manual labor assisted by horse-drawn equipment for grading and moving materials. Today, modern construction equipment is used for clearing the site, grading the subgrade, compacting the pavement base courses, transporting materials, and placing the final highway pavement. Advances in construction equipment have made the rapid building of large highway sections possible. Nuclear devices test compaction of soil and base courses, Global Positioning Systems (GPS) and Geographic Information Systems (GIS) are used to establish line and grade, and specialized equipment has been developed for handling concrete and bridge work. Large, automatically controlled mix plants have been constructed, and new techniques for improving durability of structures and for substituting of scarce materials have been developed.

Traffic Operations and Management

The operation of the nation's highway system is the responsibility of the traffic engineer. Traffic engineering involves the integration of vehicle, driver, bicyclist, and pedestrian characteristics to improve the safety and capacity of streets and highways. All aspects of the transportation system are included after the street or highway has been constructed and opened for operation. Among the elements of concern are traffic accident analyses, parking and loading, design of terminal facilities, traffic signs, markings, signals, speed regulation, and highway lighting. The traffic engineer works to improve traffic flow and safety, using engineering methods and information technology to make decisions that are supported by enforcement and education. Traffic engineers work directly for municipalities, county governments, and private consulting firms.

Maintenance Operations and Management

Highway maintenance involves all the work necessary to ensure that the highway system is kept in proper working order. Maintenance includes patching, repair, and other actions necessary to ensure that the roadway pavement is at a desired level of serviceability. Maintenance management involves recordkeeping and data analysis regarding work activities, project needs, and maintenance activities to assure that the project is carried out in the most efficient and economical manner. Scheduling work crews, replacing worn or damaged signs, and repairing damaged roadway sections are important elements of maintenance management. The work of the civil engineer in the area of maintenance involves the redesign of existing highway sections, economic evaluation of maintenance programs, testing of new products, and scheduling of personnel to minimize delay and cost. The maintenance engineer must also maintain an inventory of traffic signs and markings and ensure that they are in good condition.

1.3.5 Professional Challenges in Transportation Engineering

What will be the challenges for the transportation engineer whose career can be expected to encompass the better part of the twenty-first century? How can these challenges be addressed, and what are the necessary attributes and skills? The answers to these questions have many facets and will require continued renewal of knowledge and experience through life-long learning and participation in professional society activities. Since transportation is a complex, multidimensional, and interactive system, the transportation engineer will need an arsenal of resources to respond to the many situations that can be expected. This section identifies some of the likely major challenges and suggests the kinds of skills and abilities that should prove valuable.

The principal challenge will be to meet the expectation of the public that transportation will be efficient, effective, long lasting, and safe. Meeting this expectation is no small feat and requires extensive knowledge and experience regarding human behavior, systems performance, and technology. Transportation systems are not produced on an assembly line, and they cannot be easily discarded for something better. When introduced into service, careful integration within an existing environment is required. Transportation projects are unique; each project is "one of a kind" and require many years to complete—for example, 50 years were devoted to construction of the Interstate Highway System. A typical highway project requires 5 to 20 years from start to finish.

Transportation engineers are required to possess a long-term vision of the future. They must remain steadfast, patient, and persistent in guiding a transportation project to completion. The transportation engineer works in an environment where change is gradual and sometimes imperceptible. To illustrate using an example from history, a major milestone in transportation occurred when the Wright brothers assembled a heavier-than-air machine in 1903 and demonstrated that it could fly under its own power. Almost a quarter of a century transpired before this “flying machine” transported a single person across the Atlantic from New York to Paris.

A related challenge for transportation engineers is to understand how innovation and new technology can be used to transport people and goods in new and different ways. Were it not for the inventive spirit of transportation pioneers, such as Robert Fulton in 1807 and Henry Ford in 1903, today’s modern transportation systems would not exist. Yet another innovation with profound consequences for public transportation was the use of iron wheels on iron rails. Prior to this innovation, the “old way” relied on wheels in contact with the pavement, which was usually uneven, or more likely, nonexistent. With this new innovation—the street railway—travel became faster, smoother, and more comfortable—with less energy required to pull the trams, first by horses, then by steam engines and cables, and ultimately by electric motors. The new idea had successfully competed with the “old way” and beaten it at its own game.

Technological innovation can be expected to accelerate in the twenty-first century. Thus, the challenge for the transportation engineer will be to distinguish between technology with solutions that are looking for a problem and solutions that successfully compete with the old way. To illustrate, monorail transit has been promoted as a futuristic answer to urban congestion. The results have proven otherwise, and consequently, monorail transit remains a perennial answer to tomorrow’s transportation problems. In contrast, when railroads appeared in the 1830s, canals were the dominant mode. Many of the early railroads were built parallel to canal towpaths and soon demonstrated their superiority. Modern examples of two emerging technologies are automated highways and automated toll collection. Automated highways with driverless vehicles have been proposed as a way to increase speed and capacity while increasing safety. Automated toll collection has been successfully introduced as a substitute for manual collection.

Another important challenge for transportation engineers is to be a good steward of people’s investment in transportation. Doing so requires attention to designs that are appropriate, cost effective, and economical. Attention to maintenance is essential. Civil engineering is the professional discipline that seeks to harness nature in a cost-effective manner for the benefit of society. In the twenty-first century, with limited budgets and competition for the use of public funds, the existing system must be managed while prudently adding capacity.

Transportation engineers produce a product that is highly visible. The system is paid for by taxes and user fees and serves every segment of society. Accordingly, another major challenge is to deal with the public and their representatives at the local, state, and national level. To adequately respond to citizen and political concerns, the transportation engineer must be a technical expert and have the requisite communication skills for clearly explaining ideas and concepts. Communication involves two elements: speaking and writing. Speaking skills are gained by preparation, practice, and experience. Writing skills can be improved through practice in class assignments and personal communications, as well as by reading well-written books and articles.

Transportation engineers also must learn to be good listeners, especially under trying and tense conditions. They are often confronted by opponents who voice objections because of their belief that proposals may negatively impact their lives or property.

Transportation engineers face hostile audiences more often than supportive ones. Citizens who are not affected by a project show little interest or support. No one wants highway noise and congestion near their home and, consequently, opponents are sometimes referred to as NIMBYs, meaning, "not in my back yard." Such groups deserve a fair and complete hearing, and attempts at mitigation should be made when possible. The key challenge for transportation engineers is to convincingly and honestly communicate the project's need, importance, and design location.

A constant challenge for transportation engineers is to deal ethically and fairly with everyone involved in a transportation project, including contractors, suppliers, real estate developers, funding agencies, construction and maintenance workers, and fellow employees. Ethics is a broad topic that can be summed up simply as "doing what is right within the context of the situation." To be ethical, one must be honest, trustworthy, dependable, fair, even-handed, loyal, and compassionate. Ethical persons refrain from slander, fraud, and malicious activities. For example, a transportation engineer who withholds an alternate plan/design concept for inspection by the public because it is not favored by the agency in charge of constraction is acting unethically. Ethics involves sharing credit for work done as a team effort and not taking credit for the work of others. It involves treating subordinates and colleagues with respect and without bias.

When planning transportation projects, ethics implies evaluating cost and benefits in an objective manner and disclosing the underlying assumptions of the analysis. Ethics requires that transportation engineers wrestle with thorny issues, such as who is being served with improved mobility and safety. For example: Do rail systems or high-occupancy toll (HOT) lanes benefit suburban commuters who own automobiles while neglecting the inner-city poor, who cannot afford to purchase an automobile and depend solely on public transit for their economic survival? Should highway funds be used to reduce truck traffic and congestion on interstate highways or should resources be devoted to local and rural tourist routes near historic and scenic destinations?

In summary, if transportation engineers are to meet the challenges of the twenty-first century, they will require technical knowledge and judgment as well as emotional intelligence. Good technical judgment is based on personal behavior and work experience and includes persistence, high performance standards, emphasis on quality, a sense of priorities, and adaptability to change. Emotional intelligence reflects the ability to deal with others by being supportive and helpful, avoiding malicious behavior, and treating others as we would treat ourselves.

1.4 SUMMARY

Transportation is an essential element in the economic development of a society. Without good transportation, a nation or region cannot achieve the maximum use of its natural resources or the maximum productivity of its people. Progress in transportation is not without its costs, both in human lives and environmental damage, and it is the responsibility of the transportation engineer working with the public to develop high-quality transportation consistent with available funds and social policy and to minimize damage. Transportation is a significant element in our national life, accounting for about 18 percent of household expenditure and employing over 10 percent of the workforce.

The history of transportation illustrates that the way people move is affected by technology, cost, and demand. The past 200 years have seen the development of several modes of transportation: waterways, railroads, highway, and air. Each mode has been dominant during one period of time; several have been replaced or have lost market share when a new mode emerged that provided a higher level of service at a competitive price.

The specialties in transportation engineering are planning, design, construction, traffic management and operations, and maintenance. Planning involves the selection of projects for design and construction; design involves the specification of all features of the transportation project; construction involves all aspects of the building process; traffic management and operations involves studies to improve capacity and safety; and maintenance involves all work necessary to ensure that the highway system is kept in proper working order.

Engineering students have exciting career opportunities in transportation. In the past, transportation engineers planned and built the nation's railroads, highways, mass transit systems, airports, and pipelines. In the coming decades, additional system elements will be required, as will efforts toward maintaining and operating in a safe and economical manner the vast system that is already in place. New systems, such as magnetically levitated high-speed trains or Intelligent Transportation Systems (ITS), will also challenge the transportation engineer in the future.

PROBLEMS

1-1 To illustrate the importance of transportation in our national life, identify a transportation-related article that appears in a local or national newspaper. Discuss the issue involved and explain why the article is newsworthy.

1-2 Arrange an interview with a transportation professional in your city or state (that is, someone working for a consulting firm, city, county or state transportation department, transit or rail agency). Inquire about the job he or she performs, why he or she entered the profession, and what he or she sees as the future challenges in the field.

1-3 Keep a diary of all trips you make for a period of three to five days. Record the purpose of the trip, how you traveled, the approximate distance traveled, and the trip time. What conclusions can you draw from the data?

1-4 Identify one significant transportation event that occurred in your city or state. Discuss the significance of this event.

1-5 Describe how transportation influenced the initial settlement and subsequent development of your home city or state.

1-6 Describe your state's transportation infrastructure. Include both passenger and freight transportation.

1-7 What is the total number of miles of public roadways in your state? What percentage of the highway system mileage is maintained by the state government (as opposed to local and federal government)? What percentage of the total public highway system in your state is comprised of interstate highways?

1-8 Estimate the number of personal motor vehicles in your city or state. What is the total number of miles driven each year? How much revenue is raised per vehicle per year for each 1 cent/gallon tax? Assume that the average vehicle achieves 25 miles per gallon in fuel economy.

1-9 How many railroad trains pass through your city each week? What percentage of these are passenger trains?

1-10 Compare the extent of the U.S. railroad system of today with that of 100 years ago. What changes have occurred and what factors have led to these changes?

1-11 What proportion of American household expenditures is associated with transportation, and what is the breakdown of these expenditures by category (such as ownership, fuel, maintenance, etc.)? Estimate the proportion of your monthly budget that is spent on transportation.

1-12 Identify an ITS project or application that is underway in your home state. Describe the project, its purpose, and the way it is operated.

1-13 Most Departments of Transportation incorporate at least five major transportation engineering subspecialties within their organization. List and briefly indicate at least three tasks under each specialty.

1-14 List four major detrimental effects that are directly related to the construction and use of our highway transportation system.

1-15 Cite four statistics that demonstrate the importance of transportation in the United States.

1-16 A state has a population of 17 million people and an average ownership of 1.1 cars per person, each driven an average of 12,000 mi/year, at an average fuel economy of 24 mi/gal of gasoline (mpg). Officials estimate that an additional $60 million per year in revenue will be required to improve the state's highway system, and they have proposed an increase in the gasoline tax to meet this need. Determine the required tax in cents per gallon.

1-17 Select a single event in Table 1.1 and explain why this is a significant achievement in the history of transportation.

1-18 Name and describe the first successful turnpike effort in the newly independent United States of America.

1-19 What mode of transportation was the primary contributor to the demise of road construction in the United States in the early nineteenth century, and what advantages did the new mode offer?

1-20 What mode of transportation succeeded the mode noted in Problem 1-19, and what advantages did it offer?

1-21 What was the interest of the U.S government in supporting expansion of railroads in the mid-nineteenth century, and how did the government provide support?

1-22 Public expectations for the transportation system continue to increase. What is the principal challenge faced by the transportation engineer in meeting these expectations? What fields of knowledge beyond traditional transportation engineering are needed?

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CHAPTER 2

Transportation Systems and Organizations

The transportation system in a developed nation is an aggregation of vehicles, guideways, terminal facilities, and control systems that move freight and passengers. These systems are usually operated according to established procedures and schedules in the air, on land, and on water. The set of physical facilities, control systems, and operating procedures referred to as the nation's transportation system is not a system in the sense that each of its components is part of a grand plan or was developed in a conscious manner to meet a set of specified regional or national goals and objectives. Rather, the system has evolved over a period of time and is the result of many independent actions taken by the private and public sectors, which act in their own or in the public's interest.

Each day, decisions are made that affect the way transportation services are used. The decisions of a firm to ship its freight by rail or truck, of an investor to start a new airline, of a consumer to purchase an automobile, of a state or municipal government to build a new highway or airport, of Congress to deny support to a new aircraft, and of a federal transportation agency to approve truck safety standards are just a few examples of how transportation services evolve and a transportation system takes shape.

CHAPTER OBJECTIVES:

- Understand how transportation systems are created and developed.
- Discuss the comparative advantages of both passenger and freight transportation modes.
- Explain the use of a supply-demand curve to determine the effect of tolls on travel demand.
- Become familiar with public transportation modes, their capacity, and their service attributes.
- Understand how highway projects are developed and their sources of funds.
- Become familiar with the U.S. national highway system and the organizations and associations involved in transportation.

2.1 DEVELOPING A TRANSPORTATION SYSTEM

Over the course of a nation's history, attempts are made to develop a coherent transportation system, usually with little success. A transportation plan for the United States was proposed by Secretary of the Treasury Gallatin in 1808, but this and similar attempts have had little impact on the overall structure of the U.S. transportation system. As stated in the *TRNews* special issue on the fiftieth anniversary of the Interstate highway system, engineers and planners failed to recognize or account for the impact of this immense national system on other transportation modes or on its effect on urbanization and sprawl. The creation of the U.S. Department of Transportation (DOT) in 1967 had the beneficial effect of focusing national transportation activities and policies within one cabinet-level agency. In turn, many states followed by forming transportation departments from existing highway agencies.

The Interstate Commerce Commission (ICC), created in 1887 to regulate the railroads, was given additional powers in 1940 to regulate water, highway, and rail modes, preserving the inherent advantages of each and promoting safe, economic, and efficient service. The intent of Congress was to develop, coordinate, and preserve a national transportation system; however, the inability to implement vague and often contradictory policy guidelines coupled with the extensive use of congressionally mandated projects, known as earmarks, has not helped to achieve the results implied by national policy. More recently, regulatory reform has been introduced, earmarks have been eliminated, and transportation carriers are developing new and innovative ways of providing services.

2.1.1 Comparative Advantages of Transportation Modes

The transportation system that evolves in a developed nation may not be as economically efficient as one that is developed in a more analytical fashion, but it is one in which each of the modes provides unique advantages for transporting the nation's freight and passengers. A business trip across the country may involve travel by taxi, airplane or rail, and auto; transportation of freight often requires trucks for pick-up and delivery and railroads, barges, or motor carriers for long-distance hauling.

Each mode has inherent advantages of cost, travel time, convenience, and flexibility that make it "right for the job" under a certain set of circumstances. The automobile is considered to be a reliable, comfortable, flexible, and ubiquitous form of personal transportation for many people. However, when distances are great and time is at a premium, air transportation will be selected—supplemented by the auto for local travel. If cost is important and time is not at a premium or if an auto is not available, then intercity bus or rail may be used.

Selecting a mode to haul freight follows a similar approach. Trucks have the advantages of flexibility and the ability to provide door-to-door service. They can carry a variety of parcel sizes and usually can pick up and deliver to meet the customer's schedule. Waterways can ship heavy commodities at low cost, but only at slow speeds and between points on a river or canal. Railroads can haul a wide variety of commodities between any two points, but usually require truck transportation to deliver the goods to a freight terminal or to their final destination. In each instance, a shipper must decide whether the cost and time advantages are such that the goods should be shipped by truck alone or by a combination of truck, waterway, and rail.

Many industries have been trying to reduce their parts and supplies inventories, preferring to transport them from the factory when needed rather than stockpiling them in a warehouse. This practice has meant shifting transportation modes from rail to truck. Rail shipments are usually made once or twice a week in carload lots, whereas truck deliveries can be made in smaller amounts and on a daily basis, depending on demand. In this instance, lower rail-freight rates do not compete with truck flexibility, since the overall result of selecting trucking is a cost reduction for the industry. There is a trend toward intermodalism, which has combined the capabilities of both modes.

Example 2.1 Selecting a Transportation Mode

An individual is planning to take a trip between the downtown area of two cities, A and B, which are 400 miles apart. There are three options available:

Travel by air. This trip will involve driving to the airport near city A, parking, waiting at the terminal, flying to airport B, walking to a taxi stand, and taking a taxi to the final destination.

Travel by auto. This trip will involve driving 400 miles through several congested areas, parking in the downtown area, and walking to the final destination.

Travel by rail. This trip will involve taking a cab to the railroad station in city A, a direct rail connection to the downtown area in city B, and a short walk to the final destination.

Since this is a business trip, the person making the trip is willing to pay up to $25 for each hour of travel time reduced by a competing mode. (For example, if one mode is two hours faster than another, the traveler is willing to pay $50 more to use the faster mode.) After examining all direct costs involved in making the trip by air, auto, or rail (including parking, fuel, fares, tips, and taxi charges) the traveler concludes that the trip by air will cost $250 with a total travel time of five hours, the trip by auto will cost $200 with a total travel time of eight hours and the trip by rail will cost $150 with a total travel time of 12 hours.

Which mode is selected based on travel time and cost factors alone?

What other factors might be considered by the traveler in making a final selection?

Solution: Since travel time is valued at $25/hr, the following costs would be incurred:

$$\text{Air: } 250 + 25(5) = \$375$$
$$\text{Auto: } 200 + 25(8) = \$400$$
$$\text{Rail: } 150 + 25(12) = \$450$$

In this instance, the air alternate reflects the lowest cost and is the selected mode. However, the traveler may have other reasons to select another alternative. These may include the following considerations.

Safety. While each of these modes is safe, the traveler may feel "safer" in one mode than another. For example, rail may be preferred because of concerns regarding air safety issues.

Reliability. If it is very important to attend the meeting, the traveler may select the mode that will provide the highest probability of an on-time arrival. If the drive involves travel through work zones and heavily congested areas, rail or air would be preferred. If potential air delays are likely due to congestion, flight cancellations, or inclement weather, another mode may be preferred.

Convenience. The number of departures and arrivals provided by each mode could be a factor. For example, if the railroad provides only two trains/day and the airline has six flights/day, the traveler may prefer to go by air.

2.1.2 Interaction of Supply and Demand

The transportation system that exists at any point in time is the product of two factors that act on each other. These are (1) the state of the economy, which produces the demand for transportation; and (2) the extent and quality of the system that is currently in place, which constitutes the supply of transportation facilities and services. In periods of high unemployment or rising fuel costs, the demand for transportation tends to decrease. On the other hand, if a new transportation mode is introduced that is significantly less costly when compared with existing modes, the demand for the new mode will increase, decreasing demand for the existing modes.

These ideas can be illustrated in graphic terms by considering two curves, one describing the demand for transportation at a particular point in time, and the other describing how the available transportation service or supply is affected by the volume of traffic that uses that system.

The curve in Figure 2.1 shows how demand in terms of traffic volume could vary with cost. The curve is representative of a given state of the economy and of the present population. As is evident, if the transportation cost per mile, C, decreases, then, since more people will use it at a lower cost, the volume, V, will increase. In Figure 2.1, when the traffic volume/day is 6000, the cost is \$0.75/mile. If cost is decreased to \$0.50/mile, the volume/day increases to 8000. In other words, this curve provides an estimate of the demand for transportation under a given set of economic and social conditions.

Demand can occur only if transportation services are available between the desired points. Consider a situation where the demand shown in Figure 2.1 represents the desire to travel between the mainland of Florida and an inaccessible island that is located off the coast, as shown in Figure 2.2.

If a bridge is built, people will use it, but the amount of traffic will depend on cost. The cost to cross the bridge will depend on the bridge toll and the travel time for cars and trucks. If only a few vehicles cross, little time is lost waiting at a tollbooth or in congested traffic. However, as more and more cars and trucks use the bridge, the time required to cross will increase unless automated tollbooths are installed. Lines will be long at the tollbooth; there might also be traffic congestion at the other end. The curve in Figure 2.3 illustrates how the cost of using the bridge could increase as the volume of traffic increases, assuming that the toll is \$0.25/mile. In this figure, if the volume is

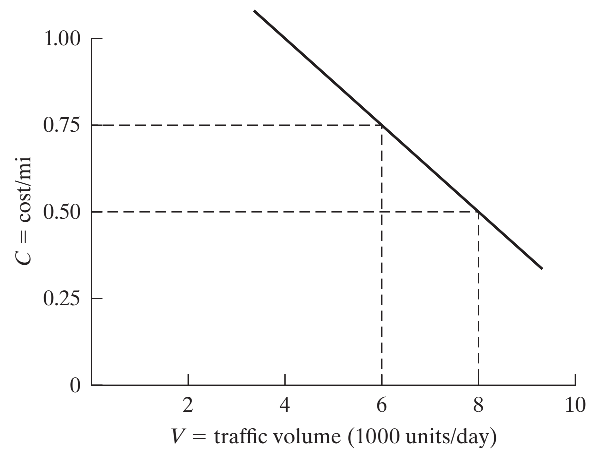

Figure 2.1 Relationship between Transportation Demand and Cost

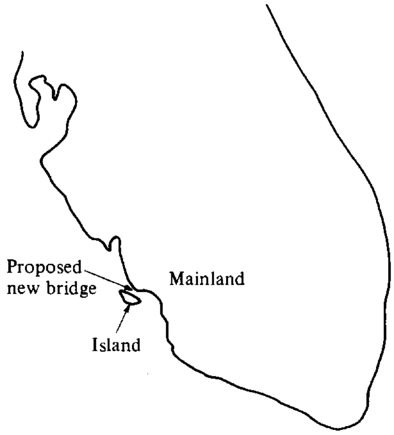

Figure 2.2 Location of a New Bridge between the Mainland and an Island

less than 2000 units/day, there is no delay due to traffic congestion. However, as traffic volumes increase beyond 2000 units/day, delays occur and the travel time increases. Since "time is money," the increased time has been converted to \$/mi. If 4000 units/day use the bridge, the cost is \$0.50/mi; at 6000 units/day, the cost is \$0.75/mi.

The two curves (Figures 2.1 and 2.3) determine what volume (V) can be expected to use the bridge. This value will be found where the demand curve intersects the supply curve as shown in Figure 2.4, because any other value of V will create a shift in demand either upward or downward, until the equilibrium point is reached. If the volume increased beyond the equilibrium point, cost would go up and demand would drop. Likewise, if the volume dropped below equilibrium, cost would go down and demand would increase. Thus, in both instances equilibrium is achieved. In this example, the number of units crossing the bridge would be 6000 units/day. The traffic volume could be raised or lowered by changing the toll—an example of congestion pricing.

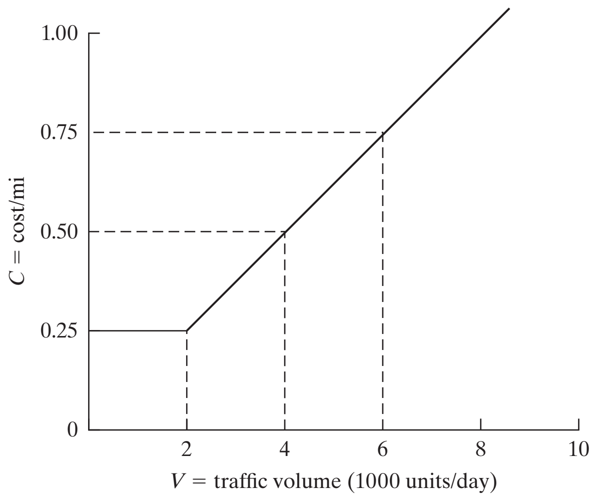

Figure 2.3 Relationship between Transportation Supply and Cost

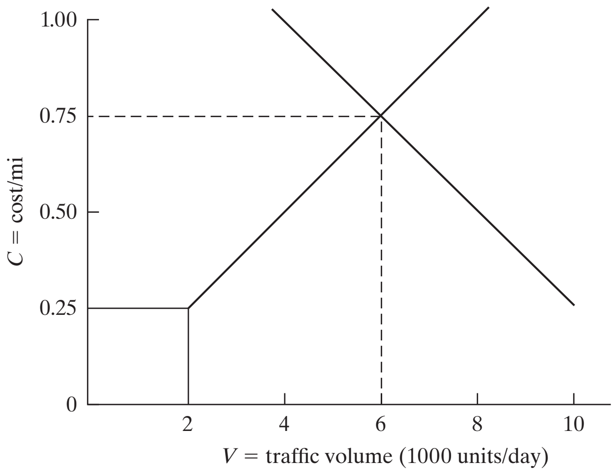

Figure 2.4 Equilibrium Volume for Traffic Crossing a Bridge

2.1.3 Forces That Change the Transportation System

At any point in time, the nation's transportation system is in a state of equilibrium as expressed by the traffic carried (or market share) for each mode and the levels of service provided (expressed as travel attributes such as time, cost, frequency, and comfort). This equilibrium is the result of market forces (state of the economy, competition, costs, and prices of service), government actions (regulation, subsidy, and promotion), and transportation technology (speed, capacity, range, and reliability). As these forces shift over time, the transportation system changes as well, creating a new set of market shares (levels of demand) and a revised transportation system. For this reason, the nation's transportation system is in a constant state of flux, causing short-term changes due to immediate revisions in levels of service (such as raising the tolls on a bridge or increasing the gasoline tax) and long-term changes in lifestyles and land-use patterns (such as moving to the suburbs after a highway is built or converting auto production from large to small cars).

If gasoline prices were to increase significantly, there could be a measurable shift of long-haul freight from truck to rail. In the long run, if petroleum prices remained high, there might be shifts to coal or electricity or to more fuel-efficient trucks and autos.

Government actions also influence transportation equilibrium. For example, the federal government's decision to build the national interstate system affected the truck-rail balance in favor of truck transportation. It also encouraged long-distance travel by auto and was a factor in the decline of intercity bus service to small communities.

Technology has also contributed to substantial shifts in transportation equilibrium. A dramatic example was the introduction of jet aircraft, which essentially eliminated passenger train travel in the United States and passenger steamship travel between the United States and the rest of the world.

2.2 MODES OF TRANSPORTATION

The U.S. transportation system today is a highly developed, complex network of modes and facilities that furnishes shippers and travelers with a wide range of choices in terms of services provided. Each mode offers a unique set of service characteristics in terms of travel time, frequency, comfort, reliability, convenience, and safety. The term *level of*

Example 2.2 Using a Supply-Demand Curve to Compute the Bridge Cost/Vehicle (Toll) That Will Maximize Total Revenue

A toll bridge carries 5000 veh/day. The current cost (toll) is 150 cents. When the cost (toll) is increased by 25 cents, traffic volume decreases by 500 veh/day. Determine the cost/veh (new toll) that should be charged such that revenue is maximized. How much additional revenue will be received?

Solution: Let x = the cost increase in cents.

Assuming a linear relation between traffic volume and cost, the expression for V is

$$V = 5000 - x/25(500)$$

The new cost/veh (toll) is the original cost plus the cost increase

$$T = 150 + x$$

The revenue produced is the product of total cost/veh (toll) and vehicle volume:

$$\begin{aligned} R &= (V)(T) \\ &= \{5000 - x/25(500)\}(150 + x) \\ &= (5000 - 20x)(150 + x) = 750{,}000 - 3000x + 5000x - 20x^2 \\ &= 750{,}000 + 2000x - 20x^2 \end{aligned}$$

For maximum value of x, compute the first derivative and set equal to zero:

$$\begin{aligned} dR/dt &= 2000 - 40x = 0 \\ x &= 50 \text{ cents} \end{aligned}$$

The total cost/veh (new toll) is the current total cost (toll) plus the toll increase. Thus the total cost/veh toll for maximum revenue = 150 + 50 = 200 cents or \$2.00 The additional revenue, AR, is

$$\begin{aligned} AR &= (V_{max})(T_{max}) - (V_{current})(T_{current}) \\ &= \{(5000 - (50/25)(500)\}\{2\} - (5000)(1.50) \\ &= (4000)(2) - 7500 \\ &= 8000 - 7500 \\ &= \$500 \end{aligned}$$

service is used to describe the relative values of these attributes. The traveler or shipper must compare the level of service offered with the cost in order to make tradeoffs and mode selection. Furthermore, a shipper or traveler can decide to use a public carrier or to use private (or personal) transportation. For example, a manufacturer can ship goods through a trucking firm or with company trucks; a homeowner who has been relocated can hire a household moving company or rent a truck; and a commuter can elect to ride the bus to work or drive a car. Each of these decisions involves a complex set of factors that require tradeoffs between cost and service.

2.2.1 Freight and Passenger Traffic

The principal modes of intercity freight transportation are highways, railroads, water, and pipelines. Traffic carried by each mode, expressed as ton-miles or passenger-miles, has varied considerably in the past 70 years. The most current information regarding modal market share is available from the Bureau of Transportation Statistics (BTS) Web site. Changes in ton-miles carried from 1960 through 2008 are illustrated in Figure 2.5.

Class I Railroads, which accounted for about 0.6 million ton-miles of freight traffic in 1960, carried about 1.8 million ton-miles by the year 2008. Oil pipelines have increased their share of freight traffic from 0.2 million ton-miles in 1960 but have remained relatively constant at about 0.6 million ton miles since 1980. Domestic water transportation has increased its ton-miles between 1965 and 1980 and has declined since then. Intercity trucking has steadily increased each year, from 0.3 million ton-miles in 1960 to about 1.3 million ton-miles in 2003. Air freight is an important carrier for high-value goods, but it is insignificant on a ton-mile basis.

The four principal carriers for freight movement (rail, truck, pipeline, and water) account for varying proportions of total number of ton-miles of freight. The railroads' share is highest on a ton-mile basis, but it has been reduced significantly due to competition from truck and pipeline. Overall the railroads have lost traffic due to the advances in truck technology and pipeline distribution. Government policies that supported highway and waterway improvements are also a factor. Subsequent to World War II, long-haul trucking was possible because the U.S. highway system was developed. As petroleum became more widely used, construction of a network of pipelines for distribution throughout the nation was carried out by the oil industry.

During the past 50 years, the railroad's share of revenue has decreased while that of trucking has increased to about 80 percent of the total. These trends reflect two factors: the increased dominance of trucking in freight transportation and the higher ton-mile rates that are charged by trucking firms compared with the railroads. Although trucks move fewer ton-miles than does rail, the value of the goods moved by truck comprises about 75 percent of the total value of all goods moved in the United States.

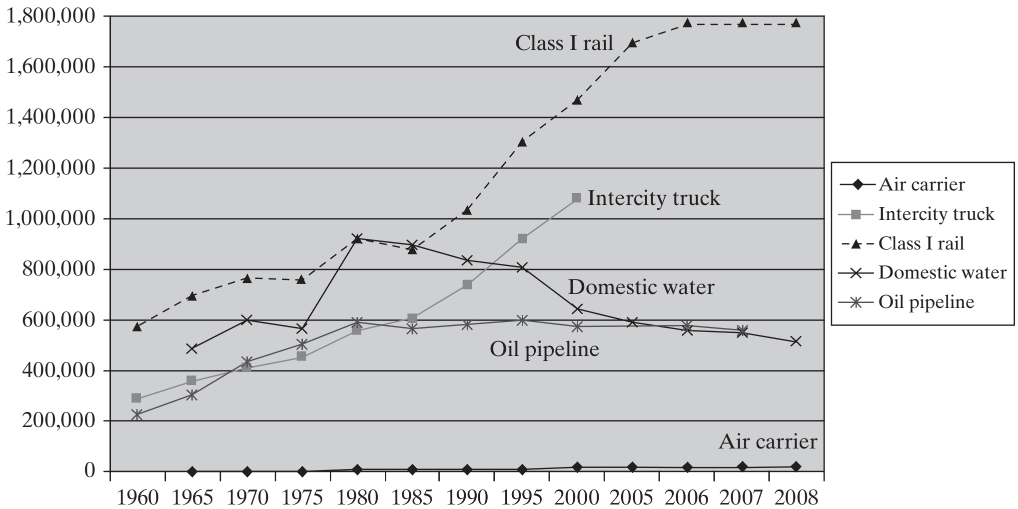

Figure 2.5 U.S. Ton-Miles of Freight (Millions)

SOURCE: U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, *National Transportation Statistics*, Table 1-46a.

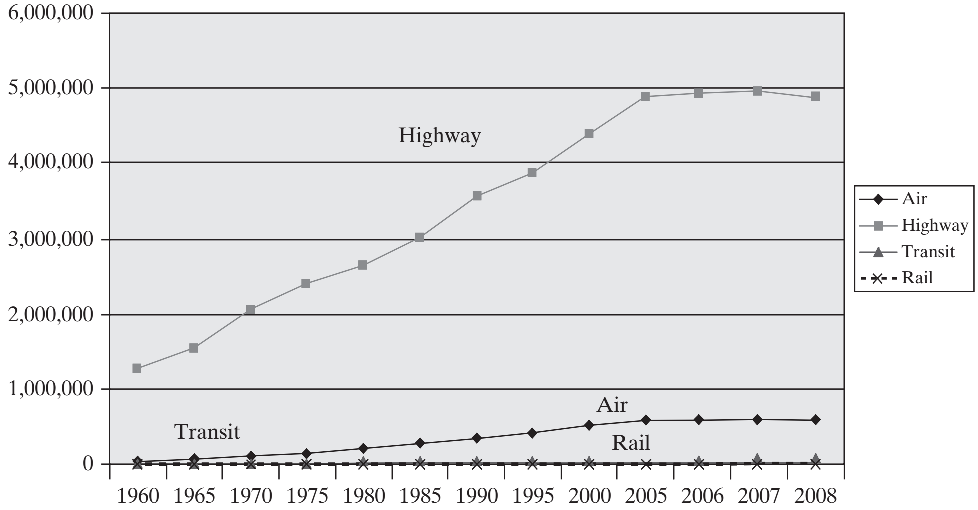

Figure 2.6 U.S. Passenger–Miles (Millions)

SOURCE: U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, *National Transportation Statistics*, Table 1-37.

The distribution of passenger transportation is much different from that for freight: one mode—the automobile—accounts for the highest number of all domestic intercity passenger-miles traveled in the United States, as illustrated in Figure 2.6. With the exception of the World War II years (when auto use declined), passenger-miles by automobile, small trucks, and vans have accounted for as much as 90 percent of all passenger-miles traveled. The remaining modes—air, bus, and rail—shared a market representing about one-quarter of the total, with air being the dominant mode and intercity bus, private air carriers, and rail representing 1 percent or less of the total.

Of the four transportation carriers for intercity passenger movement, two—air and auto—are dominant, representing 98 percent of all intercity passenger miles. If the public modes (rail, bus, and air) are considered separately from the auto, a dramatic shift in passenger demand is evident. The largest increase has occurred in air transportation, which represents over 90 percent of all intercity passenger-miles traveled using public modes. In cities, buses are the major public transit mode, with the exception of larger urban areas that have rapid rail systems. Intercity bus transportation has declined as a percentage of the total number of passenger miles. Buses now serve a market consisting primarily of passengers who cannot afford to fly or drive. As air fares have decreased with deregulation, bus travel has declined. Most passenger rail traffic is concentrated in the corridor between Washington, D.C., New York, and Boston.

2.2.2 Public Transportation

Public transportation is a generic term used to describe the family of transit services available to urban and rural residents. Thus, it is not a single mode but a variety of traditional and innovative services, which should complement each other to provide system-wide mobility.