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**3rd**  
EDITION



# Transportation Engineering

An Introduction

 Pearson

**C. JOTIN KHISTY    B. KENT LALL**

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# Transportation Engineering

An Introduction

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Third Edition

**C. Jotin Khisty**

*Illinois Institute of Technology, Chicago*

**B. Kent Lall**

*Portland State University, Portland*



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*I dedicate this book to the memory  
of my father, Dr. B. R. Khisty,  
physician and surgeon, philosopher and teacher,  
who introduced me to the "music of the spheres."*

C. Jotin Khisty

*To my wife, Margaret Vivienne, and son, Niren Nicolaus,  
for helping me know myself.*

B. Kent Lall

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# ***Preface to the Third Edition***

The attempt to express, much less understand, the nature of the relationships inherent in transportation and its myriad components is a challenge for transportation educators. Fortunately, the book you hold in your hands explains many of these interactions and complexities, as well as the design problems that go with them. Another challenge that transportation engineering poses, as a comparatively young discipline, is that professionals have to constantly deal with a plethora of new problems that seem to crop up faster than they can be tackled. In short, transportation is an exciting field.

The purpose of this edition, like previous editions, is to cover the major areas of traffic engineering and transportation planning at an introductory level, and provide the student with a basic rationale and a set of design concepts. The primary audience for this textbook is upper-division undergraduates and master-level students studying for degrees in civil engineering, as well as those in urban planning, economics, management, and other related disciplines. The orientation of the book is pragmatic and multidisciplinary, providing both students and practitioners with a variety of worked examples illustrating the basic concepts, covering an unusually wide spectrum of topics in transportation planning and traffic engineering.

While the general structure of this third edition remains generally the same as in previous editions, a number of chapters have been thoroughly revised in light of the Highway Capacity Manual, published in 2000 and issued by the Transportation Research Board, as well as the latest material on geometric design from the AASHTO Publications. In addition, three new appendices have been added to this edition. Appendix B covers the elements of statistics and probability that are frequently used in transportation engineering. Appendices C and D consist of material drawn from the Bureau of Transportation Statistics, U. S. Department of Transportation, Washington, DC. Minor additions have been made in many of the chapters to reflect changes in design practice and policies that have occurred since the last edition.

Many students, professionals, and colleagues have been curious to know the significance of the Möbius band that you see on the cover of the United States edition of the book. We are flattered, and a word regarding it is perhaps in order. The Möbius band throws some light on the interdisciplinary character and complexity embedded in transportation, which is one of its unique features. It is a paradox with geometrical and topological characteristics that are fascinating and special. In reality, the Möbius band



has only one edge and one side. If you imagine yourself standing on the band, you see two edges and two sides. But when you begin walking along the band, you eventually return to your starting place and find yourself on the other side of the band. Indeed, the Möbius band resembles the interdisciplinary nature of transportation engineering, embracing several areas of knowledge blending together—it is the *one* and yet it is the *many*. It drives home the point that it is just an accident of history that transportation engineering finds its home in civil engineering and that the recent advances in this discipline easily warrant a department of its own.

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The authors are grateful to many colleagues, professionals, and students who have suggested improvements, and many of these have been incorporated in this edition. Several of our students, past and present, have assisted us in revising this edition; namely, Dr. P.S. Sriraj, Dr. Cemal Ayvalick, Turan Arslan, Porson Chantra, Sagar Sonar, Sameer Patil, and Edward Anderson. We would also like to thank Peter T. Martin, Utah Traffic Laboratory, and Shashi Sathisan Nambisan, University of Nevada—Howard K. Hughes College of Engineering, for reviewing the manuscript. Jenny Kincaid and Margaret Lall lent invaluable assistance in proofreading sections of the book. We also acknowledge admirable support provided by Kevin Bradley, Sunflower Publishing Services, and Laura Fischer of Prentice Hall.

Finally, we would appreciate any suggestions, criticisms, and corrections from our readers.

C. JOTIN KHISTRY  
B. KENT LALL

The publishers would like to thank Professor S. Anbu Kumar, Associate Professor, Department of Civil Engineering, Delhi Technological University, Delhi, for his valuable suggestions and inputs for enhancing the content of this book to suit the requirement of Indian Universities.

# ***Preface to the First Edition***

The main purpose of this book is to cover the major areas of transportation engineering, planning, and management at an introductory level. The contents of this book are intended for use primarily at the junior or senior undergraduate level in the civil engineering curriculum, and at the graduate level in the disciplines of urban geography, economics, public administration, and city and regional planning. Professionals working directly or indirectly in the field of transportation would also find this book useful. For them, the book is intended to give sufficient background and sources to references for further elucidation, should this be desired. Informed laymen and elected officials wishing to gain a quick understanding of the technical implications of a particular transportation-related problem, method, or procedure would hopefully find the text helpful also.

This textbook would also prove useful for self-study, for both the beginning student as well as for those mature students inclined to review and integrate information. Numerous worked examples are provided in every chapter to reinforce the contents, and exercises of varying complexity are to be found at the end of each chapter. An instructor's manual is available.

Transportation engineering and planning have been developed to a large extent by the joint efforts of engineers, planners, economists, geographers, mathematicians, physical scientists, and social scientists. Transportation is a multidisciplinary area of study, which has created several problems in teaching a required course (or courses), particularly in the undergraduate civil engineering (CE) program. Some of these problems are lack of suitable, moderately priced, relatively self-contained, introductory textbooks; general deficiency among students in areas such as microeconomics and statistics, which are needed to comprehend transportation problems; lack of understanding of the systems approach necessary to address socioeconomic issues connected with transportation; lack of appreciation of the multivariable, open-ended, conflict-ridden, value-laden nature of real-world problems; and presentation of the principles of transportation from a modally oriented point of view (Khisty, 1986, 1987).

The questions stemming from these problems are: What constitutes transportation engineering education for an undergraduate CE curriculum? What do employers expect from a CE undergraduate? How should the course be developed so that it addresses the needs of a relatively large number of CE students who in all probability

do not foresee the possibility of pursuing further studies in transportation, and at the same time stimulates a relatively small number of students who may develop an active interest in transportation?

Although the master's degree is considered by most educators and practitioners as the degree of specialization in transportation, only a small percentage of undergraduates elect to pursue the master of science in civil engineering (MSCE) with a major in transportation. This is not surprising. When industry pays an individual with a BSCE a respectably good starting salary, it deprives the young engineer of any significant motivation to acquire an advanced degree. This posture is changing.

Proper grounding in the principles of transportation is essential because the entry-level BSCE in federal, state, and local government, as well as in construction, design, and consulting firms, may have had only one required course in transportation engineering. Over the years, there has been a running debate about what to include in this required course (or courses) because no two teachers seem to have identical views as to what transportation engineering topics should be taught to aspiring civil engineers.

Not too long ago, the author of a transportation textbook conducted a survey of professors teaching transportation to determine the content of a transportation course(s) that should be included as a requirement in a CE curriculum (Wright, 1983). To follow up on the results of this survey, the writer conducted another survey to identify the views of transportation practitioners working for departments of transportation, counties, cities, and private firms. The practitioners were asked to evaluate the importance of 30 topics that could possibly be included in a required course in transportation for CE students. Table P-1 shows 20 topics by rank on a 5-point scale. It also includes, as a comparison, the 10 topics that received the highest scores awarded by transportation educators. There is little doubt that there is a high congruence in the expectation of educators and practitioners in prioritizing the topics (Khisty, 1986).

Conversations with practitioners interviewed in my survey resulted in the following general observations, views, and suggestions with respect to enriching a required course in transportation:

- Students should be given the opportunity to tackle open-ended problems, defending their solutions or conclusions with short narratives.
- Students should be given every opportunity to tackle real-life problems. This could be in the form of one or more projects done individually or in a group. The group project idea should be encouraged because it provides students with a realistic experience in team dynamics.
- The ability to solve problems with incomplete or redundant data should be impressed on students through appropriate examples and class assignments.
- The fundamental principles underlying transportation should be emphasized.
- To do justice to such topics as pavement design, construction methods, maintenance of facilities, and so forth, it would be best to address these topics in courses other than the required course.

On the basis of these results, I have framed the contents of this textbook to focus on clarity of exposition, topical coverage, technical content, and pedagogical elements. The sixteen chapters in this text correspond closely to the ones indicated in the table.

TABLE P-1 Transportation Topics

Topics	Practitioners (N = 50)		Educators (N = 51)	
	Score	Rank	Score	Rank
Geometric Design of Highways	4.80	1	4.62	2
Vehicle Operating Characteristics	4.72	2	4.34	5
Highway Capacity Studies	4.69	3	4.28	6
Intersection Design	4.58	4	4.00	8
Transportation Planning	4.44	5	3.96	9
Traffic Control Devices	4.32	6	4.38	4
Economics of Transportation	4.20	7	—	—
Land-Use/Transportation Interaction	4.18	8	—	—
Evaluation Techniques	4.13	9	3.90	10
Transportation Systems Management	4.06	10	—	—
Description of Transport System	4.04	11	4.72	1
Traffic Flow Characteristics	4.04	12	4.54	3
Traffic Safety	4.00	13	4.22	7
Contracting Procedures	3.92	14	2.30	—
Specifications	3.80	15	—	—
Operational Characteristics of Modes	3.80	16	—	—
Mass Transit	3.79	17	—	—
Airport Planning	3.63	18	—	—
Human Powered Transport	3.50	19	—	—
History of Transportation	3.41	20	—	—

Source: Khisty, 1986.

Some of the text's special characteristics are as follows:

- The material is built on ideas, concepts, and observations that students are likely to be most familiar with, e.g., roads, streets, highways, buses, bicyclists, pedestrians, and so on.
- The organization of the book and individual chapters has been carefully planned for easy transition from one area to another.
- While numerical problem solving has been emphasized where appropriate, the need to substantiate these numerical results, buttressed by proper explanations and discussions, has been duly illustrated. Several exercises at the end of chapters are the open-ended type questions requiring creativity and critical thinking.
- The latest manuals, codes, reports, and practices have been incorporated, e.g., *Highway Capacity Manual*, 1985; and *A Policy on Geometric Design of Highways and Streets*, 1984.

This text is a partially multimodal work in that it deals primarily with highways and the people who use them—motorized, nonmotorized, private, and public. A separate chapter on public transport deals to a limited extent with the rail mode. No attempt

is made to describe transportation engineering as it relates to air transport, water transport, or pipelines. The results of the survey described earlier amply justifies the choice of topics.

The first three introductory chapters set the stage for the rest of the book; they are crucial and fundamental. Chapters 4 through 9 are traffic engineering-related, Chapter 10 deals with public transport, and Chapter 11 through 14 are planning-related. The last two are on evaluation and safety. A brief description of each chapter follows:

Chapter 1, "Transportation As a System," introduces the student to the field of transportation engineering, planning, and management. It provides an overview of transportation systems characteristics, hierarchies, and classifications.

Chapter 2, "Transportation Economics," covers the most elementary ideas in economics useful to the transportation engineer. Most of these principles are applied to problems taken up in later chapters.

Chapter 3, "The Land-Use/Transportation System," illustrates the basic interdependence between land use and transportation. It is a critical chapter for students to comprehend and one that introduces a myriad of basic concepts underlying this relationship.

Chapter 4, "Vehicle and Human Characteristics," describes how human beings, as vehicle operators, passengers, and pedestrians, interact with vehicles and the transportation facilities they use. This chapter synthesizes several topics connected with the human element, the vehicle, and the environment.

Chapter 5, "Traffic Flow Characteristics," examines the uninterrupted flow of vehicles moving individually or in groups on roadways or tracks, subject to constraints imposed by human behavior or vehicle dynamics. The fundamental equations of vehicular flow are derived by taking into consideration safety, speed requirements, and capacity.

Chapter 6, "Geometric Design of Highways," deals with proportioning of the physical elements of highways, such as vertical and horizontal curves, lane widths, and cross sections. The 1984 edition of *A Policy on Geometric Design of Highways and Streets*, published by the American Association of State Highway and Transportation Officials (AASHTO), is the principal source of reference.

Chapter 7, "Highway Capacity," involves the quantitative evaluation of a highway section, such as a freeway, multilane, or two-lane to carry traffic. The procedures and methodologies contained in the 1985 *Highway Capacity Manual* published by the Transportation Research Board (TRB) are used in this chapter.

Chapter 8, "Intersection Control and Design," deals with at-grade intersections and the traffic signals, signs, and markings needed to regulate, guide, warn, and channel traffic. The design of traffic signals is an important part of this chapter.

Chapter 9, "At-Grade Intersection Capacity and Level-of-Service," covers the analysis of intersections based on the procedures spelled out by the 1985 *Highway Capacity Manual*. Analysis is done at two levels: the operational and planning levels. Unsignalized intersections are also considered.

Chapter 10, "Public Passenger Transportation," describes those modes of passenger transportation open for public use, such as bus, light rail, and rail-rapid transit.

Beginning with the historical development of urban transportation, the chapter includes a classification of mass transport systems and their capabilities to carry passengers. The operational designs of a simple rail and a bus system are also explained.

Chapter 11, "Urban Transportation Planning," presents the traditional four-step sequential process of travel forecasting. The chapter initially explains the general organization and philosophy of long- and short-range (TSM) planning, currently followed in the developed and developing world.

Chapter 12, "Local Area Traffic Management," deals with problems and solutions related to existing neighborhoods and their possible expansions and renovations. The planning and design of pedestrian and bicycle facilities and parking and terminal facilities are considered in detail.

Chapter 13, "Energy Issues Connected with Transportation," provides an introduction to techniques for energy planning and energy conservation.

Chapter 14, "TSM Planning," introduces the reader to the short-range component of transportation systems. Transportation Systems Management (TSM) covers a broad range of potential improvement strategies focussing on nonfacility and low-capital-cost operations.

Chapter 15, "Evaluation of Transportation Improvements," covers the basic techniques of benefit-cost analysis of alternative proposals, including cost-effective and multicriteria evaluation.

Chapter 16, "Transportation Safety," describes the Highway Safety Improvement Program (HSIP). It begins by examining the nature and characteristics of accidents by type, severity, contributing circumstances, and environmental conditions. Methods of identifying hazardous locations are also discussed.

This textbook is designed for use in engineering, city planning, and management courses. Although the emphasis in these courses may differ to some extent, a combination of chapters can be chosen for each course to suit specific objectives. Table P-2 may be used as a guide for structuring a course outline. Two courses are indicated for engineering students. The first is assumed to be a mandatory course, and the second may be an elective. Planning and management courses can cover the first three introductory chapters followed by the planning-related chapters, 10 through 16. The traffic engineering chapters may be omitted or briefly scanned.

A companion textbook, *Laboratory and Field Manual for Transportation Engineering* (Prentice Hall, 1991), supplements this textbook for those students taking a lab course. My colleague Dr. Michael Kyte and I are the authors.

Although the initial chapters of this book were written and rewritten in Pullman, Washington, serious attempts to put several of the crucial chapters together were done at the University of Washington, Seattle, where I spent the 1984–1985 academic year on a sabbatical. I appreciate the interaction with colleagues at the University of Washington—Jerry Schneider, Nancy Nihan, Scott Rutherford, Stephen Ritchie, Joe Mahoney, Jimmy Hinze, and Sandor Veress—that proved most beneficial. Although Bob Davis of Prentice Hall at Seattle was instrumental in encouraging me to submit parts of the manuscript for possible consideration to Prentice Hall, it was Doug Humphrey, Senior

TABLE P-2

Topics	1	2	3	4
1. Transportation As a System	x		x	x
2. Transportation Economics	x		x	x
3. The Land-Use/Transportation System	p	x	x	x
4. Vehicle and Human Characteristics	x			p
5. Traffic Flow Characteristics	x			p
6. Geometric Design of Highways	x		p	p
7. Highway Capacity	x		p	p
8. Intersection Control and Design	p	x		
9. At-Grade Intersection Capacity and Level-of-Service	p	x		
10. Public Passenger Transportation	p	x	x	x
11. Urban Transportation Planning	p	x	x	x
12. Local Area Traffic Management	p	x	x	x
13. Energy Issues Connected with Transportation		x	x	x
14. TSM Planning-Framework	p	x	x	x
15. Evaluation of Transportation Improvement	x		x	x
16. Transportation Safety	p	x		x

1 = Engineering 1 course (mandatory)

2 = Engineering 2 course (mandatory/elective)

3 = Planning (graduate)

4 = Management (graduate)

x = entire chapter; p = partial chapter

Engineering Editor, who steered me through the prepublication process. It has been a delight to work with him. Also, Ms. Marianne Peters, the production editor, deserves a special word of thanks for her patience and guidance.

In writing this book I have been constantly reminded of the debt I owe to instructors, colleagues, and students, in India, Germany, and the United States. They have influenced my own views on several aspects of transportation engineering and planning. I am indebted to several individuals who reviewed various chapters of the manuscript and offered invaluable suggestions: J. D. Gupta, Michael Kyte, B. Kent Lall, Martin Lipincki, and Thomas Mulinazzi. A special word of thanks is due to Dr. Surinder Bhagat, Chairman of the Civil and Environmental Engineering Department, who provided encouragement and support.

From among my students, I particularly take great pride in mentioning the following who helped me in a number of ways: A. Alzahrani, M. Y. Rahi, Ping Yi, and Morgan Wong. Morgan deserves my special thanks for organizing and proofreading the chapters and spending many hundreds of hours typing the original manuscript. He has proved to be a dedicated and indispensable person during this long period of writing. Lastly, I thank my wife, Lena, for her constant encouragement and support. To each of those who helped in the preparation of this book, I express my deepest gratitude and appreciation. And like the rug weavers of yesteryear who chose their yarns and natural dyes from several sources, I alone am responsible for the final design and product.

Finally, I would be especially grateful for suggestions, criticisms, and corrections that might improve this text book. A solutions manual is now available from the publisher.

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C. JOTIN KHISTY



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## **Transportation as a System**

### **1. INTRODUCTION**

The importance of transportation in world development is multidimensional. For example, one of the basic functions of transportation is to link residence with employment and producers of goods with their users. From a wider viewpoint, transportation facilities provide the options for work, shopping, and recreation, and give access to health, education, and other amenities.

The field of transportation can be compared to a mansion with several stories, many chambers, and scores of connections. We would like to take the reader on a short tour of this mansion just to acquaint him or her with some of its characteristics. One of the prerequisites for accompanying us on this trip is to have an open mind. Almost everyone will have had several years of personal experience as a *user* of the transportation system, such as a car driver, a bus passenger, an elevator user, a frequent flyer, or just a sidewalk user. A very small fraction of readers may be involved in providing transportation services, such as a student who partially earns her livelihood by driving the morning express bus for the local transit company. Naturally, almost every person will tend to acquire his or her own personal viewpoint. No two persons can expect to come to the same conclusion about a problem confronting transportation even though they are each known to be highly objective and rational. Try as hard as you can to approach the field of transportation and its myriad problems with an open mind, free of presumptions and prejudice. Like food, shelter, clothing, and security, transportation is an integral part of human culture. Movement in a broad sense offers both inherent joy and pleasure as well as pain, suffering, and frustration. These factors will assume even greater importance in the years ahead.

#### **1.1 National and Individual Involvement**

Everybody is involved with transportation in so great a variety of ways that a mere listing of these ways would take us by surprise. Ultimately, all human beings are interacting over distance and time, and this interaction in itself creates involvement. To

understand the theory of transportation, one must examine its relationship to various social, economic, and political institutions, and we undertake such an examination in this book (Wolfe, 1963).

The role of transportation in the day-to-day life of Americans can be appreciated just by reading the following (U.S. D.O.T., 1994):

The transportation system includes about 200 million automobiles, vans, and trucks operating on about 4 million miles of streets and highways; over 100,000 transit vehicles operating on those streets, as well as more than 7,000 miles of subways, street car lines, and commuter railroads; 275,000 airplanes operating in and out of 17,000 airports; 18,000 locomotives and 1.20 million cars operating over 113,000 miles of railroads; 20 million recreational boats, 31,000 barges, and over 8,000 ships, tugs, and other commercial vessels operating on 26,000 miles of waterways; and 1.50 million miles of intercity pipelines.

Travel consumes roughly an hour of an average person's day, and roughly one-sixth of household expenditures. Americans make nearly a thousand trips per year per person, covering a distance of about 15,000 miles annually. It is estimated that households, businesses, and governments spend over \$1 trillion to travel 3.8 trillion miles and to ship goods 3.5 trillion ton-miles each year. In summary, transportation accounts for 12% of Gross Domestic Product. The Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation issues an annual report indicating the state of the transportation system and its consequences, and this information is of vital importance to all students of transportation engineering and planning. A representative set of tables and figures drawn from the BTS can be found in the Appendix C.

## 1.2 Progress in Transportation

The principles of transportation engineering have been evolving over many millennia. Human beings are known to have laid out and used convenient routes as early as 30,000 B.C. Although it was traders and migrants who opened up most major routes of communication, the military has generally been responsible for improving the status of early routes built by civilians. The first wheeled military vehicles were developed around 2500 B.C., and since then, significant resources have been devoted by rulers and their builders to constructing and maintaining communication routes in the form of roads (Lay, 1986).

Steady progress has since been maintained in providing the highway and street network (which forms the stationary component of the transportation system), in providing vehicles for moving people and goods over this network (which comprises the dynamic part), and in enhancing the ability of drivers (or controllers) to operate the vehicles. Basically, it is these three major interacting components that are to be studied critically in this book (Lay, 1986).

Before bicycles and motor vehicles came into fashion, vehicle speeds seldom exceeded 10 miles per hour (mph). Naturally, a surface of compacted broken stone made an ideal pavement surface, even for the solid iron wheels then in use. Today, the American highway system consists of about 4 million miles of high-class streets and highways, classified by function, into a series of interconnected networks, which translates

to 1 mile of road for every square mile of land. This level of coverage provides access to almost every part of the nation by road. The centerpiece of the highway development program in the United States is the 42,000-mile freeway system, considered to be one of the greatest public works achievements since the dawn of history. In urban areas, the thrust has been in constructing complicated freeway interchanges, pedestrian and bicycle facilities, and high-occupancy vehicle and bus lanes. During the 1980s the paucity of funds for new construction placed the accent on maintenance, rehabilitation of pavements, and pavement management systems (NCPWI, 1986).

Vehicles (and pseudovehicles) have been in use since human beings learned to walk. People who traveled on foot could manage between 10 and 25 miles per day. It is claimed that the Incas were able to transmit messages at the rate of 250 miles per day by using fast runners over short stretches, thus achieving speeds of about 10 mph. Horses, on the other hand, could make almost 40 miles per day.

By the late 1840s, the horse-drawn street car appeared in a number of cities, operating at an average speed of about 4 mph. It was not until the 1880s that electrically propelled transportation was introduced. By the beginning of World War I, the electric street car had already had a major impact on the growth and structure of the city (Gray and Hoel, 1992).

The entire picture for transportation changed in 1885 with Daimler and Benz's introduction of the gasoline-powered internal-combustion engine. Within the last 100 years, the motor vehicle has revolutionized private transportation all over the world. Before the appearance of the motor vehicle, vehicle speeds seldom exceeded 10 mph. The car soon changed the situation, and for purposes of safety and efficiency, traffic signals were introduced at intersections (Lay, 1986).

Some of the most outstanding technological developments in transportation have occurred in the preceding 200 years:

- The first pipelines in the United States were introduced in 1825.
- First railroad opened in 1825.
- The internal-combustion engine was invented in 1866.
- The first automobile was produced in 1886 (by Daimler and Benz).
- The Wright brothers flew the first heavier-than-air machine in 1903.
- The first diesel electric locomotive was introduced in 1921.
- Lindbergh flew over the Atlantic Ocean to Europe in 1927.
- The first diesel engine buses were used in 1938.
- The first limited-access highway in the United States (the Pennsylvania Turn-pike) opened in 1940.
- The Interstate Highway system was initiated in 1950.
- The first commercial jet appeared in 1958.
- Astronauts landed on the moon in 1969.
- The use of computers and automation in transportation grew dramatically through the 1960s and 1970s and continues to grow unabated.
- Microcomputers have revolutionized our capabilities to run programs since the 1980s and such capabilities have helped us to examine alternatives quickly and efficiently.

### 1.3 The Urban System and Transportation

In 1850, there were four cities in the world with more than 1 million people, and in 1950, there were about a hundred cities of this size. But what is most shocking is that in the year 2000, there were about 400 cities of this magnitude. Naturally, smaller cities will grow into bigger ones, and these in turn will form megalopolises.

Several architects, planners, and engineers have developed matrices and frameworks to represent and understand the urban scene. In the mid-1950s, C. A. Doxiadis, a Greek city planner, gave a new meaning to the science of human settlements and attempted to represent it in the form of a grid. This matrix, called the *ekistic grid*, incorporates a spectrum of the range of human settlements (Figure 1-1). The abscissa of the grid shows population figures ranging from a single human being through an ecumenopolis consisting of approximately 30 billion people. Notice that the units on this horizontal axis generally increase in logarithmic progression by multiples of between 6 and 7, and this progression has been observed by other regional scientists (Bell and Tyrwhitt, 1972).

The five elements shown on the ordinate are nature, man, society, shells, and networks. Nature represents the ecological system within which the city must exist. Man and society are constantly adapting and changing, and in turn molding the city to be a satisfactory environment. The built environment is represented by the shell, which is the traditional domain of the architectural, planning, and engineering professions. Highways, railroads, pipelines, telephones—indeed, the entire gamut of communications—provide

Community Scale	I	II	III	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Man	Room	Dwelling	Dwelling group	Small neighborhood	Neighborhood	Small town	Town	Large city	Metropolis	Conurbation	Megalopolis	Urban region	Urbanized continent	Ecumenopolis
Nature															
Man															
Society															
Shells															
Networks															
Synthesis															
Population t (thousands) m (millions)	1	2	4	40	250	1.5t	7t	50t	300t	2m	14m	100m	700m	5,000m	30,000m

Ekistic logarithmic scale

Figure 1-1 Ekistic Grid (Bell and Tyrwhitt, 1972).

the element of networks. To cater to the demands of faster and cheaper communication in the face of the growth of settlements, we are constantly devising means of substituting travel by communication. The sum total of all the elements and their interactions is represented by synthesis. Thus, the dimensions of this grid embrace not only the current situation but also the past and future. The primary advantage in looking at the "forest as well as the trees" is in understanding universal issues as well as local ones. Another, equally important issue is the need to understand the meaning of city structure and the factors determining it (Thomson, 1977). What are the elements that form the basic structure of society? How do these elements relate to one another, interact, and function? What techniques are available to understand and predict what is likely to happen in the future? These are some of the questions usually asked by professionals and citizens. The answers, if they exist at all, are complex and often contradictory.

## 2. THE FIELD OF TRANSPORTATION ENGINEERING

The desires of people to move and their need for goods create the demand for transportation. People's preferences in terms of time, money, comfort, and convenience prescribe the mode of transportation used, provided of course that such a mode is available to the user.

The Institute of Transportation Engineers (1987) defines transportation engineering as "the application of technological and scientific principles to the planning, functional design, operation, and management of facilities for any mode of transportation in order to provide for the safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods." Traffic engineering, a branch of transportation engineering, is described as "that phase of transportation engineering which deals with planning, geometric design, and traffic operations of roads, streets, and highways, their networks, terminals, abutting lands, and relationships with other modes of transportation."

## 3. THE PRACTICE OF TRANSPORTATION ENGINEERING

Transportation engineering involves a diversity of basic activities performed by such specialists as policymakers, managers, planners, engineers, and evaluators. Figure 1-2 illustrates these activities in the context of some of the transportation modes in current use. Several fringe and developing modes in this figure have not been identified. Whereas airways, conveyors, highways, pipelines, railways, and waterways are comparatively commonplace, we need to explain the last three modes listed. When two or more modes are combined to provide utility and service to the public, the combination is known as a *multimodal system*. *Exotic systems* are those modes that are not yet being used commercially but that have been tested in a pilot project. Air-cushioned magnetically levitated vehicles fall into this category. Transportation substitutes such as the telephone (as used widely in teleconferencing) and facsimile transmission of documents by wire and radio can be considered as *quasi-transport* (Hay, 1977).

	Polymaking	Admin-management	Planning	Analysis, synthesis, and design	Construction	Operations	Maintenance	Testing and evaluation
Airways								
Conveyors								
Highways								
Pipelines								
Railways								
Waterways								
Multimodal								
Exotic								
Quasi-transport								

**Figure 1-2** Transportation as a System (Khisty, 1983).

#### 4. THE NATURE OF TRANSPORTATION ENGINEERING

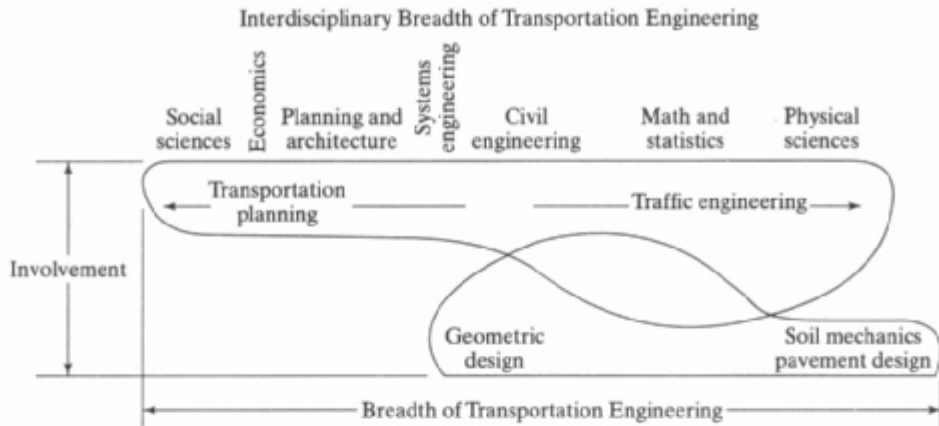
Transportation engineering is a multidisciplinary area of study and a comparatively new profession that has acquired theoretical underpinnings, methodological tools, and a vast area of public and private involvement. The profession carries a distinct societal responsibility. A wide comprehensive training in transportation is therefore the desirable goal of all transportation education (Khisty, 1981; Hoel, 1982).

Because of the multidisciplinary content of transportation engineering, we find that concepts drawn from the fields of economics, geography, operations research, regional planning, sociology, psychology, probability, and statistics, together with the customary analytical tools of engineering, are all used in training transportation engineers and planners.

Figure 1-3 illustrates, in a general way, the interdisciplinary breadth and the depth of involvement of transportation engineering. Most specialization in transportation engineering occurs at the graduate level; undergraduates receive an overall general view of the elements of transportation engineering (Wegman and Beimbom, 1973). The upper-left part of this figure traditionally represents the "soft" side of transportation engineering, and the lower-right side, representing pavement design, bridge engineering, and drainage, may be looked on as the "hard" side of transportation. However, there is no definite demarcation between the two (Khisty, 1985, 1986, 1987).

#### 5. THE SYSTEMS APPROACH

The systems approach represents a broad-based and systemic approach to problem-solving that involves a system. It is a problem-solving philosophy used particularly to solve complex problems (Khisty and Mohammadi, 2001).



**Figure 1-3** Conceptual Outline of Interdisciplinary Training for Engineering Students (Khisty, 1981; Wegman and Beimborn, 1973).

A *system* is a set of interrelated parts, called *components*, that perform a number of functions in order to achieve common goals. *System analysis* is the application of the scientific method to the solution of complex problems. *Goals* are desired end states. Operational statements of goals are called *objectives*; these should be measurable and attainable. Feedback and control are essential to the effective performance of a system. The development of objectives may in itself involve an iterative process. Objectives will generally suggest their own appropriate *measures of effectiveness* (MOEs). An MOE is a measurement of the degree to which each alternative action satisfies the objective. Measures of the benefits forgone or the opportunities lost for each of the alternatives are called *measures of costs* (MOCs). MOCs are the consequences of decisions. A criterion relates the MOE to the MOC by stating a decision rule for selecting among several alternative actions whose costs and effectiveness have been determined. One particular type of criterion, a *standard*, is a fixed objective: the lowest (or highest) level of performance acceptable. In other words, a standard represents a cutoff point beyond which performance is rejected (Cornell, 1980).

With reference to communities, we often find a set of irreducible concepts that form the basic desires and drives that govern our behavior. To these desires, the term *values* is assigned. Values form the basis for human perception and behavior. Because values are shared by groups of people with similar ties, it is possible to speak of *societal* or *cultural values*. Fundamental values of society include the desire to survive, the need to belong, the need for order, and the need for security.

A *policy* is a guiding principle or course of action that is adopted to progress toward an objective. Evaluating the current state of a system and choosing directions for change may be considered as policymaking.

#### Steps in System Analysis

1. Recognize community problems and values.
2. Establish goals.
3. Define objectives.



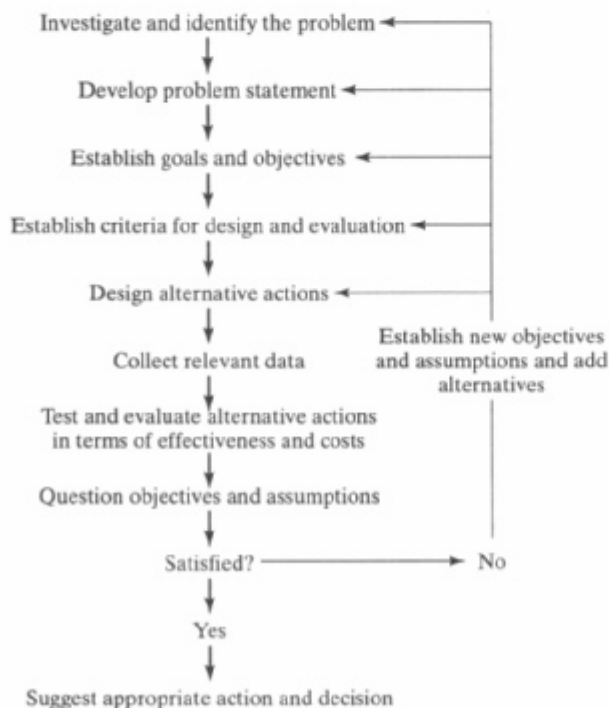
4. Establish criteria.
5. Design alternative actions to achieve steps 2 and 3.
6. Evaluate the alternative actions in terms of effectiveness and costs.
7. Question the objectives and all assumptions.
8. Examine new alternatives or modifications of step 5.
9. Establish new objectives or modifications of step 3.
10. Repeat the cycle until a satisfactory solution is reached, in keeping with criteria, standards, and values set.

A simplified system analysis process is shown in Figure 1-4.

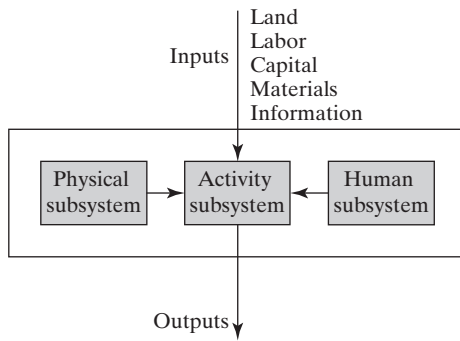
## 6. TRANSPORTATION POLICYMAKING

Transportation planners and engineers recognize the fact that transportation systems constitute a potent force in shaping the course of regional development. Transportation encompasses a broad set of policy variables, and the planning and development of transportation facilities generally raises living standards and enhances the aggregate of community values.

Engineers and planners also recognize that most transportation issues can be characterized by great size, breadth, complexity, diversity, cost, and uncertainty. An example of a transportation system model is shown in Figure 1-5. It consists of inputs,



**Figure 1-4** The System Analysis Process.



**Figure 1-5** Transportation System Model: Transportation Processor.

such as land, labor, and capital, fed into three subsystems: (1) the physical subsystem, (2) the activity subsystem, and (3) the human subsystem. The *physical subsystem* consists of vehicles, pavements, tracks, rights-of-way, terminals, and other manufactured or natural objects. The *activity subsystem* includes riding, driving, traffic control, and so on. These activities interface with the *human subsystem*—individuals and groups of people who are involved with the physical and activity subsystems. Outputs from the system include the movement of people and goods and improvement or deterioration of the physical environment.

## 7. MOVEMENT AND TRANSPORTATION

A city can be considered as a locational arrangement of activities or a land-use pattern. The location of activities affects human beings, and human activities modify locational arrangements. Interaction between activities is manifested by the movement of people, goods, and information.

The reason that people and goods move from one place to another can be explained by the following three conditions: (1) *complementarity*, the relative attractiveness between two or more destinations; (2) the desire to overcome distance, referred to as *transferability*, measured in terms of time and money needed to overcome this distance and the best technology available to achieve this; and (3) intervening opportunities to competition among several locations to satisfy demand and supply. How people and goods move from an origin to a destination is a matter of mode choice (a person might choose to take the bus downtown rather than use her car). This decision is made depending on such attributes as time, speed, efficiency, costs, safety, and convenience. Geographers describe a *trip* as an event and *travel* as a process (Abler et al., 1971).

A simple connection between land use and transportation is shown in Figure 1-6. Land use is one of the prime determinants of movement and activity. This activity, known as *trip generation*, will dictate what transportation facilities, such as streets and