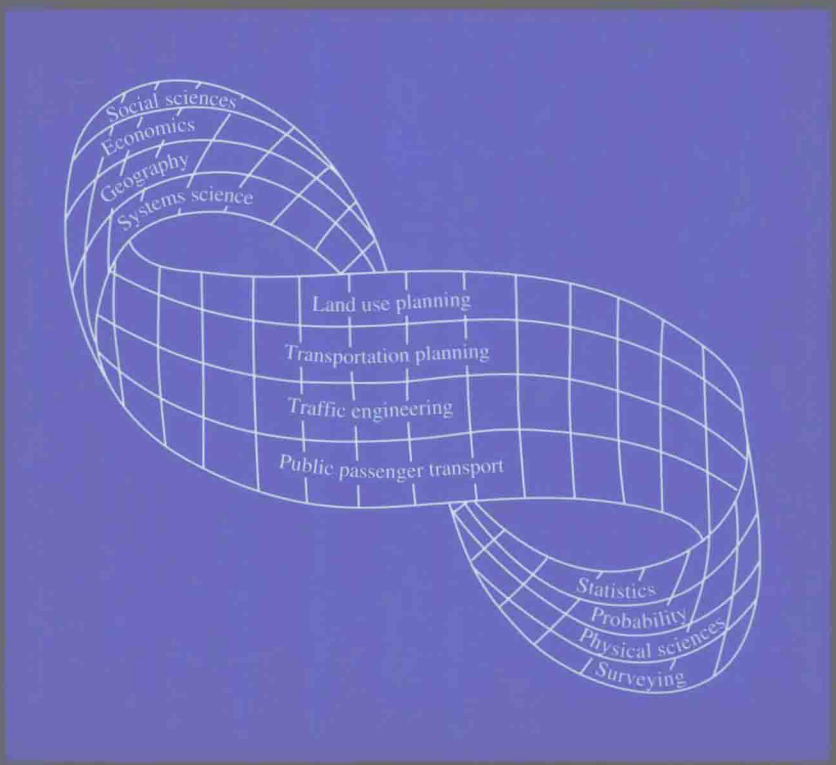
Second Edition

Transportation Engineering

An Introduction



C. Jotin Khisty • B. Kent Lall

Transportation Engineering

An Introduction

SECOND EDITION

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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

A dedication from both of us
To our students, past and present, with whom we continue to learn.

—C. Jotin Khisty
B. Kent Lall

Preface to the Second Edition

The challenges in transportation engineering education remain just as valid as at the time of the first edition. A trend toward offering two courses in undergraduate civil engineering programs is continuing. There is talk in some circles of proposing a bachelor's degree in transportation engineering as the diverse background required by the professionals expands with additional applications of computer science, electronics, and computer engineering in Intelligent Transportation Systems. The second edition should serve as a good model and a platform on which to build further knowledge.

It is heartening to see that the pace of research has picked up with increased support from the National Cooperative Highway and Transit Research Programs (NCHRP and NCTRP). A better understanding of traffic operations and highway capacity issues led to major changes in the Highway Capacity Manual during 1994. More changes are in the works and would be reflected in future publications. The text includes all changes introduced in the *Highway Capacity Manual* during 1994 and some that are proposed for 1997. Similarly, the text accommodates the recent *Policy on Geometric Design of Highways and Streets* by the American Association of State Highway and Transportation Officials (AASHTO). All chapters have undergone some rewriting and a few are completely revised. Additional exercises are included at the end of the chapters along with some reorganization of the existing ones to better serve the reader. Increasing use of software to applications in transportation engineering is recognized and appropriately emphasized.

The authors are grateful to many colleagues and friends who have suggested improvements. The revision, though enjoyable, has been painstaking and a labor of love. The authors deeply acknowledge the support and understanding shown by their families. Several of our students have directly assisted in the revisions. Notable contributions were made by Titus Reynolds, Philip Taylor, and P. S. Sriraj. Admirable support was provided by Bill Stenquist, Joe Scordato, Rose Kernan and Meg Weist of Prentice Hall.

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B. Kent Lall

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 (of 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.

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.

- 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 16 chapters in this text correspond closely to the ones indicated in the table. 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 enviroment.

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.

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

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 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 dies 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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