Fundamentals of Transportation Systems Analysis

Volume 1: Basic Concepts

Marvin L. Manheim

This book was printed and bound in the United States of America.

Library of Congress Cataloging in Publication Data

Manheim, Marvin L
Fundamentals of transportation systems analysis.

Bibliography: p.
Includes index.
CONTENTS: v. 1. Basic concepts.
1. Transportation planning. 2. Transportation—Mathematical models. 3. System analysis. I. Title.
HE199.9.M34 380.5 78–11535
ISBN 0–262–13129–3

Preface

This textbook provides a basic introduction to the field of transportation systems analysis. We shall treat this subject as a coherent field of study and shall employ an approach that will be applicable to many different types of transportation systems problems. This approach incorporates concepts from economics, engineering, operations research, and public policy analysis. Our hope is that the resulting synthesis will be intellectually coherent and stimulating, comprehensive, and pragmatic.

Enough details and numerical examples will be provided to build understanding of the concepts and to indicate how they can be applied in practice to various modes and problems. We have not, however, attempted to survey all of the models and analytical techniques that have been developed in recent years. Rather, our objective is to provide the reader with a basic framework onto which many different areas of specialization can be added by later coursework and practical experience.

Our approach integrates a number of methods from diverse areas of analysis that are now widely accepted in the profession. For example, the techniques that have been employed in most urban transportation planning studies are here described in the context of more fundamental methods of travel forecasting. Similarly, transportation systems technologies are viewed from the perspective of a unified theory, without undue concentration on the specific details of vehicle kinematics or traffic flow theory.

The theory presented in this book builds upon many current research results. For example, the approach to travel demand modeling is based upon techniques now moving from the frontiers of research into the arena of professional practice. Thus the material is sufficiently new in its perspective that professionals already working in transportation—whether their backgrounds are in engineering, economics, or other fields—should find it useful.

We expect the book to be used primarily for introductory courses in transportation systems analysis for undergraduate or graduate students.

No prerequisites are assumed except a facility with mathematical notation.

Since 1967 more than seven hundred such students have used versions of this material as it has evolved. Typical classes have included students majoring in transportation systems analysis with engineering or systems analysis preparations and also students with backgrounds in political science, urban studies, economics, management, and other fields. As we shall emphasize throughout the text, this mixture of backgrounds is an essential and exciting part of the field.

The material has also been used in intensive training programs for midcareer professionals. Two-week courses taught annually at MIT since 1970 have been taken by over five hundred professionals from more than thirty countries. Attendees have come from national, state, and local governments and from private industry. In addition, special versions of this material have been presented in intensive courses in Israel, Spain, and Switzerland.

We have not endeavored to give uniform coverage to all aspects of transportation systems analysis in this text. Our primary consideration was, rather, to identify and present concepts that are truly fundamental, in that understanding them is a prerequisite for any serious work in the field.

Our secondary consideration was to emphasize, through more detailed treatment, certain topics which are basic yet are treated insufficiently or even erroneously in much of the technical literature. These topics include transportation demand and performance and the processes of evaluation and choice. Particular attention is given to demand for several reasons. First, it is very important. Second, there is a substantial behavioral component to the determination of demand, and this has often been slighted in transportation courses in favor of more technical matters that build on the engineering or systems analysis backgrounds of most present students and practitioners in the field.

In contrast, topics that are covered briefly here—or not at all—because they are treated effectively in other texts or in the technical literature include optimization models, especially for network analysis, such as minimum-path and related algorithms; statistics; economic evaluation methods; and the details of present urban transportation forecasting models. Instead, key references are supplied at appropriate points.

The development of models is an important part of any analysis, but we have here chosen just a few basic models to illustrate the concepts we present. In the case of demand and technology models, this approach is justified by the sheer abundance and diversity of available models, so that a comprehensive inventory would require an effort quite outside the range of the book. In the case of activity-shift models, on the other hand, there is an abundant and diverse technical literature but no outstanding synthesis, so we have chosen to leave this important and complex topic for a later volume.

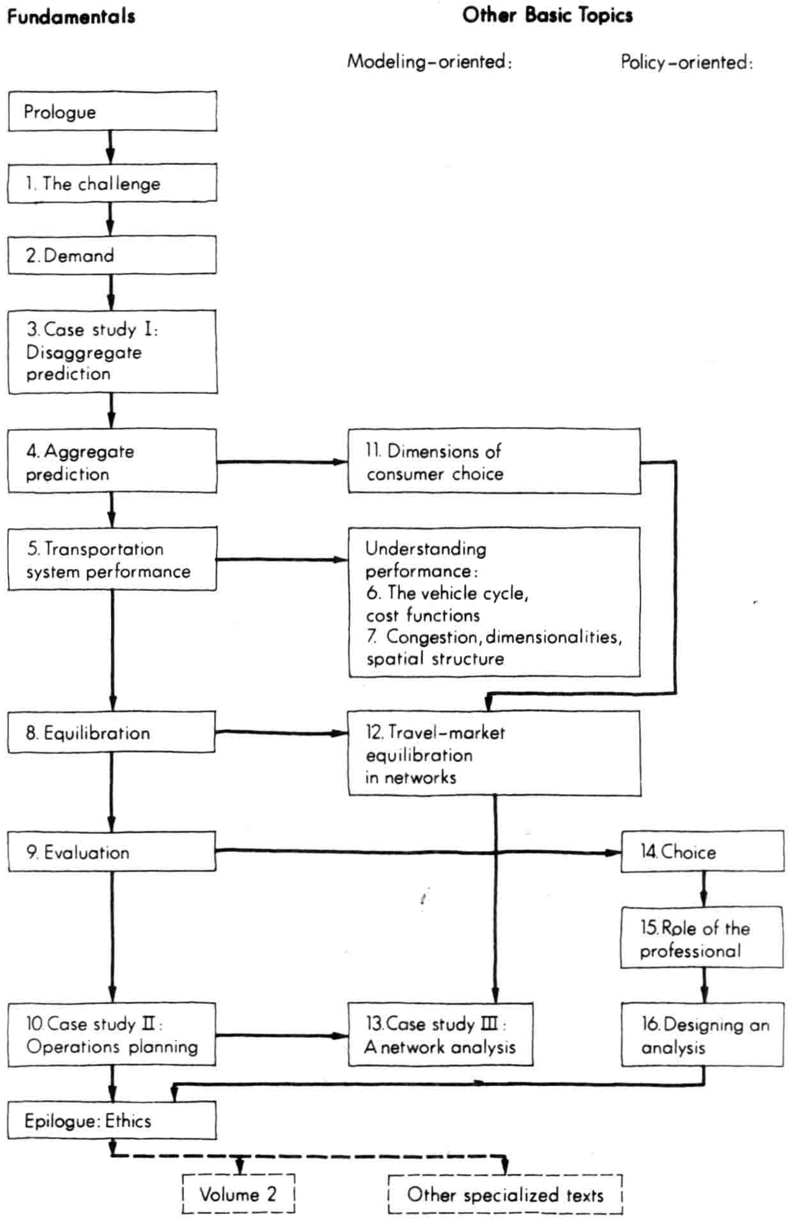
In order to emphasize the range of the field, we have deliberately chosen examples from a wide variety of modes and problem contexts. Even in courses on particular fields such as urban transportation, we believe that it is important for the student to understand that the methods he or she is learning are general and applicable to many other contexts. Instructors are encouraged to modify examples to fit local circumstances and the particular problems in which the class is most interested. The bibliography and guides to further reading found at the end of each chapter should provide useful starting points for such adaptations.

This volume is self-contained. Volume 2 will present in-depth coverage of selected topics and is intended as an advanced and supplementary text.

The text has been designed to be used flexibly for a variety of teaching and self-study approaches, as indicated on the accompanying figure. For example, one sequence of chapters (prologue, 1–5, 8–10, epilogue) covers fundamentals plus two case studies; this would be suitable for a one-semester introductory course. The remaining chapters form two additional sequences, one modeling-oriented (6, 7, 11–13) and one policy-oriented (14–16). The material can also be used for specialized courses: for example, a course on transportation engineering or transportation technology might include the prologue, chapters 1–3, 5–8, 10, and the epilogue plus portions of volume 2, which will present in-depth coverage of selected topics.

The three case study chapters form the bases for practical exercises. Although they focus on urban transportation, applications to other modes and contexts are stressed in the exercises. The first case study, on disaggregate prediction (chapter 3), provides an elementary introduction to predicting consumer response to system changes. Especially useful is the introduction of the idea of employing worksheets to organize calculations.

The second case study, on carrier operations planning (chapter 10), complements the concepts presented in the fundamentals sequence and



Teaching paths.

demonstrates the application of these concepts without elaborate computer models. It also demonstrates an operator's perspective. This study is designed so that the early portions can be done after chapters 1 and 2 and prior to, or in the course of, chapters 5 and 9.

The third case study, on network analysis (chapter 13), complements the modeling-oriented chapters (especially chapters 11 and 12). In order to focus the student's attention on the substance of the concepts rather than on calculational details, a simple Fortran program is used (see the Teacher's Manual). The case study includes a sequence of questions. The reader studying the volume alone should pause at each question, study it, and write out an answer before proceeding. In a class, the questions can be used as a basis for discussions.

A variety of study materials are included to further the goal of establishing a style of thinking about transportation systems problems. Aside from the case studies and self-checking questions included in the text, there are a number of exercises at the end of most chapters. Some of these exercises are relatively straightforward, requiring either algebraic manipulations or numerical calculations and judgments; these are meant to reinforce or test basic analytical concepts. To assist students to begin thinking about broader issues, many of the exercises are relatively open-ended and more qualitative than quantitative. To differentiate the exercises, we use the following symbols:

E: Simple exercises, usually involving numerical calculations.
C: Conceptual exercises, usually requiring substantial thought.
P: Projects, usually requiring a substantial amount of independent work.

We believe that transportation systems analysis is a single field of study and practice, with a unified theoretical foundation and a diversity of practical applications. As our acknowledgments indicate, in our search for this unified intellectual core we have learned a lot from our colleagues and associates. We see you, the readers of this work, as additional collaborators in our search. The present work is a snapshot of a rapidly evolving body of knowledge and so should evolve rapidly itself. We invite you to contribute to this effort. We look forward to getting your comments and ideas, and especially your reactions, as you test, apply, refine, and accept or reject the concepts presented here.

Acknowledgments

This work has grown out of the teaching and research activities of the transportation systems program at MIT. I have learned much from my colleagues and students.

Some of the material included here has evolved from joint efforts, initially presented in papers and technical reports. Where possible, specific acknowledgments of these debts have been made in the text. In particular, the material on demand draws heavily on the work of Moshe E. Ben-Akiva; that on choice and the role of the professional on joint works with Elizabeth Deakin, Arlee T. Reno, and John Suhrbier; and the case studies on work of George A. Kocur and Earl R. Ruiter. I have also benefited from the insights and comments of Wayne M. Pecknold, Steven R. Lerman, Jorge Barriga, Clint Heimbach, Frank S. Koppelman, Thomas Larson, and Kumares N. Sinha, as they have struggled to teach with this material in its earlier, more primitive forms.

Among those who have contributed substantially to the development of the exercises are Mark Abkowitz, Richard L. Albright, Moshe E. Ben-Akiva, Kiran U. Bhatt, Daniel Brand, Harry Cohen, Mark Daskin, Greig Harvey, George A. Kocur, Steven R. Lerman, Mary McShane, Jacques Nahmias, Wayne M. Pecknold, Leonard Sherman, and William Swan. Earl R. Ruiter developed the original case study in chapter 13, using DODOTRANS. Mark Abkowitz, Greig Harvey, and Steven Lerman were responsible for the development of TTP-1, Mark Abkowitz converted the case study to that format, and Mary McShane made later modifications.

In addition, less tangible but nevertheless important influences have come from Lowell K. Bridwell, Carlos Daganzo, Michael Florian, Ernst G. Frankel, Stuart Hill, Michael Lash, Brian V. Martin, Lance Neumann, C. Kenneth Orski, Paul O. Roberts, Robert W. Simpson, Richard M. Soberman, Joseph H. Stafford, and Martin Wohl.

Particular thanks are extended also to those at MIT and elsewhere who made it possible for me to spend substantial time developing this material and provided other support: at MIT, C. L. Miller, Peter S. Eagleson, Frank Perkins, and Joseph Sussman; at the Institut de Recherche des Transports, Paris, Michel Frybourg and Alain Bieber; at OECD, Paris, C. Kenneth Orski; and at the Israel Ministry of Transport and the Israel Institute for Transportation Planning and Research, Uri Ben-Efraim and Gideon Hashimshony.

Responsible for the production of the many preliminary and final editions over the years have been Carol Walb, Charna Garber, Gilbert High, and Janet Brown, assisted by Steven Kahn, Gary Garrels, Nancy Pfund, and Colleen Keough.

I especially want to acknowledge the guidance and inspiration of A. Scheffer Lang, who over the past twenty years has influenced so significantly not only this work but also the whole direction of our transportation systems activities at MIT.

Needless to say, the author alone is responsible for the imperfections of this material.

Contents

Fundamentals of Transportation Systems Analysis

Volume 1: Basic Concepts

Marvin L. Manheim

The MIT Press
Cambridge, Massachusetts, and London, England

This book was printed and bound in the United States of America.

Library of Congress Cataloging in Publication Data

Manheim, Marvin L
Fundamentals of transportation systems analysis.

Bibliography: p.
Includes index.
CONTENTS: v. 1. Basic concepts.
1. Transportation planning. 2. Transportation—Mathematical models. 3. System analysis. I. Title.
HE199.9.M34 380.5 78–11535
ISBN 0–262–13129–3

Prologue
The Profession of Transportation Systems Analysis

THE FIELD TODAY

In the last ten years the field of transportation systems analysis has emerged as a recognized profession. More and more government agencies, universities, researchers, consultants, and private industrial groups around the world are becoming truly multimodal in their orientation and are adopting a systematic approach to transportation problems. Specialists in many different disciplines and professions are working together on multidisciplinary approaches to complex issues.

The field of transportation systems analysis has the following characteristics:

It is ***multimodal,*** covering all modes of transport (air, land, marine) and both passengers and freight.

It is ***multisectoral,*** encompassing the problems and viewpoints of government, private industry, and the public.

It is ***multiproblem,*** ranging across a spectrum of issues that includes national and international policy, the planning of regional systems, the location and design of specific facilities, operational issues such as more effective utilization of existing facilities, carrier management issues, and regulatory, institutional, and financial policies. The objectives considered relevant often include national and regional economic development, urban development, environmental quality, and social equity, as well as service to users and financial and economic feasibility.

It is ***multidisciplinary,*** drawing on the theories and methods of engineering, economics, operations research, political science, psychology, other natural and social sciences, management, and law.

Transportation systems analysts are professionals who endeavor to analyze systematically the choices available to public or private agencies in making changes in the transportation system and services in a particular region. They work on problems in a wide variety of contexts, such as:

- urban transportation planning, producing long-range plans (5–25 years) for multimodal transportation systems in urban areas as well as short-range programs of action (0–5 years), including operational improvements in existing facilities and services and location and design decisions for new facilities and services;

- regional passenger transportation, dealing primarily with intercity passenger transport by air, rail, and highway and possible new modes (as in the Northeast Corridor Study in the United States or Project 33 in Western Europe; see Grëvsmahl 1978, Wheeler 1978, Wilken 1978);
- national freight transport, in developed countries such as the United States, where issues of truck-rail-water competition are of particular importance, as well as in developing countries, where the magnitude of investments in the transport sector, its spatial distribution, and its allocation among modes are all important components of the overall problem of national economic development planning;
- international transport, where issues such as containerization, competition between sea and air, and intermodal coordination are important for freight shippers and carriers in an era of increasing international trade.

The field of transportation systems analysis began with the application of systems analysis methods to urban transportation studies. Most of these early applications were concerned with long-range planning, were public-sector-oriented, and used similar methodological approaches. Now, many different variations in methodologies are being used in a wide variety of operational, planning, design, and policy applications, in both private and public sectors, and involving short-range as well as long-range perspectives, in all of the contexts indicated above.

Today, transportation systems analysis is a mature profession, with a unified theoretical basis and many and diverse practical applications. It is an exciting field in which the concerns extend from abstract theory and complex models to politically important policy questions and institutional change strategies. Our objective in this volume is to show the unity and the diversity of this field. We also hope to impart some of the excitement and satisfaction of practicing this profession.

UNITY AND DIVERSITY

The field today is characterized by a diversity of problem types, institutional contexts, and technical perspectives. But underlying this tremendous diversity is a central intellectual core: a body of theory and a set of basic principles to be utilized in every analysis of a transportation system. The elements of this core are introduced in chapter 1 and amplified in later chapters.

The intellectual core provides a set of unifying themes. As a consequence of the historical development of the field, however, there is a rich variety of ways in which analysts can draw on this core in performing a practical analysis of a specific set of issues. While the same basic theory and principles apply to each problem, very different types of models and methods of analysis are appropriate in different situations.

THE CHALLENGE

The focus of transportation systems analysis is on the interaction between the transportation and activity systems of a region. ***The substantive challenge of transportation systems analysis is to intervene, delicately and deliberately, in the complex fabric of a society to use transport effectively, in coordination with other public and private actions, to achieve the goals of that society.*** To know how to intervene, analysts must have substantive understanding of transportation systems and their interactions with activity systems; this requires understanding of the basic theoretical concepts and of available empirical knowledge.

To intervene effectively, and actually bring about change, analysts must also have a proper perspective on their role. ***The methodological challenge of transportation systems analysis is to conduct a systematic analysis in a particular situation which is valid, practical, and relevant, and which assists in clarifying the issues to be debated.***

An analyst will often use models and other technical means to assist in developing the analysis. There is a wide spectrum of modeling approaches available, ranging from complex computerized simulation models, to very simple algebraic models, to no formal models at all.

A key task for the analyst is to select a process of analysis, including a choice of model, that will help to produce an analysis that is relevant, valid, and practical, and that helps to clarify the issues. To implement this process effectively may involve the analyst in public participation and even in institutional change. An important element of the design of a process of analysis may be inclusion of activities that stimulate constructive and timely involvement of affected interests in an open, participatory process designed to recognize explicitly potential value conflicts and to promote constructive resolution of those conflicts.

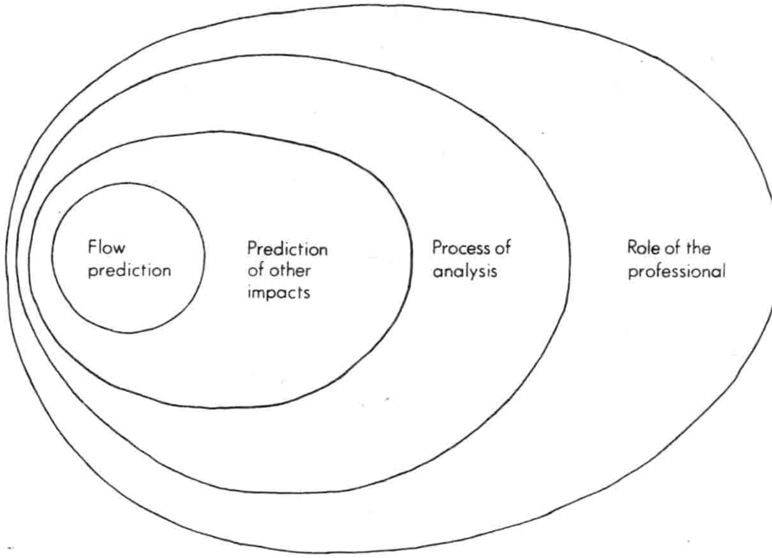


Figure P.1 The scope of transportation systems analysis.

Figure P.1 presents symbolically the image we have been describing. At the core of the field is the prediction of flows, which must be complemented by the prediction of other impacts. Prediction, however, is only a part of the process of analysis; and technical analysis is only a part of the broader problem, namely the role of the professional transportation systems analyst in the process of bringing about change in society.

Today, transportation systems analysis is a field so broad and diverse that few individuals can remain competent in all its aspects; rather, many specialties are emerging, such as demand analysis, evaluation, policy, and the development of new systems. It is an exciting field, spanning the range from abstract theory and sophisticated mathematics to important public policy questions and issues of political strategy.

Within this broad spectrum of intellectual styles and problem applications, each individual, building on the same basic foundations, can develop his or her own unique potential as a transportation systems analyst.

PROFESSIONAL TRAJECTORIES

An education in transportation systems analysis can lead to many different professional careers (figure P.2). Transportation systems analysts