MODELLING TRANSPORT

Third Edition

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WILEY

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JOHN WILEY & SONS, LTD
Chichester • New York • Weinheim • Brisbane • Toronto • Singapore

Baffins Lane, Chichester,
West Sussex, PO19 1UD, England

National 01243 779777
International (+44) 1243 779777
e-mail (for orders and customer service enquiries): cs- books@wiley.co.uk

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Other Wiley Editorial Offices

John Wiley & Sons, Inc., 605 Third Avenue,
New York, NY 10158-0012, USA

Wiley-VCH Verlag GmbH
Pappelallee 3, D-69469 Weinheim, Germany

John Wiley & Sons Australia, Ltd
33 Park Road, Milton, Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01,
Jin Xing Distripark, Singapore 129809

John Wiley & Sons (Canada) Ltd, 22 Worcester Road,
Rexdale, Ontario, M9W 1L1, Canada

Library of Congress Cataloging-in-Publication Data

Ortúzar S., Juan de Dios.
Modelling transport/Juan de Dios Ortúzar, Luis G. Willumsen.—3rd ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-471-86110-3 (alk. paper)
1. Transportation—Mathematical models. 2. Choice of transportation—Mathematical models. 3. Trip generation—Mathematical models. I. Willumsen, Luis G. II. Title.
HE147.7 .077 2001
388'.01'5118—dc21

2001024905

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 0-471-861103

Typeset in 10/12pt Times by Kolam Information Services Pvt Ltd., Pondicherry, India
Printed and bound in Great Britain by Antony Rowe Ltd, Chippenham, Wiltshire.

This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

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Preface

This book is a result of over 20 years of collaboration, sometimes at a distance and sometimes working together in Britain and in Chile. Throughout these years we discussed many times what we thought were the strong and weak aspects of transport modelling and planning. We speculated, researched and tested in practice some new and some not so new ideas. We have agreed and disagreed on topics like the level of detail required for modelling or the value of disaggregate models in forecasting; we took advantage of a period when our views converged to put them in writing; here they are.

We wish to present the most important (in our view) transport modelling techniques in a form accessible to students and practitioners alike. We attempt this giving particular emphasis to key topics in contemporary modelling and planning:

- the practical importance of theoretical consistency in transport modelling;
- the issues of data and specification errors in modelling, their relative importance and methods to handle them;
- the key role played by the decision-making context in the choice of the most appropriate modelling tool;
- the advantages of variable resolution modelling; a simplified background model coupled with a much more detailed one addressing the decision questions in hand;
- the need for a monitoring function relying on regular data collection and updating of forecasts and models so that courses of action can be adapted to a changing environment.

We have approached the subject from the point of view of a modelling exercise, discussing the role of theory, data, model specification in its widest sense, model estimation, validation and forecasting. Our aim in writing this book was to create both a text for a diploma or Master's course in transport and a reference volume for practitioners; however, the material is presented in such a way as to be useful for undergraduate courses in civil engineering, geography and town planning. The book is based on our lecture notes prepared and improved over several years of teaching at undergraduate and graduate levels; we have also used them to teach practitioners both through in-house training programmes and short skills-updating courses. We have extended and enhanced our lecture notes to cover additional material and to help the reader tackling the book without the support of a supervisor.

Chapters 3 to 9, 12 and 13 provide all the elements necessary to run a good 30 sessions course on transport demand modelling; in fact, such a course – with different emphasis in certain subjects – has been taught by us at undergraduate level in Chile, and at postgraduate level in Britain, Portugal, Colombia and Spain; the addition of material

from Chapters 10 and 11 would make it a transport modelling course. Chapters 4 to 6 and 10 to 12 provide the basic core for a course on equilibrium modelling in transport; a course on transport supply modelling would require more material, particularly relating to important aspects of public transport supply which we do not discuss in enough detail. Chapter 1 provides an introduction to transport planning issues and outlines our view on the relationship between planning and modelling. Chapter 2 is there mainly for the benefit of those wishing to brush up their analytical skills and to make the volume sufficiently self-contained.

During our professional life we have been fortunate to be able to combine teaching with research and consultancy practice. We have learnt from papers, research, experimentation and mistakes. We are happy to say the latter have not been too expensive in terms of inaccurate advice. This is not just luck; a conscientious analyst pays for mistakes by having to work harder and longer to sort out alternative ways of dealing with a difficult modelling task. We have learnt the importance of choosing appropriate techniques and technologies for each task in hand; the ability to tailor modelling approaches to decision problems is a key skill in our profession. Throughout the book we examine the practical constraints to transport modelling for planning and policy making in general, particularly in view of the limitations of current formal analytical techniques, and the nature and quality of the data likely to be available.

We have avoided the intricate mathematical detail of every model to concentrate instead on their basic principles, the identification of their strengths and limitations, and a discussion of their use. The level of theory supplied by this book is, we believe, sufficient to select and use the models in practice. We have tried to bridge the gap between the more theoretical publications and the too pragmatic 'recipe' books; we do not believe the profession would have been served well by a simplistic 'how to' book offering a blueprint to each modelling problem. There are no single solutions to transport modelling and planning. A recurring theme in the book is the dependence of modelling on context and theory. Our aim is to provide enough information and guidance so that readers can actually go and use each technique in the field; to this end we have striven to look into practical questions about the application of each methodology. Wherever the subject area is still under development we have striven to make extensive references to more theoretical papers and books which the interested reader can consult as necessary. In respect of other, more settled modelling approaches, we have kept the references to those essential for understanding the evolution of the topic or serving as entry points to further research.

We believe that nobody can aspire to become a qualified practitioner in any area without doing real work in a laboratory or in the field. Therefore, we have gone beyond the sole description of the techniques and have accompanied them with various application examples. These are there to illustrate some of the theoretical or practical issues related to particular models. We provide a few exercises at the end of key chapters; these can be solved with the help of a scientific pocket (or better still, a spreadsheet) calculator and should assist the understanding of the models discussed.

Although the book is ambitious, in the sense that it covers quite a number of themes, it must be made clear from the outset that we do not intend (nor believe it possible) to be up-to-the- minute in every topic. The book is a good reflection of the state of the art but

for leading-edge research the reader should use the references provided as signposts for further investigation.

We wrote most of the first edition during a sabbatical visit by one of us to University College London in 1988–89. This was possible thanks to support provided by the UK Science and Engineering Research Council, The Royal Society, Fundación Andes (Chile), The British Council and The Chartered Institute of Transport. We thank them for their support as we acknowledge the funding provided for our research by many institutions and agencies over the past 20 years.

We have made an equal intellectual contribution to the contents of this book but in writing and researching material for it we have benefited from numerous discussions with friends and colleagues. Richard Allsop taught us a good deal about methodology and rigour. Huw Williams's ideas are behind many of the theoretical contributions in Chapter 7; Andrew Daly and Hugh Gunn helped to clarify many issues in Chapters 3, 7 and 8. Dirck Van Vliet's emphasis in explaining assignment and equilibrium in simple but rigorous terms inspired Chapters 10 and 11. Tony Fowkes made valuable comments on car ownership forecasting and stated-preference methods. Jim Steer provided a constant reference to practical issues and the need to develop improved approaches to address them.

Many parts of the book have benefited from a free, and sometimes very enthusiastic, exchange of ideas with our colleagues J. Enrique Fernández and Joaquín de Cea at the Portifica Universidad Cathólica de Chile, Sergio Jara and Jaime Gibson at the Universidad de Chile, Marc Gaudry at the Université de Montréal, Roger Mackett at University College London, Dennis Gilbert at Imperial College and Mike Bell at the University of Newcastle upon Tyne. Many others have contributed, without knowing, to our thoughts.

Subsequent editions of the book have benefited from comments from a number of friends and readers that have helped to identify errors and areas for improvement. Among them we should mention Patrick Bonnel from the French Laboratoire d'Economie des Transports, Michael Florian from Université de Montréal, Rodrigo Garrido of the Pontificia Universidad Católica de Chile, Ben Heydecker from University College London, Frank Koppelman from Northwestern University, Mariëtte Kraan at the University of Twente, Marcela Munizaga at the Universidad de Chile, Piotr Olszewski from Nanyang Technological University, and Sofia Athanassiou, Neil Chadwick and David Pearmain at Steer Davies Gleave.

Our final thanks go to our graduate and undergraduate students in Britain, Chile, Colombia, Portugal and Spain; they are always sharp critics and provided the challenge to put our money (time) where our mouth was.

We have not taken on board all suggestions as we felt some required changing the approach and style of the text; we are satisfied future books will continue to clarify issues and provide greater rigour to many of the topics discussed here; transport is indeed a very dynamic subject. Despite this generous assistance, we are, as before, solely responsible for the errors remaining in this latest edition. We genuinely value the opportunity to learn from our errors.

Juan de Dios Ortúzar and Luis G. Willumsen

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1 Introduction

1.1 TRANSPORT PLANNING AND MODELLING

1.1.1 Background

The world, including transport, was changing fast at the turn of the century. We still encounter many of the same transport problems of the past: congestion, pollution, accidents, financial deficits and so on. However, we have learnt a good deal from long periods of weak transport planning, limited investment, emphasis on the short term and mistrust in strategic transport modelling and decision making. We have learnt, for example, that old problems do not fade away under the pressure of mild attempts to reduce them through better traffic management; old problems reappear with even greater vigour, pervading wider areas, and in their new forms they seem more complex and difficult to handle.

By the end of the century, the world had entered a stage of greater confidence in technical solutions than during the previous twenty years. This is not the earlier confidence in technology as the magic solution to economic and social problems; we have also learnt that this is a mirage. However, electronics and computing have advanced so much as to make possible new conceptions of transport infrastructure (e.g. road transport informatics) and movement systems (e.g. automated driverless trains). Of particular interest to the subject of this book is the advent of low-cost and high-capacity computing; this has practically eliminated computing power as a bottleneck in transport modelling. The main limitations are now human and technical: contemporary transport planning requires skilled professionals and, as we will argue below, theoretically sound modelling techniques with competent implementations in software.

Developing countries are suffering serious transport problems as well. These are no longer just the lack of roads to connect distant rural areas with markets. Indeed, the new transport problems bear some similarities with those prevalent in the industrialised world: congestion, pollution, and so on. However, they have a number of very distinctive features deserving a specific treatment: low incomes, fast urbanisation and change, high demand for public transport, scarcity of resources including capital, sound data and skilled personnel.

The birth of the twenty-first century was dominated by two powerful trends affecting most aspects of life and economic progress. The stronger trend is *globalisation*, supported and encouraged by the other trend, cheap and high-capacity *telecommunications*. The combination of the two is changing the way we perceive and tackle many modern issues, and their influence in transport planning is starting to be felt. Some of these influences are the role of good transport infrastructure in enhancing the economic

competitiveness of modern economies; a wider acceptance of the advantages of involving the private sector more closely in transport supply and operations; the possible role of telecommunications in reducing the need to travel.

Important technical developments in transport modelling have taken place since the mid-1970s, in particular at major research centres; these developments have been improved and implemented by a small group of resourceful consultants. However, many of these innovations and applications have received limited attention outside the more academic journals. After these years of experimentation there is now a better recognition of the role of modelling in supporting transport planning. This book attempts a review of the best of current practice in transport modelling; in most areas it covers the 'state of the art' but we have selected those aspects which have already been implemented successfully in practice. The book does not represent the leading edge of research into modelling. It tries rather to provide a survival tool-kit for those interested in improving transport modelling and planning, a kind of bridge or entry-point to the more theoretical papers that will form the basis of transport modelling in the future.

Transport modelling is not transport planning; it can only support planning, and in a few cases it may have the most important role in the process. We have known many good professionals who have developed sophisticated transport models but are frustrated because their work has been ignored in many key planning decisions. In truth, planning and implementation may change the world and transport modelling can only assist in this if adopted as an effective aid to decision making.

1.1.2 Models and their Role

A *model* can be defined as a simplified representation of a part of the real world–the system of interest–which concentrates on certain elements considered important for its analysis from a particular point of view. Models are, therefore, problem and viewpoint specific. Such a broad definition allows us to incorporate both physical and abstract models. In the first category we find, for example, those used in architecture or in fluid mechanics which are basically aimed at design. In the latter, the range spans from the mental models all of us use in our daily interactions with the world, to formal and abstract (typically analytical) representations of some theory about the system of interest and how it works. Mental models play an important role in understanding and interpreting the real world and our analytical models. They are enhanced through discussions, training and, above all, experience. Mental models are, however, difficult to communicate and to discuss.

In this book we are concerned mainly with an important class of abstract models: mathematical models. These attempt to replicate the system of interest and its behaviour by means of mathematical equations based on certain theoretical statements about it. Although they are still simplified representations, these models may be very complex and often require large amounts of data to be used. However, they are invaluable in offering a 'common ground' for discussing policy and examining the inevitable compromises required in practice with a minimum of objectivity. Another important advantage of mathematical models is that during their formulation, calibration and use the planner can learn much, through experimentation, about the behaviour and internal

workings of the system under scrutiny. In this way, we also enrich our mental models thus permitting more intelligent management of the transport system.

A model is only realistic from a particular perspective or point of view. It may be reasonable to use a knife and fork on a table to model the position of cars before a collision but not to represent their mechanical features, or their route choice patterns. The same is true of analytical models: their value is limited to a range of problems under specific conditions. The appropriateness of a model is, as discussed in the rest of this chapter, dependent on the context where it will be used. The ability to choose and adapt models for particular contexts is one of the most important elements in the complete planner's tool-kit.

This book is concerned with the contribution transport modelling can make to improved decision making and planning in the transport field. It is argued that the use of models is inevitable and that of formal models highly desirable. However, transport modelling is only one element in transport planning: administrative practices, an institutional framework, skilled professionals and good levels of communication with decision makers, the media and the public are some of the other requisites for an effective planning system. Moreover, transport modelling and decision making can be combined in different ways depending on local experience, traditions and expertise. However, before we discuss how to choose a modelling and planning approach it it worth outlining some of the main characteristics of transport systems and their associated problems. We will also discuss some very important modelling issues which will find application in other chapters of this book.

1.2 CHARACTERISTICS OF TRANSPORT PROBLEMS

Transport problems have become more widespread and severe than ever in both industrialised and developing countries alike. Fuel shortages are (temporarily) not a problem but the general increase in road traffic and transport demand has resulted in congestion, delays, accidents and environmental problems well beyond what has been considered acceptable so far. These problems have not been restricted to roads and car traffic alone. Economic growth seems to have generated levels of demand exceeding the capacity of most transport facilities. Long periods of under-investment in some modes and regions have resulted in fragile supply systems which seem to break down whenever something differs slightly from average conditions.

These problems are not likely to disappear in the near future. Sufficient time has passed with poor or no transportation planning to ensure that a major effort in improving most forms of transport, in urban and inter-urban contexts, is necessary. Given that resources are not unlimited, this effort will benefit from careful and considered decisions oriented towards maximising the advantages of new transport provision while minimising their money costs and undesirable side-effects.

1.2.1 Characteristics of Transport Demand

The demand for transport services is highly *qualitative* and *differentiated*. There is a whole range of specific demands for transport which are differentiated by time of day,

day of week, journey purpose, type of cargo, importance of speed and frequency, and so on. A transport service without the attributes matching this differentiated demand may well be useless. This characteristic makes it more difficult to analyse and forecast the demand for transport services: tonne and passenger kilometres are extremely coarse units of performance hiding an immense range of requirements and services.

The demand for transport is *derived*, it is not an end in itself. With the possible exception of sight-seeing, people travel in order to satisfy a need (work, leisure, health) at their destination. This is even more true of goods movements. In order to understand the demand for transport, we must understand the way in which facilities to satisfy these human or industrial needs are distributed over space, in both urban and regional contexts. A good transport system widens the opportunities to satisfy these needs; a heavily congested or poorly connected system restricts options and *limits* economic and social development.

Transport demand takes place over *space*. This seems a trivial statement but it is the distribution of activities over space which makes for transport demand. There are a few transport problems that may be treated, albeit at a very aggregate level, without explicitly considering space. However, in the vast majority of cases, the explicit treatment of space is unavoidable and highly desirable. The most common approach to treat space is to divide study areas into zones and to code them, together with transport networks, in a form suitable for processing with the aid of computer programs. In some cases, study areas can be simplified assuming that the zones of interest form a corridor which can be collapsed into a linear form. However, different methods for treating distance and for allocating origins and destinations (and their attributes) over space are an essential element in transport analysis.

The spatiality of demand often leads to problems of lack of coordination which may strongly affect the equilibrium between transport supply and demand. For example, a taxi service may be demanded unsuccessfully in a part of a city while in other areas various taxis may be plying for passengers. On the other hand, the concentration of population and economic activity on well-defined corridors may lead to the economic justification of a high-quality mass transit system which would not be viable in a sparser area.

Finally, transport demand and supply have very strong *dynamic* elements. A good deal of the demand for transport is concentrated on a few hours of a day, in particular in urban areas where most of the congestion takes place during specific peak periods. This time-variable character of transport demand makes it more difficult–and interesting–to analyse and forecast. It may well be that a transport system could cope well with the *average* demand for travel in an area but that it breaks down during peak periods. A number of techniques exist to try to spread the peak and average the load on the system: flexible working hours, staggering working times, premium pricing, and so on. However, peak and off-peak variations in demand remain a central, and fascinating, problem in transport modelling and planning.

1.2.2 Characteristics of Transport Supply

The first distinctive characteristic of transport supply is that it is a *service* and not a good. Therefore, it is not possible to stock it, for example, to use it in times of higher