HIGHWAY ENGINEERING

THIRD EDITION

MARTIN ROGERS AND BERNARD ENRIGHT

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Third Edition

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Preface

Highway Engineering is intended primarily as a text for undergraduate students of civil engineering while also touching on topics that may be of interest to surveyors and transport planners. First and foremost, however, it must provide an essential text for those wishing to work in the area, covering all the necessary basic foundation material needed for practitioners in highway engineering at the entry level to industry. In order to maximise its effectiveness, however, it must also address the requirements of additional categories of student: those wishing to familiarise themselves with the area but intending to pursue another speciality after graduation and graduate students requiring necessary theoretical detail in certain crucial areas.

The aim of the text is to cover the basic theory and practice in sufficient depth to promote basic understanding while also ensuring extensive coverage of all topics deemed essential to students and trainee practitioners. The text seeks to place the topic in context by introducing the economic, political, social and administrative dimensions of the subject. In line with its main task, it covers central topics such as geometric, junction and pavement design while ensuring an adequate grasp of theoretical concepts such as traffic analysis and economic appraisal.

The book makes frequent reference to the Department for Transport's *Design Manual for Roads and Bridges* and moves in a logical sequence from the planning and economic justification for a highway through the geometric design and traffic analysis of highway links and intersections to the design and maintenance of both flexible and rigid pavements. To date, texts have concentrated either on highway planning/analysis or on the pavement design and maintenance aspects of highway engineering. As a result, they tend to be advanced in nature rather than introductory texts for the student entering the field of study for the first time. This text aims to be the first UK textbook that meaningfully addresses both traffic planning/analysis and pavement design/maintenance areas within one basic introductory format. It can thus form a platform from which the student can move into more detailed treatments of the different areas of highway engineering dealt with more comprehensively within the more focused textbooks.

Chapter 1 defines highway planning and details the different forms of decision frameworks utilised within this preparatory process, along with the importance of public participation. Chapter 2 explains the basic concepts on the basis of traffic demand modelling and outlines the four-stage transport modelling process. The third edition has expanded this chapter to include a number of numerical examples detailing how the four different stages of the classical transportation model work.

Chapter 3 details the main appraisal procedures, both monetary and non-monetary, required to be implemented in order to assess a highway proposal. Chapter 4 introduces the basic concepts of traffic analysis and details various theoretical models used to determine queue lengths. Chapter 5 outlines how the capacity of a highway link can be determined. The third edition has expanded this chapter to include details of the 2010 *Highway Capacity Manual*, published since the second edition of the book. Chapter 6 covers the analysis of flows and capacities at the three major types of intersection: priority intersections, signalised junctions and roundabouts. The concepts of design speed, sight distances, geometric alignment (horizontal and vertical) and geometric design are addressed in Chapter 7. Chapter 8 deals with highway pavement materials and loading for the design of both rigid and flexible pavements, while Chapter 9 explains the basics of structural design for highway pavement thicknesses. Chapter 10 takes in the highway maintenance and overlay design methods required as the pavement nears the end of its useful life. Significant revisions have been made to Chapters 8, 9 and 10 arising from the new codes in place for highway pavement design and maintenance. Chapter 11 gives details of the technical documents which highway engineers are required to produce in order to guide a development project through the planning system in the United Kingdom and Ireland. Chapter 12, a new addition, deals comprehensively with sustainable transport planning, including the design and assessment of pedestrian footpaths, cycle lanes and bus lanes within an urban context.

In overall terms, the text sets out procedures and techniques needed for the planning, design and construction of a highway installation while setting them in their economic and political context.

Every effort has been made to ensure the inclusion of information from the most up-to-date sources possible, particularly with reference to the most recent updates of the *Design Manual for Roads and Bridges* and the *Highway Capacity Manual*. However, the regularity with which amendments are introduced is such that by the time this text reaches the bookshelves, certain aspects may have been changed. It is hoped, however, that the basic approaches underlying the text will be seen to remain fully valid and relevant.

For the third edition I have a co-author Dr. Bernard Enright who has been an invaluable colleague and co-worker on the text. This edition would not have been completed without his contribution.

Martin Rogers

Sources

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Chapter 1

The Transportation Planning Process

1.1 Why are highways so important?

Highways are vitally important to a country's economic development. The construction of a high-quality road network directly increases a nation's economic output by reducing journey times and costs, making a region more attractive economically. The actual construction process will have the added effect of stimulating the construction market.

1.2 The administration of highway schemes

The administration of highway projects differs from one country to another, depending on social, political and economic factors. The design, construction and maintenance of major national primary routes such as motorways or dual carriageways are generally the responsibility of a designated government department or an agency of it, with funding, in the main, coming from central government. Those of secondary importance, feeding into the national routes, together with local roads, tend to be the responsibility of local authorities. Central government or an agency of it will usually take responsibility for the development of national standards.

Highways England is an executive organisation charged within England with responsibility for the maintenance and improvement of the motorway/trunk road network. (In Ireland, Transport Infrastructure Ireland, formerly the National Roads Authority, has a similar function.) It operates on behalf of the relevant government minister who still retains responsibility for overall policy, determines the framework within which the agency is permitted to operate and establishes its goals and objectives and the time frame within which these should take place.

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In the United States, the US Federal Highway Administration has responsibility at the federal level for formulating national transportation policy and for funding major projects that are subsequently constructed, operated and maintained at the state level. It is one of nine primary organisational units within the US Department of Transportation (USDOT). The Secretary of Transportation, a member of the President's cabinet, is the USDOT's principal.

Each state government has a department of transportation, which occupies a pivotal position in the development of road projects. Each has responsibility for the planning, design, construction, maintenance and operation of its federally funded highway system. In most states, its highway agency has the responsibility for developing routes within the state-designated system. These involve roads of both primary and secondary statewide importance. The state department also allocates funds to local government. At the city/county level, the local government in question sets design standards for local roadways and has the responsibility for maintaining and operating them.

1.3 Sources of funding

Obtaining adequate sources of funding for highway projects has been an ongoing problem throughout the world. Highway construction has been funded in the main by public monies. However, increasing competition for government funds from the health and education sector has led to an increasing desire to remove the financing of major highway projects from such competition by the introduction of user or toll charges.

Within the United Kingdom, the New Roads and Street Works Act 1991 gave the Secretary of State for Transport the power to create highways using private funds, where access to the facility is limited to those who have paid a toll charge. In most cases, however, the private sector has been unwilling to take on substantial responsibility for expanding the road network within the United Kingdom. Roads tend still to be financed from the public purse, with central government being fully responsible for the capital funding of major trunk road schemes. For roads of lesser importance, each local authority receives a block grant from central government that can be utilised to support a maintenance programme at the local level or to aid in the financing of a capital works programme. These funds will supplement monies raised by the authority through local taxation. A local authority is also permitted to borrow money for highway projects but only with central government's approval.

Within the United States, fuel taxes have financed a significant proportion of the highway system, with road tolls being charged for the use of some of the more expensive highway facilities. Tolling declined between 1960 and 1990, partly because of the introduction of the Interstate and Defense Highways Act in 1956, which prohibited the charging of tolls on newly constructed sections of the interstate highway system, and because of the wide availability of federal funding at the time for such projects. Within the past 10 years, however, the use of toll charges as a method of highway funding has returned.

The question of whether public or private funding should be used to construct a highway facility is a complex political issue. Some feel that public ownership of all infrastructures is a central role of government and under no circumstances should it be constructed and operated by private interests. Others take the view that any measure that reduces taxes and encourages private enterprise should be encouraged. Both arguments have some validity, and any responsible government must strive to strike the appropriate balance between these two distinct forms of infrastructure funding.

Within the United Kingdom, the concept of design–build–finance–operate (DBFO) is gaining credence for large-scale infrastructure projects formerly financed by government. Within this arrangement, the developer is responsible for formulating the scheme, raising the finance, constructing the facility and then operating it in its entire useful life. Such a package is well suited to a highway project where the imposition of tolls provides a clear revenue-raising opportunity during its period of operation. Such revenue will generate a return on the developer's original investment.

Increasingly, highway projects utilising this procedure do so within the private finance initiative (PFI) framework. Within the United Kingdom, PFI can involve the developer undertaking to share with the government the risk associated with the proposal before approval is given. From the government's perspective, unless the developer is willing to take on most of this risk, the PFI format may be inappropriate, and normal procedures for the awarding of major infrastructure projects may be adopted.

1.4 Highway planning

1.4.1 Introduction

The process of transportation planning entails developing a transportation plan for an urban region. It is an ongoing process that seeks to address the transport needs of the inhabitants of the area and with the aid of a process of consultation with all relevant groups strives to identify and implement an appropriate plan to meet these needs.

The process takes place at a number of levels. At an administrative/political level, a transportation policy is formulated, and politicians must decide on the general location of the transport corridors/networks to be prioritised for development, on the level of funding to be allocated to the different schemes and on the mode or modes of transport to be used within them.

Below this level, professional planners and engineers undertake a process to define in some detail the corridors/networks that comprise each of the given systems selected for development at the higher political level. This is the level at which what is commonly termed a *transportation study* takes place. It defines the links and networks and involves forecasting future population and economic growth, predicting the level of potential movement within the area and describing both the physical nature and modal mix of the system required to cope with the region's transport needs, be they road, rail, cycling or pedestrian based. The methodologies for estimating the distribution of traffic over a transport network are detailed in Chapter 2.

At the lowest planning level, each project within a given system is defined in detail in terms of its physical extent and layout. In the case of road schemes, these functions are the remit of the design engineer, usually employed by the roads authority within which the project is located. This area of highway engineering is addressed in Chapters 4–8.

The remainder of this chapter concentrates on the systems planning process – in particular, the travel data required to initiate the process, the future planning strategy assumed for the region that will dictate the nature and extent of the network derived, a general outline of the content of the transportation study itself and a description of the decision procedure that will guide the transport planners through the system process.

1.4.2 *Travel data*

The planning process commences with the collection of historical traffic data covering the geographical area of interest. Growth levels in past years act as a strong indicator regarding the volumes one can expect over the chosen future time, be it 15, 20 or 30 years. If these figures indicate the need for new/upgraded transportation facilities, the process then begins to consider what type of transportation scheme or suite of schemes is most appropriate, together with the scale and location of the scheme or group of schemes in question.

The demand for highway schemes stems from the requirements of people to travel from one location to another in order to perform the activities that make up their everyday lives. The level of this demand for travel depends on a number of factors:

- The location of people's work, shopping and leisure facilities relative to their homes
- The type of transport available to those making the journey
- The demographic and socio-economic characteristics of the population in question

Characteristics such as population size and structure, number of cars owned per household and income of the main economic earner within each household tend to be the demographic/socioeconomic characteristics having the most direct effect on traffic demand. These act together in a complex manner to influence the demand for highway space.

The Irish economy provides relevant evidence in this regard. Over the period 1996–2006, Ireland experienced unprecedented growth, which saw gross domestic product (GDP) double (see Table 1.1). This was accompanied by an increase in population of 17% from 3.63 to 4.24 million, with an even more dramatic increase of 47% in the numbers at work. This economic upturn resulted in a 72% increase in the total number of vehicles licensed over the 10-year period and an 88% increase in transport sector greenhouse gas emissions.

The 2006–2011 period has seen these trends reversed. While the population in Ireland has increased by 8.1% from 4.24 to 4.58 million, the total number at work has