National Cooperative Highway Research Program

NCHRP Synthesis 210

Road Pricing for Congestion Management: A Survey of International Practice

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

National Cooperative Highway Research Program

Synthesis of Highway Practice 210

Road Pricing for Congestion Management: A Survey of International Practice

JOSE A. GOMEZ-IBANEZ, Ph.D.
Harvard University

and

KENNETH A. SMALL, Ph.D.
University of California, Irvine

Topic Panel

KAZEM ATTARAN, *California Department of Transportation*
KENNETH E. COOK, *Transportation Research Board*
DAVID T. HARTGEN, *University of North Carolina, Charlotte*
TIMOTHY D. HAU, *The World Bank*
LOYD R. HENION, *Oregon Department of Transportation*
ARTHUR C. JACOBY, *Federal Highway Administration*
CHARLES D. SANFT, *Minnesota Department of Transportation*
PATRICK DECORLA SOUZA, *Federal Highway Administration*

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

NATIONAL ACADEMY PRESS
Washington, D.C. 1994

Subject Areas
Planning and Administration; Energy and Environment; and Highway Operations, Capacity, and Traffic Control

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communication and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

NCHRP SYNTHESIS 210

Project 20-5 FY 1992 (Topic 24-02)
ISSN 0547-5570
ISBN 0-309-05669-1
Library of Congress Catalog Card No. 94-61900

Price $19.00

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to transportation agency administrators and managers, state and regional transportation planners, metropolitan planning organizations, policy makers, transportation economists, traffic engineers, and others concerned with reducing traffic congestion in urban areas. The synthesis describes the experience of several foreign countries that have used road pricing, or congestion pricing, as a means to manage congestion. The synthesis contains discussions of the policy, equity, and implementation issues associated with congestion pricing. Several of the schemes described were planned or implemented as methods to increase roadway funding rather than for congestion management, but have had the effect of changing travel patterns.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

The case examples describe the congestion management schemes in Singapore, Hong Kong, Norway, Sweden, France, the Netherlands, and the United Kingdom. This report of the Transportation Research Board also describes the various congestion pricing schemes implemented or proposed that rely on automated or electronic vehicle use charges. The case examples include ring roads, corridors, restricted areas or zones, and areawide applications. The opportunities and cautions for implementing similar congestion pricing measures in the United Stares are also discussed.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

Jose A. Gomez-Ibanez, Ph.D., Derek C. Bok Professor of Public Policy and Urban Planning, John F. Kennedy School of Government, Harvard University, and Kenneth A. Small, Ph.D., Professor of Economics, Department of Economics, University of California, Irvine, were responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Kazem Attaran, Chief Economist, California Department of Transportation; Kenneth E. Cook, Transportation Economist, Transportation Research Board; David T. Hartgen, Professor and Coordinator of Transportation, University of North Carolina, Charlotte; Timothy D. Hau, Public Economics Division, Policy Research Department, The World Bank; Loyd R. Henion, Manager, Economic Services, Highway Division, Oregon Department of Transportation; Arthur C. Jacoby, Transportation Economist, Industry and Economic Studies Section, Minnesota Department of Transportation; and Patrick DeCorla Souza, Community Planner, Planning Support Branch, Federal Highway Administration.

The Principal Investigators responsible for the conduct of this synthesis were Sally D. Liff, Manager, Synthesis Studies, and Stephen F. Maher, Senior Program Officer.

Scott A. Sabol, Senior Program Officer, National Cooperative Highway Research Program, assisted the NCHRP 20-5 staff and the Topic Panel. This synthesis was edited by Linda S. Mason.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

ROAD PRICING FOR CONGESTION MANAGEMENT: A SURVEY OF INTERNATIONAL PRACTICE

SUMMARY

This report examines the experience of foreign countries with the use of road pricing as a tool for congestion management, a practice usually called congestion pricing. Congestion pricing involves varying the price for road use by the level of traffic congestion to encourage people to travel during less congested hours, by less congested routes, by alternative modes, or not at all. Interest in congestion pricing has been increasing in the United States both because congestion has been growing and because the public and government officials have become frustrated with the limitations of alternative congestion remedies. Foreign countries have had more experience with congestion pricing than the United States, however, and thus their experience is particularly instructive.

Foreign countries have implemented two types of congestion pricing schemes: point and cordon pricing. Under point pricing, vehicles passing a particular point on a roadway during congested hours are charged a toll, just as with conventional toll roads, bridges, and tunnels. Point pricing is considered congestion pricing if the charge point is located at the entrance to a congested facility or area and if the toll is higher during hours of peak demand. Cordon pricing is a variant of point pricing in which an imaginary cordon is drawn around a congested area and charge points are established at all points of entry or exit. Charges may vary by direction traveled or vehicle type, as well as location and time of day.

More complex schemes have been studied but not implemented to date. Such schemes include charging based on distance traveled within a congested area or facility and charging based on time spent on congested roadways.

The congestion pricing schemes being implemented or proposed abroad rely increasingly on automated or electronic vehicle charging systems. Automated charging is not essential to congestion pricing (as the experience of Singapore indicates), but it has become more attractive with recent developments in technology and it makes complex congestion pricing schemes more practical.

Three foreign countries have actually implemented some form of congestion pricing or a close variant:

- Singapore was the first city to do so in 1975, with a cordon pricing scheme. Automobiles entering the city's central area during congested hours must purchase and display a special paper license in their windshields. Singapore plans to convert to electronic collection of the fee by 1996.
- In France, a toll road authority introduced point congestion pricing on the intercity expressway between Paris and Lille in 1989 to control traffic jams caused by Parisians returning from weekends in the country. Toll rates were increased during the peak hours on Sunday afternoons and evenings, and were reduced before and after the peak. The scheme was designed to induce motorists to travel during less congested hours without increasing the total toll revenues collected.
- Three Norwegian cities—Bergen (in 1986), Oslo (in 1990), and Trondheim (in 1991)—introduced schemes under which motorists crossing a ring drawn around the city center must pay a special toll. These toll rings are not strictly congestion pricing because

they were motivated primarily by the desire to raise revenue to finance transportation improvements and thus their toll rates do not vary much with congestion levels. Nevertheless, the rings involve many of the same practical problems as a cordon congestion pricing scheme; two of them have successfully incorporated electronic toll collection, and one of these (Trondheim) includes some time-of-day variation.

Several other foreign countries have given serious consideration to congestion pricing. These cases are interesting because the schemes studied are often more complex than those adopted elsewhere, and because the debate over implementation sheds light on the circumstances under which congestion pricing is politically acceptable:

- Between 1983 and 1985, Hong Kong conducted an extensive evaluation of multiple-cordon congestion pricing schemes including the first large-scale field test of equipment to collect congestion tolls electronically. The proposal was ultimately abandoned because of concerns about the confidentiality of electronic records on toll passage and other political factors.
- In Sweden, Stockholm has decided to implement in 1997 a toll ring somewhat like those in Norway, but with a higher toll and an explicit goal of traffic reduction in the city center. Tolls will finance completion of a ring road just inside the cordon, and are part of a broad package of highway and rail infrastructure improvements negotiated among the three major political parties.
- The Netherlands is also considering various forms of cordon pricing to reduce congestion in the Randstad area, a sprawling urban region that is home to 6 million people and includes the nation's four largest cities (Rotterdam, Amsterdam, The Hague, and Utrecht).
- Several cities in the United Kingdom have been considering congestion pricing as well, the most interesting being London and Cambridge. The London metropolitan area has studied and debated cordon congestion pricing periodically since the 1960s, and the latest and most elaborate study is scheduled for completion by 1995. Cambridge, a much smaller city, has been evaluating more complex proposals involving charging by the actual degree of congestion encountered.

The foreign experience shows that properly designed congestion pricing schemes can substantially reduce traffic congestion. Both the planning studies and the implemented schemes suggest that charges of $1 to $3 per day for entry to a congested central area will reduce traffic there by around 20 percent or more. Singapore's pricing system reduced traffic entering in the peak by 43 percent initially, for example, and has managed to reduce the rate of traffic growth over the years. The Norwegian toll rings appear to have reduced traffic by a few percentage points despite the fact that charges were designed to raise revenue rather than discourage motorists. The Sunday afternoon tolls in France also effectively spread traffic over the day.

Congestion pricing also need not be overly costly to administer. The schemes in operation require only around 10 to 12 percent of their toll revenues to cover operating and enforcement costs and only a few percentage points more if amortized capital costs are included.

Careful attention to design and implementation details appears to be important, however, if congestion pricing is to produce substantial improvements in overall travel times and convenience. This does not mean that the scheme need be complex—planning studies show, for example, that simple schemes with only one or two cordons often provide almost as many benefits as more complex schemes with multiple cordons. Nevertheless, the boundaries of the cordon or cordons, the hours of charging, and the charge level all need to be selected carefully and, if necessary, adjusted in light of experience.

Winning political approval is the most serious obstacle to congestion pricing, which has been implemented in only two countries (three, if Norway's schemes are counted). In many of the other cases, congestion pricing has been delayed or defeated by intense political controversy.

Some of the objections raised appear more manageable than others. Privacy concerns can be met, for example, by using more advanced electronic toll collection methods that do not record a vehicle's passage or by providing the option of non-electronic payment. Congestion pricing also probably does not place an undue burden on members of low-income households in most situations: they are more likely to be using public transit and, even where auto ownership is widespread, motorists driving into the city center during rush hours typically have higher than average incomes.

Perhaps the most potent political objection is simply that many motorists stand to lose, particularly if the government does not return the toll revenues to the motorists in some form. Most of those who continue to drive during congested hours will pay more in tolls than the benefits they receive in reduced travel times. The most obvious and widely adopted solutions are to use the toll receipts for transportation improvements that benefit motorists (as with the Norwegian toll rings) or to reduce other charges paid by motorists (as with the French expressway).

Finally, congestion pricing may arouse opposition simply because it represents such a drastic change in existing arrangements. People do not understand its rationale, they do not trust the new collection technologies, they fear unanticipated side effects such as traffic spillovers, and they suspect that they will pay heavily while the benefits, if any, will be reaped by others. In this light, the slow but steady accretion of international experience should be helpful in reducing the barriers in the United States and elsewhere.

CHAPTER ONE

INTRODUCTION

The idea of pricing the use of roads is an old one. In the United States, for example, many of the early turnpikes of the late 17th and early 18th centuries were built as private toll roads. During the modern era, numerous toll roads were built by public agencies in the 1940s and 1950s, particularly in the eastern states, and tolls long have been used to finance unusually expensive bridges or tunnels. The decision in 1956 to fund the Interstate and Defense Highway System as a network of untolled expressways, however, set the nation on a course that favored road finance through fuel or other fairly broad-based taxes rather than through charges for the use of specific facilities.

Recently, road pricing is again attracting interest for two different reasons. The first and more traditional reason is to generate revenue, particularly for the construction of new or the upgrading of existing highways. In the 1980s, as the construction of the federally financed Interstate system neared completion and popular resistance to tax increases grew, some states began to reconsider tolls as a means of highway finance (*1*, pp. 164–171).

The second and more recent motivation is to manage traffic congestion and air pollution. Popular concern about both of these problems appears to be growing in the United States, and both the public and government officials are frustrated by the limitations of conventional remedies to them. Building new highways, for example, is often expensive and generates intense controversies over land takings and environmental impacts. Efforts to promote mass transit and carpooling as alternatives to driving also have achieved only limited success, and stringent controls on driving or land use usually are politically unpopular. As a result, the use of road pricing to dampen demand, especially demand during peak hours, is attracting increasing attention, and has been endorsed by interest groups ranging from the Environmental Defense Fund to the business-oriented Bay Area Economic Forum in the San Francisco region.

This report focuses on foreign experience with the use of road pricing for congestion management, more commonly called congestion pricing. Congestion management and revenue generation are not incompatible—indeed, congestion pricing often generates large sums of money. Congestion pricing implies, however, that prices will be tailored to congestion levels to encourage people to travel during less congested hours, by less congested routes, by alternative modes, or not at all. By contrast, altering travel behavior is not the principal concern in pricing schemes designed primarily to raise revenue.

Foreign experience is particularly instructive because the United States has lagged behind other countries in the study and implementation of congestion pricing. There was an unsuccessful effort to promote congestion pricing demonstrations in the United States during the 1970s (*2*). The growing concern about congestion and pollution is likely to lead to the implementation of congestion pricing in several U.S. locations in the next few years, however. A recent study by the National Research Council analyzed the theoretical, practical, and technological considerations of implementing congestion pricing in the United States (*3*). Section 1012(b) of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 authorizes $150 million over 6 years for funding up to five demonstrations of congestion pricing. The Federal Highway Administration selected the San Francisco–Oakland Bay Bridge in 1993 for initial planning under this program, and it hopes to select other sites soon. Two of the new highways authorized under California's 1989 experimental private highway program (Assembly Bill 680) also are expected to use congestion pricing; the franchised companies plan to collect tolls electronically and vary the rates by time of day and level of congestion (*1*). One of these projects, on the Riverside Freeway in Orange County, began construction in 1993 and is expected to open in 1995 (see Table 1).

Europe and Asia, however, have a longer record of planning and implementing congestion pricing schemes. Singapore has applied congestion pricing to its central city since 1975, and France began an experiment on an expressway outside Paris in 1992. Three Norwegian cities—Bergen, Oslo, and Trondheim—have implemented a form of road pricing very similar to congestion pricing; in those cities, cars crossing a ring or cordon around the central area must pay a toll at some or all times of day. Stockholm plans to implement a similar scheme in 1997. The U.K. Department of Transport is embarking on a massive study of how congestion pricing would work in London. In a number of other cities—including Hong Kong, Randstad (Netherlands), and Cambridge (England)—proposals for congestion pricing have made serious headway at various times.

The purpose of this report is to summarize the experiences of these foreign ventures to provide insights into the applicability of similar ideas in the United States. The focus is on the political and policy objectives, the institutional and technical considerations in implementing the proposals, the impacts on traffic and related factors in the urban environment, and public reactions. Because the case studies are so different from each other, no single uniform set of comparisons along these dimensions is possible; but it is demonstrated, insofar as possible, how the specific features of each case lead to a particular set of results.

ROAD TAXES, ROAD PRICING, AND CONGESTION PRICING

The terms road taxes, road pricing, and congestion pricing are often confused, so it is helpful to define them at the outset. A fundamental distinction is between taxation and pricing. Taxation is the compulsory transfer of resources from private individuals or corporations to the government; its primary

TABLE 1

RECENT U.S. PROPOSALS FOR CONGESTION PRICING

Type of Congestion Pricing	Location	Status as of 1994
Time-varying toll on new expressway lanes, with discounts or free passage for carpools	Orange Co., Calif. (Route 91)	Under construction by private consortium; to open in 1995
Time-varying toll on new expressway	Orange Co., Calif. (Route 57 extension)	Approved by State; financing uncertain
Time-varying toll on bridge	San Francisco-Oakland Bay Bridge	Preliminary planning funded as ISTEA demonstration project

purpose is to raise money, not to change behavior. Indeed, if a tax significantly alters behavior by, for example, discouraging work effort, that effect is usually regarded as harmful to the efficient functioning of markets. Pricing, by contrast, implies a more direct effort to charge people for the particular goods and services they use, often with the intention of inducing some behavioral change. Economists often argue that prices should be set at marginal or incremental cost because doing so will encourage consumers to use services or goods only when they value the last unit by at least as much as it costs to produce.

The term road taxes therefore is reserved here for taxes that are levied on road users but that are only crudely related to the extent of their road use and are primarily intended to raise money rather than to alter behavior. Examples are gasoline taxes, license fees, and tire taxes. To the extent that such taxes influence behavior at all, they do so primarily through changes that are ancillary to road use itself—for example, by encouraging motorists to purchase vehicles with better fuel economy.

The term road pricing is used here when particular road trips, at well-specified places and/or times, are subjected to well-defined charges. Conventional road tolls are an example of road pricing, typically for using a particular "special" facility such as a bridge, tunnel, or expressway. The idea is that building such a costly facility provides a special service of great value to a limited set of people, who should therefore pay in proportion to their use of it. Recently this idea has been extended to charging for use of the entire street system of a central city. In the three Norwegian cities mentioned earlier, it is implemented by charging a daily use fee for entering the central area.

Congestion pricing is a particular form of road pricing that imposes higher charges on motorists who travel at times and places where the road system is congested. Higher charges are justified because travel in congested periods or places imposes high costs on society; these costs take the form of either expensive additions to roadway capacity or delays to other motorists. Rather than spreading the charges for road use evenly across all users, congestion pricing targets those who cause the greatest problem or expense.

Road pricing can be implemented in any of a wide range of forms that vary in their degree of complexity, financial arrangements, and technology (*4,5*). For example, the level of complexity can vary anywhere from simple entry fees, such as bridge tolls, to elaborate systems of time- and place-specific charges throughout an urban area, such as those proposed for Hong Kong and for the Randstad area of the Netherlands.

WHY CONGESTION PRICING?

The basic idea of congestion pricing is to charge each motorist a fee that is directly related to the amount of congestion he or she causes in using a road. The presence of a motor vehicle on a road slows other traffic. These delays may not be very serious when the traffic volume is well below the maximum capacity of the roadway. As volumes approach capacity, however, each additional motorist can significantly reduce average traffic speeds. If motorists are charged fees approximating the costs of the delays they cause, then they will be encouraged to use the road only when and where the benefits they gain equal or exceed their own average costs plus congestion costs they impose on others.

There are various ways to control congestion besides congestion pricing. Examples include increasing roadway capacity and promoting mass transit, carpooling, or other alternatives to driving. While these remedies can play an important role, they are often ineffective when implemented alone. Their effectiveness would be enhanced if combined with congestion pricing.

One advantage of congestion pricing is that it encourages motorists to find many ways to reduce congestion rather than promoting only a few. Transit and carpooling programs reduce congestion by encouraging motorists to switch modes. Pricing promotes not only switching modes, but also changing time of day, route, location, or frequency of travel.

TABLE 2
FOREIGN CASES EXAMINED

Type of Congestion Pricing	Location	Status as of 1994
Charge to enter the central area or downtown of a metropolitan area in the peak (Ch. 3)	Singapore	In operation since 1975
	Hong Kong	Pilot test in 1985 but later abandoned
Charge to enter the central area or downtown of a metropolitan area (Ch. 4)	Bergen	In operation since 1986
	Oslo	In operation since 1990
	Trondheim, Norway	In operation since 1991
	Stockholm	Agreement in 1992 to implement in 1997
Peak period toll surcharge on an intercity expressway (Ch. 5)	Paris	In operation since 1992
More complex schemes for imposing congestion charges throughout a metropolitan area (Ch. 6)	Randstad, Netherlands	In planning
	London	Under study
	Cambridge, England	Under study

In addition, congestion pricing applies to all motorists who are causing congestion and not just to selected groups. For example, employer-based carpooling programs target primarily commuters; yet people traveling for nonwork purposes make up a significant proportion of peak-hour travel in many metropolitan areas, and they may have more flexibility to change their hour, route, or location of travel than commuters.

Another key advantage of congestion pricing is that it acts by dampening demand rather than by increasing the supply of transportation capacity. Increasing the supply alone is often self-defeating because any newly available highway capacity can be quickly absorbed if it is not properly priced. Every large congested city harbors a reservoir of potential peak-period drivers known as latent demand. These are people who are deterred from adding to congestion only by congestion itself. Once a new highway or transit line eases congestion a little, these latent demanders—who may now be traveling on other modes, at other times of day, or who may even be substituting other activities for the one that requires peak travel—move into the empty spaces, driving congestion levels back up. For this reason, capacity increases alone often provide only temporary congestion relief.

Congestion pricing can help reduce the size of the new capacity investments required as well as protect them from congestion. This is because the transportation capacity required depends on peak demand, and congestion pricing encourages motorists to travel in the peak only if they are willing to pay the social costs of doing so. The two proposed private highways in California described earlier provide interesting examples: in both cases just two lanes in each direction are planned, which is unusually narrow for urban California. Although the design is partly due to geometric constraints, as well as cost and other factors, it is their proposed pricing structure that enables four lanes to handle the expected traffic. In a more outlying part of the same metropolitan area, a toll road that does not use congestion pricing is under construction as a six- to eight-lane facility (the San Joaquin Hills toll road).

OUTLINE OF THIS REPORT

To introduce the foreign experience, Chapter 2 describes briefly the variety of forms congestion pricing can take and the automated or electronic tolling technologies that often are used to implement it.

Chapters 3 through 6 recount the experiences of particular foreign schemes or plans in more detail. The order of the chapters is roughly chronological, with the countries with the longest experience presented first. Thus Chapter 3 presents the experience of Singapore and Hong Kong, as Singapore was the first city in the world to implement congestion pricing (in 1975) and Hong Kong was the first city to test (but not implement) electronic congestion pricing on a large scale (in 1985). The toll rings implemented in three Norwegian cities are presented in Chapter 4, as are the plans for a similar toll ring around Stockholm. Chapter 5 describes the application of congestion pricing to an intercity (rather than an urban) highway in France; this project, implemented in 1992, appears to be the first of its type in the world. Plans for congestion pricing in major metropolitan areas in the Netherlands and England are described in Chapter 6. The British and Dutch schemes are among the most complex of those discussed here, and perhaps for that reason, have not been implemented yet.

Finally, some tentative conclusions are drawn in Chapter 7 about the circumstances under which congestion pricing is likely to be both effective and politically acceptable.

For the convenience of the reader, Tables 2 and 3 summarize foreign congestion pricing projects reviewed in this study and the exchange rates used to convert foreign currencies to U.S. dollars.

TABLE 3
CURRENCY EXCHANGE RATES *(6,7)*

Nation	Year	Name (& abbrev.) of currency	U.S. dollar equivalent
France	1992	Franc (F)	$0.19
Hong Kong	1985	Dollar (HK $)	$0.128
Netherlands	1992	Guilder (NLG)	$0.57
Norway	1992	Krone (NOK)	$0.16
Singapore	1975	Dollar (S $)	$0.476
	1992		$0.55
Sweden	1992	Krona (SEK)	$0.17
United Kingdom	1973	Pound (£)	$2.45
	1986		1.47
	1988		1.78
	1990		1.78

CHAPTER TWO

CONGESTION PRICING SCHEMES AND TECHNOLOGIES

Congestion pricing can take a variety of forms, ranging from simple schemes in which a toll is collected from vehicles entering a congested area or facility to more complex measures in which the toll paid varies by both distance traveled and the level of congestion. The practical possibilities for implementing more complex schemes are changing rapidly with new developments in automated vehicle identification and charging. Before describing the experiences with congestion pricing in Asia and Europe, it is helpful to review briefly the range of alternative schemes for congestion pricing and the technologies available for implementing them.

CONGESTION PRICING SCHEMES

The basic idea of congestion pricing, as noted in Chapter 1, is to charge each motorist for the costs of the congestion he imposes on others. In principle, this would involve varying charges by the type of vehicle, by location and amount of driving, and by time of day, because congestion levels vary. In practice, such complex charges would be difficult to assess, collect, and enforce. Most practical congestion pricing schemes therefore compromise to some degree on the ideal.

A. D. May (*8*) and other researchers distinguish at least six types of congestion pricing. Arguably the simplest form is higher *parking charges* in congested areas. In particular, higher parking charges are often advocated for motorists who enter parking facilities in the morning rush hours or park all day, since they are likely to use the streets during the periods of highest congestion. However, most transportation planners and economists regard parking charges as a poor proxy for congestion pricing largely because the charges do not deter through traffic, which often accounts for well over one-half of the vehicles using major arterials or expressways in the congested centers of major metropolitan areas. Schemes involving only parking charges therefore are not included in this study, although in some of the cases (e.g., Singapore) higher parking charges are combined with other measures.

Point pricing schemes are more effective than parking charges because they apply to traffic traveling through as well as to a congested area. Under these schemes, vehicles passing a point on the roadway during congested hours are charged a toll, just as with many conventional toll roads, bridges, or tunnels. Point pricing is considered congestion pricing, however, if the charge point is located at or near the entrance to a congested area or facility and if the toll is higher during hours of peak demand.

Cordon pricing is a variant of point pricing in which an imaginary cordon is drawn around a congested area and charge points established at all the points of entry (or exit). Charges may vary by direction traveled or vehicle type as well as by location or time of day. Most of the Asian and European schemes examined in this study involve point or cordon pricing.

Zone pricing also involves a well-defined boundary. Under this scheme, all vehicles traveling within a congested area are required to pay a special fee. The difference between cordon and zone pricing is that under zone pricing, vehicles traveling entirely within the congested zone are also required to pay. So far as is known, no zone pricing schemes are presently under consideration. In several of the cases studied here, however, including Hong Kong and the Netherlands, multiple cordon pricing lines were proposed, which divided the city or region into numerous small cells so that the practical effect probably would have been to charge almost all vehicle trips traveling within the congested area.

A more complex scheme is pricing based on *distance traveled* within a congested area or on a congested facility. Such a scheme refines cordon or point pricing because in cordon or point systems, both short and long trips are charged the same fee even though the long trip usually creates more congestion. In practice, schemes with multiple cordons can discriminate somewhat between long and short trips, since a long trip is likely to cross more than one cordon and thus be charged more than a short trip. Under true distance-based pricing, however, the charge would be related to the actual distance traveled as well as to the location and time of day. Distance-based pricing has been studied in several European cities but has not been implemented.

Pricing based on time spent on congested roadways is yet another form of congestion pricing. Under this scheme, vehicles are charged based on the number of minutes they spend traveling, with the charge rate potentially varying by location, time of day, and vehicle type. The time spent traveling is a measure of congestion, since more time is required to complete a given journey during congested periods. Time-based pricing has been studied in a few cities but has never been implemented.

A still higher level of complexity is *congestion-specific pricing* in which charges are based on both time spent and distance traveled. Under this scheme, the charge rate per mile would be based on the speed at which the vehicle traveled. If the rate also varied with the type or capacity of the roadway and the type of vehicle, then it could closely approximate the theoretical model of congestion pricing. Congestion-specific charging schemes have been considered for Cambridge, England, but are seen (as discussed in Chapter 6) only as a long-term possibility.

AUTOMATED VEHICLE CHARGING

The simplest point or cordon congestion pricing schemes might, in theory, be implemented using conventional toll booths manned by collectors or equipped with machines that accept coins or tokens. In practice, however, conventional toll booths usually require too much land, are too expensive to

TABLE 4
IN-VEHICLE UNITS FOR CONGESTION PRICING *(8)*

Technology	Pricing schemes allowed	Other advantages	Other disadvantages
Stickers	Simple point, cordon, or zone	Proven	Requires visual or infrared enforcement
Read-only tags	Complex point, cordon, or zone	Proven	--
Read/write tags	Point, cordon, zone, or time-based	Proven; Independent transaction record; Multilane operation	Requires battery
Read/write tags with automatic debiting (smart cards)	Point, cordon, zone, or time-based	Proven; Privacy	Requires battery
In-vehicle meters	All types	Most flexible	Requires connection to odometer and battery; Not proven

build and staff, and impose too many traffic delays to be practical even for cordon pricing, let alone more complex forms of congestion pricing. Most congestion pricing schemes that have been proposed or implemented therefore rely to a large degree on automated vehicle charging systems. Such systems are being adopted by many toll road authorities in the United States and elsewhere that do not use congestion pricing. Even in such simple applications, automating toll collection offers considerable savings in collection costs and traffic delays (*9*).

The more sophisticated the congestion pricing scheme, the more dependent it is on automated charging technologies. The technology for automated charging is advancing rapidly, and numerous reviews of the alternatives are available (*5,8–13*). Every such system must accomplish three tasks: recognize the identities of valid users, detect and classify vehicles for the purpose of enforcement, and manage the financial transactions. The first task requires an *in-vehicle unit* or "tag" identifying the user and a method of *roadside-vehicle communication* to register the fact that this user is to be charged. The second task requires a system for *vehicle detection and classification* to alert the system if a vehicle lacking a valid tag is present and a method of *vehicle identification for enforcement*. The third task requires an *accounting and payment system*.

In-Vehicle Units

In-vehicle units range from simple paper or plastic stickers to complex meters connected to the vehicle's odometer (Table 4). Stickers are suitable only for simple point, cordon, or zone pricing schemes. Singapore uses paper licenses displayed in the windshield to allow police to identify motorists who have paid a special fee to enter its downtown during peak hours. Some toll road authorities use stickers equipped with a bar code that can be read by an infrared scanner to identify the vehicles of motorists who have prepaid their tolls.

More sophisticated are electronic tags. Read-only tags allow a roadside beacon to read the tag's identification number, either to debit the user's account or to allow for later billing. These tags are mounted on the vehicle and typically require no battery, since the electromagnetic waves from the roadside beacon can power the circuitry (transponder) inside the tag to send back a message with the vehicle identification number. Such tags have proven reliable in several congestion pricing applications as well as on many conventional toll roads that do not vary toll charges by time of day. Compared with windshield stickers like Singapore's, read-only tags facilitate the enforcement of congestion pricing schemes with multiple cordon lines or with charges that vary over several time periods in the day.

Read/write electronic tags allow the roadside beacon not only to identify the tag but also to store information on it for later retrieval by the vehicle owner or the toll authority. With current technology, read/write tags must be either equipped with an internal battery or connected to the vehicle's battery, which adds to their cost and the possibilities for failure or fraud. Read/write tags can allow the vehicle owner to obtain an independent record of toll crossings to check against the authority's bills. Read/write tags can include a built-in timer that can be activated by the roadside beacon when the vehicle enters a congested zone and read when the vehicle exits, thereby permitting time-based pricing.

Read/write tags also can be configured as automatic debiting transponders to work with "smart cards" or "value cards." Under this system, the vehicle owner purchases a card with a stored toll value and inserts the card in the read/write tag. The read/write tag confirms to the roadside beacon that the card has enough stored value to pay the toll and then deducts the toll from the card's value. The key advantage of smart cards is that they protect the privacy of the motorist since the toll authority need not maintain a record of the vehicle's crossing. Field tests of smart cards are underway in many locations in the United States and elsewhere, and most observers believe the technology is feasible and reliable in multilane operation.

Finally, in-vehicle meters that can communicate with roadside beacons and are connected to the vehicle's odometer allow not only cordon and time-based pricing but distance and congestion-specific pricing as well. Such in-vehicle meters were tested in Cambridge, England, in 1993 as part of the Automatic Debiting and Electronic Payment for Transport (ADEPT) project, as described in Chapter 6.

Roadside-Vehicle Communications

Several types of roadside beacons are in use. Among the earliest were infrared scanners that can read stickers with bar codes mounted on the vehicle. Infrared beacons allow only one-way communication. The vehicle stickers must be mounted in a precise location, moreover, and readings can be obscured by dirt or inclement weather. Infrared scanners have been used by some conventional toll road authorities but not in congestion pricing schemes.

Another early form of roadside-vehicle communication uses inductive loops embedded in the roadway as low-frequency antennas. This system allows only one-way communication (from the vehicle to the roadside) and thus can be used only with read-only tags. Inductive loops were used for field tests of electronic congestion pricing in Hong Kong (as explained in Chapter 3), but the loops in the pavement are expensive to install and their short range requires that the electronic tag be mounted on the underside of the vehicle. Recent development efforts have focused on radio frequency or microwave systems, since these allow two-way communications and read/write tags. They have also been used with read-only tags, such as those in use in Norway's toll rings (described in Chapter 4). Radio frequency and microwave systems use different ranges of the frequency spectrum but are otherwise similar to one another and have been proven in a number of applications. The principal problems are interference from other radio frequency or microwave sources and limitations on available frequencies that can be uniquely assigned to the systems.

Vehicle Detection and Classification

Systems are also needed to detect vehicles without tags, or with tags for the wrong class of vehicle. Inductive loops are typically used for this purpose, although they are costly. Infrared beacons and pulse-mode microwave have been used as well and are cheaper; infrared beacons can classify vehicles only by length, however, and pulse-mode microwaves sometimes allow large vehicles to obscure small ones.

Vehicle Identification for Enforcement

Enforcement requires the identification of vehicles not in compliance. License plates are currently the only way a violator can be uniquely identified. The main automated methods involve either taking a photograph or a video image of the license plates. This has certain limitations; other vehicles occasionally obscure a license plate, and vehicle owners may deliberately obscure or alter their plates to avoid identification. The photographs or video images can be read manually, although automated systems are now being developed that accurately read a high percentage of the plate numbers.

Accounting and Payment Systems

There are many ways to handle the financial payments. The choice depends especially on whether the user pays in advance (prepayment) or is debited or billed later (postpayment). In the case of prepayment, an additional choice is whether the account deduction is to be made externally by the central accounting system or internally by the in-vehicle unit. Prepayment with deduction by the in-vehicle unit (e.g., from a smart card) offers the users the greatest assurance of privacy. Privacy protection can be built into other systems as well by legislation.

Assessment

The technology for automated point or cordon congestion pricing appears well developed. One problem that remains unresolved is the detection, classification, and identification of vehicles at speed in congested multilane operations with no restrictions on traffic movements. Current (1994) technology can support a system in a multilane setting as long as traffic is prohibited from changing lanes over a short distance near the antennae (*13*, pp. 37, 43–44). However, unrestricted multilane operation is a problem high on the research agenda of the well-funded European DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) program's ADEPT project, however, and most researchers are confident that a solution will be found soon.

The most sophisticated forms of congestion pricing, such as congestion-specific pricing, are dependent on as yet undeveloped technologies for more sophisticated in-vehicle meters. These problems too seem amenable to solution.

In summary, recent developments in automated vehicle charging have made it possible to implement increasingly sophisticated forms of congestion pricing. Indeed, the primary relevant question today is not whether congestion pricing is technically feasible but rather whether it will achieve the hoped for improvements in traffic flow and will be politically acceptable. In this regard, the experiences and plans of Asian and European cities, recounted in the following four chapters, are particularly instructive.

CHAPTER THREE

THE ASIAN PIONEERS: SINGAPORE AND HONG KONG

Singapore and Hong Kong arguably have the longest experience with congestion pricing in the world: Singapore is the only city to have actually implemented a large scale congestion pricing scheme and Hong Kong is the site of the first extensive test of electronic congestion pricing technology, although ultimately the scheme was not implemented. Other Asian cities—including Bangkok, Seoul, Kuala Lumpur—have seriously considered implementing congestion pricing to cope with the extraordinarily rapid increases in auto ownership and use in the last several decades (*14*). Such schemes may have received extra consideration in Singapore and Hong Kong, however, because their geographic isolation and small size make the control of congestion both more necessary and more practical.

SINGAPORE'S AREA LICENSE SCHEME

The Republic of Singapore occupies a modest-size island and a score of much smaller ones at the tip of the Malay Peninsula in Southeast Asia. Virtually all of Singapore's 3 million inhabitants live on the largest island, which measures only 42 kilometers (27 miles) long by 22.5 km (14 mi) wide and has a land area of 360 km^2 (226 mi^2) (Figure 1). The city of Singapore, which is located on the south coast, so dominates the nation that Singapore is frequently described as a city-state.

Singapore's Area License Scheme, or ALS, is a fee charged to motorists entering a restricted zone in the Central Area (or downtown) of the city during peak hours (Figure 2). The scheme, first implemented in 1975, is designed to make compliance convenient and enforcement simple. Motorists subject to the fee must display a special paper license in their windshields. Daily or monthly licenses can be purchased at selected post offices and 16 roadside booths located on the approaches to the restricted zone. Gantries over the 33 entry points to the restricted zone are equipped with flashing lights to indicate when the restricted hours are in force, and police stationed at the entries monitor compliance. Valid licenses are easily recognized since they are color coded by month, and in the case of the daily licenses, the date is printed in bold black numerals.

Singapore's ALS has been modified many times since it was first implemented, and in 1989 the government announced its intention to shift to electronic fee collection by 1996. To understand the achievements and problems of the ALS, it is helpful to describe first its origins, then its initial effects in 1975, and finally the motives for and results of the subsequent modifications.

Origins of the ALS

Singapore gained its independence from Britain in 1965 and the new government made strenuous efforts to develop its economy, motivated partly by concern about the economic effects of the closure of British naval bases. These efforts have been enormously successful: real per capita income has more than doubled every decade since independence. By 1990, Singapore's per capita gross national product was approximately US $12,000, the second highest in Asia after Japan (*15*). Singapore is now a major commercial and tourist center in Southeast Asia, and the operator of the world's second busiest port.

Economic development has exacerbated Singapore's transportation problems directly by encouraging growth in automobile ownership and indirectly by stimulating the redevelopment of the city. Since independence, the government has made major efforts to improve the quality of housing and to accommodate population growth, largely by building a series of major new towns on the outskirts of the traditional city (*16*). Although industrial estates and shopping centers have been located in and near the new towns, many new town residents still work and shop in the Central Area. At the same time, the Central Area, or downtown, of the city has been promoted as the focus for the country's office and commercial activities, in part by tearing down its older housing to make way for new office and shopping developments. The combination of increased Central Area employment, dispersal of residences to new towns, and rapid growth in motor vehicle ownership has greatly increased traffic volumes and congestion in Singapore.

Beginning in 1967, the government of Singapore conducted a series of transportation and land use studies to determine how best to cope with the city's growing transportation problems. The first of these, the Singapore Concept Plan, was completed in 1971 and recommended the construction by 1992 of a 119-km (69-mi) urban expressway system and a 32-km (20-mi) rail rapid transit system. Construction of the proposed expressways began almost immediately, but the rail rapid transit proposal proved more controversial and its construction was not begun until the early 1980s, after several further studies.

The analysis in the Singapore Concept Plan suggested that even the proposed expressway and rail rapid transit systems would not be sufficient to keep traffic congestion at reasonable levels, given the expected growth in population, income, auto ownership, and downtown employment. Accordingly, in 1973, the government formed a Road Transportation Action Committee (RTAC), composed of representatives of relevant ministries, to devise a plan to control congestion. Using the travel forecasting models developed for the Singapore Concept Plan and assuming the proposed expressway and rail systems were built, the RTAC concluded that congestion would seriously increase by the 1990s unless measures were taken to limit the level of automobile ownership to one auto per twelve persons. Even if such measures were implemented, however, additional controls on traffic congestion would be necessary in the Central Area.

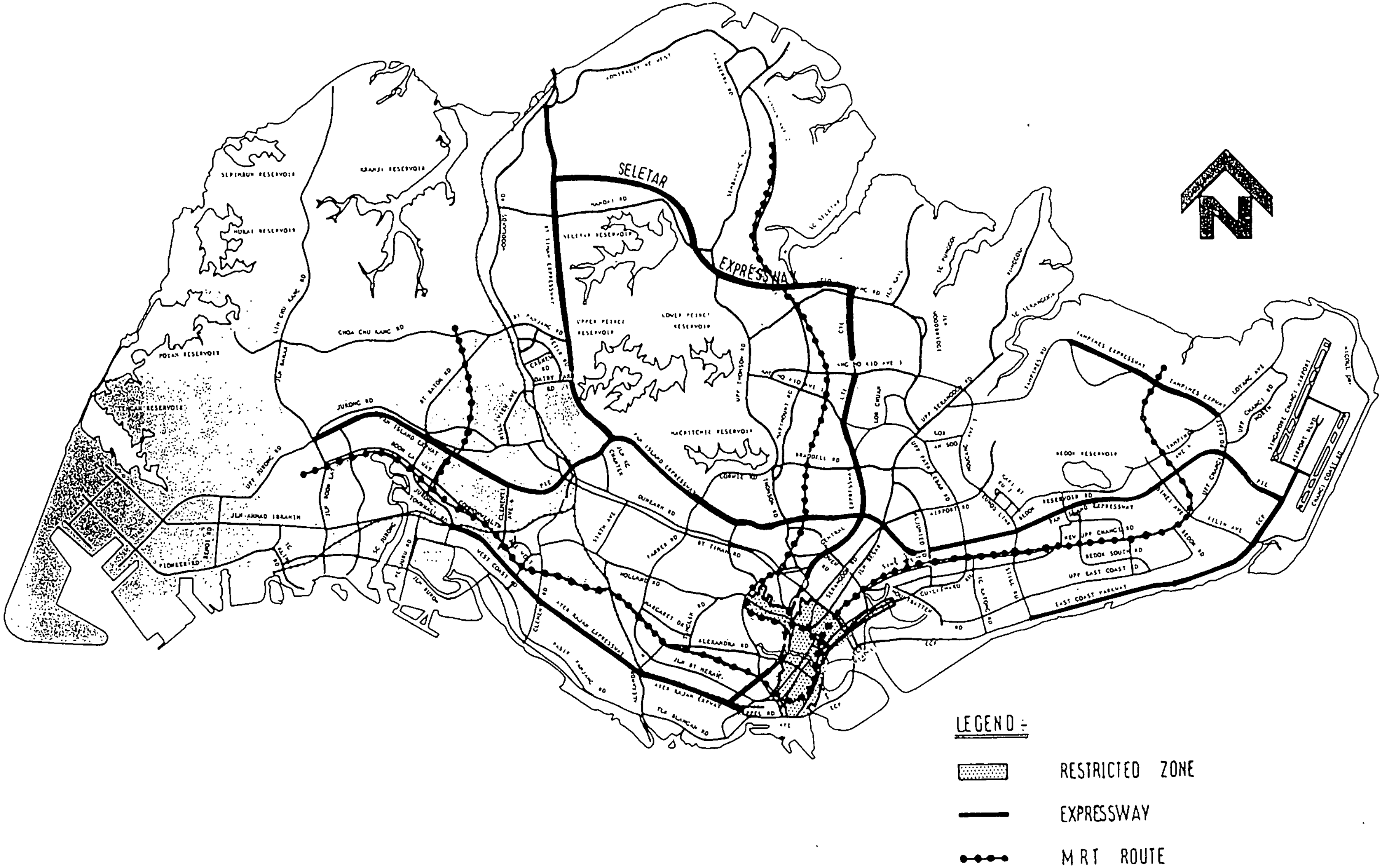

FIGURE 1 Map of Singapore.

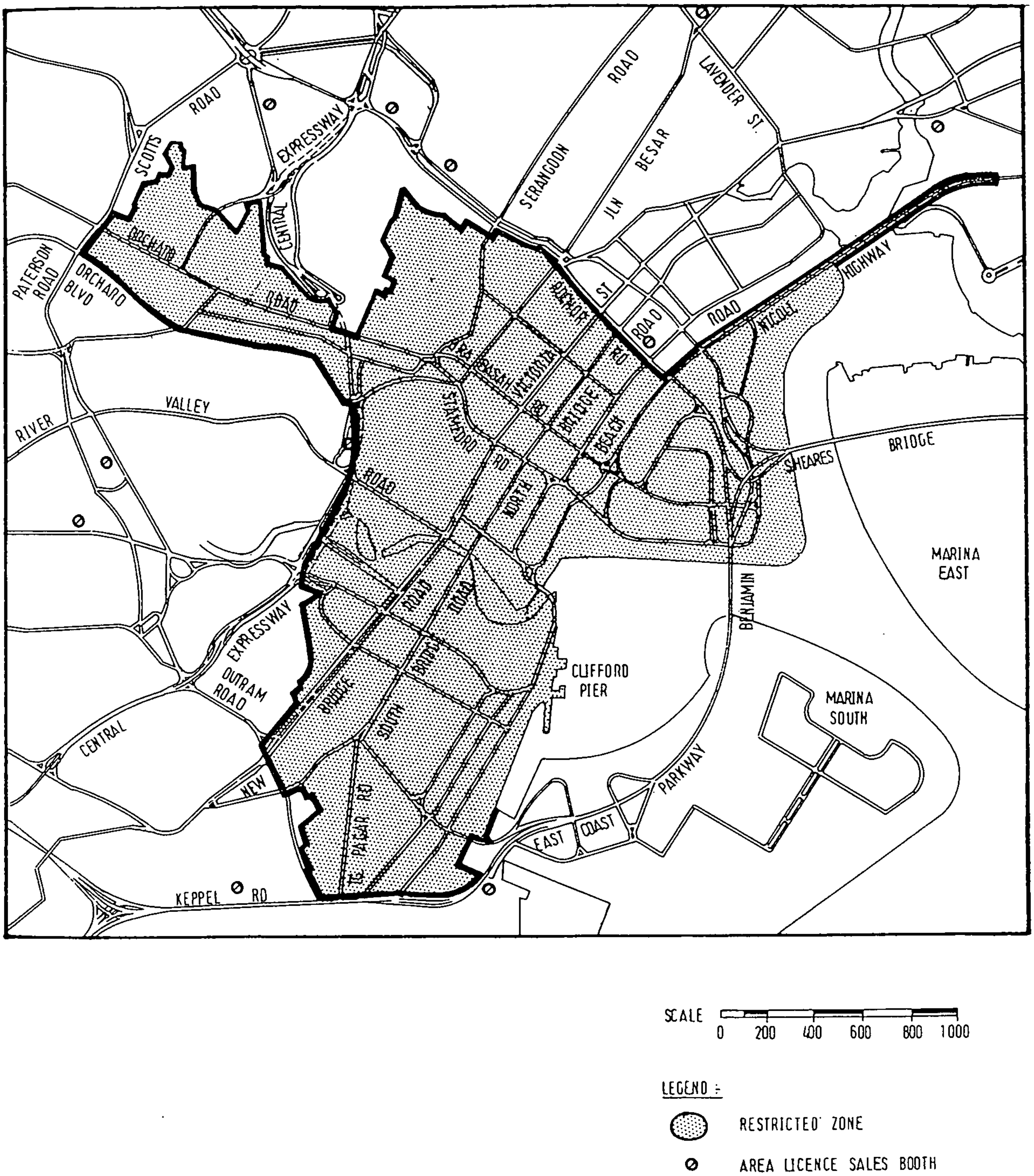

FIGURE 2 Singapore's restricted zone, 1993.

The RTAC considered four major criteria in evaluating alternative schemes to control Central Area congestion:

1. Accessibility and mobility in the Central Area are essential to the economic vitality of Singapore, and should be preserved by improving mass transit;
2. The benefits of private automobiles should be acknowledged, and controls applied only when needed to control local congestion;
3. The strategy should be easily administered and enforced; and
4. The strategy should require no subsidy.

Four road pricing schemes were identified for detailed consideration: congestion pricing using sophisticated electronic vehicle detection and billing, conventional road tolls, increased downtown parking charges, and an ALS. The electronic billing scheme was quickly eliminated from further consideration because of problems with the cost and reliability of the necessary hardware at the time. Toll roads were considered difficult to implement because of lack of space for high-capacity toll stations and because of the lengthy delays that might be expected from manually collecting tolls.

Increased parking charges were considered somewhat more practical. Parking fees would be easy to collect; the increases could be targeted to commuters to discourage them from entering the Central Area, moreover, while still permitting shoppers and others to maintain existing travel patterns. By themselves, however, parking fees to control congestion were perceived as flawed because they failed to discourage through traffic and chauffeur-driven cars, common in Singapore.

For these reasons, the RTAC decided to place primary reliance on an ALS. After an extensive publicity campaign to explain its benefits and how it would work, the scheme was put into effect on June 3, 1975.

The Design of the 1975 ALS

The RTAC drew the boundary of the restricted zone to include areas with congestion problems but to exclude the inner ring road, a major circumferential arterial that provides a bypass route for motorists with destinations beyond the Central Area. The initial restricted zone covered 620 hectares (2.4 square miles), including the Central Area and part of the adjacent Orchard Road shopping district (Figure 2 shows the 1993 zone, which is slightly larger).

The restraints initially applied only to automobiles carrying fewer than four persons, although within 3 weeks the scheme was modified to require taxis to pay the same fee as automobiles. The RTAC exempted public transit vehicles to promote transit use. Carpools or taxis carrying four persons or more were exempted to increase auto occupancy and counter charges that the fees favored the wealthy. Trucks and motorcycles were exempted to encourage commerce and to avoid penalizing low-income motorists. Also exempted were police, military, and emergency vehicles. The fee was initially set at S $3 per day (then US $1.42), and monthly licenses were sold for 20 times the daily rate (S $60 or US $28.57).

Restraints were enforced only during the morning rush hours. Initially, the restraint hours were from 7:30 to 9:30 a.m., but within 2 months (on August 1) they were extended to 10:15 a.m. to reduce problems caused by a large number of motorists arriving immediately after the restraint period ended. The RTAC had rejected all-day enforcement because congestion was not high in the midday, and it did not wish to needlessly discourage midday shoppers and others from doing business in the Central Area. The RTAC rejected evening enforcement because they hoped that the morning restraints would effectively reduce congestion for the home-bound commute as well. Evening restraints would also require license sales points in the Central Area for motorists caught downtown after restraint hours, which would increase administrative costs and might add to congestion if motorists had to stop to buy licenses. The restraints were imposed on Monday through Saturday mornings, since the typical Singapore work week is 5-½ days.

To provide alternatives for motorists, bus service to the Central Area was increased, including premium express and air-conditioned bus services designed to appeal to car users. In addition, 10 fringe parking lots were built outside the restricted zone, with shuttle bus service between the lots and the zone. These fringe lots were not heavily used, however, apparently because motorists found the other alternatives (shifting time of day, forming carpools, boarding a bus near their homes) more convenient. Ultimately, the shuttle bus service was discontinued and the lots converted to other uses.

Parking charges were also raised in the Central Area shortly before the ALS was put into effect to provide added discouragement for auto users (*17*). Monthly fees at government owned lots, formerly around S $40 (US $19.05) per space, were increased by S $20 (US $9.52) in the core of the restricted zone and S $10 (US $4.76) elsewhere in the zone. To ensure that charges at private parking lots increased as well, a tax of S $10 to S $20 per space per month was imposed on owners of lots in the restricted zone.

The RTAC conceived of the ALS as a supplement to measures aimed directly at curbing the growth in auto ownership. In 1972, the government had raised import duties on new motor vehicles from 30 to 45 percent, and had imposed a new "additional registration fee," or ARF, of 25 percent of the market value of new cars. On the recommendation of the RTAC, the ARF was raised to 55 percent in 1974 and then to 100 percent in December 1975, but with a lower rate for new purchasers who scrapped or exported an older car (*18*).

The Initial Effects of the ALS

Enforcement and Finances

Enforcement for the ALS proved not to be a problem. The windshield licenses are large enough to be visible to police without stopping the vehicles. Vehicle registration numbers of violators are recorded by police and the owners sent summonses, as vehicle owners in Singapore are responsible for identifying the drivers of their vehicles. The fine for a violation was set at S $50 (US $23.81), and violations soon declined to less than 100 per month (*17*, pp. 31–32; *19*, p. 20).

The scheme generated a considerable financial profit to the government (*17*). Capital costs for implementation were S $6.6 million (then US $3.0 million). Only about 5 percent was for gantry construction and publicity, however, while 92 percent was for the poorly used fringe parking lots and shuttle buses. (Some of the costs associated with the fringe lots were eventually recouped when the fringe lots were converted to other uses.) Sales of area licenses generated revenues of S $472,000 (US $225,000) per month for the government, while costs for attendants at license sales booths and fringe parking lots, agency fees for license sales, and police enforcement amounted to only S $50,000 (US $24,000) per month. The net operating revenue of S $420,000 (US $200,000) per month was enough to recover all capital costs in less than 2 years.

Traffic and Travel Patterns

Within a month, the ALS had cut the volume of traffic entering the restricted zone during the restraint hours by 47

TABLE 5
DAILY TRAFFIC ENTERING SINGAPORE'S RESTRICTED ZONE, 1975

	Before ALS (March 1975)	After ALS (7:30-9:30a.m.; July 1975)	After ALS (7:30-10:15a.m.; Sept.-Oct. 1975)
During Restricted Hours			
7:30-9:30			
All vehicles	55,313	29,532 (-47%)	n.a.
Cars (inc. pools)	32,421	8,130 (-75%)	n.a.
Taxis	7,397	1,248 (-83%)	n.a.
Carpools	2,334	3,581 (+53%)	n.a.
Trucks	1,572	3,557 (+126%)	3,523 (+110%)
7:30-10:15			
All vehicles	74,014	n.a.	41,198 (-44%)
Cars (inc. pools)	42,790	n.a.	11,363 (-73%)
Taxis	10,923	n.a.	3,787 (-65%)
Carpools	n.a.	4,083	4,217
Trucks	1,572	3,557 (+126%)	3,523 (+124%)
Before Restricted Hours			
7:00-7:30			
All vehicles	9,800	11,510 (+17%)	11,073 (+13%)
Cars (inc. pools)	5,384	6,685 (+24%)	6,640 (+23%)
Taxis	1,080	851 (-21%)	854 (-21%)
Carpools	687	672 (-2%)	702 (+2%)
Trucks	1,762	3,346 (+90%)	2,810 (+59%)
After Restricted Hours			
9:30-10:15			
All vehicles	12,775	14,041 (+10%)	n.a.
Cars	7,059	7,082 (+0.3%)	n.a.
Taxis	2,452	2,372 (-3%)	n.a.
Carpools	258	332 (+29%)	n.a.
Trucks	1,937	4,104 (+112%)	n.a.

Source: (*17*, pp. 41-51)

percent, significantly more than RTAC's goal of 25 percent. Autos and taxis with fewer than four persons, which were subject to the fees, declined by 75 percent and 83 percent, respectively, while carpools and trucks, which were exempt, increased somewhat (Table 5). The percentage changes in entering traffic remained roughly similar after the morning restraint hours were extended to 10:15 a.m. in August 1975.

An extensive evaluation by the World Bank (*17,20–22*) suggests that the reductions in auto and taxi traffic were due primarily to travelers shifting to carpools and buses, and secondarily to travelers changing their routes and hours of travel. The shift to alternative modes was greatest among inbound commuters from vehicle-owning households who worked in the restricted zone, according to World Bank surveys (see Appendix A, Table A-1). Among those households, the percentage commuting in autos carrying fewer than four persons dropped from 48 to 27, while the percentage in carpools of four or more increased from 8 to 19 and the percentage in buses increased from 33 to 46. Commuters to the restricted zone from households not owning vehicles remained heavily dependent on buses before and after the ALS, although small numbers of them shifted from taxis and buses to carpools.

TABLE 6

DAILY TRAFFIC EXITING THE SINGAPORE RESTRICTED ZONE ON EIGHT MAJOR ROADS IN THE EVENING, 1975

	Before ALS (March 1975)	After ALS (July 1975)	After ALS (Sept.-Oct. 1975)
4:00 - 5:00 p.m.	15,900	15,070 (-5%)	15,820 (-0.5%)
5:00 - 6:00 p.m.	19,275	17,840 (-7%)	19,050 (-1%)
6:00 - 7:00 p.m.	16,395	15,760 (-4%)	15,575 (-5%)
Total, 4:00 - 7:00 p.m.	51,570	48,670 (-6%)	50,445 (-2%)

Source: (*17*, p. 59).

Commuters to jobs beyond the restricted zone responded less by shifting modes than by changing routes to avoid passing through the zone. Among vehicle-owning households, the percentage of commuters traveling to work beyond the zone in cars with fewer than four persons declined from 47.5 percent to 36 percent, about half the reduction made by their counterparts working in the zone. The percentage of car drivers commuting to jobs beyond the zone who passed through the zone declined from 88 to 66. This comparison suggests that route shifts were twice as important as mode shifts in accounting for the reduction in vehicle trips entering the zone by these commuters.

Finally, some motorists started their trips earlier to avoid the restricted hours. The percentage of car drivers who began their trip before 7:30 a.m. increased from 28 percent to 42 percent for those who worked in the restricted zone, and from 50 percent to 60 percent for those who worked beyond (Appendix A, Table A-1). This shift to earlier hours accounted for perhaps 5 percent of the reduction in auto traffic during the restraint hours (Table 5 shows that excluding carpools, 25,538 fewer cars entered the restricted zone during restraint hours while 1,316 more cars entered immediately before). However, truck traffic entering the restricted zone in the periods immediately before and after restraints increased substantially (Table 5), so much so in fact that average rates of flow were higher just before and after the restraint hours than during them. Nevertheless, during no morning half-hour period did traffic flows reach the maximum half-hour flow that prevailed before restraints were introduced (*17*, p. 41).

To the planners' surprise, the ALS had very little effect on traffic exiting the restricted zone during the evening. Evening traffic on the eight most important roads exiting the zone fell by only 6 percent within the first month after the ALS was imposed and was down by only 2 percent by the fall of 1975, as shown in Table 6.

Two factors appear to account for the failure of the ALS to reduce evening traffic. In the first place, some commuters who changed their behavior in the morning did not do so in the evening, contrary to the RTAC's expectations. Considering vehicle-owning households only, the fraction of commuters to the zone who traveled in cars with fewer than four persons dropped only 17 percentage points in the evening, compared to a 21-point drop in the morning (compare Appendix A, Tables A-1 and A-2). More important, the fraction of car drivers working beyond the zone who traveled through it fell by only 10 percentage points in the evening compared with a 22-point drop in the morning. Furthermore, commuters who had changed their hours of travel in the morning did not appear to do so in the evening (*17*, pp. 155–156).

The second factor undermining the effect of the ALS in the evening was an apparent increase in nonwork trips to, from, or through the Central Area. To the extent that homebound commuters still shifted to bus or carpool or used routes around the Central Area in the evening, their places appear to have been taken by other types of vehicle trips.

Speeds and Travel Times. The ALS improved average traffic speeds within the restricted area but reduced speeds outside it (*17*). The reduction in auto commuting to the Central Area increased average morning speeds by 22 percent inside the restricted zone and by 10 percent on inbound radials. Speeds declined by 20 percent on the ring road, however, due to the increase in the number of through commuters using that route to bypass the restricted zone. Speeds in the evening peak presumably were unchanged, although no data were collected.

Average travel times for morning commutes to the restricted zone did not change appreciably, according to the World Bank's household surveys. Average commuting times for bus riders dropped by about 1 minute while the average commuting times for car drivers and car passengers increased by 1 and 2 minutes respectively (*17*, p. 131). A more detailed analysis matching modes used both before and after the ALS is even more discouraging, as shown in Appendix A, Table A-3. Those who commuted by bus after the ALS experienced increased travel times, even if they had been bus users before the ALS. Those who commuted by carpools after the ALS generally experienced increases in travel times as well, the most notable exceptions being former bus riders and some former carpool drivers. The sample size for some of these groups was small and thus the detailed results are not very reliable. Nevertheless, the overall impression is that the travel time benefits to commuters were modest at best, with some groups, particularly those shifting to bus, losing considerably.

Business Activity in the Central Area

Interviews with business people conducted by World Bank researchers immediately before and several months after the ALS was implemented suggest that the ALS had little immediate effect on business activity (*17*, pp. 210–227). Shopping was not thought to be greatly affected because most stores opened at 10:00 a.m. and peak shopping periods were in the midday and late afternoon. Office vacancy rates in the Central Area increased in 1975, but this was attributed to the recent completion of several major new buildings and to the recession that Singapore was experiencing that year.

Developments Since 1975

Singapore has modified its ALS many times since 1975 (see Appendix A, Table A-4). The reforms can be divided into three periods: 1975 to 1988, when the government adjusted the fees and the boundaries of the restraint zone several times, but otherwise left the scheme fundamentally unchanged (*19,23,24*); 1989, when evening restraints were introduced and the exemptions for carpools, trucks, and motorcycles were eliminated (*24–26*); and post 1989, when the government began planning the introduction of all-day and electronic road pricing (*25,28–31*).

Changes in Fees and Traffic, 1975–1988

Between 1975 and 1988, both the ALS fees and the zone boundaries were adjusted three times. In 1976, the daily license fee for privately owned cars and taxis was raised to S $4 and the fee for company-owned cars increased to twice that of a private car license (S $8 per day) to compensate for the fact that company licenses are a tax-deductible business expense. In 1977, taxi licenses were reduced to S $2 per day in response to pressure from the taxi industry and public complaints about lack of availability of taxis in the Central Area. In 1980, private and company car licenses were further increased to S $5 and S $10 per day, respectively. The restraint zone was expanded to include major new developments on its periphery in 1984, 1986, and 1989, so that by the end of the decade it covered an area of 725 hectares (2.8 mi^2).

Despite the fee increases, traffic entering the restricted zone during the morning restraint hours increased by 24 percent from late 1975 to 1988 (Table 7). The growth was uneven: entering traffic increased rapidly between late 1975 to 1982 and then declined from 1982 to 1988. The pattern followed roughly the course of the Singapore economy, which emerged from the 1975 recession late in the decade and then went back into a brief recession in the mid 1980s. During the period of rapid traffic growth (from late 1975 to 1982), three quarters of the traffic increase was due to vehicles other than autos. The traffic volumes entering immediately before and after the restraint hours also increased, although by fairly modest amounts. Even at its peak around 1982, however, entering traffic volumes were still well below pre-ALS levels.

The 24 percent increase in morning peak inbound traffic between 1975 and 1988 was remarkably small considering the trends in land use, auto ownership, and highway construction during those years. In the first place, a larger traffic increase might have been expected given the demographic changes that occurred in the restraint zone. Between 1972 and 1988, the residential population fell sharply while the number of jobs increased dramatically in the two traffic planning zones that correspond closely to the restraint zone. These shifts imply that the number of workers commuting into the restraint zone by all modes must have increased by at least 74 percent between 1972 and 1981 and at least another 27 percent from 1981 to 1988 (see Appendix A, Table A-5).

Auto ownership in Singapore also grew much more rapidly than the number of vehicles entering the restraint zone. Between 1974 and 1988, the number of vehicles of all types increased by 73 percent while the number of automobiles increased by 60 percent (Appendix A, Table A-6). Auto registrations increased faster than the population and the number of persons per car fell from 15 in 1974 to 11.1 in 1988. This growth in auto ownership occurred, moreover, despite a steady tightening of the measures to discourage auto ownership that had been originally introduced with the ALS (see Appendix B).

Finally, Singapore significantly improved its highway system during this period, which probably increased the incentives for Central Area workers to commute by automobile. By 1988, Singapore had completed 96 km (62 mi) of expressways criss-crossing the main island (Appendix A, Table A-6). The government also installed and gradually expanded a computerized system to monitor traffic, and to control and synchronize traffic signals within and near the Central Area. This system increased traffic speeds in and around the Central Area (*24*, pp. 17–19), and probably somewhat encouraged Central Area traffic growth.

Why did morning inbound traffic grow so slowly given these trends in land use, auto ownership, and highway improvement? Three factors appear to have moderated the traffic growth. First, the increases in ALS fees, though sporadic, were on average sufficient to keep pace with inflation. The real (net of inflation) cost of an ALS license was highest shortly after the 1976 and 1980 fee increases. Nevertheless, by 1988, despite 8 years without a fee increase, the ALS fee for autos was still 18 percent higher in real terms than in 1975, as measured by the Singapore consumer price index (*6*).

Second, mass transit services were improved significantly. Singapore opened its new Mass Rapid Transit rail system in stages between November of 1987 and 1990 (*16*). The 101-km (66-mi) system consists of two lines that connect the Central Area with several important new towns and shopping districts. Even more important was the rapid increase in the bus fleet (Appendix A, Table A-6), which reduced overcrowding and facilitated the expansion of express or premium bus services. The proportion of workers commuting to the Central Area by mass transportation increased from 46 percent in 1976 to 69 percent in 1983, although it then fell to 66 percent in 1988 (Table 8).

Finally, some of the highway improvements of the 1980s increased the effectiveness of the ALS by improving bypass routes. Particularly important in this regard is the East Coast Parkway, an expressway that opened in 1981 and provided an alternative route around the Central Area for vehicles traveling across the island. The computerized traffic system may have

TABLE 7

TRAFFIC ENTERING THE SINGAPORE RESTRAINT ZONE IN THE MORNING, 1975–1990

	7:00-7:30	7:30-10:15[a]	10:15-10:45
All vehicles			
March 1975 (pre-ALS)	9,800	74,014	n.a.
Sept.-Oct. 1975	11,073	41,198	13,925
Nov. 1976	10,639	43,593	14,971
Nov. 1978	10,634	48,358	14,875
Nov. 1980	11,612	56,395	16,094
Nov. 1982	10,590	57,893	16,817
Nov. 1984	10,304	57,744	14,080
Nov. 1986	8,957	50,950	14,988
Sept. 1988	9,476	51,054	15,523
Nov. 1989	8,582	43,711	13,950
Nov. 1990	6,498	42,795	12,992
Automobiles only			
March 1975 (pre-ALS)	5,384	42,790	n.a.
Sept.-Oct. 1975	6,640	11,363	6,529
Nov. 1976	5,910	10,529	6,966
Nov. 1978	5,632	11,700	6,418
Nov. 1980	6,001	14,337	6,807
Nov. 1982	5,639	15,596	7,081
Nov. 1984	5,776	16,911	7,414
Nov. 1986	5,120	15,635	6,738
Sept. 1988	5,685	16,637	7,185
Nov. 1989	4,642	20,127	5,725
Nov. 1990	5,129	18,732	5,274

[a]Restraint hours effective August 1975.
Sources: (*17*, pp. 44-51), (*14*, p. 33), (*15*, pp. 296-297), (*19*, p. 11), and published figures supplied by the Singapore Ministry of National Development, Public Works Department.

TABLE 8

MODE USED BY COMMUTERS TO SINGAPORE'S RESTRICTED ZONE, 1975–1988

Mode	Before ALS	1976	1983	1988
Automobiles	56%	46%	23%	23%
Bus	33%	46%	69%	55%
Rail transit	-	-	-	11%
Motorcycle	7%	6%	6%	8%
Other	4%	2%	2%	3%

Source: Home interview travel surveys as summarized by (*19*, p. 7) had a similar beneficial effect to the extent that it improved the performance of the inner ring road.

The 1989 Reforms and Their Effects

In 1989, stimulated by the resumption of rapid growth in vehicle registrations after the 1985–1986 recession, the government corrected two perceived shortcomings in the ALS. First, beginning June 1, 1989, licenses were required for vehicles entering the restraint zone in the evening as well as the morning peaks. Initially, the evening restraint hours were from 4:30 to 7:00 p.m. Mondays through Fridays; later in January 1990, the hours were cut back to 4:30 to 6:30 p.m. Restraints on vehicles entering during the evening were thought likely to be nearly as effective as restraints on exiting, and did not require new license sales points (*25*). The same ALS license was valid for both morning and evening restraint periods.

Second, licenses were now required for all but buses and emergency vehicles. The exemption for carpools was eliminated on the grounds that public transport service had improved significantly, especially after the opening of the rail system in 1987, and thus most carpool passengers were now thought to be diverted from mass transit rather than private cars. Commercial trucks, which had been a major source of Central Area traffic congestion since the ALS, were charged a fee of S $3 per day and motorcycles and scooters a fee of S $1 per day. Fees for private and company cars were reduced to S $3 and S$6 per day, respectively, since the expected reductions in truck and motorcycle traffic would allow for some increase in automobile traffic.

The reforms dramatically reduced traffic in both the evening and the morning restraint periods, as shown in Table 9. During the evening restraint period, entering traffic declined by 54 percent and exiting traffic declined by 34 percent between May 1989 (just before the reforms) and May 1990. Autos, trucks, and motorcycles were about equally affected, while taxi and bus traffic declined the least (Appendix A, Table A-7). Entering traffic also dropped 3.5 percent in the half hour immediately before the evening restraints, but increased by 12.4 percent in the half hour immediately following.

During the morning restraint hours, total entering traffic volumes dropped by 14 percent between May 1989 and May 1990. Trucks and motorcycles, which had not been subject to the fees before, dropped by 53 and 46 percent, respectively. Cars increased by 13 percent and taxis by 40 percent, as the effect of reducing their fees more than offset the effect of eliminating the exemption for autos and taxis carrying four or more persons (Appendix A, Table A-7). The fee reduction induced at least a 14 percent and perhaps as much as a 50 percent traffic increase, if the offsetting effects of eliminating the carpool discount are factored in. Unfortunately, there are no data available on autos carrying four persons or more for May 1990, after the 1989 reforms. In May 1989, before the reforms, 4,420 of the 17,551 cars entering the restraint zone were carrying four or more persons. If the elimination of the carpool exemption eliminated most four-person carpools, the increase in noncarpool traffic was 50 percent. The overall declines in morning and evening traffic were all the more striking in that they occurred despite a 12 percent increase in Singapore's gross domestic product and a 7 percent increase in auto ownership in 1989 (*26*, pp. 5–7). Traffic volumes have crept up only slowly in the 4 years since the reforms (Table 9), moreover, although this was due partly to the opening of the Central Expressway in September 1991, which provided yet another bypass around the restraint zone (*25*, pp. 14).

The 1989 reforms were not subject to as extensive an evaluation as the initial 1975 scheme, so fewer data on the changes in travel patterns and speeds are available. The reduction in evening traffic probably resulted from a combination of changes in mode, routes, and times of day of travel (*24*, *25*). Average speeds within the restraint zone increased by about 20 percent, to approximately 22 miles per hour (*15*, p. 297; *25*, p. 13), approximately the same speeds achieved immediately after the initial imposition of restraints in 1975. Speeds on the inner ring road decreased during the evening restraint hours, however, until late 1991, when the Central Expressway opened (*25*, pp. 25–26). There are, unfortunately, no data available on changes in travel times.

Plans for Electronic and Whole-Day Road Pricing

The 1989 reforms were introduced as interim measures, pending the introduction of a comprehensive electronic road pricing scheme planned for the mid 1990s. The initial intent is simply to substitute electronic controls for police officers at the entry points to the existing restraint zone (*5*, p. 57). In the long term, however, the government views electronic pricing as a means to vary charges more finely. It could charge according to the number of entries, for example, or vary the charge over the course of the restraint period, or create several restraint zones with different fees.

In 1990, the government called for bids to build and maintain an electronic pricing system using either read-only tags or read/write tags with smart cards. Ten consortia were prequalified and five submitted bids; none were accepted, however, as they did not meet the intent of the specifications. The specifications were revised in 1992, and five consortia submitted new bids. The bid prices for the capital (installation) cost ranged from S $193 million to S $514 million (US $106 million to US $283 million), while those for 5 years of maintenance ranged from S $23 million to S $96 million (US $13 million to US $53 million). Because of the wide range of bids and technologies, the government negotiated with three of the five bidders to participate in a demonstration of read/write tags with smart cards. Each of the bidders will receive S $1 million to equip 100 vehicles with its tags and install the needed roadside equipment at one entry point to the restricted zone. At the end of the demonstration in October 1994, the three teams are to submit their best and final bids for a complete system (*29*).

By 1993, the growth of traffic entering the restraint zone during the midday had reached a point where the government felt it could not delay midday restraints until the new electronic pricing system was in place. Volumes of entering traffic were significantly higher in the midday than during restraint hours (*30*), and midday speeds had dropped to 15–25 kmph compared to 30–37 kmph during restraint hours (*25*, p. 14).

TABLE 9

TRAFFIC ENTERING AND EXITING THE SINGAPORE RESTRAINT ZONE BEFORE AND AFTER THE JULY 1989 REFORMS

	Morning hours:			Evening hours:			
	7:00-7:30	7:30-10:15[a]	10:15-11:00	4:00-4:30	4:30-6:30[b]	6:30-7:00	7:00-7:30
Entering restraint zone							
May 1989	9,717	51,817	22,130	12,859	51,500	11,694	10,614
Aug. 1989	9,425	43,173	21,453	12,691	27,356	6,125	11,154
May 1990	9,659	44,838	21,800	12,410	23,781	13,142	10,973
May 1991	8,684	46,167	20,853	12,826	26,366	12,999	10,561
May 1992	9,341	48,925	21,850	12,970	26,935	15,323	12,944
May 1993	8,442	48,785	21,676	12,842	28,594	13,449	12,020
Exiting restraint zone							
May 1989	4,832	33,018	15,585	11,937	57,540	13,809	12,387
Aug. 1989	4,936	27,744	12,700	11,278	38,461	8,788	9,233
May 1990	4,380	27,654	12,462	11,350	37,890	10,011	9,680
May 1991	4,899	32,017	13,892	12,263	41,560	11,471	11,630
May 1992	5,000	33,820	14,126	12,773	44,234	13,576	12,334
May 1993	5,613	34,082	15,352	12,291	40,091	12,029	10,958

[a]Restraint hours throughout period.
[b]Additional restraint hours effective January 1990.
Source: (*25*, p. 29).

Therefore, a new scheme, which went into effect on January 3, 1994, extends the hours of restriction to 7:30 a.m. to 6:30 p.m. on weekdays and 7:30 a.m. to 3:00 p.m. on Saturdays. It creates two classes of special area license: whole-day and part-day. Vehicles with a whole-day license can enter at any time during the restraint period, while vehicles with a part-day license can enter only from 10:25 a.m. to 4:30 p.m. on weekdays and from 10:15 a.m. to 3:00 p.m. on Saturdays. The prices of the whole-day licenses are the same as the previous daily license (S $6 for company cars, S $1 for motorcycles, and S $3 for all other vehicles), while prices for part-day licenses are two-thirds as high.

The government has promised that the special registration fees and other measures used to restrain the growth in auto ownership will be relaxed if the new whole-day restraints are effective in reducing midday congestion. The new whole-day program is so recent, however, that its effects have still not been evaluated.

Lessons from Singapore's Experience

Singapore's experience offers both encouraging and cautionary lessons about the potential for congestion pricing. Perhaps the most encouraging result is that congestion pricing can cause large reductions in vehicle use. The S $3 per day fee imposed in 1975 represented a significant increase in auto commuting costs at the time, which were only about S $0.085 per kilometer for out-of-pocket costs plus S $20 to S $30 per month for parking (*32*, p..196; *17*); the fee induced an equally dramatic 75 percent reduction in auto traffic entering during the morning restraint hours. Similarly, the S $3 fee imposed on trucks in 1989 induced a 53–60 percent drop in entering traffic. The response to the 40 percent reduction in auto fees in 1989 offers further evidence that traffic is highly responsive to pricing.

Singapore's experience also suggests that traffic reductions can be sustained over time. The increases in ALS fees and improvements to public transport and by-pass roads helped to hold down the growth of traffic entering the restraint zone in the morning despite large increases in total commuting to the Central Area and in auto ownership.

Equally important, Singapore's ALS demonstrates that congestion pricing need not involve enormous initial or operating costs. Singapore's scheme required very small capital costs, and the expenses for selling licenses, enforcement and maintenance were only nine percent of annual license revenues in 1992 (Table 10).

A final encouraging lesson is that congestion pricing is not a bar to increased business activity in the restraint zone. The effects of the ALS on Central Area business activity are hard to determine because so much else has changed in Singapore's

TABLE 10

REVENUE AND OPERATING EXPENSE OF THE ALS, 1992

	Singapore dollars (thousands)	U.S. dollars (thousands)
Revenue		
Sale of licenses	38,000	20,900
Operating Expense		
Policing	1,710	940
License sales	1,797	988
Subtotal	3,542	1,948
Net operating revenue	34,458	18,952

Source: unpublished figures supplied by the Ministry of National Development, Public Works Department.

economy since 1975. Nevertheless, there were few discernable effects immediately after restraints were imposed and Central Area employment has grown considerably since. The rate of employment growth has been slower in the Central Area than in Singapore as a whole (Appendix A, Table A-5), but some decentralization of employment growth was probably inevitable and desirable in such a rapidly growing city.

The principal cautionary lesson from Singapore's experience is that congestion pricing may not improve the performance of the transport system unless the pricing scheme is carefully designed and implemented. The results immediately following implementation of the ALS in 1975 show how this can happen: Average travel times for commuters to the restraint zone changed very little, while some commuters were inconvenienced by changing the times they traveled and other travelers not destined for the restraint area were delayed by increased congestion on the ring road. These results have led several analysts to argue that, as a whole, travelers were probably made worse off immediately after the scheme was implemented (*15,32–34*). Such a conclusion is very plausible if one ignores the financial profit to the government from the scheme. Even if the government's financial profit was somehow returned to the travelers, however, they might still be worse off because the scheme, at least initially, did not result in any overall reduction in travel times.

Most analysts blame a combination of too high an ALS fee and insufficient transit options for the disappointing travel time savings in 1975 (*17*, pp. 165–167; *32*, p. 208; *15*, pp. 294–296). According to this argument, a lower fee would have meant a smaller improvement in traffic speeds within the Central Area, but more motorists would have enjoyed the improvements and fewer commuters would have suffered the potential inconveniences of mode, route, and time-of-day changes. Bus services were probably inadequate, given that travel times did not improve for commuters who used the bus both before and after the ALS was implemented. The lack of improvement probably reflected additional boarding delays caused by overcrowding buses as well as traffic congestion on the ring roads.

The disappointing travel time improvements of 1975 may also have been due in part to flaws inherent in the simple scheme initially adopted. It is difficult to avoid increases in traffic immediately before and after restraint hours, for example, if a single fee is charged for the entire restraint period. Similarly, it is difficult to avoid increased congestion on the periphery if a single restraint zone is used. These compromises were necessary to make the scheme simple to administer and enforce, and Singapore designed and adjusted its restraint hours and boundaries with these problems in mind. Nevertheless, some increases in congestion immediately before and after restraint hours and on the periphery were probably inevitable given the nature of the scheme.

Many of these problems appear to have moderated since 1975, increasing the chances that travelers are now, on the whole, better off with the ALS than they would be without it. The modest increase in entering traffic from late 1975 to 1988 probably was desirable, for example, given that street space in the restraint area was underused in late 1975. The increase in the number of buses and the opening of Singapore's rail system reduced bus overcrowding and may have greatly improved the convenience of the transit alternative (*16*, p. 245). Finally, the opening of the East Coast Parkway and Central Expressway and the installation of computerized traffic controls on the inner ring road almost surely alleviated the congestion problems on the periphery of the restraint zone.

The planned procurement of an electronic charging scheme will provide Singapore with further opportunities for improving its scheme. Indeed, the principal attraction of electronic pricing is its ability to correct some of the problems caused by the simple zone and fee system currently in place. If the results of the latest round of bidding are a reliable guide, capital costs will be much higher than the 1975 investment and annual operating expenses will approximately double. This may, nevertheless, be a reasonable price to pay for the added flexibility provided by the electronic system.

HONG KONG'S ELECTRONIC ROAD PRICING PILOT SCHEME

Hong Kong is a British colony on the south coast of China which, under an agreement signed in 1984, is to become a Special Administrative Region of the Peoples' Republic of China on July 1, 1997. The colony includes the Kowloon Peninsula and numerous islands, the most important of which is Hong Kong Island.

Hong Kong's transportation system, like Singapore's, has been affected by restricted geography and rapid economic growth. Real per capita incomes have approximately doubled every decade since 1970, as Hong Kong has become a major regional center for trading, finance, and commerce. Most of this activity is concentrated in only 96 km^2 (37 mi^2) of urbanized area, however, since the remainder of Hong Kong's land area of 1070 km^2 (413 mi^2) consists largely of steep hills or uninhabited islands (*35*). Nearly 4 million people live and work on the north shore of Hong Kong Island, on the tip of the Kowloon Peninsula, and in a rapidly developing hinterland to the north known as the New Territories.

Between 1983 and 1985, the Hong Kong government conducted an extensive evaluation of a proposal for congestion pricing called the Electronic Road Pricing (ERP) Pilot Scheme. Under the proposal, state-of-the-art electronic equipment was to be used to identify and charge automobiles that crossed a series of cordons surrounding the dense commercial districts on the tip of the Kowloon Peninsula and the north shore of Hong Kong Island. The planning studies revealed that ERP would generate large travel time savings, and field tests demonstrated that the electronic equipment was reliable. Nevertheless, popular opposition eventually forced the government to abandon the scheme.

Origins of the ERP

Hong Kong's first Comprehensive Transport Study was commissioned in the early 1970s in response to several years of rapid economic growth and increasing traffic congestion. The plan was completed in 1976 and endorsed, after public consultations, in a 1979 white paper. It called for a three-pronged attack on Hong Kong's transport problems. First, the government would invest heavily in highway infrastructure, including several new expressways. Second, public transport, on which 90 percent of Hong Kong's residents relied, would be improved, in part by building a new subway system and electrifying an existing commuter rail line. Finally, better use of scarce roadway capacity would be encouraged by restraining the use of private automobiles and giving priority to commercial goods and public transport vehicles.

Efficient roadway use was important, the planners argued, because three-quarters of Hong Kong's roadway capacity was then being used by private cars and taxis, which carried only one-quarter of the roadway passengers (*36*, p. 204). Moreover, it was physically, financially, and environmentally impossible for Hong Kong to build enough new roadways to accommodate the projected demand in private motoring. However, direct measures were eschewed. Parking controls were rejected because of doubts about their effectiveness in curbing congestion and because controlling private nonresidential spaces would be difficult. A supplementary licensing scheme like Singapore's was likewise rejected as too difficult to implement given Hong Kong's complex road system and the lack of bypass routes. Instead, the Comprehensive Transport Study's planners endorsed fiscal policies to discourage auto ownership as the least undesirable option for restraining private traffic growth.

A package of fiscal measures was finally adopted in May 1982, after the rate of growth in Hong Kong's auto fleet had risen to 12 percent per year. The initial registration taxes for new automobiles and motorcycles were doubled to 70 to 90 percent of the import price (depending on engine size). Annual license fees for private automobiles were tripled, while gasoline taxes were doubled (to HK $1.40 per liter or US $0.68 per gallon). The annual license fees were further increased soon after in 1983, to offset a shortfall in other government revenues caused by the recession of 1982/1983. In combination, these measures increased the real (net of inflation) cost of owning and operating a typical family car by 35 percent (*37*, p. 2.32).

The new auto taxes rekindled interest in congestion pricing as an alternative. Hong Kong's Legislative Council, a body at that time appointed by the British governor (*38*, p. 39), complained that the government should consider less "blunt and inequitable measures" than the new taxes (*37*, p. 1.2). The fiscal measures proved less effective in controlling traffic congestion than had been hoped, even though they severely inconvenienced car owners and car dealers. The combination of the auto taxes and a recession caused a 42 percent decline in the number of registered private automobiles between 1981 and 1984. Auto ownership declined most among lower income households, however, who drove their cars less and tended to live in the outer New Territories; as a result, auto travel fell by only 22 percent in the colony as a whole and less in the central congested areas. Total traffic also continued to increase, in part because some Hong Kong residents evaded the new auto taxes by buying vans and registering them as commercial goods vehicles; 90 percent of new vans were registered as commercial vehicles after the tax increases, whereas only 30 percent had been registered as commercial before (*37*, pp. 2.32–2.35).

The controversy stimulated a government review of traffic restraint measures, which concluded that electronic pricing might be technically feasible given advances in microelectronics since the 1976 transport study. In March 1983, the Hong Kong government contracted with Transpotech, a firm established by the British government to offer the consulting expertise of its Transport and Road Research Laboratory, for a 2-year detailed evaluation of the potential of ERP. The evaluation included both a field trial of the technology and the development and assessment of alternative schemes for full-scale implementation (*37,39–45*).

The Results of the ERP Pilot Scheme

The recommended technology incorporated a read-only tag, which the consultants called an electronic number plate (or ENP). The ENP was about the size of a video cassette and would be attached to the bottom of a vehicle chassis. The cordon points would be equipped with inductive loops and antennas imbedded in the pavement. The low-frequency radio waves generated by the loops would provide power for the ENP, which needed no battery, to send a signal to the antenna with the vehicle identification number. Closed circuit cameras would photograph the license plates of vehicles without an ENP for later enforcement. An automated accounting system would prepare a monthly bill for each motorist.

The consultants assumed that only private automobiles would be charged in a full-scale system, in accordance with the priorities established in the 1976 transport study and the government's 1979 white paper. They recognized that a case could be made for charging other types of vehicles as well, particularly taxis, which were about as inefficient users of road space as automobiles, and commercial trucks, whose numbers were increasing rapidly. In the near term, however, taxis and trucks were to be exempt. Trucks were important to commerce, they argued, and the number of taxis could be directly controlled by government licensing. Including taxis would also raise difficult questions of how to pass the charges on to customers, and might threaten the livelihood of taxi drivers (*37*, pp. 2.53–2.55).

TABLE 11
PREDICTED EFFECTS OF ERP SCHEMES AND CAR OWNERSHIP RESTRAINT ON 1991 HONG KONG TRAVEL

	ERP scheme A	ERP scheme B	ERP scheme C	Car ownership restraint
Design of restraint scheme				
Number of zones	5	5	13	
Charging points	130	115	185	n.a.
Peak direction surcharges	no	yes	yes	n.a.
Motorists average monthly bill (HK $); without any reduction in auto ownership taxes	120	140	160	495
Changes in overall travel demand				
Car trips, peak	-20%	-21%	-24%	-21%
Car trips, all day	-9%	-11%	-13%	-20%
Public transport trips, all day	+2%	+3%	+3%	+2%
Changes in travel behavior for car trips (all day)				
Wholly uncharged (outside cordons or charged time)	41%	41%	41%	0%
"Stay and pay"	45%	42%	40%	80%
Change time	5%	5%	6%	0%
Change mode	9%	11%	13%	20%[a]
Economic gain or loss from changes in travel time and convenience (HK $ millions/year)				
Cars	202	235	216	-29
Taxi	53	61	68	38
Public transport	299	350	389	158
Goods vehicles	180	225	246	134
Total	734	871	919	301
Gross revenue (HK $millions/year)	395	465	540	1200

Source: (*37*, pp. 2.69, 2.70, 2.74 and 2.79)
[a] Includes reductions due to trips foregone altogether as well as to mode shifting.

Different cordon crossing charges would be assessed during five time periods each weekday. The highest charges would be during the two morning and evening peak periods (8:00 to 9:30 a.m. and 5:00 to 7:00 p.m.). Lower charges would be assessed during two "shoulder peak" periods (7:30 to 8:00 a.m. and 7:00 to 7:30 p.m.) and during the interpeak period (9:30 a.m. to 5:00 p.m.). There would be no charge for crossing a cordon between 7:30 p.m. and 7:30 a.m. or on Saturdays and Sundays.

Three alternative cordon schemes, each with different charge levels, were evaluated (Table 11). Scheme A was relatively simple and had the lowest charge levels. Its cordons created five cells, three on Kowloon and two on Hong Kong Island (Figure 3). On the Hong Kong side several cordon "tails" extended beyond the cells to discourage motorists from traveling along the outer edge of the cell. Charges varied by cordon, and commuters might cross several cordons to complete a trip. For example, a commuter traveling from the New

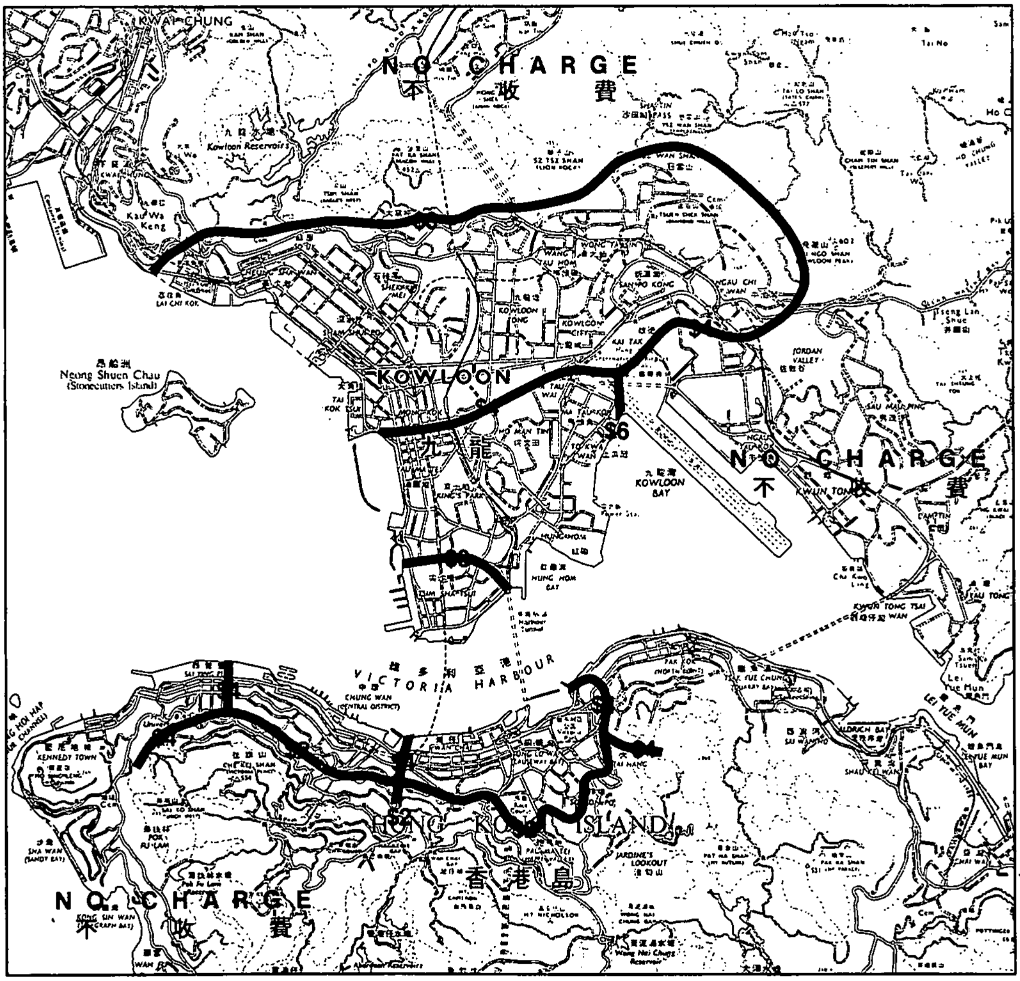

FIGURE 3 Hong Kong's ERP Scheme A.

Territories to the tip of the Kowloon Peninsula would cross three cordons and pay a total of HK $13 (then US $1.67) in the peak, HK $6 (US $0.77) in the shoulder peak, and HK $8 (US $1.02) in the interpeak period.

Scheme B also had five cells, but covered a slightly larger area on the Hong Kong Island side so that the cordon tails could be eliminated (Figure 4). Scheme B also differed in that surcharges of HK $1 to HK $2 were added to peak-period cordon tolls for vehicles crossing in the peak direction. Due to a combination of these directional surcharges and higher charges in the interpeak period, the average monthly bill for a motorist was expected to be slightly higher: HK $140 (US $17.95) under Scheme B compared to HK $120 (US $15.38) under Scheme A.

Scheme C was the most complex, covered the largest area, and had the highest overall charge levels. The cordon lines created 13 cells, and directional surcharges were again added in the peak (Figure 5). Because of the more extensive geographic coverage and the more fine-grained cells, the average monthly bill for a motorist was expected to be HK $160 (US $20.51).

The consultants predicted the effects of these schemes on 1991 traffic flows using a travel simulation model. The model assumed that the ERP would change the modes travelers used and the time of day they traveled, but not the routes they used (since the cordons intercepted virtually all routes). The assumed willingness of travelers to change mode was based on a conventional mode split model calibrated using 1981 Hong Kong travel data. Their assumed willingness to shift time of day was based on special panel surveys in which Hong Kong motorists were asked how they would respond to ERP changes that varied by time of day (*37*, pp. 2.9–2.10; *44*).

The consultants predicted that the three ERP schemes would reduce car trips by 9 to 13 percent all day and by 20 to 24 percent in the peak (Table 11). As expected, Schemes B and C achieved slightly higher reductions in car usage than Scheme A because of their more extensive geographic coverage and higher charges. Forty-one percent of all car trips would be unaffected by the ERP schemes because they did not enter the cordon areas or did so after charging hours. Between 40 and 45 percent would pay the charges but not alter their behavior; 5 to 6 percent would change travel times, and 9 to 13 percent would shift modes.

In addition to the three ERP schemes, the consultants evaluated restraints on auto ownership designed to generate similar reductions in overall private auto use. The restraint policy considered was an increase of HK $10,000 (US $1,282) in the annual license fee, which the consultants predicted

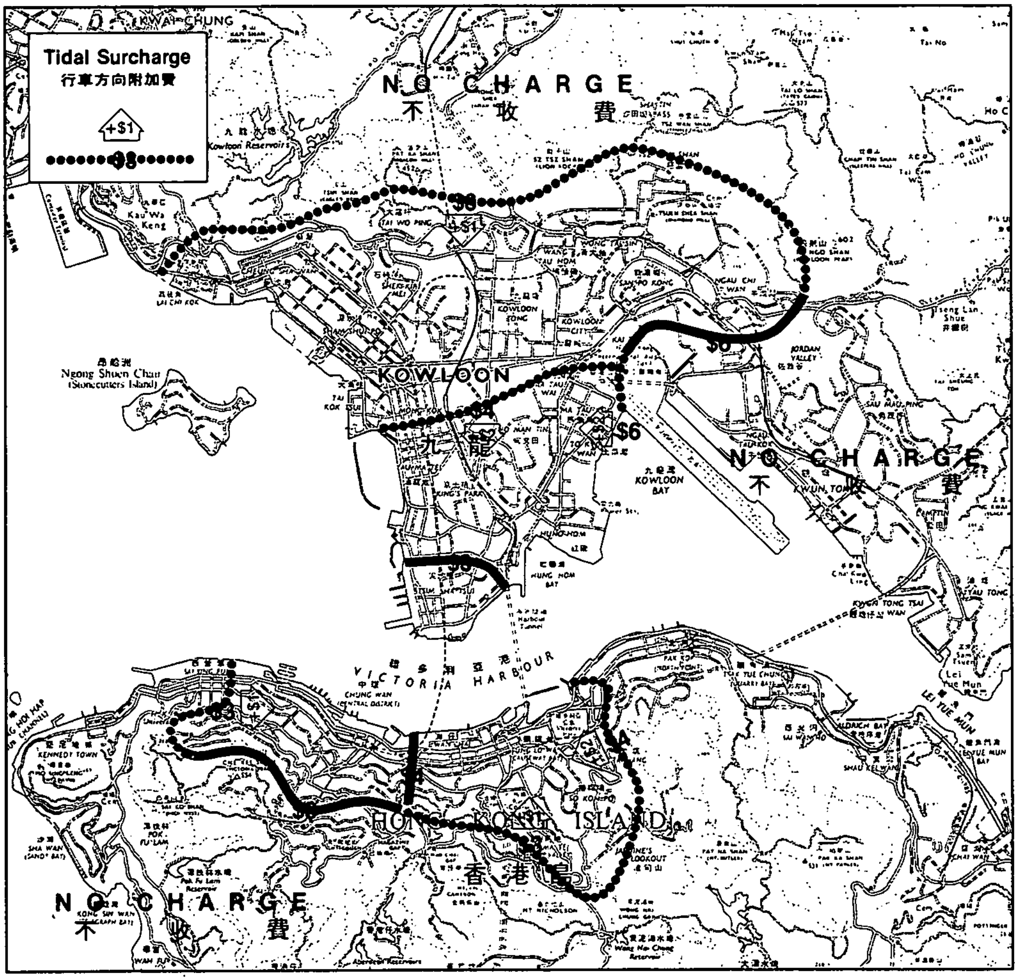

FIGURE 4 Hong Kong's ERP Scheme B.

would decrease auto ownership to 200,000 vehicles from the 275,000 vehicles forecast in 1991. The car ownership restraints were predicted to reduce traffic 20 percent all day and 21 percent in the peak. Motorists who gave up their cars were expected to shift modes or to forego certain trips all together.

The estimated economic value of the time saved by travelers, less the inconvenience of shifting modes, ranged from HK $919 million (US $118 million) per year for Scheme C to HK $301 million (US $38.6 million) per year for the auto ownership restraints (Table 11). Taxi and public transport riders all would benefit from reduced travel times in the peak. Car users who "stayed and paid" would benefit from the reduced travel time as well, although they would also have to pay between HK $395 million (US $50.6 million) to HK $540 million (US $69.2 million) in cordon tolls to do so. Car users who shifted to other modes or times of day would suffer some inconvenience.

As expected, the car ownership restraints were estimated to produce far fewer economic benefits than any of the ERP schemes, largely because the ownership restraints would discourage traffic at all times and places while the ERP schemes would discourage traffic only at the times and places where congestion was severest. Somewhat surprisingly, however, the added economic benefits from increasing the complexity and geographic coverage of the ERP schemes were modest. Compared with Scheme C (the most complex), Scheme A generated only 20 percent fewer benefits while Scheme B generated only 5 percent fewer benefits.

Several months of field trials demonstrated that the ERP Schemes were technologically feasible. ENPs were installed on 2,500 vehicles owned by government agencies and by private individuals and firms who volunteered to participate. Loops and antennas were installed at 20 sites in congested areas and connected to a central computing facility that automatically monitored their performance, collected data on vehicle crossings, and generated prototypes of the monthly bills that would have been sent in a real application.

Based on the field trials, the consultants estimated that the full-scale system would require an investment of HK $240 million (US $30.8 million) and annual operating expenses of HK $20 million (US $2.6 million). Approximately 41 percent of the investment (HK $99 million) was for buying and fitting

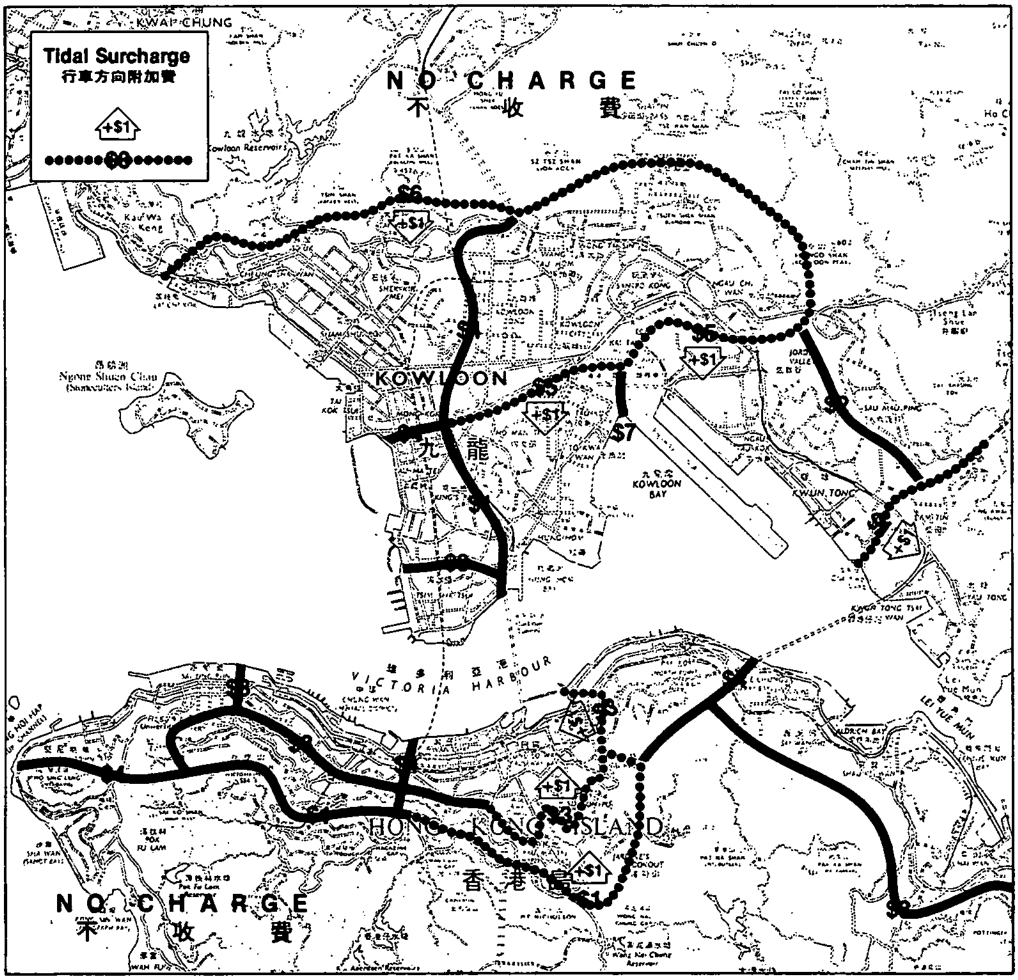

FIGURE 5 Hong Kong's ERP Scheme C.

ENPs to 210,000 vehicles, at an average cost of HK $471 (US $60) each. The balance of the investment was required for the loops, antennas, and cameras at the toll sites; for hardware and software at the control and accounting center; and for publicity and contingencies (*37*, pp. 4.35–4.40). These investment and operating costs were small relative either to the annual toll revenues or to the annual economic benefits generated by the ERP Schemes (Table 11).

Popular Rejection of the ERP

The ERP proposal drew sharp criticism and very little public support, particularly when the government consulted its 19 District Boards about the scheme. The boards had been created in the 1970s to advise the government on district matters. Originally, all the board members were appointed by the government but, beginning in 1982, a portion were popularly elected—the only popularly elected officials in Hong Kong at the time, and jealous of their independence (*38*, p. 4). When the government first discussed ERP with the boards in late 1984 and early 1985, before the study was complete, only 2 of the 19 endorsed the scheme. A more serious round of consultations was held after June 1985, when a 40-page *Results Brief* was released to the public based on the consultant's completed report. Of the 11 boards that voted on the proposal, nine voted against it and two voted for delay. The remaining eight boards were all thought to be opposed or neutral at best (*38*, p. 40).

The rejection was due in part to unfortunate timing. The consultations with the district boards occurred soon after the British government had signed the agreement to transfer the colony to China in 1997. In preparation for the transfer, the colonial administration planned to strengthen democratic institutions by consulting more closely with the district boards and by providing for the election of a portion of the Legislative Council (a change that occurred in September 1985). The ERP was the first major issue that the government brought to the district boards after the signing of the agreement, and some observers argue that the boards wanted to demonstrate to the public that they were taking their new responsibilities seriously (*38*, p. 41). Equally important was the resentment that the boards had not been closely consulted in the past, especially over the transfer of the colony to China.

A further factor was that auto ownership and use had declined sharply since 1982, making the ERP seem less necessary (*45*, pp. 83–85). The consultants' forecast that auto ownership would increase to 275,000 cars by 1991 seemed less credible given that car ownership had fallen from 190,000 just before the 1982 tax increases to 148,000 in late 1984 (*37*, p. 2.35). Moreover, the continuing construction of new rail rapid transit lines and highways promised further relief from traffic congestion without resorting to an ERP scheme.

The government also made some tactical errors in developing and presenting the proposals (*36*, p. 211; *46,47*). The main consultants' report was not released to the public, for example, which made it difficult to check the accuracy of the forecasts. Moreover, the *Results Brief* released in June 1985 did not provide practical and understandable illustrations of how much different types of travelers might benefit from the ERP scheme. The selection of a British consultant for the study and the use of an ENP technology patented by a British firm (Plessey) was widely viewed as insensitive (*36*, p. 211). The government also chose for its first consultation a district board next to the downtown, where anxiety about the ERP plan was high, and the board voted unanimously against it.

Sanford Borins (*38*) and others (*45*) have suggested that the proposal might well have failed even if the timing and tactics had been better, given the strength and the nature of the objections from motoring interests. One objection raised frequently was that the monitoring of vehicle movements through ENPs and the photographing of vehicles for enforcement was an invasion of privacy. The government attempted to overcome this concern by offering a variety of safeguards, including promises that the data would remain confidential and would be destroyed after 3 months, and that motorists would have the option of receiving bills that did not itemize specific cordon crossings. These safeguards failed to reassure motorists, however, perhaps because the transfer of the colony to the Chinese government was only a few years off. The smart card tolling technology, which makes government records of travel patterns unnecessary, was not sufficiently developed at the time to be offered as an option.

Motoring interests also argued that charging only private cars made the scheme both unfair and ineffective. The exemption of taxis drew special criticism. The Crown Motor Company, a large car dealer that helped organize the opposition, undertook a survey in August 1984; it reported that private cars constituted only 26 percent of the traffic entering the central areas during peak hours, while taxis and buses were 54 percent and goods vehicles 20 percent (*45*, p. 85). The government's announced goal of reducing entering traffic by 10 percent therefore would require a 40 percent reduction in private auto use, a difficult goal to attain. The government disputed the Crown Motor figures, arguing that its surveys showed private cars accounted for 38 percent of entering traffic and that autos' share would further increase by 1991. Nevertheless, private car owners felt, with some justification, that they were being unfairly singled out as the primary culprit for traffic congestion.

Private car owners were also suspicious that the government was interested in ERP largely as a revenue raising device (*48*, p. 64; *47*, p. 211). Indeed, the consultants' own figures showed that auto owners as a group might well be worse off with ERP than without it, if the government retained the toll receipts for other purposes. Under Scheme B, for example, car users as a group would gain HK $235 million (US $30 million) per year in net travel time savings and convenience but they would pay HK $465 million (US $59.6 million) per year in cordon tolls (Table 11). Late in the consultation process, the government proposed to offset the toll receipts with a reduction in the annual license fee charged car users, so that the scheme would be revenue neutral and car owners as a group would be better off. This promise was apparently not believed, in part because the concession came so late and in part because the government had in 1983 demonstrated its willingness to increase annual license fees to cover its budget shortfalls.

The government half-heartedly attempted to revive interest in ERP in the late 1980s as part of its Second Comprehensive Transportation Study. The second study, completed in 1989, considered "area pricing" among various options for restraining auto use. The area pricing scheme considered was in fact a minor variant of Scheme B from the ERP pilot study, renamed to avoid the public hostility that the term ERP now generated (*36*, p. 212). Perhaps recognizing political realities, the final report of the Second Comprehensive Transport Study recommended only that area pricing be "reinvestigated" and that the possibility of charging types of vehicles other than private autos be considered (*49*, p. 48). After public consultations on the results of the study, the government released a new white paper in 1990 to govern its future transportation policies. The white paper noted that the privacy objections to area pricing probably could be overcome by emerging smart-card technologies. Area pricing would be retained only as a "longer term option," however, and the government would monitor the future developments of the pricing technologies and the experiences of other cities (*35*, p. 39).

Lessons from Hong Kong

The Hong Kong pilot scheme was the first practical demonstration of the technological feasibility of large-scale electronic road pricing. Some critics objected that the field trials never tested the ability of the central control and accounting system to handle the enormous number of daily transactions that would be involved in a full-scale system. Nevertheless, the ENPs and the roadside inductive loops and antennae performed reliably in a wide variety of traffic and roadway conditions.

The results of Hong Kong's planning studies also suggested that the ERP scheme need not be very complex to generate significant travel improvements. Hong Kong's officials cited enforcement problems with numerous entry points as the primary reason for using electronic road pricing rather than Singapore's simple paper licenses. Electronic pricing probably would have been necessary in Hong Kong for other reasons, however; in particular, the single cordon and single charge level used in Singapore probably would have caused serious problems given Hong Kong's more extensive congested area and its lack of by-pass routes. But although one cordon might have been insufficient, the simple five-cell Schemes (A) and (B) were sufficient to capture most of the possible benefits in Hong Kong.

The most important lesson from Hong Kong, however, is the need to anticipate and resolve likely objections early in the planning process. The motoring interests raised understandable concerns, some of which probably could have been overcome had the planners been more sensitive to them from the start. The potential invasion of privacy was arguably the most difficult objection to overcome given the electronic pricing technologies available at the time and the pending transfer of the colony to China. The inequity and inefficiency of charging only private automobiles could have been dealt with by imposing charges on taxis and perhaps commercial trucks, with an increase in the Scheme's effectiveness as well as fairness.

The most egregious mistake, however, probably was the failure of the government to commit at the outset to reducing Hong Kong's high annual vehicle license fees. In the absence of such a reduction, or some other tangible and credible plan for redistributing the revenue to the public, car owners who traveled frequently to the congested areas and who did not value highly the travel time savings from reduced congestion could only expect to be made much worse off by the introduction of road pricing. By way of contrast, a revenue-neutral scheme would have left car owners as a group better off without undermining greatly the congestion reductions induced by pricing incentives.

CHAPTER FOUR

THE SCANDINAVIAN TOLL RINGS

The first of the toll rings that surround several Scandinavian cities opened in 1986 in Bergen, Norway's second most populous city. The toll ring idea spread to Oslo, Norway's capital, in 1990, and to Trondheim, Norway's third largest city, in 1991. A toll ring is also the central component of a pricing package agreed on in 1993 for Stockholm, Sweden.

The Scandinavian toll rings do not represent congestion pricing in the strict sense of the term. The primary motivation of the three Norwegian toll rings was not to reduce traffic congestion but rather to generate revenue to finance desired improvements in local transportation infrastructure. As a result, tolls on the rings are low, ranging from approximately $0.70 to $1.75 per entry, and do not vary much by time of day. Furthermore, the locations of toll stations were chosen not to facilitate congestion management, but rather to capture a large portion of the region's trips, to achieve a rough distributional balance among residents of city and suburban jurisdictions, and to alter people's trip-making behavior as little as possible.

Revenue generation is also a controlling factor in the design of the proposed Stockholm toll ring. Although traffic reduction for environmental reasons is also an explicit objective, congestion management is a lower priority. As a result, Stockholm does not plan to vary its tolls by the level of congestion or time of day.

Nevertheless, the Scandinavian toll rings are included in this survey because they offer important lessons for congestion pricing. They are the first citywide applications of road pricing outside of Singapore. They are also virtually identical to a cordon scheme for congestion pricing, excepting only that their toll rates do not vary greatly with time of day or congestion levels. As a result, the Scandinavian toll rings test many of the practical problems of implementing large-scale cordon pricing.

In addition, each Scandinavian toll ring has been more technologically sophisticated than its predecessor. Economical toll collection in built-up areas requires minimizing the number of manual toll transactions, and the Scandinavians have developed and tested a variety of technologies, subscription plans, operational procedures, and enforcement mechanisms. Two of the three Norwegian toll rings use electronic toll collection systems, and the Swedes plan an even more sophisticated electronic system. This gradual increase in sophistication illustrates many of the key details involved in implementing a large-scale urban congestion pricing scheme. Indeed, the technologies adopted for the toll rings in Oslo, Trondheim, and Stockholm could be readily adapted to use for congestion management, and this possibility is under continuing discussion in all three cities.

BERGEN

Bergen's local authorities inaugurated its toll ring, despite considerable skepticism among residents, to finance needed road improvements throughout the urban area (*50–52;5*, Annex 2). The national government provided an added inducement by agreeing to raise its usual 50 percent contribution to 75 percent for road improvements financed by the new scheme. Car drivers are charged the equivalent of NOK 5 ($0.80) to enter the central area, except during late-night hours (after 10 p.m.) and on weekends when entry is free; heavy vehicles are charged twice the rate of cars and scheduled buses are exempt (*51*). Figure 6 and Table 12 present the locations of and basic facts about the Bergen ring and the two later Norwegian toll rings.

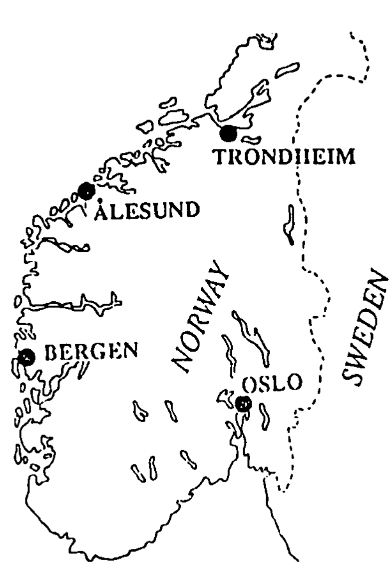

FIGURE 6 Road toll projects with no-stop payment lanes in Norway *(52)*.

Recognizing that urban toll collection for an entire city would be feasible only if a substantial portion of people paid their toll nonstop, Bergen adopted a simple subscription option in which a prepurchased seasonal pass allows unlimited travel for a given vehicle for a specified period (1 month, 6 months, or 1 year). The pass, visible through the windshield, permits the driver to pass through a dedicated nonstop lane. Manual toll collection is available for nonsubscribers. About 60 percent of all crossings are with passes (*52*).

Implementation of the toll-ring concept was facilitated by the very small number of access routes to the central city, three of them being bridges. There are just seven toll stations, as shown in Figure 7, and these operate weekdays from 6 a.m. to 10 p.m. (The seventh was added in 1992 when a new tunnel west of the city was opened.) The seven stations handle about 70,000 vehicles per day. Manual payments are made to an attendant, while vehicles with seasonal passes travel nonstop through a subscription lane. Toll collection does not cause much queuing except on the first working day of each

TABLE 12

OVERVIEW OF NORWAY'S TOLL RINGS

	Bergen	Oslo	Trondheim[a]
Urban area population, '000s	300	700	136
-- % inside toll ring	10	28	40
Starting date of toll ring	Jan 2,1986	Feb 1,1990	Oct 14,1991
Number of stations	7	19	11
Entry fee for cars (NOK):[b]			
Single trip (manual or coin)[c]	5	11	10
Per trip (subscription):[d]			
With postpayment[e]	NA	NA	8
With prepayment[f]	4.50	7.43	7
Off-peak discount[g]	NA	NA	2
Monthly pass[h]	100	250	NA
Times charges are in effect:			
Days	Mon-Fri	all days	Mon-Fri
Hours	6am-10pm	all hours	6am-5pm
Average daily crossings during toll hours, 1992 ('000s)	68	204.4	40.5
% by subscription	59	63	85
1992 gross revenue, NOK millions	63	628	70.7

[a] Figures exclude the pre-existing Ranheim toll station, which has higher rates (not shown) applicable in both directions and at all times.

[b] For 1992. Exchange rate: NOK 1 = $0.16.

[c] Bergen: all stations manned. Oslo: all stations manned, 8 also have coin lanes. Trondheim: 1 station manned, others coin or magnetic card only.

[d] In Trondheim, subscribers are charged for no more than one trip per hour, and no more than 75 per month. Trondheim subscription rates rose in 1994 for people making 10 or fewer crossings per month.

[e] Charges are withdrawn from bank account once a month, per debiting agreement.

[f] Charges shown are for the following prepayment quantities. Bergen: booklets of 20. Oslo: 350 trips (subscriptions for 25 or 175 trips are also available, at a price per trip of NOK 9.20 or 8.29, respectively). Trondheim: NOK 2500 prepayment (NOK 500 or NOK 5000 are also available, with peak entry fee of NOK 8 or 6, respectively).

[g] Off-peak discount applies 10 a.m.-5 p.m. on all subscriber schemes;not available for single-trip (manual) payment.

[h] Six- and twelve-month passes are also available for NOK 575 and 1,100 (Bergen) and for NOK 1,350 and 2,500 (Oslo).

NA means not applicable.

Sources: (*50, 52-54*) and personal communications with E. Backer-Røed (Bro-og Tunnelselskapet A/S, Bergen), K. Waersted (Directorate of Public Roads), G. Fredriksen (Trøndelag Toll Road Company, Trondheim), T. Tretvik (SINTEF, Trondheim).

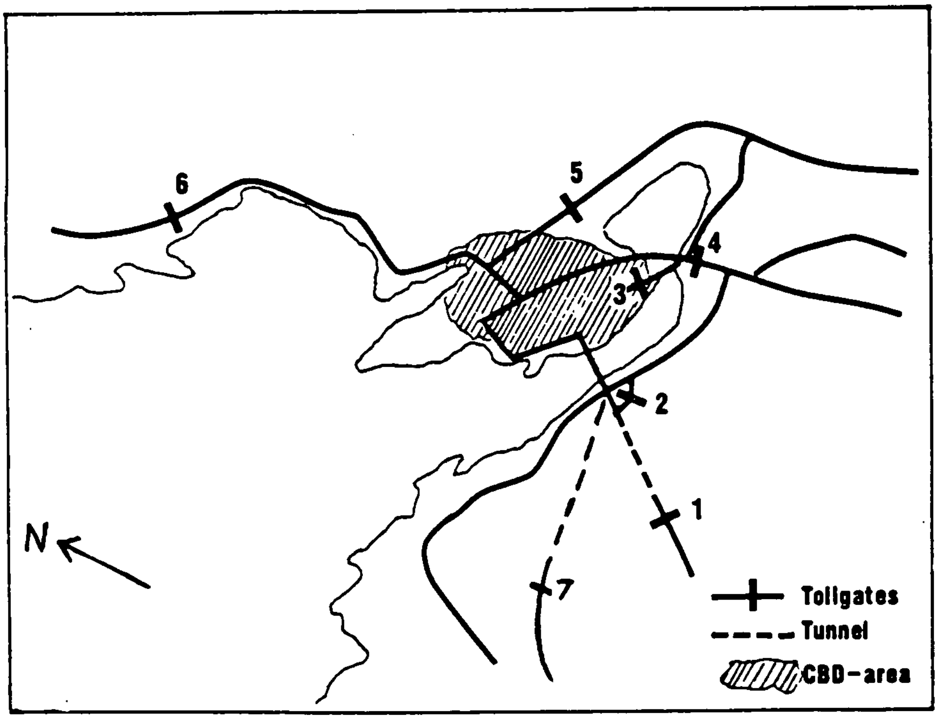

FIGURE 7 Bergen toll ring. (Source: *(50)* and Norwegian Directorate of Roads)

month when many people stop to purchase a monthly pass. Within the first 10 months of operation, the number of passes in use rose to 21,000, or about 25 percent of all vehicles in the area.

Enforcement in the nonstop lanes is by random video pictures of license plates, which are checked against valid seasonal passes. Fines are sent to the registered owners of violating vehicles. At least in the initial years, the sampling rate for these pictures was five percent, and the violation rate was about two percent, which is regarded as acceptable.

Capital costs for the toll booths, equipment, engineering, and so forth were NOK 12.8 million ($2 million), and annual operating costs were NOK 9.8 million ($1.6 million) (*52*). If capital is depreciated and amortized at six percent interest over 15 years, these figures imply annualized capital and operating costs of NOK 11.1 million ($1.8 million). This is 17.6 percent of gross revenue (Table 12), or approximately NOK 0.65 ($0.10) per crossing.

Impact on Travel Behavior

Bergen's tolls appear to have restrained weekday traffic growth slightly despite the low level of the charge. Traffic crossing the cordon during the tolled hours changed little over a 1-year period spanning the opening of the toll ring, while traffic during the untolled hours increased about 10 percent. Exactly how much the ring might have cut weekday traffic is unclear, however, because a number of suburban shopping malls opened and there were changes in center city parking and traffic regulations during the period (S.P. Strandenes, personal communication, August 28, 1993). Before and after surveys revealed that cars paying per trip reduced their crossings significantly over a 5-month period including the opening, whereas cars with seasonal passes increased their crossings (see Table 13); this latter finding is not conclusive because it could simply reflect a tendency of people making frequent crossings to buy seasonal passes. Making allowances for the defects in the data, Larsen (*50*) estimates that the toll ring reduced traffic crossings by six to seven percent during its hours of operation.

Public Attitudes

Public opinion has shifted from strong opposition to cautious support for Bergen's toll ring. A month before the opening of the toll ring, a newspaper poll showed only 13 percent in favor, with 54 percent opposed; within a year, however, 50 percent were in favor and 36.5 percent opposed. Larsen speculates that this shift resulted from the absence of anticipated queues at toll gates, the ability of frequent users to lower their payments by using a seasonal pass, and the ability of local authorities to link the toll revenues to some visible road improvements completed during the first year of operation (*50*, pp. 221–222).

OSLO

Oslo was the second Norwegian city to implement a toll ring. Oslo's scheme represents the first European attempt to charge a cordon toll for a large metropolitan area (population 700,000, with 230,000 vehicles entering downtown Oslo each weekday) and the first implementation anywhere of electronic pricing on a massive scale. Oslo's success results from the combination of a relatively simple concept, careful planning and the use of sophisticated yet conceptually straightforward

TABLE 13

REPORTED CHANGES IN CORDON CROSSINGS, BERGEN: NOVEMBER 1985 TO APRIL 1986 (PERCENT)

Time Period (Mon.-Fri.)	Cars with seasonal pass	Cars paying per trip
6-9 a.m.	-0.3	-40.8
9 a.m.-5 p.m.	12.2	-21.1
5-10 p.m.	2.1	-35.2
Total Toll Period Trips	5.4	-29.8

Source: (*50*, p. 221).

technology. This description relies on a 1994 work by Ramjerde *(52)*, and on interviews with Kristian Waersted (Directorate of Public Roads) and with Svend Larsen and Lars Lind (A/S Fjellinjen).

The Oslo toll ring opened in 1990 as part of a large package of transportation improvements emphasizing new road capacity, safety and environmental improvements, and public transit. One of the most visible of these projects, the Oslo tunnel, opened the previous month with bond financing to be paid off by toll revenues. This and other proposed tunnels are intended to divert traffic from city streets, and therefore are being justified as environmental improvements. As in Bergen, the desire to accelerate funding for these road improvements led to the political decision to install a toll ring.

The design of the Oslo ring was greatly influenced by the successful use of electronic toll collection on two conventional toll projects several years earlier. In 1987, the Ålesund tunnel on Norway's western coast became the first toll facility in Norway to offer an electronic toll collection option, and in 1988, a new toll-financed section of the E6 motorway with electronic collection opened at Ranheim, a suburban town northeast of Trondheim in central Norway. At both Ålesund and Ranheim the toll is deducted from the user's account each time the user's electronic tag is detected. Enforcement is accomplished by electronically checking the validity of the toll tag in real time so that video pictures are taken only in case of a violation. This greatly reduces the number of license plate pictures that must be processed even though every car is checked rather than just a fraction of them.

Oslo is surrounded by mountains and water on all sides, so traffic entering the city is concentrated in three corridors. As a result, only 19 toll stations and four street closures were needed to control virtually all traffic crossing a cordon line surrounding the central city (Figure 8). (There is a very small amount of "leakage" across the cordon through private driveways and bus-only barriers.) The toll stations, all manned, range in size from small two-lane plazas, each handling a few thousand trips per day, to a six-lane station with a capacity for nearly 5,000 vehicles per hour. By adopting the Ranheim technology, the planners of the Oslo project were able to create a system by which large numbers of transactions could be handled at moderate cost.

The cordon was chosen with both political and practical goals in mind. It lies inside the city boundaries and encloses about one-half of the population of the city of Oslo, or just over one-fourth that of the urban area. Placing it farther out, say at the city border, would have reduced the number of stations and their cost; however, residents of surrounding Akershus County would then have supplied the bulk of the toll revenue, much of which will go for projects inside the city. Moving the cordon in, closer to the central business district, would have raised its cost and reduced the volume of traffic subject to the toll (*53*, p. 2). The location chosen both spreads the burden evenly between city and suburban residents, and maintains high revenues.

Annual net revenue is currently about NOK 530 million ($85 million). Of this, approximately 20 percent is earmarked for public transit, and the rest goes to finance the local share of the 50 road projects included in the Oslo package. Estimated total costs of these 50 projects are NOK 10 billion ($1.6 billion) over a 15-year period.

Toll Operations, Technology, and Procedures

Users have three options for payment: manual collection by an attendant (available at all stations), payment to a coin machine (at the eight larger stations), and electronic payment. Motorists opting for electronic payment can either purchase a seasonal pass or pay per trip at a substantial discount. The 1992 rates for light-duty vehicles are shown in Table 12. Heavy vehicles pay twice as much in every category. Transit buses, emergency vehicles, motorcycles, and disabled persons are exempt, and account for about eight percent of all crossings.

The toll plazas have booths at both manual and coin lanes, and signs indicating the lane type. (Having booths in coin lanes permits these lanes to be temporarily switched to manual operation as needed.) Lanes marked "Abonnement" (meaning "subscription") are nonstop and contain the electronic equipment for charging people with accounts. These lanes have capacities of about 1,600–2,000 vehicles per hour, some four to five times as high as the capacities of lanes in which people must stop to pay. Toll collection and financial operations are carried out by A/S Fjellinjen, a corporation owned jointly by Oslo city (60 percent) and Akershus County (40 percent). The

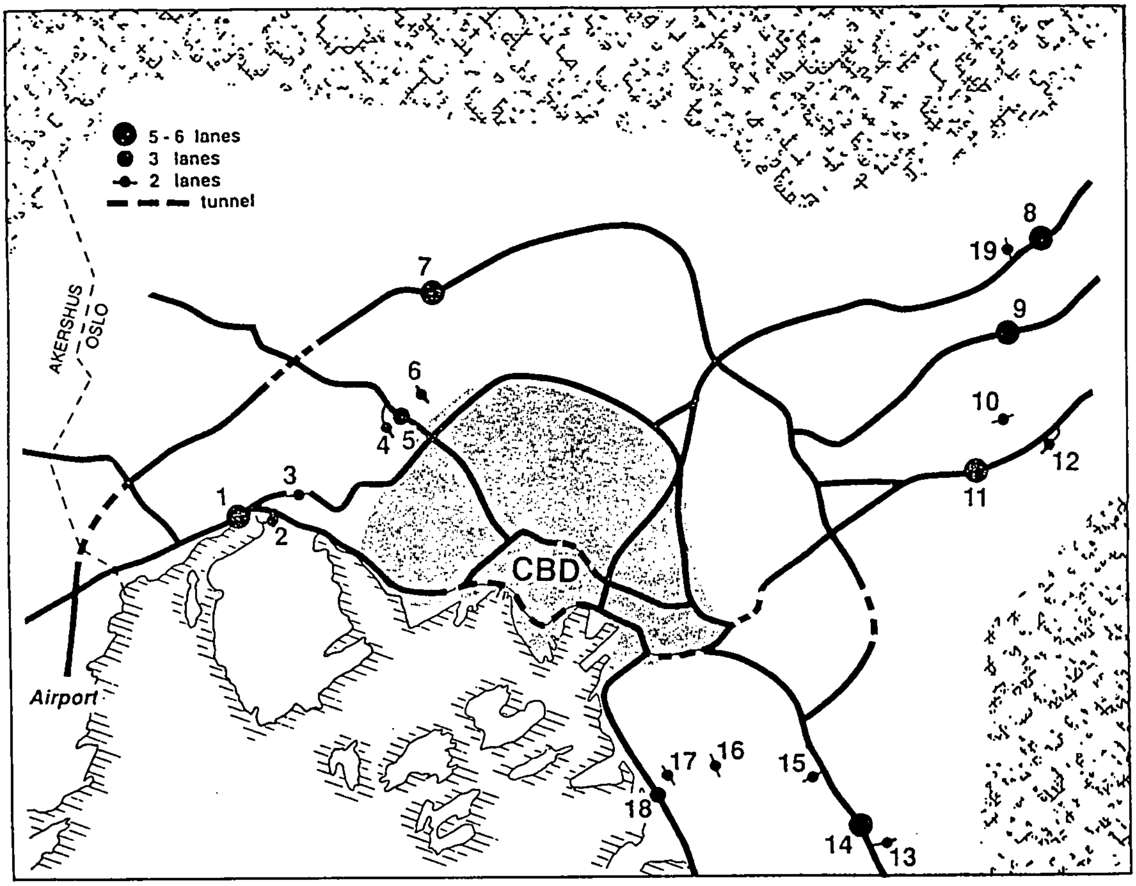

FIGURE 8 Oslo toll stations *(52)*.

corporation employs approximately 30 headquarters workers and 160 toll collectors.

The electronic tag used in Oslo is a small plastic box that attaches to the windshield just behind the rear-view mirror. It contains a passive responder, operating at microwave frequency (856 megahertz), with no battery or other power source. The transponder absorbs power from the signal it receives upon approaching a toll station and uses it to transmit its identification number. While this number is being checked electronically against account records, a video image of the front license plate is taken. If the identification number is valid, the video image is immediately discarded; otherwise, it is saved on tape and later processed for billing of a penalty. (Norwegian law permits a penalty of NOK 250 ($40) to be assessed against the vehicle owner for nonpayment of a toll.) A signal light immediately informs the driver if there is a violation; another color and symbol warn of a low account balance. The length of the charging lane, from first encounter with the AVI antenna to the final signal light, is 30 meters.

Subscribers making innocent errors, such as driving a spouse's car lacking a tag, can pay a small penalty (NOK 25) ($4) within 2 days to avoid the fine. This system, along with reasonable flexibility in dealing with user errors, appears to keep complaints about incorrect fines quite low. Overall violation rates in the nonstop lanes are about 0.2 percent, one-tenth that of Bergen and a huge decrease from the first 10 months of operation, when the means of enforcement in the nonstop lanes was, as in Bergen, by random video pictures.

Much of the system's operation is automated, including vehicle identification, preparation of bills, and notification of fines. The principal exception is reading and entering the license plate numbers of violators from video pictures. This operation takes less than 5 seconds per picture, and a single full-time employee can process the roughly 5,500 pictures generated each day.

Evasion is possible but rare. Motorists occasionally obscure their license plates with dirt or black tape, tailgate another vehicle to block the camera, or even install a lever to pivot the license plate temporarily out of camera view. Most violations, however, are more prosaic: tags improperly mounted, unauthorized switching of tags between vehicles, accounts out of money, or people simply hoping the system will not catch them. Foreign motorists lacking tags sometimes use the restricted lanes, perhaps out of confusion, but they generally are not fined due to the difficulty of tracing their license plates.

Toll collection costs absorb 16 percent of toll revenues, or about NOK 97 million ($15.5 million) in 1991 *(55)*. This amounts to NOK 1.30 ($0.21) per crossing. Of these costs, 28 percent are for depreciation and amortization of the NOK 260 million ($41.6 million) in initial capital outlay for toll plazas, equipment, and electronic tags. The remaining 72 percent is for operating cost. A major portion of the operating cost results from the decision to provide an attendant at all stations at all times for security reasons. Capital costs were increased by the decision to provide coin machines, which cost two or three times more to install per lane than the electronic toll collection system *(8)*.

Privacy

The Norwegian government's Data Inspectorate is responsible for ensuring the privacy of all data registers containing personal information, including data collected during electronic toll collection. Video pictures of license plates cannot be kept longer than necessary for enforcement purposes. Video records of nonviolators are kept only for the fraction of a second needed to verify the subscriber's account information. Furthermore, the video processing equipment automatically blocks out the passenger area from any video pictures.

Records of passage of subscribers holding seasonal passes may not be kept at all, even for statistical purposes. For per-passage ("clipcard") subscribers, records of valid transactions may be kept for 3 days, although the actual practice is to keep them only until the account list is updated each night. Records of illegal passages may be kept until 30 days after a fine is paid.

Subscribers may request in advance that a detailed account of their charges be kept for a specified period. This period is usually limited to 2 weeks to discourage the possible use of the system by a subscriber for surveillance of other family members. These restrictions limit the ability to verify transactions, and the staff is trained to be flexible in dealing with subscribers who believe an error has occurred.

If a tag is stolen, the system can be alerted to retain the corresponding video picture at each passage to facilitate recovery. In principle, this capability could be used to facilitate other criminal investigations, but this would require court approval and normally is not allowed.

Impacts on Travel Behavior

The impact of the Oslo toll ring on traffic appears to have been quite small, consistent with its design. Precise measurements from traffic counts have proven impossible because of the confounding effects of a deepening recession, a sharp increase in gasoline prices, and several changes in the system during its first 2 years of operation.[1] Early reports showed that traffic crossing the ring dropped about 3 to 4 percent for a few months after the toll began, then rose back to its pre 1990 level (*53; 56*, p. 140). A more complete analysis of traffic data between spring 1989 and spring 1990 suggests to some researchers that the toll may have reduced crossings by as much as 5 to 10 percent (*57,58*). Most of this drop was during off-peak periods, implying that mainly nonwork trips were eliminated or diverted.

A similar conclusion was reached by Ramjerdi (*59*) based on before-and-after panel surveys conducted in the fall of 1989 and 1990. Respondents to the second survey unfortunately appear to have under-reported trips of all kinds, judging from a comparison of survey results with traffic counts and with transit ridership statistics. Once the bias in the second survey is accounted for, Ramjerdi estimates that the toll reduced the number of private vehicles crossing the cordon by somewhat less than 5 percent. The analysis of the panel surveys suggested the fall in cordon crossings was due to small but statistically significant numbers of car drivers switching to carpooling, public transport, walking, and bicycling. Aggregate traffic statistics reveal no observable change in auto occupancy or public transit usage, however, so most of the drop in auto traffic may have been due to trips foregone or trips diverted to destinations that did not require crossing the ring.

There is no evidence of the effects the tolls may be having on business or land use. We do know that 60 percent of subscriptions are paid by employers (*53*, p. 6), which suggests that downtown Oslo businesses may feel themselves slightly disadvantaged by the toll.

TABLE 14

POLL RESULTS ON ATTITUDES TOWARD OSLO TOLL RING

	Percentage of respondents		
Year	Positive	Negative	Unsure
1989	29	65	6
1990	34	60	6
1991	36	57	7
1992	39	56	5

Source: A/S Fjellinjen (presentation by Mr. Thorleif Haug visit of the British Secretary of State for Transport, May 10, 1993).

Public Attitudes

Public support for the Oslo toll ring has increased since it opened, but not by as much as in Bergen. Surveys reveal that the percentage favoring the ring increased from 29 percent immediately before implementation to 39 percent 2 years later (Table 14). There were a few incidents of vandalism at toll stations before the system opened, and video pictures of obscene gestures are occasionally recorded. Nevertheless, the system continues to operate smoothly and there is no significant political movement to dismantle it.

Evaluation of Benefits

Congestion pricing is designed to achieve net benefits to society by reducing the inefficiency of time wasted in traffic. These net benefits can be quantified by combining four components: value of travel time saved, plus revenues received by the government, minus loss of consumer welfare from the higher price of auto travel, minus collection costs. The theory of congestion pricing shows that when congestion is present, there is some peak-period toll for which the first three components sum to a positive amount. If collection costs are small enough, then, the entire scheme produces positive net benefits.

The Norwegian toll rings, however, are not congestion pricing. Rather, they are explicitly designed to raise revenue while minimizing effects on traffic. This produces little congestion relief, hence the first component of net benefits (value of time saved) is small. In these circumstances, there is no reason to expect the Oslo toll scheme to have positive net benefits according to the above measure. Instead, it will produce a net welfare loss, exactly comparable to the "deadweight loss" from other tax instruments.

Ramjerdi and Larsen (*55*) point out that it is therefore appropriate to compare this welfare loss with that produced by typical tax instruments used in Norway, which they state to be 40 percent of revenues. By way of contrast, they estimate the welfare loss from the toll rings at 16 percent of revenues. If these figures are correct, the toll ring is a relatively efficient way of raising revenues compared to alternatives that might otherwise have been used to fund road improvements. This relative efficiency comes from the fact that there are some benefits of congestion relief, even if they are insufficient in these toll schemes to overcome other losses. It is worth noting that the estimated welfare loss is about equal to collection costs, which are rather high in Oslo as a percentage of revenues.

Ramjerdi and Larsen also consider alternative cordon schemes to determine whether the welfare loss might be reduced or turned into a benefit. In doing so, they test a hypothetical congestion pricing scheme: a toll ring with the cordon somewhat closer to the central business district and with the toll about twice as high as now but charged during peak hours only. The advantage of the smaller cordon is that it would divert a higher proportion of through trips away from the central business district (*5*, p. 41). Ramjerdi and Larsen estimate that this hypothetical scheme would produce a net welfare gain instead of a loss, and this gain would be 14 percent of net revenue. Net revenue would be only NOK 180 million ($28.8 million) instead of the NOK 503 million ($80.5 million) collected under the present scheme, however, so there is a tradeoff between the goals of efficiency and revenue generation.

Ramjerdi (*60*) also estimates the results of a more elaborate congestion pricing scheme in which the social cost of travel on each link is charged on that link. This produces an even lower net revenue (NOK 152 million or $24.3 million), but total benefits about 50 percent higher than from the optimized cordon scheme just described.

TRONDHEIM

Trondheim, Norway's third largest city (with a population of 136,000 in its urban area), opened a more complex and flexible system than Oslo's in late 1991. Its purpose, like Oslo's, is to raise funds for a package of road and public transport improvements—in Trondheim's case, 60 percent of improvements costing NOK 2.3 billion ($368 million) over 15 years are to be financed from the toll ring revenues (*61*). The pre-existing Ranheim toll station was incorporated into the new 12-station system, although with a different toll structure and a special mechanism for revenue dedication. A map is shown in Figure 9.

Trondheim's small traffic volumes make manned operation of toll plazas uneconomical, so all but two of them are completely automated: users can either pay at a coin machine (which also takes a rarely used prepaid magnetic card) or enroll in one of several electronic payment schemes that allow subscribers to pass through the plaza without stopping. The electronic tags and antennae are of the same types used in Oslo; other components of the charging system, such as communications and central processing equipment, are more advanced.

The toll rates are comparable to those in Oslo, but differ in two important ways (Table 12). First, there is no seasonal pass: all payment schemes charge per passage. Frequent users can get a discount by enrolling in the electronic payment system, however, because electronic subscribers pay for a maximum of one trip during any hour and 75 trips during any month. Second, and more important, the toll rate varies over the day; tolls are highest from 6 a.m. to 10 a.m., slightly lower (for subscribers) from 10 a.m. to 5 p.m., and there is no charge after 5 p.m. or on weekends. Most of these complications are made possible only by the use of electronic toll collection.

Whether Trondheim's system should be regarded as congestion pricing or not is debatable. On the one hand, it is technically indistinguishable from congestion pricing in that motorists pay per trip (with limits) and they pay more during peak periods. On the other hand, it is not intended to manage congestion and the peak toll is set so low (a maximum of NOK 8, or $1.28, for subscribers) and the peak/off-peak differential is so small (NOK 2, or $0.32) that it is unlikely to reduce congestion significantly. Trondheim's system is clearly close to the definitional boundary of congestion pricing, and it could be easily converted into a congestion management tool. Indeed, Trondheim's planners may have designed the system with this conversion in mind (*61*, p. 5).

Total weekday crossings averaged about 70,000 per day during the 252 working days of 1992. Of these crossings, 8,150 were at Ranheim (counting both directions and all days and hours, in accordance with the Ranheim toll structure). Another 40,455 were inbound trips crossing the other 11 toll stations during charging hours (T. Tretvik, personal communication, August 1993). Revenue in 1992 was NOK 45.1 million ($7.2 million) from the Ranheim station and NOK 70.7 million ($11.3 million) from the other 11 stations.

Toll Operations, Technology, and Procedures

The system is managed by the Trøndelag Toll Road Company, whose six employees handle back-office operations and subcontract all the money handling to a private security firm.

Electronic payment is very popular, accounting for more than 80 percent of all payments (*62*, p. 4) and more than 90 percent during peak hours (G. Fredricksen, personal interview, September 1992). As of May 1993 there were 65,500 subscribers, who owned 85 percent of the entire stock of registered vehicles in the urban area (*61*, p. 5). Appendix C reproduces from a consumer information booklet the full text of the legal agreement between the toll road company and each subscriber.

Just under one-half of the subscriptions are personal post-payment accounts. In contrast to designers of the Oslo system, who chose not to offer a post-payment plan, Trøndelag officials prefer post-payment because direct monthly transactions with thousands of subscribers are replaced by transactions with a much smaller number of banks with which the subscribers have debiting agreements. Presumably, this is advantageous if banks are more efficient than the toll road company at the operations involved in handling individual accounts.

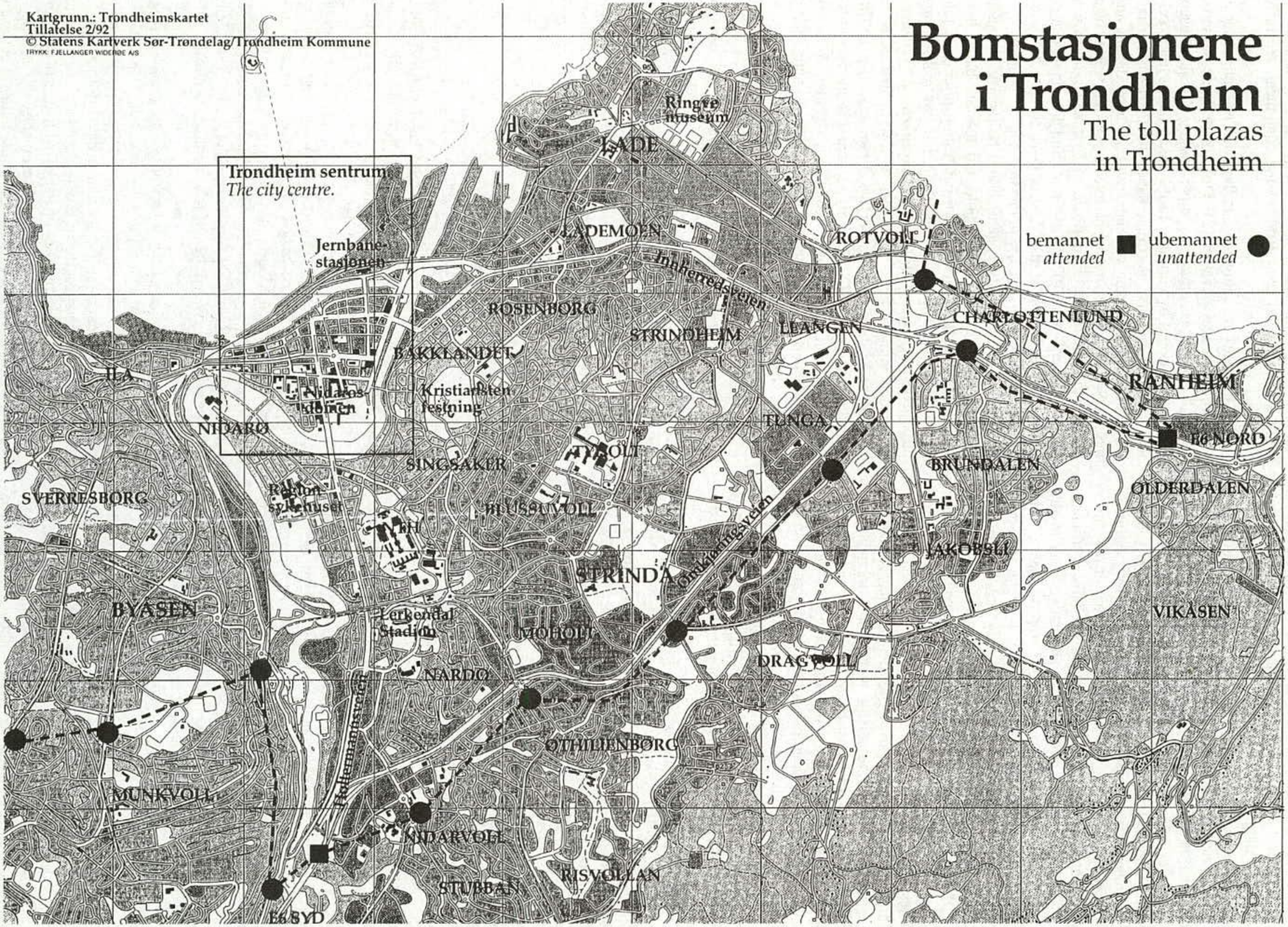

FIGURE 9 Trondheim toll ring. (Source: Trøndelag Toll Road Company)

TABLE 15

COLLECTION COSTS OF TRONDHEIM TOLL RING

	Norwegian Kroner	U.S. Dollars
Capital Costs (millions)		
Ranheim station	unknown	unknown
Eleven other stations 45	7.2	
Annual costs in 1992 (millions)		
Operating		
Ranheim station	5.2	0.83
Eleven other stations	7.2	1.15
Annualized capital		
Eleven other stations	4.6	0.74
Costs as percentage of revenues		
Operating		
Ranheim station	11.5	11.5
Eleven other stations	10.2	10.2
Capital		
Eleven other stations	6.5	6.5

Source: Personal communication from T. Tretrik, June 29, 1993 and August 26, 1993. Capital costs authorized over 15 years at 6 percent interest.

Enforcement is similar to that in Oslo. Approximately 1,200 video pictures are taken per day, of which one-half turn out not to be violations (motorcycles, bicycles, trailers, and vehicles with incorrectly mounted tags). Most of the rest are people lacking a coin, who can push a button for instructions. Flexibility is shown toward routine lapses, such as prepaid accounts being overdrawn. People illegally passing through the nonstop lane are warned by a signal and can pay without penalty if they promptly telephone the toll road company. True violations are about 0.3 percent of crossings; 90 percent pay after a single notice and the rest are referred to a collection agency.

Other problems are few. Video surveillance of unmanned stations seems to prevent vandalism. There is some illegal parking shortly before the start of free passage at 5:00 p.m.; none, apparently, at the transition to off-peak rates at 10:00 a.m.

Capital costs for the 11 stations other than Ranheim, including their equipment, amounted to NOK 45 million ($7.2 million). Capital cost for the Ranheim station is unknown because it was part of a larger project including research and development in toll collection technology. Operating costs in 1992 were 11.5 percent of revenues at the Ranheim station and 10.2 percent of the revenues at the other 11 stations (Table 15). If capital costs are annualized at 6 percent interest over 15 years, the total annual collection costs are 16.8 percent of revenues for the 11 non-Ranheim stations. From this accounting, operating cost per paid crossing is approximately NOK 0.71 ($0.113) and capital adds another NOK 0.45 ($0.072) for the stations other than Ranheim.

Revenues from the toll ring have been somewhat lower than planned, probably due mainly to the severe national recession. The construction schedule for the road improvements has been slowed considerably as a result, and some road projects are being reconsidered. Some officials are also considering extending the hours of operation or adding a new ring inside the current one to increase revenues. At time of writing, the only concrete decision taken was to reduce the subscriber discount for people making 10 or fewer crossings per month, effective January 1, 1994 (Solveig Meland, personal communication, January 18, 1994).

Impacts on Travel Behavior

Prospective surveys indicated that 91 percent of the area's residents had some alternative to paying the toll. Most could avoid it by using bus transit; for nonwork trips, about 20 percent could travel to an alternative destination. Many work and nonwork travelers also indicated some flexibility in time of travel; their responses implied an average willingness to shift a trip about 11 minutes earlier or later in order to save $1.00 in toll charge.[2]

Preliminary analyses of panel surveys conducted in the fall of 1990 and again 2 years later suggest the toll ring induced some significant changes in travel behavior (*61*, pp. 7–11). A surprisingly large number of respondents living outside the ring reported some change in behavior as a result of the toll ring: 20 percent in the case of work trips, 45 percent for shopping trips, and 35 percent for other trips. For work trips, the most common changes were mode, followed by time of day. For shopping trips, changes in time of day predominated, followed by changes in destination and frequency.

Those who changed mode usually reported doing so only occasionally rather than consistently. For example, public transport might become an occasional substitute for the car. Thus, while the proportion of commuters *never* using the car rose only from 5 percent in 1990 to 7 percent in 1992, the proportion using a mode other than car at least *some* days rose from 63 percent to 89 percent. This pattern of modal variety has important implications for the distribution of impacts of road pricing schemes, because it suggests that the distinction between those who pay the toll and those who instead alter their behavior is not as sharp as is often assumed. Of course, this kind of behavior is facilitated by Trondheim's good bus transit system.

Motorists were encouraged to change the time of day they traveled by the fact that the charging period ended at 5:00 p.m., 1 hour after the end of the normal work day. About 3 percent of inbound home-to-work trips, 13 percent of inbound work-to-home trips, and 19 percent of inbound shopping trips shifted in time to cross the cordon after 5:00 p.m. The large shift in shopping trips was encouraged by downtown shop owners who lengthened their late afternoon shopping hours in hopes of overcoming any adverse effects the toll ring might have on their businesses. Perhaps because of this, no decrease in downtown retail revenues has been observed (Solveig Meland, personal communication, January 1994). No estimate is available of any additional costs that downtown merchants or shoppers might have incurred.

In the prospective surveys, travelers had indicated that further increases in the toll would induce dramatic changes in behavior. One analysis of survey responses suggested that doubling the toll would increase revenue by only 28 percent and cause traffic to decrease by 36 percent during toll hours (*64*, Figure 6). Such a large reduction seems doubtful in light of the evidence from Bergen and Oslo, even accounting for the incentive built into the Trondheim toll structure to reschedule trips to the evening. The survey respondents probably overstated their willingness to find ways to avoid paying the toll, perhaps to discourage public officials from imposing higher toll rates than those actually introduced.

Public Attitudes

Public attitudes about the toll ring prior to its opening were more negative than in Bergen or Oslo, perhaps because traffic congestion was not perceived to be a serious problem by most Trondheim residents. Only 7 percent viewed the toll ring positively, against 72 percent negatively (Table 16). The ring opened without incident, however, and with remarkably little adverse publicity (*65*). The fraction viewing the toll ring positively rose after it opened, but only to 20 percent (Table 16).

TABLE 16
PUBLIC ATTITUDES TOWARD TRONDHEIM ROAD POLICIES

	Percentage of respondents		
	Positive	Negative	Unsure
Toll Ring:			
Before[a]	7	72	21
After[b]	20	48	32
Policy Package:			
Before[a]	28	28	44
After[b]	32	23	45

[a]April/May 1991

[b]December 1991

Source: Surveys by NOREAKTA, as reported in (*54*, p. 7 and Figure 4).

The public has been much more positive, however, when asked about the combined package of the toll ring and the improvements it is to finance. Opinion was about evenly divided initially, and became mildly favorable 2 months after it opened, but with a large number still unsure.

STOCKHOLM

Swedish interest in road pricing has arisen in a quite different political context than in Norway. Sweden has little history of toll finance of roads, bridges, or tunnels; however, it does have a very active and politically potent environmental movement. As a result, the Swedish program has had a greater emphasis on reducing environmental problems associated with traffic, especially in inner cities, rather than on raising money or reducing congestion.

Despite these differences, Sweden has decided to create a toll ring for Stockholm that resembles the Oslo scheme in many respects. Discussions are also underway about toll rings in Sweden's other large cities, Gothenberg and Malmo. The fact that different goals have produced such a similar solution may be testimony to the appeal of relatively simple pricing schemes that have been demonstrated elsewhere.

Stockholm is more than twice the size of Oslo, with a population of 1.64 million in Stockholm County, including 0.67 million in Stockholm City (*66*). Approximately 177,000 vehicles entered the city between 6:00 a.m. and 10:00 p.m. every workday in 1988 (*67*, p. 7). Since the late 1980s, politicians in the city have been discussing proposals for restraints of various kinds on automobile traffic to reduce congestion, pollution, accidents, and noise, and to increase the speed of transit buses.

In 1989, the Social Democrat Party, which is the most influential political party among Stockholm-area local governments, requested a study of a combined central area motoring fee and transit pass known as a "car card." Such a pass would permit daytime travel within the inner city, by car or transit, and would be priced at SEK 25 ($4.25) per day or SEK 300 ($51) per month (*67*). An alternative proposal involved electronic pricing of cars either crossing a ring cordon or crossing one of a set of screenlines trisecting the inner city; this proposal, estimated to reduce inner-city traffic by 20 percent, exempted traffic traversing the city on either of two designated through routes (*68*).

The City's 1990 Traffic Master Plan combined the electronic pricing proposal with an ambitious package of parking regulations, relief roads, transit improvements, and a fuel-tax surcharge of SEK 1/liter ($0.64/gal); the plan estimated that this package would reduce inner-city vehicular traffic to 30 percent of 1987 levels by the year 2010 (*69*). The planners had also considered a charge based on the amount of time spent in the inner city (B. Gellstedt, personal communication, September 1992).

In response to Stockholm's emerging plan and similar discussions in Sweden's other large cities, the national government convened a Metropolitan Traffic Committee to reconsider national policy toward urban traffic. The Committee recommended increased national funding for mass transit and traffic bypass routes, along with automobile restrictions and more stringent emissions-control regulations. Road pricing was viewed primarily as an environmental measure:

> It is also necessary to introduce measures that restrict the amount of car traffic. In the inner-city areas, this is necessary in order to meet the targets for exhaust fumes and congestion ... Car tolls are an extremely important feature of an overall traffic policy in order to restrict the effects of traffic on the health and environment in inner city areas. (*70*, p. 25)

The national government convened negotiations among the chief political parties in each of the three largest metropolitan areas, leading to three separate agreements in January 1991. All three include toll financing, and Gothenberg's includes a "green zone" in the inner city with limited road investments, priority for transit vehicles, and local option to ban "environmentally disruptive" vehicles (*71*, pp. 19–23). It is the Stockholm agreement, however, that involves the most extensive toll system and that has evolved into a ring toll rather than just tolls on new facilities.

In the Stockholm region, the appointed negotiator was Bengt Dennis, Governor of the Bank of Sweden. The resulting three-party agreement, known as the Dennis package, set the structure for subsequent negotiations that were completed in September 1992. The Dennis package and the process producing it demonstrate the key role that allocation of revenues can play in bringing road pricing into a comprehensive package.

The Dennis Package for Stockholm

The central components of the agreement by the three major parties in Stockholm are improvements to public transit, new bypass roads, and road pricing. The bypass roads and some minor road related investments are to be financed by new road-use fees, which will accelerate their construction and allow the diversion of some highway funds to public transit improvements. At the same time, the national and county governments signed funding agreements for the public transit improvements.

The package agreed upon involves SEK 35.8 billion ($6.1 billion) in investments over the period 1992–2006, stated at January 1992 prices. Somewhat more than one-half of these expenditures are for roads, the rest for public transit, primarily rail (Table 17). Of the funds for transit improvements, one-tenth are from diversion of road funds that would otherwise have been allocated to roads now to be toll financed. Further analysis has subsequently revealed that the cost of the road package will in fact be SEK 5 billion higher than that assumed in the agreement (*72,73*).

TABLE 17

INVESTMENT COMPONENTS FOR STOCKHOLM REGION IN THE REVISED DENNIS AGREEMENT OF SEPTEMBER 1992 (SEK MILLIONS, JANUARY 1992 PRICES) (*75*)

Public transport	15,750
Inner ring road	10,510
Outer cross-route	7,650
Local road related investments	1,860
TOTAL	35,770

Two major and controversial road investments are included, both designed to divert traffic away from the inner city. The first is completion of the eastern two-thirds of an inner ring road within the city limits, to be built mostly as a six-lane motorway with design speeds of 70 km/hr (44 mi/hr). This ring road includes the Österleden, or East Link, part of which would pass via tunnel under a greenbelt (Figure 10). The second is a bypass route (the "Outer Cross-Route") for north-south traffic about 25 km west of the city center. This route is partly motorway and partly a two-lane road with intersections, but all designed for speeds of 90 km/hr (56 mi/hr). The bypass includes a lengthy and expensive segment known as the Västerleden, or West Link, which crosses Lake Mäleren via tunnels and bridges along several sparsely developed islands, and is therefore environmentally sensitive.

The decision to charge for entry to the inner city of Stockholm was equally controversial and designed in part to also reduce intercity traffic. The final agreement calls for a ring toll on inward crossings of a cordon lying just outside the ring road, as well as a toll on crossing the West Link in either direction. The ring toll is initially to be SEK 15 ($2.55) at January 1992 prices, and will go into effect once the initial portion of the East Link ring road is opened in 1997 (*74*). The toll of SEK 5 ($0.85) on the West Link will begin on its completion in the year 2006. Heavy vehicles will pay three times these rates. Some as yet undetermined toll discounts will be offered,

FIGURE 10 Proposed Stockholm toll ring. (Source: Stockholmsleder AB)

and "other possible differentiations" will be considered (*75*, p. 24), a provision that appears to open the door to possible time-of-day pricing. In an important provision that departs from typical U.S. practice, the three parties not only provided for automatic inflation adjustment of toll rates, but also relinquished to the national government the power, subject to consultation, to adjust toll rates as necessary for the full financing of the road investments included.

Each of the three main political parties opposed one of the three controversial elements: the Social Democrats objected to the East Link, the Liberals objected to the West Link, and the Moderates (a conservative party) objected to the toll ring. In the local negotiations, the Moderate Party preferred a conventional toll on the new ring road itself. However, other negotiators argued that this would undermine the ring road's main purpose, which is to divert traffic from the inner city. By placing the cordon line just outside the ring road, a conceptual compromise is attained: the toll will help limit traffic coming into the inner city, while still being viewed partly as a toll on the ring road itself, since most people using that road will come from outside the cordon. The language of the agreement states explicitly that the ring toll serves the twin goals of finance and traffic control:

> [T]he Ring and the Outer Cross-route [will] be financed by fees ... [which] will be so devised as ... to reduce vehicular traffic in the inner city and thereby improve the environment there. (*75*, p. 23)

Toll Operations, Technology, and Procedures

The Stockholm toll collection system will be built by the Swedish National Road Administration and operated by its subsidiary, Stockholmsleder AB. Only the main characteristics of the pricing scheme had been decided as of late 1993 (*74*).

The Dennis agreement states that toll collection initially will allow for both cash and electronic payment. However, the agreement also directs the Swedish National Road Administration to undertake technical development of a fully automated electronic fee-collection system for eventual use. The system is to allow fees to be varied by time of day, and by type of emission control on the vehicle (*76*, p. 30). In carrying out its mandate, the Road Administration started developing a test site in 1991, with the following technical characteristics (*77*, pp. 3–6):

- Automatic debiting using smart card technology,
- Compatibility with European standards being developed as part of the DRIVE projects PAMELA/TARDIS,
- Capability of fully anonymous operation with transaction records stored on the user's smart card,
- Microwave responder mounted on the windshield, and
- Overhead gantries at charge points.

Subsequently, the Road Administration has decided on a system with 28 toll stations using a combination of manual, coin machine, and electronic payment (*74*). The electronic payment is to be based on prepaid smart cards that permit fully anonymous payment via automatic debiting. It is to be compatible with the European standards now being developed and is to operate in a free-flow multilane environment with video enforcement. This specification admittedly requires a technology not yet fully developed. The smart cards are eventually intended to be usable as part of an integrated payment mechanism covering not only the toll ring, but also public transport and parking.

The legal structure for charging tolls is less well developed in Sweden than in Norway. Parliament will have to define the penalty for toll evasion, which might be modeled after the present noncriminal "control charge" of SEK 400 ($68) that applies to evasions of charges for parking or public transit. Similarly, Parliament will need to clarify the extent of the vehicle owner's responsibility for toll violations, perhaps by extending the responsibility now in place for parking violations.

Impacts on Travel Behavior

Early modeling efforts suggested that completion of the ring road and Western Bypass would together reduce inner-city traffic (vehicle-miles traveled) by up to 18 percent (*78*, p. 15). Analyses by consultants indicated that a combination of these investments and ring and West Link tolls somewhat similar to those now agreed upon would reduce inner-city traffic by 33 percent (*78*, p. 21). The Dennis agreement cites a study by the Stockholm County Office of Regional Planning and Urban Transportation Projects, which estimates that the package agreed on will reduce inner-city traffic by 35 percent (*75*, p. 24).

Comprehensive modeling efforts were undertaken by the Stockholm Streets and Traffic Administration to simulate effects on mode and route choice and degree of congestion. These results were extended to include land-use impacts in a joint effort by researchers from the Stockholm County Council and the Royal Institute of Technology (*79,80*). Simulation results show that building the East and West Links increases average highway speed and the amount of automobile use (Table 18). Adding tolls (of magnitude SEK 5 higher than those later decided on) further increases speeds, but reduces automobile use—so much so that the number of vehicle-miles traveled under the combined package is less than it would be without the bypass roads, and in fact about the same as with no investments at all.

Together, these modeling efforts suggest that the toll ring will add significantly to the ability of the bypass routes to succeed in their goal of reducing motor vehicle travel in inner Stockholm. The tolls may even compensate for the regionwide traffic inducement effects of the new roads. The package therefore offers both improved travel conditions and a limitation on congestion and adverse environmental effects of road traffic.

LESSONS FROM THE SCANDINAVIAN TOLL RINGS

Norway and Sweden have adopted a pragmatic approach to congestion pricing. Road pricing has been initiated primarily to finance desired transportation investments. At the same time, however, the possibility of using it to ameliorate the

TABLE 18

TRANSPORTATION INDICATORS FOR COMMUTING TRIPS: STOCKHOLM COUNTY, YEAR 2005

	I-E-W	I	I+P	% Change: I+P vs. I
Modal share by car (%)	36.2	37.7	35.0	-7.2%
Average one-way trip distance (km)	16.8	17.1	17.0	0.6%
Average speed for car trips (km/hr)	33.5	36.4	38.6	+6.1%
Total vehicle-km traveled (Index: Do-nothing scenario =100)	105.0	115.9	99.7	-14.0%

KEY:
- I-E-W: Investment Program without East & West Links
- I: Investment Program with East & West Links
- I+P: Investment Program with East & West Links plus Road Pricing (SEK 20 ring toll and SEK 10 West-Link toll)

Source: Calculated from (*79*, p. 15, Table 2a).

congestion and environmental effects of traffic has increasingly been exploited. While Bergen's and Oslo's schemes are strictly revenue raisers, Trondheim's applies a mild incentive to spread the afternoon rush hour, and Stockholm's is designed to make significant reductions in inner-city traffic.

The toll rings are of impressive scope and ambition. Each surrounds an entire center city, and thereby affects many of the region's motorists. The scale of the rings is also an advantage, in that it spreads the burden of financing local improvements widely. The burden on any one household is further limited by the use of seasonal passes or, in Trondheim, limits on the maximum number of crossings charged to electronic subscribers. These policies substantially increase the acceptability of the projects to the public, although they also weaken somewhat the incentive effects to reduce motor vehicle use.

The incremental development of the institutional, operational, and technological features of the toll rings highlights the advantages of demonstrations. Each project has been carefully planned and has used methods and equipment that are sufficiently simple and well tested to promote a smooth, relatively problem-free introduction. At the same time, each has taken advantage of the experience of its predecessors to add new features that increase the convenience to users and the degree to which congestion management occurs. In this way, a level of public confidence in the workability of increasingly sophisticated pricing systems has been built, while keeping the schemes closely tied to well-articulated and widely shared objectives.

[1] (For example, the 1992 toll rates shown in Table 12 have applied only since January 1, 1991 (*53*, p. 5); before then, the toll was only NOK 10 per passage (with 10 percent discount for books of 20 coupons), and seasonal rates were 12 percent below 1992 levels. Electronic tags were not introduced until December 1990, and the electronic "clipcard" was not introduced until October 1991).

[2] Calculations based on Table 5.1 *(63)* Column 1a, which implies marginal rates of substitution between toll and trip retiming of NOK 0.586 per minute of retiming earlier and 0.549 per minute of retiming later. (These are the ratios of coefficients of CarES and CarLS, respectively, to TOLL). Averaging these and converting to U.S. currency implies a tradeoff of $0.091 per minute, or $1.00 per 11 minutes.

CHAPTER FIVE

INTERCITY CONGESTION PRICING IN FRANCE

In April 1992, a French toll road company initiated the first application of congestion pricing to an intercity rather than an urban highway. Intercity highways often suffer from congestion, although, unlike urban highways, their heaviest traffic loads are typically at the beginning and end of weekends and holidays rather than during weekday mornings and evenings. The French experience is important because it suggests that intercity highway congestion is sensitive to pricing, and that a carefully designed congestion pricing scheme can win public support and acceptance.

ORIGINS OF THE PROPOSAL

In France, intercity expressways are generally financed out of tolls while urban expressways are toll free (*1*, Ch. 8). Most of the intercity expressway system is operated by eight major toll road companies. One is privately owned and the other seven are "mixed-investment companies" (sociétés d'économie mixte), which in theory can have both private and public stockholders but which in practice are fully government owned in most cases. The intercity toll road companies, both private and mixed, are largely self-supporting as a group, although there are important cross subsidies among them.

One of these companies, The Société des Autoroutes du Nord et de l'Est de la France (SANEF), is the nation's third largest intercity toll road company and operates 1,016 km (631 mi) of expressways to the north and east of Paris. SANEF's A-1 expressway from Paris to Lille has three lanes in each direction and is one of the most heavily traveled in France, connecting two large urban regions less than 200 km (124 mi) apart. The A-1 suffers from serious congestion on Sunday afternoons and evenings when Parisians return home from weekends in the countryside, augmented by residents of outlying areas who work in Paris and maintain temporary quarters there during the working week.

The idea for implementing congestion pricing on the A-1 originated with SANEF's president, Daniel Tenenbaum. Tenenbaum was previously the Director General of the Civil Aviation Authority, the agency that regulates France's airlines and airports. France's airlines had been allowed to vary their prices by season and direction to cope with peak demands since 1974, and French electricity, telephone, and gas utilities all had long employed some form of peak-period surcharges. To Tenenbaum, the parallels between peak highway congestion and peak demands in airline and utilities were obvious.

SANEF's suggestion of varying toll rates to control Sunday congestion won support from senior officials of the government agencies that supervise intercity toll roads. The Ministry of Finance, which sets toll rates, was supportive as long as the scheme was revenue neutral (i.e., did not increase overall average tolls). Senior officials of the Ministry of Equipment, which has overall responsibility for the highway system, were also in favor. Members of the Ministry of Equipment's technical staff were opposed, however, on the grounds that it would be unfair to charge different motorists different tolls and that motorists would cause safety problems by speeding up or slowing down to arrive before or after peak toll hours. These staff members also argued that the scheme would have little effect on traffic levels since tolls were only a small part of the total cost of a weekend trip.

SANEF attempted to meet these concerns and to gauge the public response by distributing 10,000 questionnaires to motorists driving toward Paris on the A-1 one Sunday. The questionnaire explained that SANEF was considering raising tolls in peak hours and reducing them in the off-peak, and outlined the expected benefits: reduced travel time and fatigue, increased fuel economy and safety. Motorists were asked whether they would favor the proposal and whether they would change the hour they traveled in response to various toll differentials between peak and off-peak. Twenty-two percent of the questionnaires were returned, with most commenting favorably on the proposal. Of those responding, only 25 percent reported that they would not change their hour of travel while 32 percent said they would change hours even if the peak-period toll were only 20 percent higher than the normal tariff (*81*, p. 7).

SANEF also made efforts to explain the proposal to journalists and to win favorable advance press coverage. The press stories were largely supportive, according to Tenenbaum, because journalists viewed the proposal as an unusual innovation among the otherwise conservative practices of toll road companies, and because these journalists were familiar with the merits of peak-period pricing in airlines and other industries.

DESIGN OF THE VARIABLE TOLL SCHEME

The A-1 expressway is operated by SANEF as a tolled facility from the outskirts of Lille to the Charles de Gaulle Airport, a distance of 166 km (103 mi). From the airport south into Paris, a distance of about 25 km, the A-1 is operated and maintained by the regional government as a toll-free expressway. SANEF collects tolls on most of the A-1 through a closed ticket system in which motorists receive a ticket on entering and surrender the ticket and pay their toll on exiting (see Figure 11). The closed ticket system ends at the Chamant toll barrier, located 25 km north of the Charles de Gaulle Airport, where all southbound motorists must surrender their tickets and pay tolls and where northbound motorists receive their tickets. There are three entrances and exits between the Chamant toll barrier and the beginning of the untolled road segment at the airport. Two of these are tolled and one, which leads only to a public park (parc Asterix), is free because a payment to SANEF is included in the parking fee there.

Toll Entrance/Exit or Barriers

From Lille (north)

- L'Arrageois
- Bapaume
- Vallée de la Somme
- Roye
- Ressons
- Arsy
- Chevrieres
- Chamant/Senlis (toll barrier plus northbound toll entrance)
- Bonsecours/Senlis (southbound toll entrance)
- Parc Astérix (toll included in parking fee)
- St. Witz

To Paris (south)

FIGURE 11 Schematic Diagram of the A-1, Lille-Paris.

SANEF's scheme affects tolls collected southbound (toward Paris) on Sunday afternoons and evenings. These tolls are collected primarily at the Chamant toll barrier. The variable toll scheme also applies to exits north of Chamant to prevent diversion to parallel untolled roads (especially national route N17); it also applies to the Senlis entrance, which is south of Chamant and is the closest tolled entrance to Paris.

The scheme works as follows. From 4:30 to 8:30 p.m. motorists must pay a "red tariff," which is approximately 25 percent higher than the normal toll rate for longer trips, and as much as 56 percent higher for shorter trips (Table 19). Before and after the red-tariff period—specifically, from 2:30 to 4:30 p.m. and from 8:30 to 11:30 p.m.—SANEF charges a "green tariff" that is 25 to 56 percent *lower* than the normal tariff. The differential between green and red period is quite substantial: 10 francs ($1.90) for the shortest trips and 26 francs ($4.94) for the longest trips. This schedule was designed so that the revenue gained from raising tolls during the red period is almost exactly offset by the revenue lost from lowering tolls in the green period.

Motorists were informed in advance of the scheme by distributing 400,000 brochures. Permanent signs were also erected on the A-1 informing motorists of the red- and green-tariff hours, and variable message signs were installed before the toll stations to let motorists know which tariff is in effect as they approach. SANEF estimates their investment in publicity and signage amounted to 1.5 million francs ($285,000) (D. Tenenbaum, personal communication, January 5, 1993).

EFFECTS

The variable toll scheme, first implemented on April 26, 1992, has distributed traffic flows more uniformly over the Sunday afternoon and evening hours. Table 20 shows the average southbound hourly volumes for 30 Sundays in 1992 after the scheme went into effect and for 30 comparable Sundays in the previous year. While the average traffic for the entire Sunday increased by 1.3 percent between 1991 and 1992, traffic during the hours when the red tariff prevailed for the entire time declined by between 4.4 and 8.2 percent.

A study by SANEF reaches similar conclusions based on a comparison of traffic counts every 10 minutes between Sundays in 1992 and Sundays at comparable seasons during the previous 5 years (*83*). Overall, SANEF found southbound traffic at Chamant declined approximately 4 percent during the red period and rose approximately 7 percent during the green periods relative to the 6-year trend (*83*, p. 11). The predominant shift was from the red period to the later green period. The proportion of traffic during the entire afternoon and evening that occurred during the peak 3 hours (5 to 8 p.m.) declined by 10 percent, comparing November 15 and 22, 1992 with comparable Sundays in the previous 6 years (*82*, p. 12). The shift is especially pronounced during the last 10 minutes of the red period, but is quite noticeable for at least an hour before and after the boundary between the red and late green periods (*83*, p. 18).

A survey of southbound motorists at the Chamant toll barrier in November 1992 confirms that many deliberately shifted the timing of their trips (*82*). Of those traveling in the early and late green periods, 18 percent and 21 percent respectively said they had changed their time of travel to take advantage of the lower toll rate. In the case of the later green period, one-third of those who delayed did so by stopping along the way at one of the service areas where meals and fuel are available (*82*, pp. 8–10). [There is a typographical error for "trajet mixte (arret)" on p. 10, as can be seen from the column total and as was confirmed by M.H. Costa Elias (interview, September 9, 1993.)].

It is revealing that so many people traveling in the early green period say they advanced their trip, yet the traffic levels during this period grew little if at all. A likely explanation is that as congestion during the red period lessened, some people who previously had traveled early to avoid congestion now found it more convenient to travel between 4:30 and 8:30 p.m. and were willing to pay the higher toll to do so. This is an example of the kind of efficient reallocation of peak traffic, to those for whom timing is most important, that is predicted by the theory of congestion pricing.

At first, there was a slight shift of traffic to the main parallel route, national route N17, amounting to about 100 vehicles per hour. No such shift was observable after the variable toll scheme had been operating for a few months (*83*, p. 7). This favorable result is probably because the alternative routes are not built to expressway standards (*81*, p. 10), and because the

TABLE 19

SAMPLE SUNDAY AUTO TOLLS, SOUTHBOUND ON THE A-1 EXPRESSWAY, FRANCE, 1992

	Shortest trip (Senlis-Paris)		Longest trip (Lille-Paris)	
	Francs	Dollars	Francs	Dollars
Normal tariff (Sundays before 2:30p.m. and after 11:30p.m. and all other days)	9	1.71	52	9.88
Red tariff (Sundays 4:30-8:30p.m.)	14	2.66	65	12.35
Green tariff (Sundays 2:30-4:30p.m. and 8:30-11:30p.m.)	4	0.76	39	7.41

Sources: (*82*, p. 3; *81*, p. 9).

TABLE 20

TRAFFIC VOLUMES SOUTHBOUND AT CHAMANT TOLL BARRIER BEFORE AND AFTER THE INTRODUCTION OF SUNDAY PEAK PRICING

	Before (30 Sundays in 1991)	After (Same 30 Sundays in 1992)	Change (%)
Average all day volume	31,395	31,797	+1.3
Average hourly volume			
0-8	364	359	-1.5
8-9	774	786	+1.5
9-10	1165	1188	+2.0
10-11	1505	1494	-0.7
11-12	1569	1540	-1.9
12-13	1169	1177	+6.7
13-14	973	984	+1.1
Green begins 14:30			
14-15	1142	1205	+5.8
15-16	1548	1747	+12.8
Red begins 16:30			
16-17	1999	2104	+5.3
17-18	2467	2316	-6.1
18-19	2704	2585	-4.4
19-20	2711	2493	-8.2
Green begins 20:30			
20-21	2461	2479	+0.7
21-22	2535	2781	+9.7
22-23	2253	2397	+6.4
Green ends 23:30			
23-24	1526	1652	+8.2

Source: Calculations by the authors based on unpublished data supplied by SANEF. Note that similar effects occur at the Senlis Bonsecours entrance, just south of the Chamant toll barrier, when congestion pricing was also applied.

toll differential is graduated by distance so that one cannot gain much by taking only a short detour off the toll road.

One potential drawback to the scheme is the lack of tolls at exits and entrances closer to Paris, where the A-1 is operated by public authorities rather than SANEF. There was some concern that lower congestion might attract new peak-period traffic entering southbound on the untolled ramps, thereby offsetting some of the benefits otherwise accruing on the section near Paris. Unfortunately, there are no data readily available on traffic volumes on the untolled segment. The company suspects that this problem is minor, however, since Sunday evening is not a popular period for short urban trips and traffic from Charles de Gaulle Airport is not very time-sensitive. One of the fortuitous effects, in fact, appears to be a shift in the intercity traffic peak so that it no longer coincides with the southbound traffic peaks leaving the airport and parc Asterix (*83*, p. 11; H. Costa Elias, personal interview, September 9, 1993).

Whether the smoother traffic flows on the tolled segment have translated into significant reductions in travel time is unclear, since no travel speed data have been collected. SANEF reports no excessive or dangerous behavior around the times when the rates change, largely because the limited access to the expressway makes such behavior easy to deter by police presence. Some people apparently travel more slowly or stop at rest areas along the way to arrive at the toll station after the red tariff is removed (*83*, p. 17).

The scheme is very close to revenue neutral, as intended. Actual toll receipts at the affected toll stations over the first 33 Sundays were just 1.2 percent lower than they would have been if all traffic had paid the normal tariffs (data supplied by D. Tanenbaum, personal communication, January 5, 1993).

The scheme was initially designated as an experiment to run only from April to November of 1992. SANEF decided to extend it beyond November, however, given its public acceptance and apparent effectiveness in smoothing traffic flow.

LESSONS FROM THE FRENCH EXPERIENCE

SANEF's experience suggests that congestion pricing can successfully smooth traffic flows on intercity as well as urban roads. Perhaps more importantly, the scheme seems to have been accepted by both the general public and government officials. This acceptance appears to be due in part to SANEF's careful planning and its efforts to explain the scheme to motorists and journalists. The fact that tolls were already being collected on the road and that the new tariff scheme was revenue neutral were probably more critical, however, because this implies that the change for motorists was minor: SANEF could argue that it was not using the scheme to extract more revenue from motorists, but rather to improve the service they enjoyed.

TRB
Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Suggestions for synthesis topics may be sent to the Transportation Research Board at any time. Topics suggested must be accompanied by a brief scope statement or discussion of the problem (a paragraph or two). Suggestions for updates of published syntheses are also welcome.

Interested in writing a synthesis? For details, contact Sally D. Liff, Stephen F. Maher, or Donna L. Vlasak at (202)334-3242.

ear Reader,

his Synthesis of highway practice is one f a series of reports issued by the TRB-dministered National Cooperative ighway Research Program (NCHRP), hich is sponsored by the American ssociation of State Highway and ransportation Officials (AASHTO) in ooperation with the Federal Highway dministration (FHWA). This is the 210th ynthesis to be published in this series, and e are interested in obtaining reader esponse to this document, as well as to the ntire Synthesis series, to aid us in formu-ting future Synthesis reports. So that everal readers may respond, three ostage-paid cards are attached for use in plying to two brief questions. We will, of ourse, welcome any additional comments at you wish to make. Your assistance is reatly appreciated.

Robert E. Skinner, Jr.
Executive Director
Transportation Research Board

Please detach and mail NCHRP SYNTHESIS 210

1. Please comment on this report and indicate what opportunities you see for the practical application of this Synthesis report to the work of your organization.

____

2. Are you familiar with the NCHRP Synthesis series?______ If so, do you find it useful?______ Please comment.

____

Name: ____________ Title: ____________
Affiliation ____________
Address ____________
Telephone ____________ FAX ____________

Please detach and mail NCHRP SYNTHESIS 210

1. Please comment on this report and indicate what opportunities you see for the practical application of this Synthesis report to the work of your organization.

____

2. Are you familiar with the NCHRP Synthesis series?______ If so, do you find it useful?______ Please comment.

____

Name: ____________ Title: ____________
Affiliation ____________
Address ____________
Telephone ____________ FAX ____________

Please detach and mail NCHRP SYNTHESIS 210

1. Please comment on this report and indicate what opportunities you see for the practical application of this Synthesis report to the work of your organization.

____

2. Are you familiar with the NCHRP Synthesis series?______ If so, do you find it useful?______ Please comment.

____

Name: ____________ Title: ____________
Affiliation ____________
Address ____________
Telephone ____________ FAX ____________

No Postage Necessary If Mailed in the United States

BUSINESS REPLY MAIL

First Class Permit No. 10207 Washington, D.C.

Postage will be paid by:

Transportation Research Board
National Research Council
Sally D. Liff GR322 N
2101 Constitution Avenue, NW
Washington, DC 20078-5576

No Postage Necessary If Mailed in the United States

BUSINESS REPLY MAIL

First Class Permit No. 10207 Washington, D.C.

Postage will be paid by:

Transportation Research Board
National Research Council
Sally D. Liff GR322 N
2101 Constitution Avenue, NW
Washington, DC 20078-5576

No Postage Necessary If Mailed in the United States

BUSINESS REPLY MAIL

First Class Permit No. 10207 Washington, D.C.

Postage will be paid by:

Transportation Research Board
National Research Council
Sally D. Liff GR322 N
2101 Constitution Avenue, NW
Washington, DC 20078-5576

CHAPTER SIX

PLANNING FOR LARGE-SCALE CONGESTION PRICING IN THE NETHERLANDS AND THE UNITED KINGDOM

Except for Hong Kong, the plans discussed in earlier chapters are limited in scope and complexity, and each either has been implemented or appears close to implementation. More ambitious and more speculative proposals are described next. Two of these, for the Randstad region in the Netherlands and for metropolitan London, would be the largest road pricing schemes ever implemented, involving complex technology and covering regions with upward of 6 million people. The third is in Cambridge, England, a small but very congested city, which developed an unusual proposal for congestion pricing using on-board meters that respond to the actual degree of congestion encountered.

THE NETHERLANDS: RANDSTAD

In The Netherlands, as in Sweden, a combination of local concern about traffic congestion and national concern about automobile air pollution has stimulated serious consideration of road pricing. The plan first proposed involved a sophisticated electronic charging scheme, which has since been simplified several times to meet objections about technological feasibility and privacy. The most recent proposal was a once-per-day charge of perhaps NLG 5 ($2.85 at the 1992 exchange rate) for using the network of primary roads during morning peak hours.

The Randstad, as shown in Figure 12, is a sprawling urban region that covers 5,800 km^2 (2,239 mi^2) and is home to about 6 million people (*84*, p. 9). It includes the nation's four largest metropolitan agglomerations: Rotterdam (1.03 million people), Amsterdam (1.02 million), The Hague (0.68 million), and Utrecht (0.52 million) (*85*, p. 2). Other cities of note in the region include Delft, Dordrecht, Haarlem, and Leiden. The Randstad includes two of the largest trans-shipment points on the European continent: the port of Rotterdam and Schiphol Airport near Amsterdam. Road congestion is severe, and is estimated to cost the economy NLG 1.2 billion ($684 million) annually in wasted time (*86*, p. 1)

The Randstad's urban form and congestion problems resemble those of the larger Los Angeles region in the United States. Both are polycentric with complex peak-hour commuting flows; both are densely populated and very congested over a rather dispersed region; both contain international transportation terminals whose road connections with the rest of the region are deemed crucial to the local economy. Furthermore, transportation planners and public officials in both areas recognize the impossibility of financing or building enough new capacity to solve regional congestion problems, and hence have increasingly promoted the need for congestion management (*87*, *88*, *89*).

During the late 1980s, the national government developed a proposal for the Randstad called Rekening Rijden (Road Pricing). This scheme was conceived as a multiple-cordon system in which numerous cordon lines (not concentric in this case) were defined and 140 charge points were located on all roads crossing them. Virtually all trips of more than 7.5 km would pay, and longer trips would pay two or more times. The primary motivation for the scheme was not to raise funds but rather to reduce congestion and overall automobile use and, secondarily, to strengthen public transportation (*90*, p. 112; *91*, pp. 40–41).

The charge at each toll point was to vary by time of day. In one version, it would be NLG 3.00 ($1.71) from 8:30 to 9:30 a.m. and 4:00 to 6:30 p.m. but only one-tenth as high during other hours (*5*, p. 52). In a version designed to achieve greater reduction in overall traffic, the peak charge would be NLG 2.50 ($1.42) and the off-peak charge NLG 1.50 ($0.85) (*92*, p. 6).

Electronic charging was to be used to meet the Ministry of Transport and Public Works' concerns about low cost, ease of use, reliability, flexibility with respect to location and time of day, and capability for multilane operation at highway speeds. The Ministry's desire to protect privacy led them to recommend the use of an in-vehicle transponder and a smart card containing a prepaid value, which the Dutch planners called a value card or electronic purse (*92*, pp. 2–4; *86*, pp. 9–10). The charge points were to be located so as to achieve a fair distribution of charges, to concentrate the charges on points of heavy congestion, to minimize adverse spillover effects, and to maintain compatibility with land-use policies. Investment costs were estimated at NLG 360 million ($205 million) and annual operating costs at NLG 65 million ($37 million) (*92*, pp. 5–6).

The version with peak and off-peak charges of NLG 2.50 and 1.50 was expected to reduce vehicle mileage traveled by 17 percent during peak hours and by 8 percent overall. The number of vehicles passing the charge points during charging hours would decline by approximately 35 percent due to the combination of the reduction in vehicle mileage and shifts in route, destination, and time of day (*92*, p. 6; *93*). Preliminary .modeling of land-use impacts suggested some effect on residential location but little on employment location (*94*, p. 14).

By early 1990, however, it had become apparent that the plan was too radical to win Parliamentary approval. Critics questioned whether the new technology would work, privacy could be protected, and spillover effects would be tolerable. Privacy was a special concern, despite the value card proposed: "the possibility that [the system] could register each illegal passage ... is a menace to all; perfection in the repression of illegality is not at all desirable to most citizens" (*90*, p. 115).

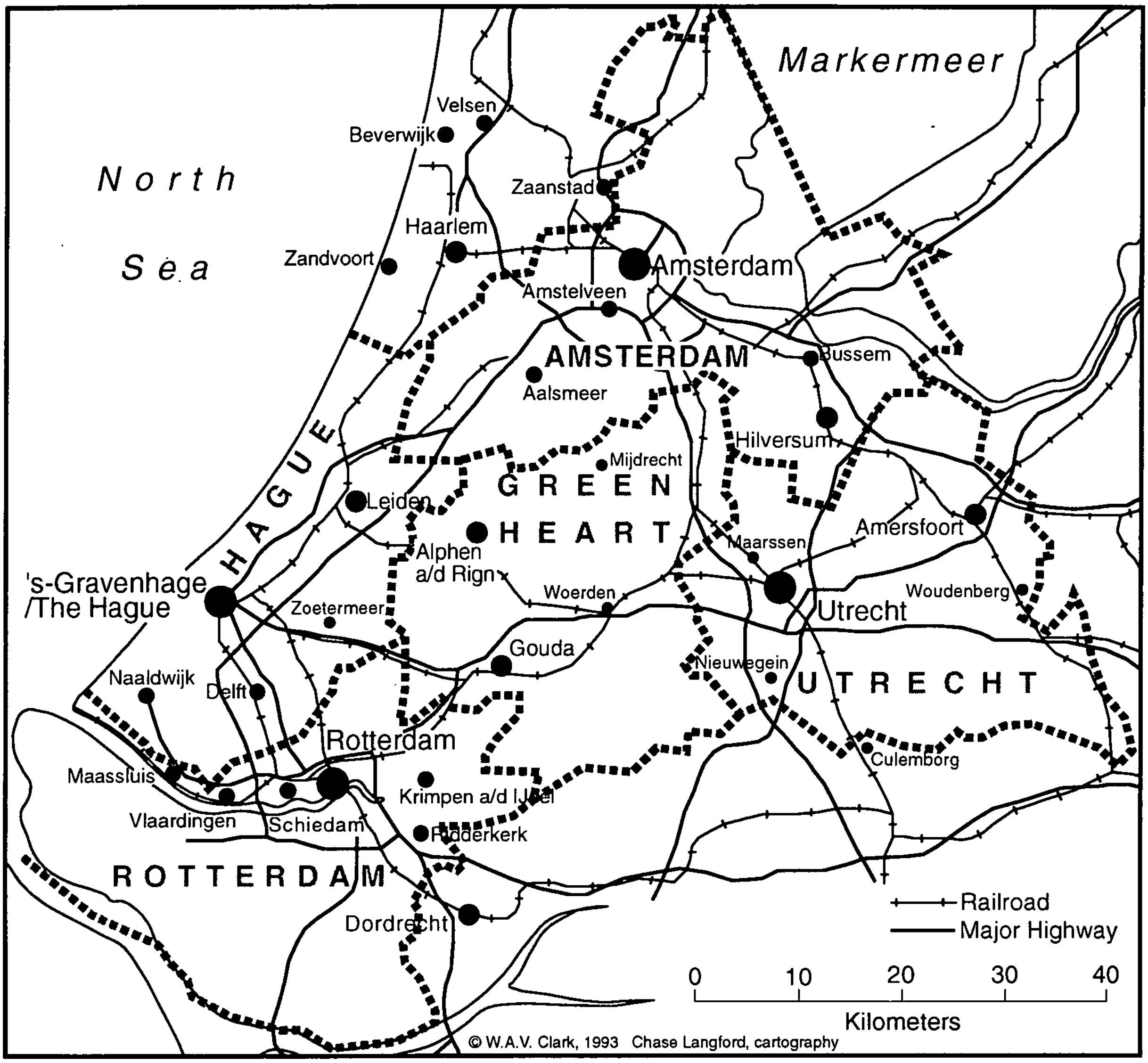

FIGURE 12 The Randstad area *(83)*.

The Government responded to Parliament's concerns by proposing a more conventional toll scheme, with far fewer toll sites and toll collection options more like those used in Norway (*91*, pp. 36–37, 48–49). This was viewed as a temporary measure, with more elaborate electronic pricing still a long-term goal. The plan was approved in principle by Parliament and research into the newly endorsed proposal was undertaken within the Ministry under the name Project Tolheffing (Toll Collection).

The new toll proposal included several other options in addition to the basic toll scheme. One was a supplementary license scheme put forth as an interim measure if it took too long to get the toll systems in place. Under this scheme, a special license required for peak-hour travel would be sold on a daily, monthly, or annual basis (*91*, p. 38). A second option was to build new exclusive highway lanes for freight traffic and high-occupancy vehicles but to allow single-occupant vehicles to use them if they paid a special charge. A third option was private funding of new road tunnels, to be repaid by toll revenues (*91*, p. 112). Finally, it was suggested that a tax or other restrictions might be imposed on employee parking (*91*, p. 31).

The use of the toll revenues was considered almost as an afterthought. The preferred scheme was to use them to fund road projects, and to divert the road funds thereby freed to public transportation, just as is proposed in Stockholm (*91*, p. 112). This system would effectively use the new funds for both road and public transportation improvements, while complying with a legal provision that restricts the use of toll revenues for roads only.

By 1992 the proposal was revised once again, however, after the Ministry of Transport and Public Works became convinced that the 1990 toll scheme would require too much land for toll plazas and cause too much local traffic diversion. The new plan would impose a daily charge for travel on main roads during the morning peak. Both local authorities and the national government agreed to this approach, which is close to an area license (H.D.P. Pol, personal communication, June 1993).

The specific proposal entailed a fee of perhaps NLG 5 ($2.85), charged once during a given day for use of the main road network during morning peak hours (6 to 10 a.m.). Cash or bank-card sales would occur at service stations, banks, post offices, roadside restaurants, 24-hour vending machines, and over the telephone. Users could purchase permission to travel either on a given day or for a 3- or 12-month period. In either case, the user's vehicle registration number would be recorded as paid for that day, and enforcement would be by random video pictures of license plates (*86*, pp. 4–8).

This latest proposal was a true congestion pricing scheme because the charges would be both location- and time-specific and the principal purpose was congestion management. Travelers were expected to respond primarily by changing their time-of-day and mode of travel, with a resulting one-third reduction in traffic delays (*86*, p. 8). Increased carpooling would occur, despite the lack of explicit discounts for carpools, because the peak vehicle charge would be high enough to induce people to try to divide it among several occupants. Some long-run effect on locational patterns was also hoped for.

These plans were set back, however, by the results of the May 1994 national elections. The Ministry of Transport and Public Works had delayed submitting the proposal to Parliament until after the elections, to be sure that the election results did not affect government support for the scheme. The governing coalition was not reelected and the new Minister of Transport and Public Works is thought to be unsympathetic to road pricing.

Assessment

The Netherlands experience confirms two lessons from Sweden: drastic road-pricing innovations are difficult to introduce all at once, but such proposals can stimulate other solutions. The Netherlands differs from Sweden, however, in that the Dutch have been developing a system of time-of-day pricing, motivated primarily by the desire to solve problems of congestion and environment and only secondarily by the need to raise revenue. Perhaps the Dutch have been encouraged to do so by the more complex travel patterns in their capital region; or perhaps technological development and practical experience in other nations have emboldened the Dutch to aim for a somewhat more elaborate system. It remains to be seen whether, in this instance, the combination of thorough planning and incremental politics that has been practiced will eventually lead to road pricing for congestion management.

THE UNITED KINGDOM: LONDON

Britain has been a leader in studies of road pricing beginning with the report of the Smeed Commission on traffic problems in the early 1960s (*95*). That report is widely recognized as a landmark in transportation policy in that it was the first government report to strongly endorse congestion pricing. The report suggested a number of principles for successful

TABLE 21

POPULATION, EMPLOYMENT, AND AUTOMOBILE OWNERSHIP IN GREATER LONDON[a]: 1986 AND 2001

	1986	2001	Change[b] (%)
Population (millions)[c]	7.11	7.24	1.9
Households (millions)	2.79	2.97	6.2
Employed residents (millions)	3.32	3.53	6.2
Employment (millions)			
Region	3.82	4.20	9.9
Central Area	1.19	1.34	13.1
Percentage of households owning:			
No car	37.1	32.0	-13.7
One car	41.4	44.0	6.3
Two or more cars	21.5	24.0	11.6

[a] Figures are for the study area of the London Transportation Studies (LTS) model. This area differs slightly from that termed "Greater London" by the Central Statistical Office, whose population is given in Chapter 7 of this report.

[b] Computed from unrounded figures in source, so may not precisely match the first two columns.

[c] Persons in private households.

Source: (*100*, pp. 25-26)

implementation that are still widely accepted, and it argued that the technical means to carry out congestion pricing already existed.

Although the Smeed Commission's recommendations were not adopted, they stimulated a long debate about the merits of congestion pricing and other traffic restraint measures in British cities (*96,97*). As traffic and congestion have continued to grow, moreover, interest in congestion pricing appears to be increasing. Transport planning studies in London have long incorporated time-of-day road pricing as an option, and those in other cities, such as Edinburgh (*98*), have begun to do so as well. Meanwhile, the market-oriented Conservative government has proposed that the nation consider tolling its entire motorway system (*99*), giving further impetus to the idea of road tolls and to applications of electronic toll-collection technology. This chapter concentrates on proposals for two urban areas: London and Cambridge.

The Greater London region contains about 7 million people and 4 million jobs (Table 21). Nearly one-third of the jobs are located in Central London; this area roughly takes the form of a circle with a radius of 2.8 km (1.7 mi) that is centered on the Charing Cross railway station and bounded by London's Inner Ring Road. Surrounding Central London is Inner London, consisting of a "doughnut" whose outer radius is about 9 km (5.6 mi). On the map shown in Figure 13, Central London is zone 1 and Inner London is approximately zones 2–5. Greater London's population is expected to grow only 2 percent over the 15-year period 1986–2001. Congestion on Central London roads is still expected to increase, however, since employment in Central London is expected to grow by 13 percent and the past steady growth in automobile ownership is expected to continue.

Greater London has been the site of a remarkable series of comprehensive studies of congestion pricing, covering a variety of time periods, policies, and models. Each study has produced congestion pricing proposals that have garnered considerable support, but none has been adopted. The most recent such study is a massive 3-year research program sponsored by the UK Department of Transport; begun in 1991, it promises to produce the most comprehensive analysis ever of all aspects of congestion pricing policy.

The London Planning Advisory Committee (*101*), the London Boroughs' Association (*102*), and the Chartered Institute of Transport (*103*) have all gone on record in support of congestion pricing in London even before the latest round of studies is completed. The London Boroughs' Association also reports considerable support among the borough governments in greater London, one of which, Richmond-upon-Thames, has expressed interest in being part of a road pricing experiment (*102*). The central Government has been unwilling to commit itself, however, in advance of the results from the studies to be completed in 1994.

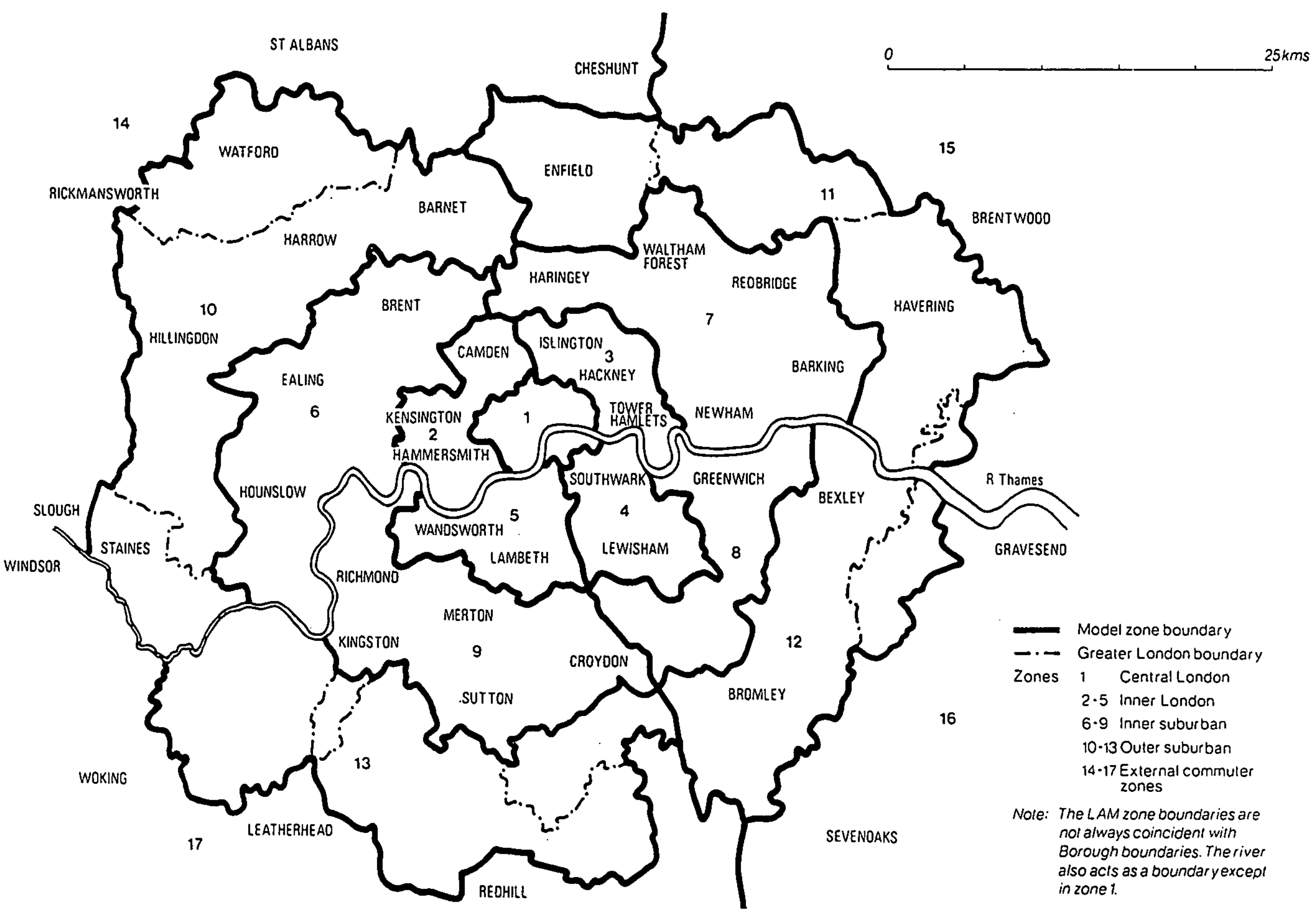

FIGURE 13 Greater London: Zoning system for the London Area Model *(99)*.

The Greater London Council Studies

During the 1970s, the Greater London Council, a regional governmental organization, became interested in restraining traffic through supplementary licensing, a form of congestion pricing in which a special daily license is required to operate a vehicle within a defined area. Extensive simulation studies were performed using the network model CRISTAL, developed for the purpose by the Transport and Road Research Laboratory (*104*). These simulations predicted how various hypothetical policies would change travel behavior and congestion. Net benefits were then calculated as the value of the travel time savings less the consumer surplus losses due to changes in travel behavior.

Three of the options studied showed the greatest promise, generating net benefits ranging between £25 million and £38 million ($61 to 93 million) per year. All three imposed a daily charge of £0.75 to 0.90 ($1.84 to 2.20) to drive within Central London (1973 prices and exchange rate) between 8 a.m. and 6 p.m. on weekdays (*104*, p. 164). In two of them, there was an additional charge, equal to one-fourth to one-half of the base charge, in Inner London during the morning peak only (8 to 10 a.m.).

Net benefits were considerably lower for schemes that charged motorists entering Central London only in the morning peak, or for schemes that charged motorists entering Inner London all day. The reason is fairly simple: congestion in Central London was (and is today) an all-day affair, while congestion in Inner London was highly concentrated during morning and afternoon peaks. (Charging during afternoon peaks was not studied.)

The analysis also suggested that it is better to err on the low side when setting charging levels. Compared to the base rate of £0.75 to 0.90 ($1.84 to 2.20), for example, doubling the charge reduced net benefits by roughly 20 to 70 percent while halving it reduced them by only 15 percent (*104*, Figure 3). Again, the reason is simple: when congestion is very severe, even the small traffic reduction obtainable from a small charge creates significant time savings; raising the fee beyond the optimal level, however, just wastes valuable road capacity without realizing much further savings in travel times.

Revenues from the more attractive schemes were estimated to be roughly in the range of £55 to 70 million ($135 to 172 million) annually, or about twice as high as the net benefits. This figure includes the increased transit fare revenue and the decreased fuel-tax revenue resulting from people shifting from car to public transport. The estimated annual costs of operating and enforcing the system were in the range of £6 to 9 million ($15 to 22 million), or about 10 to 15 percent of revenue. Most of the additional passengers on public transportation would be accommodated through replacement of smaller buses with larger ones and from increased productivity due to the higher operating speeds; as a result, public transport operators would incur only £2 to 3 million ($5 to 7 million) in additional annual costs (*104*, pp. 164–165). The preceding statements are based on May's work (*104*, pp. 164–165) for scenarios B, C, and D, which have the highest net benefits among the scenarios tested (*104*, Figure 3). The cost figures are the costs of license issuing, enforcement, and traffic management (*104*, Table III, Col. B–D).

The predicted impacts on traffic were quite dramatic. A charge somewhat below the optimum was projected to reduce the volume of car traffic entering Central London by 45 percent, and that entering Inner London by 30 percent. Commercial traffic would be reduced somewhat less, and there would be some diversion of traffic onto ring roads, both within and outside Inner London. Total traffic (vehicle-kilometers traveled) within Central and Inner London would be reduced by 37 and 11 percent, respectively, raising peak-hour speeds by 40 and 15 percent.

There are two main reasons why the expected impacts are this large. First, a large portion of through traffic is diverted around Central London. More than one-third of the cars entering the Central Area during the morning peak in 1974 were just passing through it (*104*, Figure 1), and 60 percent of these were predicted to be diverted. Second, London's extensive transit service would enable one-third of the inbound motorists with destinations in Central London to switch to public transit, especially bus. Bus ridership was forecast to increase by 25 percent (*105*, p. 182).

Supplementary licensing was forecast to significantly improve traffic flow even if it were combined with a drastic program of Central London street closings. If one-quarter of Central London's street capacity were eliminated, for example, supplementary licensing would still reduce average traffic volume per lane by 14 percent (*104*, p. 164). Closing so many streets is unlikely in U.S. cities, but scaling back plans for new construction is a serious policy option; the London analysis suggests that the efficiency gains from congestion pricing may be captured in the form of either improved speeds or reduced capacity requirements, or in some combination of the two.

The London Planning Advisory Committee Studies

The Conservative Government abolished the Labour-dominated Greater London Council in 1985 and transferred some of its planning and advisory functions to the newly created London Planning Advisory Committee (LPAC). The LPAC is composed of representatives from various local authorities, including London's 33 Boroughs, and beginning in 1987, it commissioned a series of transport studies in an attempt to develop a traffic policy for the area (*106*).

The first of these studies, known as the "Transportation Strategic Advice Scenario Testing Exercise" or TASTE I, was carried out by The MVA Consultancy (*107*) using a regional model provided by the government's Transport and Road Research Laboratory. The model, called the London Area Model (LAM), is designed for broad-brush strategic analysis and uses relatively large traffic zones or areas and an aggregate highway speed-flow relationship for each area.

LPAC's consultants simulated four scenarios (*107*, Chapter 2 and Appendix 5; *108*, pp. 260–263; *101*, p. 2):

- Scenario 1 served as the baseline in that it represented a continuation of current government policies, including new roads, some new rail projects, bus deregulation, elimination of rail subsidies, and a halving of bus subsidies;
- Scenario 2 incorporated slightly less road investment, greater investment in rail transit, and rail and bus subsidies sufficient to maintain current fares;

TABLE 22
ECONOMIC EVALUATION OF LONDON PLANNING ADVISORY COMMITTEE SCENARIOS (TASTE I) *(107)*

Component of benefit	Benefits relative to baseline scenario in which current policies continued (in millions of 1986 pounds)					
	Basic Scenarios			Other Variants		
	2 (transit expan.)	3 (road expan.)	4 (congest.p ricing	2A (2 w/ pricing)	3A (3 w/ pricing)	4A (4 w/ transit subsidy)
Benefits to Travellers						
Time savings	487.0	164.9	371.3	539.3	479.9	598.8
Vehicle operating cost saving	56.9	7.7	79.7	113.5	80.1	98.3
Accident cost reductions	9.4	2.8	6.9	18.9	11.6	21.9
Reductions in fares, taxes, and road fees	461.5	9.0	-331.2	148.1	-323.4	-199.1
SUBTOTAL	1014.8	184.4	126.7	819.7	248.2	519.9
Benefits to Treasury						
Reduced public transport deficit	-679.2	0.3	4.6	-620.8	6.0	-207.0
Accident cost reductions	6.3	1.9	4.6	12.6	7.8	14.6
Infrastructure cost reductions	-92.9	-126.2	0.0	-92.9	-126.2	0.0
Revenues from taxes, parking fees, and road fees	51.0	-6.3	286.1	300.2	282.2	286.4
SUBTOTAL	-714.8	-130.3	295.3	-400.9	169.8	94.0
TOTAL BENEFITS	300.0	54.1	422.0	418.8	418.0	613.9

- Scenario 3 involved more road building emphasizing orbital roads, and traffic management measures; and finally
- Scenario 4 assumed the implementation of a congestion pricing scheme consisting of an area charge of £5.00 ($7.35) per day for driving anywhere within Central London during the morning peak as well as raising Central London public transport fares by £0.50 ($0.74) (1986 prices and exchange rate).

The results, summarized in Table 22, show marked advantages of the congestion pricing scheme (Scenario 4) over all the others. Scenario 4 has the largest total benefits—£422 million ($620 million) relative to Scenario 1. Furthermore, it is the only policy that, relative to Scenario 1, both increases the benefits for travelers as a group and improves the financial position of the government treasury. Positive benefits accrue to travelers as a group, despite the charges, because a large portion of travelers to Central London use public transport, whose speeds and service frequencies are greatly improved. Even those travelers switching to public transport to avoid the congestion fee reap significant benefits. Because the number of existing and new transit users is large, the benefits to them more than offset the disbenefits to continuing drivers (*107*, Table 3). The revenues brought in by congestion pricing, after adjustment for lower intake of parking fees and fuel taxes, are substantial: £286 million ($420 million) per year. The costs of accommodating the increase in public transport are covered by increased fares.

Some later descriptions of these studies assume incorrectly that it must be continuing drivers who benefit and people "forced" to switch modes who lose. In fact, the presumption normally should be that people with no viable options to driving lose the most. People who can switch are able to cushion the impact of the fees and may even benefit on balance if, as in this example, their transit alternative is greatly improved by the policy.

Scenarios 2 and 3 provide greater direct benefits to travelers, but cause substantial losses to the treasury. A variant of Scenario 4 that includes a charge of £2.00 ($2.94) per day for travel in Inner London (not shown in the table) has somewhat higher benefits than Scenario 4, but a much more problematic distribution: very high intake to the treasury (£737 million ($1,083 million)) at the expense of considerable direct losses to travelers (£264 million ($388 million)). This is a case where a refinement of the pricing scheme improves efficiency but may not be worth the political cost, unless a very compelling use of those revenues can be found.

If revenues from Scenario 4's area charge are used to further subsidize bus and rail fares and improve service frequency, total benefits are even larger and more of them accrue to travelers (Scenario 4A in Table 22). The treasury gets £201 million ($29.5 million) less than in Scenario 4, but travelers get £393 million ($578 million) more. This suggests that given the heavy public transport use in London, congestion pricing revenues can be used to great advantage on public transport improvements, thereby magnifying the benefits already reaped because of buses facing less traffic congestion.

Of course, the finding of aggregate benefits to travelers does not mean that every traveler would benefit. Among current drivers, clearly some, perhaps most, would be made worse off if revenue uses are ignored. For example, car users as a group are made significantly worse off by Scenario 4 relative to Scenario 1, whereas users of public transport are not (*107*, p. 47). The LPAC consultants argued that this gives congestion pricing a favorable rating on distributional grounds because drivers have higher incomes than users of public transport. By way of contrast, they found the road-building scenarios regressive because their benefits accrue predominantly to people who own automobiles. Neither of these conclusions will necessarily generalize to the United States, where automobile use extends throughout the income distribution.

To better isolate the effects of road pricing per se, the consultants created variants of Scenarios 2 and 3 that include the same cordon pricing scheme as Scenario 4. These Scenarios are shown as 2A and 3A, respectively, in Table 22. The resulting comparisons show that the congestion pricing element of these plans is responsible for large benefits, especially in the context of the severe congestion forecast for Scenario 3. Adding cordon pricing to Scenario 3 adds benefits of £64 million ($94 million) to travelers and increases treasury revenues by £300 million ($441 million). Adding cordon pricing to Scenario 2 involves the tradeoff more normally expected, with large revenue gains to the treasury at the expense of making travelers somewhat worse off, despite considerable reduction in time costs.

Further qualitative studies, called TASTE II, considered electronic road pricing of a more flexible structure, with charges taking place at three concentric rings surrounding Central London and at several screenlines within it. Such a scheme was judged to be somewhat preferable to the simpler area charges because of its greater ease of enforcement and the greater flexibility it allows in setting charging levels for different kinds of trips. The consultants suggest that it might have 20 percent higher benefits to travelers than Scenario 4 (*105*, p. 192).

As a result of these studies, in 1988 the LPAC formally recommended a transportation strategy whose most significant element is traffic restraint, including pricing measures in Central London and possibly other areas (*106*). The strategy also includes significant investments in rail systems, comprehensive traffic management on roads, no increases to road capacity in Central or Inner London, and improved bus service. These recommendations were also later included in a formal submission to a committee of Parliament, explaining LPAC's position on the importance of traffic restraint (*101*).

Subsequently, the national Government issued a white paper containing a quite different vision of London traffic policy. The white paper called for more road building, and declared road pricing to be impractical. In response to this challenge to its recommendations, LPAC commissioned a further Scenario Testing Exercise (TASTE III) based on the model used by the Department of Transport in its white paper—the London Transport Studies (LTS) model. It is a network-based strategic transportation model with the conventional four stages (trip generation, distribution, modal choice, and route assignment), originally developed by the Greater London Council (*100*, p. 6).

These studies contrasted a scenario developed to represent Government policy with a "Strategic Advice Scenario" elaborating LPAC's recommendations. The Strategic Advice Scenario

> combines extensive investment in rail infrastructure ... with environmental traffic management, road pricing, and assumes bus fares will remain constant and rail fares will rise by 30 percent in real terms in the period 1986-2001. (*101*, p. 9)

The pricing component includes three cordon rings: one encircling Central London just inside the Inner Ring Road, a second about 5 km (3 mi) from Charing Cross, and a third about 8 km (5 mi) from Charing Cross, roughly encircling Inner London. In addition, screenlines would divide Central London into six cells. The charge for crossing a cordon or screenline would be £0.50 ($0.89 at 1988 prices and exchange rates). For the innermost cordon and for the screenlines, the charge would apply in both directions and all day (7 a.m. to 7 p.m.) on weekdays; for the other cordons, the charge would apply during peak periods and in the peak direction only (7 to 10 a.m. inbound, 4 to 7 p.m. outbound).

The results of TASTE III are stated as changes relative to a "do-minimum" scenario similar to the previous Scenario 1. The road pricing scheme was found to yield net revenues of £206 million ($367 million) per year (*100*, p. 43). These revenues would cover a substantial fraction of the additional funds required for the improvements in public transport that were part of the Strategic Advice Scenario. This scenario was also found to reduce traffic levels by 40 percent in Central London and 30 percent in Inner London relative to "do-minimum." The road pricing by itself appears to reduce inbound trips to Central London by 25 percent and those to Inner London by 15 percent (*109*, Table 1). Comparing the Government's policy with LPAC's, the latter was found to provide benefits that are greater overall, more evenly distributed between car and public transport users, and more concentrated among residents of Central and Inner London (*101*, p. 10). These results occur despite failure of the model to adjust bus speeds for changes in congestion levels, which causes it to underestimate the modal shift to bus transit and the benefits to bus riders (*100*, pp. iv, 23).

Further analysis of the Strategic Advice Scenario was carried out with a strategic model known as START, first developed for Edinburgh and intended as an improvement of LAM

TABLE 23

IMPACTS OF CONGESTION PRICING IN LONDON PLANNING ADVISORY COMMITTEE'S STRATEGIC ADVANCED SCENARIO

	Without pricing	With pricing	Change (%)
Modal share by car for trips to Central London (%)	11.9	9.3	-21.8
Flow in Central London (millions of vehicle-km)			
a.m. peak (3 hours)	1.36	0.97	-28.7
off-peak (6 hours)	2.47	2.10	-15.0
p.m. peak (3 hours)	1.33	0.95	-28.6
all day (12 hours)	5.16	4.02	-22.1
Speed in Central London (km/hour)			
a.m. peak	23.1	28.2	22.1
off-peak	21.8	24.6	12.8
p.m. peak	22.5	27.8	23.6

Source: (*110*, Table 2.1)

(*110,111*). This analysis isolated the effects of congestion pricing by simulating the Strategic Advice Scenario both with and without the cordon fees. A comparison, presented in Table 23, shows that congestion pricing reduces daytime traffic flow in the Central Area by 22 percent and increases peak speeds by nearly one-fourth.

The analysis also disaggregated benefits and costs by income class to look at the distributional effects of congestion pricing. Different modal propensities and different values of time were assumed for different income classes. If the potential uses of the government revenue are ignored, all household types are made worse off by the policy, with car-owning middle-income households suffering the greatest direct losses and non-car-owning poor households suffering the least. If revenues are spent so as to benefit each household equally, all non-car-owning households gain from congestion pricing, especially the poorest ones. Truck operators gain due to their high savings in labor costs. If the cordons and screenlines are replaced by a single cordon around Central London with a much higher charge (£5.00 ($8.90)), the distributional effects become more favorable to car-owning households, but less revenue is raised. The single Central Area cordon has another practical disadvantage: net benefits are very sensitive to setting the charge too high, a problem apparent in the Greater London Council study and possibly in Singapore.

The UK Department of Transport Studies

In late 1991, the UK Department of Transport began a massive 3-year study of congestion pricing in London. The study consists of more than a dozen separately contracted pieces, many of which are to fit together into a new strategic transportation model that, it is hoped, will provide realistic answers to a whole host of questions about effects of the scheme. In addition, the older and more geographically detailed London Transportation Studies (LTS) model will be used to analyze effects in detail, and other models specialized in particular localities will provide case studies of effects on local traffic conditions.

The strategic model was largely completed in late 1993 (*112*). Known as APRIL, the model incorporates the usual behavioral responses such as trip frequency, destination, mode, and route. It also incorporates several novel features, however, including traveler choice of time of day of travel and analyses of the effects on behavior of travel reliability, crowding on public transport, and employer-paid commuting subsidies, which are quite common in London.

Time-of-day choice is perhaps the model's most innovative feature. The model predicts shifts among eight time periods: two 3-hour peaks, four 1-hour shoulder periods adjacent to the peaks, the daytime inter-peak period, and night. Behavioral response is based on results of an extensive stated preference survey (*113*), and these results are compared with the few previous studies of time-of-day choice in the United States, such as those done by Small (*114*) and Mannering (*115*).

Survey respondents indicated a high degree of flexibility in their trip timing, making this feature of the model potentially very important in predicting the effects of time-specific congestion charges. For example, respondents were asked for the maximum amounts they could either accelerate or delay their arrival at the destination, and the maximum amounts they could either contract or expand the duration of the time spent at their destination. Selected results for home-based trips are shown in Table 24. Even work trips are surprisingly flexible, with the average respondent able to shift arrival time 50 minutes earlier or 40 minutes later, and to decrease time at work by 1 hour or expand it by 2–2/3 hours. Trips for shopping or for social or leisure activities are generally more flexible. The survey also revealed that London commuters are already shifting their arrival times times at work by an average of 16 minutes to avoid congestion (*113*, Table 2).

TABLE 24

SUMMARY INDICATORS OF FLEXIBILITY OF HOME-BASED TRIPS

	Tour Purpose			
Average maximum shift in: (minutes)	Commute	Employer's Business	Shopping	Social & Leisure
Arrival at destination:				
Earlier	50	54	84	75
Later	40	84	159	92
Duration at destination:				
Shorter	60	64	68	72
Longer	161	162	131	199

Source: (*113*, Table 3)

The research on reliability of travel time has also produced notable results *(116)*. More than 600 London-area residents were asked about the day-to-day variation in travel times they experience for typical trips. On average, car users report a maximum variation in travel time equal to 98 percent of the average travel time. Answers to more detailed questions reveal that the distribution of travel times that they believe they experience has a standard deviation equal to one-fifth the mean travel time, a finding roughly consistent with engineering studies of London traffic (*116*, pp. 14, 22). The survey respondents were also presented with a series of choices of alternatives in which reliability was varied hypothetically, along with the mean travel time and the cost, to represent possible combinations that could result from alternative pricing policies. From their responses, it was determined that the average car driver places a value on improved reliability, as measured by a 1-minute reduction in the standard deviation of travel time, equal to 0.79 ± 0.15 times the value of a 1-minute reduction in average travel time (*116*, p. 26).

Together, these results imply that the cost of the uncertainty typically facing a car traveler is on the order of $(1/5) \bullet 0.79 = 0.16$ times the average travel-time cost typically measured in transportation studies. If one-half of the average travel-time cost is due to congestion, this implies that unreliability adds another 32 percent or so to congestion costs. This figure may be compared to estimates that nonrecurrent or "incident" delay on U.S. expressways and arterials accounts for more than one-half of all congestion costs in large urban areas (*117*, p. 29). The reliability work will be supplemented by a study of supply effects: that is, of how various policies alter the variability of travel times experienced by users (*118*, p. 3).

Other issues studied include toll collection technology (*13*), commercial vehicle responses (*119*), and public attitudes (*120*). The work on toll collection, described briefly in Chapter 2, suggests that technology developed elsewhere may not easily transfer to the narrow streets, very high traffic densities, and enormous scale of London. The work on commercial vehicles was unfortunately limited to surveys of firms operating those vehicles, such as trucking and delivery services, and did not investigate the responses that their customers would make if congestion charges were passed through to them.

The research on public attitudes reveals surprising potential public support for some kind of road pricing. Support is greater when pricing is perceived as part of an integrated package of policies aimed at solving transportation problems, and in particular when a clear relationship is seen between the goals of the policy package and the use of the revenues collected. People want to see revenue uses that are transparent and reasonable, such as improving alternatives to the car; they also seem to support using the revenue to benefit London in general (*118*, pp. 5–6), presumably to offset adverse effects on local business. Support is also greater when the charging scheme is easy to comprehend, when the charges are predictable, and when the scope of road pricing is relatively limited (for example, to Central London only). These public desires conflict to some degree with other goals such as efficiency and distributional equity, requiring careful tradeoffs in program design. Attitudinal surveys also show that carpooling is likely to be limited unless it is linked with explicit incentives, and that family needs are quite important in determining the response to time-of-day incentives.

Assessment of London Experience

The London studies consistently show significant net benefits from congestion pricing. In some cases, these consist of losses to travelers as a group being offset by even greater gains in treasury revenue; presumably the government revenue could be spent in such a way that travelers as a group do not suffer on balance. In other cases, the impact of congestion pricing on the public transport system is so favorable that travelers as a whole benefit even without accounting for the use of revenues; this result becomes more likely the smaller the proportion is of travelers initially using private automobiles.

Public transport benefits from congestion pricing in three ways. First, bus service is speeded up because of less road congestion. Second, the service frequency on both bus and rail transit can be improved economically because more fare-paying passengers will use it. Third, service frequency and comfort can be further improved by using some of the congestion-pricing revenue for that purpose. Offsetting these advantages is the potential for overcrowding of transit vehicles and for the aggravation of the costly imbalance between peak and off-peak ridership.

The studies reveal some difficult tradeoffs in policy design. Generally, scenarios with a single, narrowly focused congestion charge in Central London had fewer benefits and more adverse effects on people with low incomes than scenarios involving more complex pricing schemes covering more of the city. However, the more narrowly focused policies affect fewer people and tend to provide more benefits to travelers and less to the treasury, all of which increase their political appeal. The current series of studies, while not yet complete, offers evidence that changes in the time of day at which people take trips may be an important component of behavioral response to congestion pricing, and that improved reliability of travel may be an important benefit.

The long history of debate and study in London has produced a remarkable degree of knowledge of and interest in road pricing. The current Department of Transport studies are furthering that knowledge and interest, and bringing closer the time when one can predict with confidence just how a comprehensive pricing system in such a massive metropolis would work in practice.

THE UNITED KINGDOM: CAMBRIDGE

The city of Cambridge is the site for a unique proposal that carries congestion pricing close to its theoretical extreme. Under this proposal, charges on a given vehicle would vary in real time to match the amount of congestion actually experienced. In effect, the price adjusts automatically in response to congestion, falling to zero if no congestion is encountered. While not likely to be implemented in its original form, the proposal has sparked further technological development and considerable debate about how to deal with traffic in a historic medium-sized city center.

The city of Cambridge, located 100 km (62 mi) north of London, has a population of about 100,000. The city's population grew by only 3 percent between 1981 and 1991, but the population in the surrounding countryside grew rapidly and jobs in the city increased by 25 percent. The job growth in the

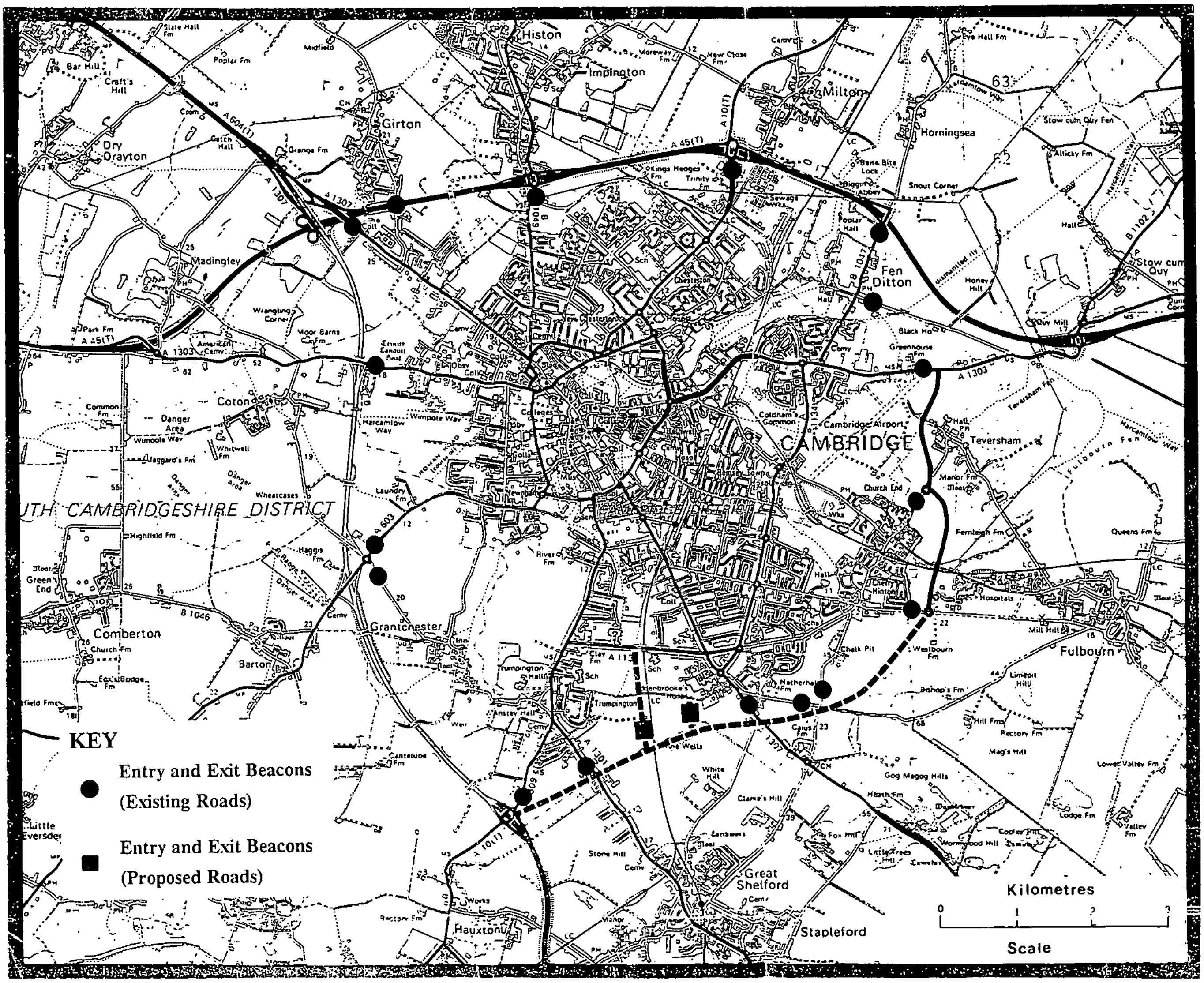

FIGURE 14 Proposed cordon for Cambridge, England. (Source: Cambridgeshire County Council, Director of Transportation)

city, coupled with higher automobile ownership, has caused a 50 percent increase in inbound traffic over the same 10-year period. The city's streets are narrow and hemmed in by historic structures so there is little possibility for expanding capacity (*121*).

The city is part of Cambridgeshire, whose government has jurisdiction over transportation policy throughout the shire (county). In 1990 Brian Oldridge, then Director of Transportation for the shire, proposed that congestion pricing be implemented in Cambridge city to solve its congestion problems. The proposal won preliminary approval of the County Council but would require authorizing legislation by the national Parliament which, while supportive of road tolls, has not thus far favored urban congestion pricing.

The particulars of the proposal were strongly shaped by Oldridge, with the collaboration of transportation experts at the University of Newcastle upon Tyne (*122*). Real-time congestion pricing was to be implemented by means of an in-vehicle meter, which contains a clock and is connected to the car's odometer. The meter assesses a charge of perhaps £0.20 ($0.36 at the 1990 exchange rate) for traversing a fixed distance (such as 0.5 km) either (a) at a speed less than a specified value (such as 10 km/hour) or (b) with more than a specified number of stops (such as four) (*122,123*).

Aside from the meters, the technology is similar to that proposed for the Dutch system. Charges would be deducted from the balance contained in a prepaid "smart card" or "electronic purse," thereby preserving the user's anonymity. The charging regime would be activated when the vehicle passes one of 17 microwave beacons placed at entry points around the city perimeter, just inside a set of existing and planned ring roads (Figure 14). It would be deactivated when passing the beacons in the outward direction, and also when passing temporary beacons at construction sites where charging is suspended. Special beacons would check for valid equipment in each vehicle and either photograph the license plate or notify a police officer in the event of a violation. Visitors would be accommodated by a daily pass, in the form of a smart card capable of responding to the enforcement beacons and sold at a fixed daily price.

Brian Oldridge retired in 1993 and his replacement, J. Michael Sharpe, is expanding the range of schemes under consideration to include more conventional forms of road pricing such as cordon charges for zone fees. Sharpe apparently

apparently recognizes the potential for public ire in a scheme whose charges are both unpredictable and unavoidable once their severity is known. From the user's point of view, real-time charging means that on those very days when travel conditions are unexpectedly poor, a financial penalty would be added to the aggravation already experienced. It seems likely that many citizens would find reasons to blame politicians or traffic planners for incidents of severe congestion, rather than accepting the idea of paying higher charges because of such incidents.

An election in May 1993 altered the power structure of the Cambridgeshire County Council, casting doubt on its willingness to support implementation of this or any other road pricing scheme. The Conservative party lost its majority, and an "accommodation government" now operates with virtually equal representation from the Liberal Democratic and Labour parties. Congestion pricing was one of the few issues that divided these two partners during the campaign: Liberal Democrats were generally supportive, but Labour was opposed despite the national Labour Party's endorsement of road pricing as an option for consideration (*124*, pp. 14, 24; J.M. Sharpe, personal interview, August 19, 1993).

The metering technology was tested in 1993 as part of ADEPT, the larger project on automatic debiting and electronic payment for transport within the European Union's DRIVE-II program (*125*). No further technological development or moves toward implementation are underway in Cambridge at present. Instead, the shire is collaborating with the UK Department of Transport in sponsoring a series of modeling studies to gather more complete information on the effects of a variety of road pricing possibilities. At the same time, local officials are awaiting national developments with the expectation that progress on electronic pricing of motorways might provide renewed impetus for local projects that would use compatible technology (J.M. Sharpe, personal communication, February 1, 1994).

Assessment of Cambridge Experience

The Cambridge developments demonstrate that congestion can be a severe problem in small as well as large cities, and that pricing measures are a technologically feasible means of attacking it. Furthermore, the city has served as a useful setting for investigating the technical feasibility of more sophisticated forms of road pricing. However, there is a need to develop grass roots support simultaneously with concrete proposals, especially ones as radical as the original Cambridge plan. It is unlikely that any locality would accept a real-time pricing proposal that violates the principle of predictability of charges, at least in the absence of lengthy prior experience with more prosaic pricing schemes.

SUMMARY

The Netherlands and the United Kingdom have undertaken the first full-scale studies of congestion pricing for huge metropolitan areas, and thereby have greatly advanced our knowledge of what to expect from such policies and how they might be implemented. The results of the studies suggest that the very simplest schemes have some drawbacks, including the danger of reaping few or no benefits if the charge is set too high. Slightly more complex schemes, such as two or three cordons around London, achieve greater benefits and distribute them more evenly, but are less politically attractive because of the much larger number of people who pay the charges. These studies also suggest that technology is adequate to meet virtually all the goals set by system planners.

In the Netherlands and the United Kingdom, politicians appear to be leading rather than following the public in advocacy of road pricing. The earlier Dutch proposal had cleared all hurdles within the national executive government before public skepticism forced a retreat; even so, the government kept coming back with further proposals. In the United Kingdom, many important political groups have advocated congestion pricing despite lack of clear public support.

Even a proposal as radical as that of Cambridge was advocated by many political figures, and the publicity it created may yet result in a favorable climate there for some form of road pricing. If this occurs, it will most likely be after people become used to toll-collecting technology associated with other initiatives such as pricing on the national intercity motorway system.

CHAPTER SEVEN

CONCLUSIONS

Several important conclusions or generalizations emerge from the experiences of the cities that have implemented or seriously considered congestion pricing. These conclusions are somewhat tentative, of course—the number of cases is relatively small and they vary in the type of pricing scheme used or proposed, the geographic area of the city, and the economic and political environment in which the scheme is evaluated. Some clear tendencies can be discerned, nevertheless, both about the types of pricing schemes that are likely to be practical and effective in reducing congestion and about the circumstances under which congestion pricing might be politically acceptable.

EFFECTIVE AND PRACTICAL SCHEMES

One key conclusion is that properly designed congestion pricing schemes can substantially reduce traffic congestion. Table 25 summarizes the estimated effects of pricing on traffic volume in the various cases studied; the table also reports the average peak-period toll charged in dollars and the GNP per capita of the country relative to that of the United States. Planning studies—such as those for Hong Kong, Stockholm, and London—have long forecast that charges of between $1 and $3 per day for entry to a restricted area would reduce traffic by around 20 percent or more. These results might be expected to apply very roughly in the more congested U.S. cities as well, in part because per capita incomes are not so very different (especially for car drivers, who tend to have incomes far higher than average in places like Hong Kong). These reductions in traffic volumes would of course have implications for speeds, air emissions, and other variables of policy interest.

The cases where congestion pricing or a close cousin was actually implemented provide the most convincing evidence, however, of its ability to control congestion. Most striking is the experience of Singapore, the only city to implement a major urban congestion pricing scheme. Singapore's Area Licensing Scheme (ALS) induced an initial 43 percent reduction in auto traffic entering the restricted zone during peak hours, much larger than planners had expected. In the nearly two decades since the ALS was implemented, moreover, traffic levels have grown considerably more slowly than otherwise would have been expected given Singapore's growth in real incomes and downtown employment. Probably the reduction in peak-period traffic was so large because the charge was high relative to income levels. Adding to the Singapore experience is that of Norway, whose toll rings may have reduced traffic by 5 to 10 percent despite the fact that the charges are low and were designed primarily to raise revenue rather than to control congestion. The introduction of congestion pricing on the A-1 expressway outside of Paris also reduced peak traffic by 4 to 10 percent, confounding the predictions of some skeptics.

It is also increasingly obvious that congestion pricing need not be costly to implement or administer. Table 26 summarizes the capital and operating costs incurred and the revenues collected from each of the various schemes in operation and plan, as well as the approximate population of the metropolitan area served (to give some idea of the scale of the system involved). One striking result is that except for the all-manual Bergen system, the schemes in operation appear to require only about 10 to 12 percent of their revenues to cover operating and enforcement costs, and a few percent more if amortized capital costs are included.

This result seems to hold over a wide range of toll collection technologies and pricing schemes. Singapore proved that costs could be modest in 1975 with its simple cordon and paper windshield license scheme: capital costs were modest, enforcement easy and relatively inexpensive, and the purchase of licenses fairly convenient for motorists. The rapid development of automated or electronic toll collection since 1975 has made it possible to implement and administer even more complex congestion pricing schemes without increasing costs greatly. The toll rings recently established around Norway's three largest cities demonstrate the feasibility of combining a variety of collection methods, including manual, subscription, and electronic. Although the tolls on the Norwegian rings do not vary greatly by the level of congestion or time of day, they easily could be adapted to do so in Oslo and Trondheim, where the toll collection and enforcement functions needed for an areawide congestion pricing scheme are already in place.

Careful attention to design and implementation details appears to be important, however, if the scheme is to produce a substantial improvement in overall travel times and convenience. In this regard, the Singapore experience is particularly instructive. The initial ALS fees appear to have been set too high, so that too many travelers were diverted to less convenient modes or times of day and too few motorists were left to enjoy the relatively uncongested streets in the restraint zone. The benefits of the ALS were also undermined by increased congestion on the surrounding ring roads, and in the central area immediately before and after restraint hours. Bus capacity also appears to have been inadequate to handle the influx of new riders.

This does not mean that improvements in travel times and convenience are impossible or even difficult. The smoothing of travel flows on the A-1 expressway has probably reduced overall travel times to Paris significantly, for example, although speed data are not available to confirm this. The performance of the Singapore scheme also appears to have improved greatly over time as real income growth partially offset the high fees and as the bypass roads and public transit services were improved. Moreover, the planning studies in London and many other cities typically predict substantial improvements in overall transport system performance.

Nor does the need for close attention to detail imply that a scheme must be complex to be successful. Indeed, the cases

TABLE 25

SUMMARY OF EFFECTS OF CONGESTION PRICING ON TRAFFIC

Case Study	Date of data or plan	Per capita GNP as percentage of United States	Typical charge for auto entering restraint area (in current U.S. dollars)	Reduction in peak traffic in restraint area
SCHEMES IN OPERATION				
Singapore (cordon)	1975	38%	1.42	43%
	1992	64%	1.65	n.a.
Paris (A-1 Expressway)	1992	92%	0.95-2.47[a]	4-10%
Bergen (toll ring)	1992	109%	0.72[b]	6-7%
Oslo (toll ring)	1991	109%	1.19[b]	5%
Trondheim (toll ring)	1992	109%	1.12[b]	n.a.
SCHEMES IN PLANNING				
Hong Kong (multiple cordon)	1985	36%	0.70-0.93[c]	20-24%
Stockholm (toll ring)	1992	113%	2.55[d]	up to 18%
Randstad (multiple cordon)	1989	78%	1.42	17%
Randstad (area license)	1992	84%	2.85	n.a.
London (GLC area license)	1973	50%	1.84-2.20[e]	45%
London (LPAC area license)	1988	65%	1.78-8.90[f]	22%
Cambridge (congestion specific pricing)	1990	73%	variable[g]	n.a.

[a] Differential between normal and peak-period tolls (varies by length of trip).
[b] Rate for prepaid trips.
[c] Charges vary by exact rate and trip length; figures given are estimated typical monthly payments divided by 22 days per month.
[d] Discount to be determined may apply.
[e] Charge for entering Central London.
[f] The charge is $0.89 for crossing one cordon or screenline. Most daily round trips to the central area during peak hours would incur between two and ten such charges, depending on location and distance.
[g] Proposed charge is $0.36 per half-kilometer traveled under very congested conditions.
n.a. means not available
Source: GNP per capita figures for 1992 are actually 1991. The GNP figures are from (*126*), for other sources see text.

TABLE 26

SUMMARY OF OPERATING COSTS OF CONGESTION PRICING SCHEMES

			Costs and revenues (millions of US dollars)			Annual costs as fraction of revenues (percent)	
Case study	Date of data or estimate	Approx. population of metro area (thousands)	Capital outlay	Annual operating cost	Annual revenues	Operating	Capital plus operating
SCHEMES IN OPERATION							
Singapore (cordon)	1975 1992	2,000 2,800	2.7 n.a.	0.3 1.9	2.7 20.9	10.7 9.1	21.0 n.a.
Paris (A-1 Expressway)	1992	8,589	0.3	0	0	--	--
Bergen (toll ring)	1992	300	2.0	1.6	10.1	15.6	17.7
Oslo (toll ring)	1991	700	41.6	11.2	96.0	11.6	16.1
Trondheim (toll ring)	1992	136	7.2	1.15	11.3	10.2	16.8
SCHEMES IN PLANNING							
Hong Kong (multiple cordon)	1985	4,000	30.8	2.6	59.8[a]	4.3	9.7
Stockholm (toll ring)	1992	1,640	n.a.	n.a.	n.a.	n.a.	n.a.
Randstad (multiple cordon)	1989	6,000	205	37	n.a.	n.a.	n.a.
Randstad (area license)	1992	6,000	n.a.	n.a.	n.a.	n.a.	n.a.
London (GLC area license)	1973	7,345	n.a.	n.a.	n.a.	n.a.	10-15
London (LPAC area license)	1988	6,735	94	12.5	380	3.3	5.8
Cambridge (congestion specific pricing)	1990	100	n.a.	n.a.	n.a.	n.a.	n.a.

[a]This is the midpoint of the range, 50.6-69.1, given in (*36*, p. 208).
n.a. = not available
Capital costs are amortized at 6% interest assuming 15-year lifetime.
Percentages are computed from unrounded figures in sources, so may not agree precisely with those calculated from preceding columns.
Sources: see text, also (*126*); (*100*, pp. 31,34,43); (*127*, p. 20); (*128*, Table 2.9); and (*129*, p. 846).

studied here suggest the opposite: there may be rapidly diminishing returns to complexity in the design of a congestion pricing system. On the one hand, very simple schemes like Singapore's (prior to the 1994 changes) may cause problems. Some increases in congestion on the bypass roads or just before and after restraint hours may have been inevitable given Singapore's single-cordon and single-fee system. On the other hand, very complex schemes do not necessarily yield commensurately greater benefits. In Hong Kong, schemes with just a few cordons were predicted to provide nearly the same improvements in travel times as schemes with many cordons. Similarly, in London, single-cordon schemes were forecast to provide almost as many travel benefits as two-cordon schemes.

THE PROSPECTS FOR POLITICAL APPROVAL

The international experience suggests that winning political approval for congestion pricing is a difficult task in a democracy. Congestion pricing has been implemented in only a few places to date; if the Norwegian toll rings are excluded, the number of sites is just two, only one of which has a strong tradition of participatory democracy. Moreover, in many of the other cases studied—Hong Kong, Stockholm, London, and the Randstad, for example—congestion pricing proposals have been defeated or delayed by the intense political controversies that they generated.

The sources of controversy are complex and varied (*130*), but several objections appear repeatedly. One is the concern for the protection of privacy with automated toll collection and enforcement systems. This concern may be intensely felt in certain special cases, such as Hong Kong. Modern read/write tags equipped with smart cards appear to offer a reasonable assurance of privacy. Moreover, privacy objections have not prevented the successful introduction of read-only tags on the Norwegian toll rings or, for that matter, conventional toll roads throughout the world. Granted, in these cases motorists also have the option of using nonelectronic means of payment, a possibility that may be difficult to preserve with more complex congestion pricing schemes.

Another frequently heard objection is the burden congestion tolls place on low-income motorists. The case studies provide only limited information on this question. In some cases, such as Hong Kong, these objections are hard to understand because the vast majority of poor and moderate-income people are transit users rather than car owners. Even where auto ownership is more widespread, motorists driving into the center of the city during rush hours typically have higher than average incomes (*107,131,132*). For these reasons, the London studies found that congestion tolls would have a considerably more egalitarian distributional impact than heavy subsidies to road building. The London studies also demonstrated that the poor benefit disproportionately from improvements in transit service, which may be quite substantial where transit buses use congested city streets and also where the increased transit patronage can be accommodated through the addition of more buses or trains (*133*).

Nevertheless, some accommodation or relief for low-income motorists may be necessary. This could be done by using revenues to offset regressive taxes or to improve public services that benefit low-income people; possibilities are discussed in several articles (*131,134,135*). Alternatively, using electronic pricing technology, one could design a toll system that either exempts or allows a discount for a fixed number of trips per month, somewhat analogous to the "lifeline" telephone tariffs that permit limited use of the network at low cost.

Also common is the concern that congestion pricing will hurt businesses in the congested area. This objection can lead to exemptions for commercial vehicles, such as trucks and taxis, which may undermine the effectiveness of the scheme (as in Singapore before the 1989 reforms) or which may intensify the opposition of other motorists (as in Hong Kong). There are reasons for believing that businesses will gain rather than lose from congestion pricing, however, particularly those dependent on deliveries or with many high-income managers or clients (*136*). Singapore's experience is also encouraging in this regard, although it is difficult to know whether Singapore's downtown would have grown even faster without the ALS.

Perhaps the most potent political objection to congestion pricing is that many motorists stand to lose, particularly if the government does not return the toll revenues to motorists in some form (*137*). In particular, most of those who continue to drive during congested hours will pay more in tolls than the benefits they receive from reduced travel times. This result was demonstrated repeatedly in the planning studies for congestion pricing examined here, as in Hong Kong (Chapter 3) and London (Chapter 6).

The most obvious, and widely adopted, solution is to use the toll receipts for purposes that benefit motorists. Traditionally this has been done by financing improvements in transportation facilities with the toll revenues. Indeed, it is striking that while tolls to control congestion are rare, tolls to finance transportation improvements are common in many parts of the world. Tolls have been the predominant means of financing high-performance intercity expressways in the countries of southern Europe and the developing world, for example, and recent government budget problems have rekindled interest in toll-financed expressways in northern Europe and the United States. Among the cases examined here, the toll rings of Norway and Sweden have been successfully promoted in large part as the means of financing needed road improvements.

The use of congestion tolls to finance transportation improvements has its limitations, however. Congestion pricing may generate more revenue than can be usefully spent on local highway improvements, particularly where new highways into or around the congested area would involve controversial land takings or environmental problems. The revenues might be spent on public transit improvements, but motorists who must drive despite the tolls are likely to perceive themselves as benefiting relatively little from improved transit services unless, as in Trondheim, they become occasional transit users.

Another possibility is to devise revenue-neutral schemes by reducing other charges normally paid by motorists. A direct rebate of congestion tolls to individual motorists is undesirable, of course, since it would undermine the behavioral incentives of congestion pricing. There are other possibilities, however, especially where motorists already pay high tolls or other charges and fees. The A-1 expressway scheme was politically acceptable, for example, because the highway was already tolled and the peak-period surcharges were offset with off-peak discounts. Similarly, Hong Kong seems to have missed an important opportunity to build political support for congestion pricing by committing itself to using the congestion toll receipts to reduce Hong Kong's high annual vehicle registration taxes. Some motorists will still be worse off under these compensation schemes, but their numbers would be drastically reduced.

Finally, congestion pricing may arouse opposition simply because it represents such a drastic change in existing arrangements. People do not understand its rationale, they do not trust the technology and institutions to work correctly, they fear unanticipated side effects such as traffic spillovers, and they suspect that some individuals will pay heavy costs while the gains, if any, will be reaped by others. Some of these sources of resistance seem to have been factors in slowing or halting the most far-reaching proposals in Hong Kong, Stockholm, London, and the Randstad.

However, the progression of innovations reviewed here offers hope for a solution to these barriers through incremental change. The Norwegian toll rings began with the very simple manually collected toll scheme in Bergen, to which Oslo and Trondheim each added further technological innovations and degrees of flexibility. The Stockholm plan is clearly influenced by the operational success of the Norwegian toll rings, and the willingness to consider going somewhat further toward congestion pricing in the Randstad may be attributable in part to confidence gained from observing the Norwegian operations. Certainly the intense worldwide interest in these projects indicates that many other nations are hoping to learn something useful from the Norwegians.

The primary danger in an incremental approach is that an ill-advised project may be implemented that highlights the potential drawbacks of congestion pricing without reaping its benefits. One advantage of the British approach is that thorough study should reduce the chance of unpleasant surprises and may encourage planners to incorporate controversial or unproven elements if they are found to be essential for achieving of policy goals. The danger of a highly visible failure is one that planners in the United States need to be especially aware of in implementing the demonstration programs funded in 1991 highway legislation.

In sum, the international experience with congestion pricing is both cautionary and encouraging. It suggests some important pitfalls, such as the need for attention to detail in design and implementation and the difficulty of building political support. But it also demonstrates that congestion pricing can be an effective and practical means of managing congestion and improving overall travel times and that the political problems, though difficult, may not be insoluble.

REFERENCES

1. Gomez–Ibanez, J.A., and J.R. Meyer, *Going Private: The International Experience with Transport Privatization,* Brookings Institution, Washington, D.C. (1993), 310 pp.
2. Higgins, T., "Road Pricing—Should and Might it Happen?" *Transportation,* Vol. 8 (1979), pp. 99–113.
3. *Special Report 242: Curbing Gridlock: Peak-Period Fees to Relieve Traffic Congestion,* Vols. 1 and 2, Transportation Research Board, National Research Council, Washington, D.C. (1994), 143 pp. (Vol. 1) and 553 pp. (Vol. 2).
4. Morrison, S.A., "A Survey of Road Pricing," *Transportation Research,* Vol. 20A, No. 2 (1986), pp. 87–97.
5. Hau, T.D., "Congestion Charging Mechanisms for Roads: An Evaluation of Current Practice," Working Paper WPS .1071, Infrastructure and Urban Development Department, World Bank, Washington, D.C. (December 1992), 99 pp.
6. International Monetary Fund, International Financial Statistics Yearbook, Vol. 45 (1992).
7. Council of Economic Advisers, Economic Report of the President, Transmitted to the Congress, U.S. Government Printing Office, Washington, D.C. (January 1993), 474 pp.
8. May, A.D., "Potential of Next Generation Technology," in (3), Vol. 2, pp. 405–463.
9. Pietrzyk, M.C., and E.A. Mierzejewski, *National Cooperative Highway Research Program Synthesis 194: Electronic Toll and Traffic Management (ETTM) Systems,* Transportation Research Board, National Research Council, Washington, D.C. (1994), 63 pp.
10. Hensher, D.A., "Electronic Toll Collection," *Transportation Research,* Vol. 25A, No. 1 (1991), pp. 9–16.
11. Thorpe, N., and P. Hills, "The DRIVE Project PAMELA 2: The Scope of Automated Pricing Systems," *Traffic Engineering and Control,* Vol. 32, No. 7/8 (1991), pp. 364–370.
12. Blythe, P., "Demand Management and Road-Use Pricing: The ADEPT Project Approach," University of Newcastle upon Tyne, presented to the DRIVE-ATT Second Concertation Meeting, Brussels (April 1992), 35 pp.
13. University of Newcastle upon Tyne, London Research Center, and Intercai Advanced Telematic Skills (Utrecht), *A Review of Technology for the Road Use Pricing in London,* UK Department of Transport, Her Majesty's Stationary Office, London (1993), 55 pp.
14. Armstrong-Wright, A.T., "Road Congestion Pricing and User Constraints: Opportunities and Constraints in Developing Countries," *Transportation Research,* Vol. 20A, No. 2 (1984).
15. Toh, R., "Experimental Measures to Curb Road Congestion in Singapore: Pricing and Quotas," *Logistics and Transport Review,* Vol. 39, No. 2 (September 1992), pp. 289–317.
16. Yong, P.S., *Housing Markets and Urban Transportation: Economic Theory, Econometrics and Policy Analysis for Singapore,* McGraw-Hill, Singapore and New York (1992).
17. Watson, P.L., and E.P. Holland, *Relieving Traffic Congestion: The Singapore Area License Scheme,* World Bank Staff Working Paper No. 281, Washington, D.C. (June 1978), 286 pp.
18. Spencer, A.H., and L.S. Chia, "National Policy Toward Cars: Singapore," *Transport Reviews,* Vol. 5, No. 4 (1985), pp. 301–323.
19. Menon, A.P.G., and S.H. Lam, *Singapore's Road Pricing System, 1975–1989,* Transportation Research Report NTU/CTS/92-2, Center for Transportation Studies, Nayang Technical University, Singapore (September 1992).
20. Holland, E.P., and P.L. Watson, "The Design of Traffic Pricing Schemes," *Transportation Engineering,* (February 1978), pp. 32–38.
21. Holland, E.P., and P.L. Watson, "Traffic Restraint in Singapore," *Traffic Engineering and Control,* Vol. 19, No. 1, (January 1978), pp. 14–22.
22. Watson, P.L., and E.P. Holland, "Congestion Pricing: The Example of Singapore," *Finance and Development,* Vol. 13, No. 1 (March 1976), pp. 20–23.
23. Behbehani, R., V.S. Pendakur, and A.T. Armstrong-Wright, "Singapore Area Licensing Scheme: A Review of the Impact," Water Supply and Urban Development Department, The World Bank, Washington, D.C. (July 1984), 55 pp.
24. Ang, B.W., "Traffic Management Systems and Energy Savings: The Case of Singapore," presented at the ATAS Workshop on "New Energy Technologies: Transportation and Development," United Nations Centre for Science and Technology for Development, Ottawa, Canada (September 20–22, 1989), 21 pp.
25. Menon, A.P.G., and S.H. Lam, *Singapore's Road Pricing Systems, 1989–1993,* Transportation Research Report NTU/CTS/93-2, Center for Transportation Studies, Nanyang Technological University, Singapore (November 1993), 33 pp.
26. Menon, A.P.G., and P.A. Seddon, "Traffic in the Central Area—Part I: Volume Characteristics," *Singapore Journal of the Institution of Engineers* (1991), pp. 1–12.
27. Olszewski, P., and T.Y. Weng, "Traffic in the Central Area—Part II: Speed Characteristics," *Singapore Journal of the Institution of Engineers* (1991), pp. 21–27.
28. Singapore, Ministry of National Development, Public Works Department, "Electronic Road Pricing (ERP) Scheme," photocopied (1991), 8 pp.
29. Der, L.Y., J. Lee, and A.P.G. Menon, "Electronic Road Pricing in Singapore: Demonstration Project," in *Proceedings of the International Conference on Advanced Technologies in Transportation and Traffic Management,* Center for Transportation Studies, Nanyang Technological University, Singapore (May 1994), pp. 105–112.
30. Singapore, Feedback Unit, "Perspective—Feedback Unit: Brief on Major Government Policies and Issues no. 93/8—Whole Day Area Licensing Scheme (ALS)," photocopied (1993), 4 pp.

31. Menon, A.P.G., S.-H. Lam, and H.S.L. Fan, "Singapore's Road Pricing System: Its Past, Present, and Future," *ITE Journal,* Vol. 63, No. 12 (December 1993), pp. 44–48.
32. Wilson, P.W., "Welfare Effects of Congestion Pricing in Singapore," *Transportation,* Vol. 15, (1988), pp. 191–210.
33. Toh, R., "Road Congestion Pricing: The Singapore Experience," *Malayan Economic Review,* Vol. 22 (1977), pp. 52–61.
34. McCarthy, P., and R. Tay, "Economic Efficiency vs. Traffic Restraint: A Note on Singapore's Area License Scheme," *Journal of Urban Economics,* Vol. 34 (1993), pp. 96–100.
35. Hong Kong, Transport Branch, Moving into the 21st Century: The White Paper on Transport Policy in Hong Kong, Government Secretariat, Hong Kong (1990).
36. Hau, T.D., "Electronic Road Pricing: Developments in Hong Kong 1983–1989," *Journal of Transport Economics and Policy,* Vol. 24, No. 2 (May 1990), pp. 203–214.
37. Transpotech, *Electronic Road Pricing Pilot Scheme: Main Report,* prepared for the Hong Kong Government (May 1985), pp. 1.1-4.40.
38. Borins, S.F., "Electronic Road Pricing: An Idea Whose Time May Never Come," *Transportation Research,* Vol. 22A, No. 1 (1988), pp. 37–44.
39. Dawson, J.A.L., and F.N. Brown, "Electronic Road Pricing in Hong Kong: 1. A Fair Way to Go?" *Traffic Engineering and Control,* Vol. 26, part 2 (November 1985), pp. 522–529.
40. Catling, I., and B.J. Harbord, "Electronic Road Pricing in Hong Kong: 2. The Technology," *Traffic Engineering and Control,* Vol. 26, part 2 (December 1985), pp. 608–617.
41. Harrison, B., "Electronic Road Pricing in Hong Kong: 3. Estimating and Evaluating the Effects," *Traffic Engineering and Control,* Vol. 27 (January 1986), pp. 13–18.
42. Dawson, J.A.L., "Electronic Road Pricing in Hong Kong: 4. Conclusion," *Traffic Engineering and Control,* Vol. 27 (February 1986), pp. 79–83.
43. Harrison, W.J., C. Pell, P.M. Jones, and H. Ashton, "Some Advances in Model Design Developed for the Practical Assessment of Road Pricing in Hong Kong," *Transportation Research,* Vol. 20A, No. 2 (March 1986), pp. 135–143.
44. Dawson, J.A.L., and I. Catling, "Electronic Road Pricing in Hong Kong," *Transportation Research,* Vol. 20A, No. 2 (1986), pp. 129–134.
45. Fong, P.K.W., "An Evaluative Analysis of the Electronic Road Pricing System in Hong Kong," *Hong Kong Economic Papers,* Vol. 17 (1986), pp. 75–90.
46. Catling, I., and G. Roth, "Electronic Road Pricing in Hong Kong: An Opportunity for Road Privatization?," in *Transportation Research Record 1107,* Transportation Research Board, National Research Council, Washington, D.C. (1987), pp. 51–55.
47. Hau, T.D., "Road Pricing in Hong Kong: A Viable Proposal," *Built Environment,* Vol. 15, Nos. 3/4 (1989), pp. 195–214.
48. Ho, L.–S.,"On Electronic Road Pricing and Traffic Management in Hong Kong," *Hong Kong Economic Papers,* Vol. 17 (1986), pp. 64–74.
49. Hong Kong Transport Department and Wilbur, Smith and Associates, *Hong Kong: Second Comprehensive Transport Study,* Hong Kong Government, Government Printer, Hong Kong (May 1989).
50. Larsen, O.I., "The Toll Ring in Bergen, Norway—The First Year of Operation," *Traffic Engineering and Control,* Vol. 29, No. 4 (1988), pp. 216–222.
51. Lauridsen, H., "The Toll Rings in Bergen and Oslo: Evolution and Experience," Institute of Transport Economics, Oslo, Norway, No. O–1626, (December 1990), 17 pp.
52. Ramjerdi, F., "The Norwegian Experience with Electronic Toll Rings," in *Proceedings of the International Conference on Advanced Technologies in Transportation and Traffic Management,* Centre for Transportation Studies, Nanyang Technological University, Singapore (May 1994), pp. 135–142.
53. Waersted, K., "Automatic Toll Ring No Stop Electronic Payment Systems in Norway—Systems Layout and Full Scale Experiences," Directorate of Public Roads, Norway, presented to the Sixth IEE International Conference on Road Traffic Monitoring and Control, London (April 1992) (Institution of Electrical Engineers).
54. Tretvik, T., "The Trondheim Toll Ring: Applied Technology and Public Opinion," SINTEF Transport Engineering, Trondheim, Norway, presented at the joint OECD/ECMT/GVF/NFP Conference on The Use of Economic Instruments in Urban Travel Management, Basel, Switzerland (June 1992).
55. Ramjerdi, F., and O.I. Larsen, "Road Pricing as a Means of Financing Investments in Transport Infrastructure, The Case of Oslo," Institute of Transport Economics, Oslo, Norway, in *Draft Proceedings of the OECD Conference on Public/Private Partnerships in Urban Mobility,* Organisation for Economic Development and Cooperation, Paris (April 1991), pp. 90–106.
56. Jones, P., and A. Hervik, "Restraining Car Traffic in European Cities: An Emerging Role for Road Pricing," *Transportation Research,* Vol. 26A, No. 2 (1992), pp. 133–145.
57. Solheim, T., "The Toll–Ring in Oslo," English summary of Report 126/1992, Institute of Transport Economics, Oslo, Norway (1992), 6 pp.
58. Larsen, O.I., "Virkninger av Bompengeringen i Oslo på Biltrafikken" ["Effects of the Oslo Toll Ring on Car Traffic"], Institute of Transport Economics, Oslo, Norway (August 1992), 13 pp. (in Norwegian).
59. Ramjerdi, F., "An Analysis of the Impact of the Oslo Toll Scheme on Travel Behavior," in *Road Pricing: Theory, Empirical Assessment and Policy,* B. Johansson and L.–G. Mattsson, eds., Kluwer Academic Publishers, Dordrecht, Netherlands (1994), pp. 107–129.
60. Ramjerdi, F., "Road Pricing in Urban Areas: A Means of Financing Investment in Transport Infrastructure or of Improving Resource Allocation, the Case of Oslo," Institute of Transport Economics, Oslo, Norway, presented at the Sixth World Conference on Transportation Research, Lyon, France (1992), 12 pp.
61. Meland, S., and J. Polak, "Impact of the Trondheim Toll Ring on Travel Behaviour: Some Preliminary Findings," presented to the PTRC Summer Annual Meeting, Sep-

tember 1993, Transport Studies Unit Ref. 762, University of Oxford, United Kingdom (July 1993), 13 pp.

62. Polak, J., and S. Meland, "User Acceptance and Market Penetration of Automatic Debiting Technology: Evidence from the Trondheim Toll Ring," Transport Studies Unit Ref 720, University of Oxford, United Kingdom (August 1992), 12 pp.
63. Polak, J., P. Jones, P. Vythoulkas, S. Meland, and T. Tretvik, "The Trondheim Toll Ring: Results of a Stated Preference Study of Travellers' Responses," Transport Studies Unit Ref 662, University of Oxford, United Kingdom (September 1991), 82 pp.
64. Polak, J., and S. Meland, "Development and Validation of a Toll Ring Revenue Forecasting Model," Transport Studies Unit Ref 723, University of Oxford, United Kingdom (September 1992), 12 pp.
65. Fredriksen, G., "The Trondheim Tollring after One Year Experience," Trøndelag Toll Road Company, presented to International Bridge, Tunnel and Turnpike Association, annual meeting, New Orleans (October 1992), 19 pp.
66. Stockholm County Council, Office of Regional Planning and Urban Transportation, "Regional Plan 90 for the County of Stockholm: Summary in English of Consultation Proposals," (March 1990), 12 pp.
67. Stockholm Streets and Traffic Administration, "Zone Fee Proposal Using Car Cards," (June 1989), 9 pp.
68. Stockholm Streets and Traffic Administration, "Proposal for an Electronic Fee System for Car Traffic in the Stockholm Inner City Area," (Draft April 1989), 10 pp.
69. Stockholm Streets and Traffic Administration, "Traffic Plan 90," (October 1990), 4 pp.
70. Metropolitan Traffic Committee, "Storstadstrafik 5—Ett Samlat Underlag" ["Metropolitan Traffic 5—1A Compilation of Basic Data"], Final Report of the Metropolitan Traffic Committee, Staten Offentliga Utredningar 1990:16. Stockholm: Swedish Department of Communications (1990) (in Swedish). English Summary, pp. 21–33.
71. "Traffic for Growth and a Better Environment: A Summary of Provisions in Government Bill 1990/91:87 Relating to the Ambit of the Ministry of Transport and Communications," Stockholm: Regerinkgskansliets Offsetcentral (1991), 29 pp.
72. Johansson, B., "Analysis of the Dennis Agreement Package," Swedish National Road Administration, Stockholm (September 1993), 5 pp.
73. Stockholm City, Stockholm County, Swedish National Rail Administration, and Swedish National Road Administration, "Dennispaketet: Överenskommelse om Traffik- och miljö i Stockholmsregionen" ["The Dennis Package"] (December 1991), 8 pp. (in Swedish).
74. Cewers, M., "Stockholm Toll Collection System," *Proceedings of the International Conference on Advanced Technologies in Transportation and Traffic Management,* Center for Transportation Studies, Nanyang Technological University, Singapore (May 1994), pp. 105–112.
75. Social Democratic Party, Moderate Party, and Liberal Party, "Agreement on Enhancing the Traffic Infrastructure in the Stockholm Region," signed by E. Nilsson et al., Stockholm, Sweden (September 29, 1992), 26 pp.
76. Social Democratic Party, Moderate Party, and Liberal Party, "The Greater-Stockholm Negotiation on Traffic and Environment: The Dennis Agreement," signed by O. Lindkvist et al., transmitted by Bengt Dennis to The Minister of Transportation and Communication, Stockholm, Sweden (January 23, 1991), 44 pp.
77. Peterson, B., "Traffic and Environmental Policies in Sweden: A Test Bed for Europe?", Stockholm Transport (September 15, 1991), 6 pp.
78. Tegnér, G., "Road Pricing in Stockholm: Some Model Simulated Experiences," TRANSEK consulting company, presented at the OECD/CETUR conference on Public/Private Partnerships in Urban Mobility, Paris (April 1991), 29 pp.
79. Anderstig, C., and L.-G. Mattsson, "Policy Applications of an Integrated Land-Use Transport Model in the Stockholm Region," presented at the Sixth World Conference on Transport Research, Lyon, France (June/July 1992), 24 pp.
80. Johansson, B., and L.-G. Mattsson, "From Theory and Policy Analysis to the Implementation of Road Pricing: The Stockholm Region in the 1990s," in *Road Pricing: Theory, Empirical Assessment, and Policy,* B. Johansson and L.-G. Mattsson, eds., Kluwer Academic Publishers, Dordrecht, Netherlands (1994), pp. 181–204.
81. Tenenbaum, D., "How to Regulate Traffic Demand and Absorb Congestion by Using Variable Toll Rates," *Proceedings of the 60th Annual Congress of the International Bridge, Tunnel and Turnpike Association*, International Bridge, Tunnel and Turnpike Association, Washington, D.C. (1992), 16 pp.
82. Centre d'Etudes Techniques de l'Equipement Nord–Picardie, "Modulation des Péages sur A.1" [Variable Toll Rates on A1], study prepared for Service d'Etude Technique des Routes et Autoroutes (SETRA), Government of France (1993), 27 pp.
83. Groupe SEEE, "Evaluation Quantitative d'une Expérience de Modulation de Péage sur l'Autoroute A1: Note de Synthèse" [Quantitative Evaluation of an Experiment in Variable Toll Rates on Autoroute A1: Synthesis], Note 90601800-4f, prepared for Service d'Etude Technique des Routes et Autoroutes (SETRA), Government of France (April 1993), 25 pp.
84. Bramezza, I., and J. van der Borg, "Governing Polycentric Regions: The Case of the Randstad in the Netherlands and that of the Padania Region in Italy," Tinbergen Institute, Erasmus University Rotterdam, presented at Regional Science Association International, European Meetings, Brussels (August 1992), 14 pp.
85. Boyce, D.E., L.J. LeBlanc, and G.R.M. Jansen, "Design of a Toll System for a Congested Intercity Road Network: The Dutch Road Pricing Scheme," Urban Transportation Center, University of Illinois at Chicago, presented at Regional Science Association International, North American Meetings, Boston (November 1990), 26 pp.
86. Netherlands Ministry of Transport and Public Works, "The Peak-Hour Surcharge," draft information leaflet, The Hague, Netherlands (January 1994), 10 pp.
87. Netherlands Ministry of Transport and Public Works, Rekening Rijden: Road Pricing in The Netherlands, The Hague (1989), 14 pp.

88. Giuliano, G., and K.A. Small, "Alternative Strategies for Coping with Traffic Congestion," forthcoming in the proceedings of the Egon-Sohmen Foundation Symposium on Urban Agglomerations and Economic Growth, Springer-Verlag, Berlin (1994).
89. Stoelhorst, H.J., and A.J. Zandbergen, "The Development of a Road Pricing System in The Netherlands," *Traffic Engineering and Control,* Vol. 31 (1990), pp. 66–71.
90. In 't Veld, R.J., "Road Pricing: A Logical Failure," in *Environmental Protection: Public or Private Choice,* D.J. Kraan and R.J. in 't Veld, eds., Kluwer Academic Publishers, Dordrecht (1991), pp. 111–121.
91. Netherlands Government, *Second Transport Structure Plan, Part D: Government Decision,* The Hague (1990), 160 pp.
92. Pol, H.D.P., "Road Pricing: The Investigation of the Dutch Rekening Rijden System," Netherlands Ministry of Transport and Public Works (February 1991), 7 pp.
93. Bates, J.J., N.R. Shepherd, M. Roberts, A.I.J.M van der Hoorn, and H.D.P. Pol, "A Model of Departure Time Choice in the Presence of Road Pricing Surcharges," presented at the PTRC Annual Meeting, Manchester, United Kingdom (September 1990), 17 pp.
94. May, A.D., P.G. Hopkinson, N.W. Marler, and N. Sherwood, "Road Pricing: The Potential for Comparative Monitoring," Report to the London Planning Advisory Committee, Working paper 329, Institute for Transport Studies, University of Leeds (March 1991), 41 pp.
95. UK Ministry of Transport, *Road Pricing: The Economic and Technical Possibilities,* Her Majesty's Stationery Office, London (1964), 61 pp.
96. May, A.D., and M. Roberts, "Demand Management for Urban Road Traffic in the United Kingdom: Towards a Sustainable Transport Policy for Urban Areas," *IATSS Research,* Vol. 15, No. 1 (1991), pp. 14–26.
97. Nevin, M., and L. Abbie, "What Price Roads," *Transport Policy,* 1 (1993), pp. 68–73.
98. May, A.D., and P. Mason, "The Development of Transport Strategies for Edinburgh," Proceedings of the Institution of Civil Engineers, *Transport,* Vol. 95 (1992), pp. 51–59.
99. UK Department of Transport, The Scottish Office, and the Welsh Office, *Paying for Better Motorways: Issues for Discussion,* Her Majesty's Stationery Office, London (May 1993), 56 pp.
100. MVA Consultancy, *Scenario Testing Exercise (TASTE III),* London Planning Advisory Committee, Romford, United Kingdom (May 1990), 84 pp. + appendices.
101. London Planning Advisory Committee, "Submission on Traffic Restraint to House of Commons Select Committee on Transport," Romford, United Kingdom (1989), 23 pp.
102. London Boroughs' Association, *The Case for Road Pricing,* London (1990).
103. Chartered Institute of Transport, *Paying for Progress: A Report on Congestion and Road Use Charges,* London (1990), 48 pp.
104. May, A.D., "Supplementary Licensing: An Evaluation," *Traffic Engineering and Control,* Vol. 16 (1975), pp. 162–167.
105. MVA Consultancy, and Colin Buchanan & Partners, *Desk Studies of Transportation Topics,* London Planning Advisory Committee, Romford, United Kingdom (March 1989), 482 pp.
106. London Planning Advisory Committee, *Strategic Planning Advice for London,* London, (1988).
107. MVA Consultancy, in association with Colin Buchanan and Partners and the Transport and Road Research Laboratory, *Transportation Strategic Advice: Scenario Testing Exercise (TASTE I),* London Planning Advisory Committee, Romford, United Kingdom (1988), 100 pp. + appendices.
108. May, A.D., and K.E. Gardner, "Transport Policy for London in 2001: The Case for an Integrated Approach," *Transportation,* Vol. 16 (1990), pp. 257–277.
109. May, A.D., P.W. Guest, and K. Gardner, "Can Rail–Based Policies Relieve Urban Traffic Congestion?" *Traffic Engineering and Control,* Vol. 31 (1990), pp. 406–407
110. Fowkes, A.S., D.S. Milne, C.A. Nash, and A.D. May, "The Distributional Impact of Various Road Charging Schemes for London," Institute for Transport Studies Working Paper 400, University of Leeds (June 1993), 31 pp.
111. Bates, J.J., M. Brewer, P. Hanson, D. McDonald, and D. Simmonds, "Building a Strategic Model for Edinburgh," presented at the PTRC Annual Meeting, Manchester, United Kingdom (September 1991), 17 pp.
112. Williams, I.N., and J. Bates, "APRIL-a Strategic Model for Road Pricing," presented at the PTRC Annual Meeting, Manchester, United Kingdom (September 1993), 13 pp.
113. Polak, J., P. Jones, P. Vythoulkas, R. Sheldon, and D. Wofinden, "Travelers' Choice of Time of Travel under Road Pricing," presented at the PTRC Annual Meeting, Manchester, United Kingdom (September 1993), 17 pp.
114. Small, K.A., "The Scheduling of Consumer Activities: Work Trips," *American Economic Review,* Vol. 72 (1982), pp. 467–479.
115. Mannering, F.L., and M.M. Hamed, "Occurrence, Frequency, and Duration of Commuters' Work–to–Home Departure Delay," *Transportation Research,* Vol. 24B (1990), pp. 99–109.
116. Black, I.G., and J.G. Towriss, *Demand Effects of Travel Time Reliability,* UK Department of Transport, Her Majesty's Stationery Office, London (1993), 34 pp.
117. Schrank, D.L., S.M. Turner, and T.J. Lomax, *Estimates of Urban Roadway Congestion—1990,* U.S. Federal Highway Administration Report No. FHWA/TX-90/1131-5, National Technical Information Service (March 1993), 69 pp.
118. UK Department of Transport, "London Congestion Charging Research Programme Progress Note No. 4," UK Department of Transport, London (July 1993), 9 pp.
119. Fearson, J., M. Scott, and M. Green, *Commercial Vehicle Responses to Road Pricing,* UK Department of Transport, Her Majesty's Stationery Office, London (1993), 55 pp.
120. Jones, P., *Review of Available Evidence on Public Reactions to Road Pricing,* UK Department of Transport, Her Majesty's Stationery Office, London (1992).

121. Sharpe, M., "Demand Management: The Cambridge Approach," *Transportation Studies,* Cambridgeshire County Council, Cambridge, United Kingdom (May 1993), 17 pp.
122. "SERC Funds Research on Congestion Pricing, with Cambridge a Possible Candidate Site for Demonstration," *Traffic Engineering and Control,* Vol. 31, No. 10 (1990), pp. 532–533.
123. Oldridge, B., "Congestion Metering in Cambridge City, United Kingdom," in *Road Pricing: Theory, Empirical Assessment, and Policy,* B. Johansson and L.-G. Mattsson, eds., Kluwer Academic Publishers, Dordrecht, Netherlands (1994), pp. 131–140.
124. Labour Party, *Moving Britain into the 1990s: Labour's New Programme for Transport* (1992).
125. Blythe, P.T., and P.J. Hills, "Electronic Road-Use Pricing and Toll Collection: The Results of the ADEPT Project," in *Proceedings of the International Conference on Advanced Technologies in Transportation and Traffic Management,* Centre for Transportation Studies, Nanyang Technological University, Singapore (May 1994), pp. 309–318.
126. World Bank, *World Tables 1993,* Johns Hopkins University Press, Baltimore (1993).
127. UK Central Statistical Office, *Annual Abstract of Statistics, 1974,* Her Majesty's Stationery Office, London (1974).
128. UK Central Statistical Office, *Annual Abstract of Statistics, 1992,* Her Majesty's Stationery Office, London (1992).
129. U.S. Bureau of the Census, *Statistical Abstract of the United States: 1993,* U.S. Government Printing Office, Washington, D.C. (1993), 1,009 pp.
130. Richards, M.G., "Road User Charges: A British Perspective," in *Proceedings of the International Conference on Advanced Technologies in Transportation and Traffic Management,* Centre for Transportation Studies, Nanyang Technological University, Singapore (May 1994), pp. 69–76.
131. Small, K.A., "The Incidence of Congestion Tolls on Urban Highways," *Journal of Urban Economics,* Vol. 13 (1983), pp. 90–111.
132. Giuliano, G. "Equity and Fairness Considerations of Congestion Pricing" in (3), Vol. 2, pp. 250–279.
133. Kain, J., "Impacts of Congestion Pricing on Transit and Carpool Demand and Supply," in (3), Vol. 2, pp. 502–553.
134. Goodwin, P.B., "The Rule of Three: A Possible Solution to the Political Problem of Competing Objectives for Road Pricing," *Traffic Engineering and Control,* Vol. 29 (1989), pp. 495–497.
135. Small, K.A., "Using the Revenues from Congestion Pricing," *Transportation,* 19 (1992), pp. 359–381.
136. Deakin, E., "Urban Transportation Congestion Pricing: Effects on Urban Form", in (3), Vol. 2, pp. 334–355.
137. Gomez-Ibanez, J.A., "The Political Economy of Tolls and Congestion Pricing," *Transportation Quarterly,* Vol. 46, No. 3 (July 1992), pp. 343–360.

APPENDIX A

SINGAPORE DATA TABLES

This appendix includes additional tables describing changes in travel behavior that accompanied the introduction of Singapore's ALS in 1975 (Tables A-1 through A-3), the history of subsequent modifications to the ALS scheme (Table A-4), demographic and vehicle ownership trends in Singapore (Tables A-5 and A-6), and changes in traffic flows by vehicle type after the 1989 ALS reforms (Table A-7).

TABLE A-1

CHANGES IN TRAVEL BEHAVIOR FOR HOME TO WORK TRIPS BY VEHICLE-OWNING AND NON-VEHICLE-OWNING HOUSEHOLDS IN SINGAPORE, 1975

	Work in restricted zone		Work beyond restricted zone	
	Before ALS	After ALS	Before ALS	After ALS
Mode used to work (percent)				
Vehicle-owning households				
Car driver[a]	32	20	37.5	31
Car passenger[a]	16	7	10	5
Carpool	8	19	5	14
Bus	33	46[b]	31.5	40
Motorcycle	7	6	13	9
Other	4	2	3	1
Nonvehicle-owning households[c]				
Car passenger[a]	1	3	n.a.[e]	n.a.[c]
Carpool	0	2	n.a.	3
Bus	88	89[d]	90	85
Bicycle	5	4	3	9
Taxi	3	0	n.a.	n.a.
Walk	2	2	n.a.[e]	n.a.
Route used by car drivers from vehicle-owning households (percent)				
Around restricted zone	n.a.	n.a.	12	34
Through restricted zone	n.a.	n.a.	88	66
Percentage of trips that started before 7:30 am (vehicle-owning households only)				
Car driver[a]	28	42	50	60
Car passenger[a]	19	38	40	64
Carpool	29	30	n.a.	n.a.
Bus rider	38	32	73	65

[a] Excludes carpools of 4 or more persons.
[b] Includes 3 percent who used the shuttle bus service from the new park-and-ride lots.
[c] Some columns do not add to 100 because of rounding.
[d] Includes 2 percent who used the shuttle bus service from the new park-and-ride lot.
[e] Six percent classified as "other."
[f] Three percent classified as "other."
n.a. = not available or not applicable.
Source: (1, pp. 85, 99, 100, 101, 109, 143, and 146).

TABLE A-2

CHANGES IN TRAVEL BEHAVIOR FOR WORK TO HOME TRIPS BY VEHICLE-OWNING AND NON-VEHICLE-OWNING HOUSEHOLDS IN SINGAPORE, 1975

	Work in restricted zone		Work beyond restricted zone	
	Before ALS	After ALS	Before ALS	After ALS
Mode used from work (percent)				
Vehicle-owning households				
Car driver[a]	35	23	36	35
Car passenger[a]	13	8	10	6
Carpool	5	12	5	12
Bus	36	48	34	38
Motorcycle	7	6	10	13
Other	4	3	2	1
Non-vehicle-owning households				
Car passenger[a]	2	3	0	0
Carpool	0	0	0	3
Bus	86	90	94	85
Bicycle	5	4	3	9
Taxi	2	0	3	3
Other	0	0	0	0
Route used by drivers from vehicle-owning households (percent)				
Around restricted zone	n.a.	n.a.	10	20
Through restricted zone	n.a.	n.a.	90	80

[a] Excludes carpools of 4 or more persons
n.a. = not applicable
Sources: (*1*, pp. 106-110, 144).

TABLE A-3

MEAN TRAVEL TIMES TO WORK IN SINGAPORE'S RESTRICTED ZONE FOR CAR-OWNING HOUSEHOLDS IN 1975 (MINUTES)

		Post-ALS Mode					
Pre-ALS Mode		Bus rider	Car[a] driver	Car[a] pass.	Car-Pool driver	Car-Pool pass.	Total[b]
Bus Rider	Before	40.4	38.0	46.7	43.6	35.4	40.3
	After	41.0	29.0	20.0	29.3	36.4	--
	Sample	(193)	(5)	(3)	(7)	(12)	(229)
Car Driver[a]	Before	30.2	26.8	29.6	31.4	30.0	28.2
	After	39.1	27.9	29.6	31.2	31.2	--
	Sample	(37)	(110)	(11)	(35)	(8)	(214)
Car Passenger[a]	Before	26.4	29.4	26.3	25.7	26.6	27.0
	After	42.8	30.6	27.5	28.6	23.3	--
	Sample	(38)	(9)	(28)	(7)	(4)	(16)
Carpool Driver	Before	30.0	33.3	--	34.2	30.0	32.5
	After	45.0	26.7	--	30.7	38.7	--
	Sample	(1)	(3)	--	(7)	(4)	(16)
Carpool Passenger	Before	32.7	--	27.0	29.4	28.7	29.6
	After	41.9	--	21.0	40.8	37.6	--
	Sample	(11)	--	(5)	(9)	(19)	(45)
Total[b]	Before	--	--	--	--	--	--
	After	41.0	28.2	26.4	32.1	31.1	--
	Sample	(301)	(129)	(50)	(67)	(74)	--

[a] = Non-carpool.
[b] = Includes users of "other" modes.
Source: (*1*, p. 133)

TABLE A-4

THE INITIAL SINGAPORE ALS SCHEME AND SUBSEQUENT MODIFICATIONS

				Daily license fee in Singapore dollars				
Implementation date	RZ Size (hectares)	Weekday Hours of operation	Exempt carpool size	Private car	Company car	taxi	Commercial truck	motorcycle
Initial Scheme								
June 2, 1975	620	7:30-9:30am	4	3	3	0	0	0
June 23, 1975						3		
August 1, 1975		7:30-10:15am						
Subsequent Changes								
Jan. 1, 1976				4	8	4		
Apr. 1, 1977						2		
Mar. 1, 1980				5	10			
Feb. 13, 1984	extended							
Nov. 19, 1986	710							
June 1, 1989		7:30-10:15am elim. 4:30-7:00pm		3	6	3	3	
July 1, 1989								1
Dec. 1989	725							
Jan. 31, 1990		7:30-10:15am 4:30-6:30pm						
Jan. 3, 1994		Whole day license M-F: 7:30am-6:30pm Sat: 7:30am-3:00pm		3	6	3	3	1
		Part day license M-F: 10:15am-4:30pm Sat.: 10:15am-3:00pm		2	4	2	2	0.70

Sources: (*1*, pp. 23, 53; *2*, pp. 11-13; *3*, p. 14; *4*, pp. 1-2).

TABLE A-5

CHANGES IN POPULATION AND EMPLOYMENT IN THE CENTRAL AND ORCHARD ROAD TRAFFIC ZONES IN SINGAPORE, 1972–1988

	1972	1981	1988	Change 1972-1988
Central zone				
Residential population	222,900	149,130	99,073	-56%
Resident workers (a)	100,310	73,340	47,020	-53%
Employment (b)	194,600	226,640	230,030	+18%
Minimum in-commuters (b-a)	94,290	153,300	183,010	+94%
Orchard Road zone				
Residential population	69,130	43,820	48,014	-31%
Resident workers (a)	29,340	21,780	22,760	-22%
Employment (b)	44,700	59,200	81,103	+81%
Minimum in-commuters (b-a)	15,360	37,420	58,343	+280%
Central and Orchard zones				
Minimum in-commuters	109,650	190,720	241,353	+74%
All Singapore (thousands)				
Residential population	2,150	2,437	2,648	+23%
Employment	700	1,113	1,256	+79%

Source: (*5*, p. 272).

Note: The Central and Orchard Road traffic zones probably correspond closely to the restraint zone since 315,000 persons were employed in the restraint zone in 1990 (*6*, p. 1) while the two zones were the site of 288,373 jobs in 1988. The minimum inbound commuters calculated above understates the number of inbound commuters because it assumes that all employed residents of the Central and Orchard Road zones also work in those zones.

TABLE A-6

CHANGES IN THE NUMBER OF VEHICLES, POPULATION, AND KILOMETERS OF ROAD IN SINGAPORE, 1974–1990

	1974	1980	1988	Change '74-'88	1990 (or 1989)	Change '74-'90
Motor vehicles						
Automobiles	148,980	164,496	238,984	+60%	272,475	+83%
Buses	4,779	6,512	8,788	+83%	9,298	+95%
Trucks and vans	36,424	78,020	105,640	+190%	114,350	+214%
Truck tractors	1,834	3,968	8,290	+352%	10,930	+495%
Motorcycles	84,849	118,345	116,476	+37%	121,338	+43%
Total	276,866	371,341	478,178	+73%	528,391	+91%
Roads (kilometers)					(1989)	
Expressways	0	39	96	--	102	--
Major arterials	250	313	500	+100%	512	+105%
Collector roads	115	157	238	+107%	242	+110%
Local roads	1,790	1,847	1,891	+6%	1,896	+6%
Total	2,155	2,356	2,725	+26%	2,752	+28%
					(1989)	
Population (thousands)	2,230	2,414	2,647	+19%	2,685	+20%
Persons per vehicle						
Persons per automobile	15.0	14.7	11.1		9.9	
Persons per bus	466.6	370.7	293.4		288.8	

Sources: (*5*, pp. 207-208) and (*7*, pp. 20-21 and 68-69).

TABLE A-7

CHANGES IN TRAFFIC ENTERING AND EXITING THE SINGAPORE RESTRAINT ZONE FROM MAY 1989 TO MAY 1990

	Entering traffic		Exiting traffic	
	Before reforms (May 1989)	After reforms (May 1990)	Before reforms (May 1989)	After reforms (May 1990)
Evening				
During restraint hours (4:30-6:30)				
All vehicles	51,500	23,781 (-54%)	57,532	37,890 (-34%)
Cars	25,920	8,374 (-68%)	29,001	17,852 (-38%)
Taxis	7,264	6,494 (-11%)	7,237	6,447 (-11%)
Buses	3,250	2,691 (-17%)	3,142	2,680 (-14%)
Trucks	8,395	3,333 (-60%)	9,485	5,255 (-45%)
Motorcycles	6,671	2,889 (-57%)	8,667	5,656 (-35%)
Before restraint hours (4:00-4:30)				
All vehicles	12,859	12,410 (-4%)	11,937	11,350 (-5%)
Cars	5,797	5,573 (-4%)	5,309	4,902 (-8%)
Taxis	2,244	2,365 (+5%)	2,121	2,189 (+3%)
Buses	720	638 (-11%)	678	556 (-18%)
Trucks	2,510	2,263 (-10%)	2,453	2,160 (-12%)
Motorcycles	1,588	1,571 (-1%)	1,376	1,543 (+12%)
After restraint hours (6:30-7:00)				
All vehicles	11,694	13,142 (+12%)	13,809	10,011 (-28%)
Cars	6,173	7,411 (+20%)	7,726	5,539 (-28%)
Taxis	1,898	2,315 (+22%)	1,886	1,726 (-9%)
Buses	735	640 (-13%)	777	638 (-18%)
Trucks	1,532	1,499 (-2%)	1,884	1,001 (-47%)
Motorcycles	1,356	1,277 (-6%)	1,536	1,107 (-28%)
Morning				
During restraint hours (7:30-10:00)				
All vehicles	47,880	41,345 (-14%)		
Cars	17,551	19,856 (+13%)		
Taxis	4,853	6,801 (+40%)		
Buses	4,177	3,891 (-7%)		
Trucks	11,121	5,266 (-53%)		
Motorcycles	10,178	5,523 (-46%)		
Before restraint hours (7:00-7:30)				
All vehicles	9,717	9,659 (-1%)		
Cars	6,125	5,732 (-6%)		
Taxis	792	795 (+0%)		
Buses	729	713 (-2%)		
Trucks	1,006	1,165 (+15%)		
Motorcycles	1,065	1,254 (+18%)		
After restraint hours (10:30-11:00)[a]				
All vehicles	14,255	14,298 (+0%)		
Cars	6,049	5,905 (-2%)		
Taxis	2,823	2,932 (+4%)		
Buses	617	502 (-19%)		
Trucks	2,745	3,081 (+12%)		
Motorcycles	2,021	1,878 (-7%)		

[a] Note that the morning restraint hours are actually 7:30-10:15 a.m. The data supplied by the Singapore Public Works Department for May 1990 were for half-hour periods only, which did not permit the calculation of traffic changes for the full restraint period or for the half hour immediately after (10:15 to 10:45 a.m.).

Source: Calculated from unpublished data supplied by the Singapore Public Works Department.

REFERENCES

1. Watson, P.L., and E.P. Holland, *Relieving Traffic Congestion: The Singapore Area License Scheme,* World Bank Staff Working Paper No. 281, Washington, D.C. (June 1978), 286 pp.
2. Behbehani, R., V.S. Pendakur, and A.T. Armstrong-Wright, "Singapore Area Licensing Scheme: A Review of the Impact," Water Supply and Urban Development Department, The World Bank, Washington, D.C. (July 1984), 55 pp.
3. Ang, B.W., "Traffic Management Systems and Energy Savings: The Case of Singapore," presented at the ATAS Workshop on New Energy Technologies: Transportation and Development, United Nations Centre for Science and Technology for Development, Ottawa, Canada, (September 20–22, 1989), 21 pp.
4. Menon, A.P.G., and S.H. Lam, *Singapore's Road Pricing Systems, 1989–1993,* Transportation Research Report NTU/CTS/93-2, Center for Transportation Studies, Nanyang Technological University, Singapore (November 1993), 33 pp.
5. Yong, P.S., *Housing Markets and Urban Transportation: Economic Theory, Econometrics and Policy Analysis for Singapore,* McGraw–Hill, Singapore and New York (1992).
6. Menon, A.P.G., and P.A. Seddon, "Traffic in the Central Area—Part I: Volume Characteristics," *Singapore Journal of the Institution of Engineers (1991),* pp. 1–12.
7. International Road Federation, *World Road Statistics, 1986–1990,* Washington, D.C. (1991).

APPENDIX B

SINGAPORE'S EFFORTS TO DISCOURAGE AUTO OWNERSHIP

Singapore's Area Licensing Scheme (ALS) has always been conceived of as a supplement to efforts to discourage auto ownership directly by raising taxes on new cars and by increasing car registration fees. These measures have been progressively strengthened and reformed over the last 20 years (*1-6*).

AUTOMOBILE REGISTRATION FEES

The government's efforts to discourage auto ownership began in earnest in 1972, before the ALS was implemented, when it raised import duties on new motor vehicles from 30 to 45 percent and imposed an "additional registration fee," or ARF, of 25 percent of the market value of new cars. On the advice of the Road Transportation Action Committee that had also recommended the ALS, the government increased the ARF to 55 percent in 1974 and to 100 percent in 1975. When the ARF was increased to 100 percent, the government also introduced a lower "preferential" ARF, or PARF, for new car purchasers who scrapped or exported an older car (not necessarily their own). The PARF is 35 to 55 percent of the normal ARF, depending on engine size.

For the next 15 years, auto ownership continued to grow fairly steadily despite further increases in the ARF rate to 125 percent of a car's value in 1978, 150 percent in 1980, and 175 percent in 1983. After 1977, company-owned cars were also made ineligible for the PARF discount.

Additional measures were adopted in 1981 to discourage owners from keeping cars longer than 10 years to avoid new car fees and taxes. New car buyers scrapping cars over 10 years old were no longer eligible for the preferential ARF rates and annual registration fees for cars over 10 years old were also increased significantly to encourage their retirement (*3*, p. 312; *1*, pp. 209-210). In 1983, the preferential ARF for those scrapping cars was also increased by 10 percentage points (to 45 to 65 percent of the usual ARF, depending on engine size).

By the mid 1980s, the cost of registering a new car in Singapore, including the various import duties and registration fees, was more than triple the pre-tax cost of importing the vehicle. A car with a wholesale, pre-tax landed cost of US \$10,000, for example, would cost at least US \$32,600, including an ARF of US \$17,500, import duties of US \$4,500, a "normal" registration fee of \$1,000, equivalent to about US \$8,000 to the price of the car (*1*, p. 299).

In addition, Singapore car owners had to pay an "annual road use tax" far higher than the comparable annual registration fees in the United States. The annual road use tax rates vary with engine size, and company cars pay twice the rates of private cars (*2*, p. 210). In the mid 1980s, the owner of a private car with a 1600 cc engine would pay 75 Singapore cents per cc, for example, or around US \$750 per year.

Auto ownership undoubtedly would have increased even faster without these measures, given the rapid growth in per capita incomes and the decentralization of residences that was occurring in Singapore at the time. Some analysts argue, however, that flaws in the ARF system weakened its effectiveness (*2*, pp. 219-220). The establishment of the preferential ARF in 1975 increased the market value of used cars that were less than 10 years old (cars older than 10 years were not eligible for the preferential ARF after 1981), for example, and the rapid increases in the ARF with only modest increases in the PARF during the late 1970s and early 1980s created windfall increases in used car prices and incentives to buy a new car on the chance that the ARF would increase further. Additional problems were caused by the fact that the buyer of a luxury car could scrap an economy car and still be eligible for the preferential ARF, as long as the scrapped car had an equal size or larger engine than the new car.

THE QUOTA AND WEEKEND CAR SYSTEMS

The inability of ARF increases to stem the growth in auto ownership during the 1980s led the government in 1990 to try to control auto ownership more directly through a system of new car quotas. After May 1, 1990, new car purchasers must buy a "certificate of entitlement" from the government. Each month the government establishes the number of certificates to would-be new car buyers. The price of the certificate in each vehicle class is determined by the lowest successful bid (*1*,*4*). Certificates can be used to register a new vehicle within 3 months, and remain valid for that vehicle for 10 years. Certificates are not required to purchase a used car, but the owner of a car that is 10 years old must purchase a certificate to register it. The ARF was reduced from 175 to 160 percent in November 1990, and to 150 percent in February 1991, to compensate for the introduction of the certificate system.

In May 1991, the government introduced a new "weekend car" scheme under which car owners who agreed to use their vehicles only during off-peak periods would be subject to reduced road use taxes and ARF. The owner of an existing vehicle converted to a weekend car received a 95 percent reduction in the annual road use tax. The buyer of a new weekend car must purchase a certificate of entitlement, but a special category for weekend cars has been established and enough certificates offered so that weekend car certificates are cheaper than regular car certificates. The new weekend car buyer also receives a 70 percent reduction in the annual use tax as well as reduced ARF and import duties. Weekend cars can be driven after 7:00 p.m. and before 7:00 a.m. on weekdays, after 3:00 p.m. on Saturdays, and all day Sundays and public holidays. In addition, weekend car owners can use their car for 5 weekdays per year and can purchase special permits for additional weekdays at a high daily cost. Weekend cars have special red license plates to facilitate enforcement.

The government has used the quota system to reduce the annual rate of auto ownership growth from 8.2 percent in 1989 (the year before it was implemented) to 5.4 percent in 1990 and 4.5 percent in 1991. The government intends to ultimately reduce the growth rate to 3 percent per year, only one percentage point above the current rate of population growth (*4*, p. 366).

Some observers worry that this target will require substantial increases in the costs of the certificates of entitlement (*1*, *2*,*4*). Winning bids for certificates of entitlement constituted 12 to 27 percent of the cost of buying and registering a new car (depending on size) after the first 30 months of the quota system (*1*, p. 299; *4*, p. 363), more than offsetting the reduction in the ARF rates that accompanied the quota scheme. If weekend cars are included in the government's 3 percent growth target, or if they are excluded but prove unpopular, achieving the target is likely to require continuing and significant increases in the winning bids for certificates.

REFERENCES

1. Toh, R., "Experimental Measures to Curb Road Congestion in Singapore: Pricing and Quotas," *Logistics and Transport Review*, Vol. 39, No. 2 (September 1992), pp. 289–317.
2. Yong, P.S., *Housing Markets and Urban Transportation: Economic Theory, Econometrics and Policy Analysis for Singapore*, McGraw-Hill, Singapore and New York (1992).
3. Spencer, A.H., and L.S. Chia, "National Policy Toward Cars: Singapore," *Transport Reviews*, Vol. 5, No. 4 (1985), pp. 301–323.
4. Olszewski, P., and D.J. Turner, "New Methods of Controlling Vehicle Ownership and Usage in Singapore," *Transportation*, Vol. 20 (1993), pp. 355–371.
5. Seventh Parliament of Singapore, *Report of the Select Committee on Land Transportation Policy, First Session, Parl. 1 of 1990,* presented to Parliament: 2nd January, 1990 printed for the Government of Singapore by the Singapore National Printers Ltd. (1990).
6. Seah, C.-M., "Mass Mobility and Accessibility: Transport Planning and Traffic Management in Singapore," *Transport Policy and Decision Making*, Vol. 1, (1980) pp. 55–71.

APPENDIX C

THE TRONDHEIM SUBSCRIBER'S AGREEMENT CONCERNING THE USE OF THE Q-FREE PAYMENT SYSTEM

1. The Scope of the Agreement

The Agreement covers the use of the Q-FREE payment system when passing through Ranheim toll plaza and the Trondheim toll ring.

Agreements may be signed by individuals or by companies. Issued as part of this Agreement are the Q-FREE tag, the instructions for fitting and instructions for use, and a list of current prices.

2. The Liability of the Toll Road Company

The Toll Road Company shall allow the subscriber access to drive on that section of the E6, which is a toll road, and past the toll plazas in the Trondheim toll ring against payment of a charge approved by the Norwegian Ministry of Transport and Communication.

The Toll Road Company manages the collection of charges according to current prices and carries all costs in this connection. Exceptions are the fees and penalties stated in the price list, and normal bank charges.

The Toll Road Company records all traffic through the toll plaza, but all recorded data that may be linked to the subscriber will automatically be deleted after the charge has been entered in the subscriber's account.

In the event of discrepancies between notes kept by a subscriber and the records kept by the Toll Road Company, the subscriber may request that his traffic data be recorded over a period of time. It is the responsibility of the Toll Road Company to protect information about subscribers and traffic from unauthorized use.

3. The Liability of the Subscriber

The subscriber is responsible for prepayment or postpayment of charges according to current price lists. The price list in force at any time is part of this Agreement. The price list may be amended at 1-month's notice. Prepaid entries may be used under the old prices for one additional month following a price change. On signing the Agreement, the subscriber selects the method of payment and the amount to be paid each time. Under the option "direct debiting," renewal takes place automatically and in time. However, this is subject to the account providing cover. Under the option "bank giro" (authorized direct transfer of funds), the subscriber is responsible for due payment being made. A white light at the toll plaza means that payment of an amount due has not been received. Postpayments are only accepted against confirmation of a contract with a bank for direct drawing. Unless such confirmation is submitted, or if a contract for direct debiting is terminated, the Toll Road Company reserves the right to change the Agreement to the lowest prepaid subscription with immediate effect.

Any entry which is not prepaid, i.e., an unauthorised entry, will entail a penalty fee to be stipulated by the Ministry of Transport and Communication.

The subscriber must handle the Q-FREE tag in accordance with the user's guide and the fitting instructions. The tag remains the property of the Toll Road Company and must be returned to the Toll Road Company if the Agreement is terminated (see also 4).

The subscriber is at all times responsible for the use of the issued tag and must report to Trondelag Toll Road Company without undue delay if the tag is lost or stolen. Lost tags must be replaced. The subscriber is also responsible for the removal of the tag when the vehicle is sold.

All changes to this Agreement such as transfer to another car, changes in the subscription particulars, address, account number should be notified to the Toll Road Company.

The tag should only be used in the vehicle stated in this Agreement. The use of the tag in a different car will entail a penalty if the entry is recorded as unauthorised. Notice of change of car should be made immediately to the Toll Road Company.

The Toll Road Company reserves the right to make random checks in the toll plazas. The subscriber should pass the toll plaza in the lane designated for automatic entry. Any entry by the manual lane should be paid cash. Subscribers are not entitled to claim a discount when entering by the manual lane.

On termination the Q-FREE tag must be returned to the Toll Road Company and payment will be made within a fortnight from the Toll Road Company to the subscriber of prepaid charges less any unpaid entries and damage to the Q-FREE tag. Post payment subscribers must pay any entries not paid on termination.

4. Default

In the event of default of this Agreement, either party may give notice to terminate it with immediate effect.

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encouraging education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences, by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 8970

000021-05
Robert M Smith
Research & Asst Matls Engr
Idaho DOT
3311 W State St
P O Box 7129