NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT **340**

ASSESSMENT OF ADVANCED TECHNOLOGIES FOR RELIEVING URBAN TRAFFIC CONGESTION

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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ASSESSMENT OF ADVANCED TECHNOLOGIES FOR RELIEVING URBAN TRAFFIC CONGESTION

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST

Human Factors
Vehicle Characteristics
Operations and Traffic Control
(Highway Transportation, Public Transit)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D. C. DECEMBER 1991

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.

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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, 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.

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February 7, 1992

REPLY TO: Robert J. Reilly
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TO: CHIEF ADMINISTRATIVE OFFICERS
STATE HIGHWAY AND TRANSPORTATION DEPARTMENTS

FROM: Thomas B. Deen
Executive Director

SUBJECT: National Cooperative Highway Research Program Report 340
"Assessment of Advanced Technologies for
Relieving Urban Traffic Congestion"
Final Report on Project 3-38(1) of the FY '87 Program.

A copy of the subject report is enclosed. Individuals who have selected the Areas of Interest shown on the title page of the report will also receive a copy.

The NCHRP staff has provided a foreword that succinctly summarizes the scope of the work and indicates the personnel who will find the results of particular interest. This will aid in the distribution of the report within your department and in practical application of the research findings. These finding add substantially to the body of knowledge concerning Intelligent Vehicle/Highway Systems (IVHS) and the potential applications and benefits from implementing the various technologies

Enclosure

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FOREWORD

By Staff
Transportation Research Board

This report will be of special interest to transportation officials involved in the subject of Intelligent Vehicle Highway Systems, or IVHS. The research reported herein was initiated before the IVHS rubric emerged. However, the research progressed in parallel with the development of the IVHS concept and in the final analysis, the subject matter falls completely within the scope of IVHS.

Under NCHRP Project 3-38(1), research was undertaken by Castle Rock Consultants, Leesburg, Virginia, to identify and assess the most promising advanced technologies and systems that can improve urban highway traffic operations by achieving significant increases in capacity and traffic flow; and, for the most promising of these technologies and systems, to formulate a plan for research, development, testing, and demonstration.

In accomplishing the objectives, technologies were reviewed in the areas of traveler information systems, traffic control systems, and automatic vehicle control systems. The study also included a brief review of the application of these technologies to transit and rideshare needs. Both qualitative and quantitative assessments of a broad range of technologies were undertaken in order to select the three most promising technologies available for short-term implementation. These technologies comprise the radio data system for traffic information broadcasting, externally linked route guidance, and adaptive traffic control. Detailed benefit-cost analyses were performed on these technologies, together with a review of funding sources, jurisdictional and institutional issues, and consumer and user reactions to the systems. The study included a review of current steps being taken to develop a national intelligent vehicle/highway systems (IVHS) program. An outline of projects and activities to be included in an IVHS program was prepared, along with a preliminary time schedule. These activities are grouped into advanced traveler information systems (ATIS), advanced traffic management systems (ATMS), fleet management and control systems (FMCS), and automatic vehicle control systems (AVCS). The report concludes by recommending the urgent need for a national program for developing, demonstrating, and implementing advanced transportation technologies.

When the research being conducted under NCHRP Project 3-38(1) was nearing completion, the research agency was requested to perform a similar study under the National Cooperative Transit Research and Development Program (NCTRP). Under NCTRP Project 60-1A, "Assessment of Advanced Technologies for Transit and Rideshare Applications," sponsored by the Urban Mass Transportation Administration (UMTA), advanced technologies which would benefit transit and ridesharing applications were assessed and reported on. Taken together, NCHRP Report 340 and a companion report on NCTRP Project 60-1A provide a comprehensive description and assessment of virtually all the concepts that are now being considered under the IVHS concept. The final reports, for both NCHRP Project 3-38(1) and NCTRP Project 60-1A, each contained an appendix which outlined a recommended national IVHS research and development program. After completion of the two reports, the research agency was requested to synthesize the two recommended national programs into a single report, "Outlining a National IVHS Program." These IVHS-related publications are published by TRB's Cooperative Research Programs Division as follows: (1) NCTRP Project 60-1A report, "Assessment of Advanced Technologies for Transit and Rideshare Applications," $10.00; and (2) "Outlining a National IVHS Program," $10.00. The reports are available from: Business Office, Transportation Research Board, 2101 Constitution Avenue, Washington, D.C. 20418.

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ACKNOWLEDGMENTS

The Principal Investigator and major contributors to this final report are: Dr. Peter Davies, President, Castle Rock Consultants (CRC); Dr. Nick Ayland, Principal, CRC; Dr. Chris Hill, Principal, CRC; Dr. Scott Rutherford, Director, Washington State Transportation Center (TRAC); Mark Hallenbeck, Senior Research Engineer, TRAC; and Dr. Cy Ulberg, Research Engineer, TRAC.

The authors wish to acknowledge the excellent cooperation and assistance provided by the Federal Highway Administration, Urban Mass Transportation Administration, state departments of transportation, research establishments, and system manufacturers. We wish also to acknowledge the cooperation afforded us by overseas research institutions, programs, and transportation agencies. Their contributions to this project have greatly enhanced its scope and value. Finally, sincere thanks are extended to our colleagues at CRC and TRAC for their help and advice in completing this project.

ASSESSMENT OF ADVANCED TECHNOLOGIES FOR RELIEVING URBAN TRAFFIC CONGESTION

SUMMARY This report presents the results of an extensive investigation, conducted under NCHRP Project 3-38(1), into the potential of advanced technologies for relieving urban traffic congestion. The specific objectives of the research were: (1) to identify and assess the most promising advanced technologies and systems that can improve urban highway traffic operations by achieving significant increases in capacity and traffic flow; and (2) for the most promising of these technologies and systems, to formulate a plan for research, development, testing, and demonstration.

The study identified and assessed the most promising of a wide range of advanced technologies and systems for improving urban traffic flow. While many of the technologies examined showed potential benefits, public agencies will have to concentrate scarce research and development resources on those technologies that offer the most congestion relief for the least costs. The study recommended three technologies for short-term implementation and two technologies for longer term research. The project involved a detailed examination of the benefits and costs of the three recommended technologies. It also provided a research, development and demonstration plan for a national intelligent vehicle/highway system (IVHS) program covering a broad range of technologies and systems. The recommended technologies and the findings are briefly described in the following sections.

Findings

The initial review of potential systems encompassed a wide spectrum of technologies in varying degrees of development. Comparing systems was often difficult in that some systems have been heavily tested, while others are still in preliminary design. Consequently, the project team stratified its recommendations into short- and long-term research efforts.

Short-Term Research

Externally linked route guidance includes electronic route planning and following aids that link in-vehicle equipment with external systems that provide real-time network information. Externally linked route guidance has been shown to have a potentially high benefit and cost ratio, with a potential to significantly impact travel patterns and congestion levels. Existing technologies appear capable of providing reliable performance at reasonable costs.

Externally linked guidance could also benefit from private sector involvement in the development, funding, and operation of the systems as commercial ventures. Such involvement would minimize public sector investment and risk. However, the federal government should be involved in externally linked route guidance to help establish standards and ensure compatibility between commercial systems.

Radio data system (RDS) traffic message channel (TMC) is a broadcast standard currently being implemented in Europe and is under consideration in Canada and other countries. RDS inaudibly superimposes digitally encoded data onto the stereo multiplex signal of a conventional FM broadcast. These data are decoded by a suitably adapted car radio and can either be immediately received by the user or be stored for broadcast at a time of the user's selection.

RDS transmission of traffic information also shows a potentially high benefit in relation to the estimated implementation and operation costs. RDS traffic broadcasts could help reduce spontaneous congestion build-up at traffic incidents such as vehicle disablements and accidents on heavily traveled highways. It also could supply motorists with general purpose traffic condition information.

As with route guidance, there are significant opportunities for private sector involvement in RDS-TMC. The cost of the RDS receivers could be borne directly by the system's users. Development of suitable receivers would likely be market driven, while government involvement would be necessary to ensure adherence to worldwide RDS standards to promote the RDS-TMC concept, and help provide the traffic information being broadcast. Infrastructure costs would be minimal because RDS is able to use existing FM transmitters without interfering with the normal reception of those transmissions.

Adaptive traffic control is the implementation and expansion of the traffic signal control philosophy that is capable of adjusting traffic signals in real time to meet the demands of detected traffic flows. It provides timing plans that operate better than conventional, fixed-time plans. In addition, adaptive signal plans do not need to be retimed because the system automatically updates traffic control parameters as it operates.

Like RDS and external route guidance, adaptive traffic control offers the prospect of substantial returns on the required investment. Also, adaptive traffic control is a proven technology that simply must be adapted to the U.S. needs.

Long-Term Research

Automatic vehicle control consists of systems for performing braking, headway control, steering, and merging or diverging automatically. Combined, the automatic vehicle control technologies result in the concept of the automated highway system. Such a system offers the potential for quantum increases in highway capacity; however, before any gains can be achieved, significant technology and safety concerns must be overcome. Solving these technological problems will require considerable time and effort.

Interactive traffic control combines the origin, destination, and routing information from externally linked route guidance systems with adaptive traffic control techniques. The result is a traffic signal control system that can change traffic signal plans before traffic arrives in the signalized network, thus delaying the onset of congested conditions. The required components of an interactive system are addressed in the short-term research efforts described previously.

National Intelligent Vehicle/Highway Systems (IVHS) Program

The report recommends the development of a U.S. national IVHS program as an urgent priority. This program would include the research and development efforts described previously, together with demonstration, standard-setting, implementation, and on-going support activities for a broad range of advanced transportation technologies. An outline IVHS program describing potential projects and activities and a preliminary program schedule through the year 2000 has been developed.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

Traffic congestion is rapidly becoming one of the most serious problems affecting urban areas. Urban travel, in general, is increasing at a rate of 4 percent per year, but construction of new facilities is expected to accommodate less than one-fourth of this additional demand. Today, the 37 largest metropolitan areas in the United States are annually experiencing over 1.2 billion vehicle-hours of delay on freeways alone. Current predictions are for nearly a 50 percent increase in travel demand on urban freeways between the years 1984 and 2005. This would result in more than a 200 percent increase in recurring congested travel and over a 400 percent increase in delay. Therefore, a continued loss of mobility is expected.

Against this backdrop of serious existing and growing congestion, traffic control techniques and information systems are needed that can substantially increase capacity and improve traffic flow efficiency. Application of advanced technologies in areas such as motorist information and navigation systems, improved traffic control systems, and vehicle guidance and control systems has significant potential for relieving traffic congestion. Prior to this project, issues related to applying such systems to help alleviate traffic and transportation problems had not been fully explored.

The objectives of this research project (NCHRP Project 3-38(1)) were: (1) to identify and assess advanced technologies and systems that can improve urban highway traffic operations by achieving significant increases in capacity and traffic flow; and (2) for the most promising of these technologies and systems, to formulate a plan for research, development, testing, and demonstration.

In order to meet these objectives, a two-phase research approach was used. In the first phase, a comprehensive review was undertaken of advanced technologies which show potential for alleviating urban congestion. This review was international in scope, covering the major development efforts undertaken in the United States, Europe, Japan, and other countries with experience of advanced technologies.

Issues associated with implementing these advanced technologies were also examined in the first phase of the project. These included financing options, jurisdictional concerns, public and private sector roles, and consumer and user issues. In addition, the study team conducted an initial assessment of each of the technologies in the first phase. This considered the full range of benefits and impacts that may result from implementation of each technology, together with likely implementation costs and timescales.

The second phase of the project encompassed two main research efforts. First, a detailed assessment was carried out of three technologies selected for further investigation on the basis of the first phase evaluation. This included detailed benefit and cost appraisal under various urban operating scenarios, and investigation of specific implementation issues associated with the three technologies. Second, a proposed national intelligent vehicle/highway system (IVHS) program was developed in outline. This outline program was designed to meet the increasingly recognized need for a coordinated U.S. program, which will ultimately allow the full benefits of IVHS technologies to be realized.

This report focuses on the application of new technologies to the individual automobile driver traveling in an urban area. However, the role of mass transit and ridesharing in reducing urban traffic congestion is fully recognized and the use of advanced technologies in improving their operations is introduced in the report. A detailed evaluation is contained in a companion report, entitled "Assessment of Advanced Technologies for Transit and Rideshare Applications" (*1*).

Following this introductory chapter, Chapters 2, 3, and 4 present the results of the international review of advanced technologies undertaken in the first phase of the project. Chapter 2 covers motorist information and communication systems, and describes the following technologies: electronic route planning, traffic information broadcasting, onboard navigation systems, externally linked route guidance, automatic vehicle identification, and automatic vehicle location.

Chapter 3 discusses traffic control systems, and includes technologies aimed at the following control measures: isolated intersection control, improved fixed-time coordination, partially adaptive coordination, fully adaptive coordination, freeway and corridor control, incident detection, and interactive signal coordination.

Chapter 4 describes automatic vehicle control systems, and includes the following technologies: antilock braking systems, speed control systems, variable speed control, automatic headway control, radar braking, automatic steering control, and automated highway systems.

Chapter 5 describes the application of new technologies to mass transit and ridesharing. The technologies are divided into categories covering advanced traveler information systems, advanced traffic management systems, and fleet management and control systems. The chapter includes the following technologies: pretrip planning systems; trip reservation and payment systems; in-terminal information systems; in-vehicle information systems; traffic signal priority systems; systems for specialized highway environments; enforcement systems; ticketing systems, onboard computers, and smart cards; automatic vehicle location systems; and automatic vehicle monitoring systems.

In each of these review chapters, the basic mode of operation of each individual technology is outlined, and its applicability for relieving urban congestion is discussed. Prominent examples of current systems are given and instances of implementation and use are described.

Chapter 6 discusses key issues associated with implementation of advanced technologies for relieving urban congestion. Chapter 7 presents the results of the initial assessment of alternative technologies. Interim conclusions and recommendations are presented, based on the results of the first phase investigation.

The detailed second-phase assessments of the three technologies selected for further investigation (externally linked route guidance, the Radio Data System (RDS) for traffic information broadcasting, and adaptive traffic control) are summarized in Chapters 8 and 9. Chapter 8 presents the results of benefit-cost analyses for each of the three technologies, and specific implementation issues associated with each technology are discussed in Chapter 9.

Chapter 10 addresses the development of a national IVHS program. National and international efforts are described which relate to the development and implementation of coordinated RD & D programs for IVHS technologies. The proposed national IVHS program plan prepared in this study is also outlined.

Finally, Chapter 11 presents the overall conclusions of NCHRP Project 3-38(1). Recommendations are also made for further work in the area of IVHS technologies. The recommended actions should lead to technology implementation in the most timely and cost-effective manner possible, and substantially benefit traffic movement on the nation's highway system in the coming decade and century.

References and a list of acronyms are included following Chapter 11.

CHAPTER 2

DRIVER INFORMATION SYSTEMS

2.1 INTRODUCTION

This chapter describes systems designed to provide drivers with information on highway conditions and route availability. Driver information systems can assist motorists in making decisions on appropriate route choice and in following the chosen route for a particular trip. Improved motorist route selection and route following should lead to more efficient use of the highway network, and consequent benefit to traffic as a whole.

Research studies carried out in the United States and Europe (*2, 3, 4, 5, 6*) have shown that, for a variety of reasons, many drivers are currently inefficient in selecting and following a route. This inefficiency leads to excess travel, contributing to unnecessary congestion of certain routes and consequent waste of resources, which can amount to many millions of dollars every year in a large metropolitan area. Excess travel can generally be defined in terms of time, distance or cost, or some combination of these criteria.

Providing drivers with accurate information can help remove a proportion of excess travel caused by driver inefficiency in carrying out the three key trip activities of route planning, route following, and trip chain sequencing.

Route planning takes place largely at the pretrip stage. Conventionally, drivers plan their journeys either using maps or from information held in the driver's memory. Drivers can use any of a variety of route selection criteria, and are typically considered to allocate an "impedance" to each route, based on their personal criteria. The minimum impedance route is then selected for the trip being planned. Replanning may take place en route as drivers become aware of traffic conditions, causing a conceptual change in the relative impedance of alternative routes. Inefficiency in route planning can be caused by inadequate attention to alternatives, or planning on the basis of inadequate or inaccurate information.

Route following involves implementation of the trip plan. This activity is conventionally aided by road signs and maps, to supplement drivers' recognition of their surroundings and sense of direction. Inefficiency in the route following task generally results in drivers losing their way, taking unplanned detours, or making other unnecessary deviations from their planned progress along a route.

Trip chain sequencing concerns complex trips that have multiple stops or multiple purposes (*3*). Such a trip chain can incur significant excess travel if the sequencing of stops or trip segments is not optimized. Similarly, use of several single trips rather than a single, complex trip can result in a considerable amount of excess travel.

A number of approaches to providing improved information exist for assisting drivers in one or more of these activities. The remainder of this chapter covers the main approaches and describes previous experience of their use.

2.2 ELECTRONIC ROUTE PLANNING

Sources such as maps or memory can, at best, supply only historic data on which routes are available. Supplementary information is required to describe transient road and traffic conditions, and to show which route is "best" at any particular time. One possible solution to this need for additional real-time pretrip information lies in the development of electronic route planning and information systems (*7*).

Electronic route planning systems link minimum path computer algorithms to highway network databases. Minimum paths can be determined in terms of journey time, distance or cost. Users access the route planning computer either directly or over a telephone line, and see details of their optimum route displayed or printed out. Most electronic route planning systems have been developed within this decade. Some of the significant developments are described below.

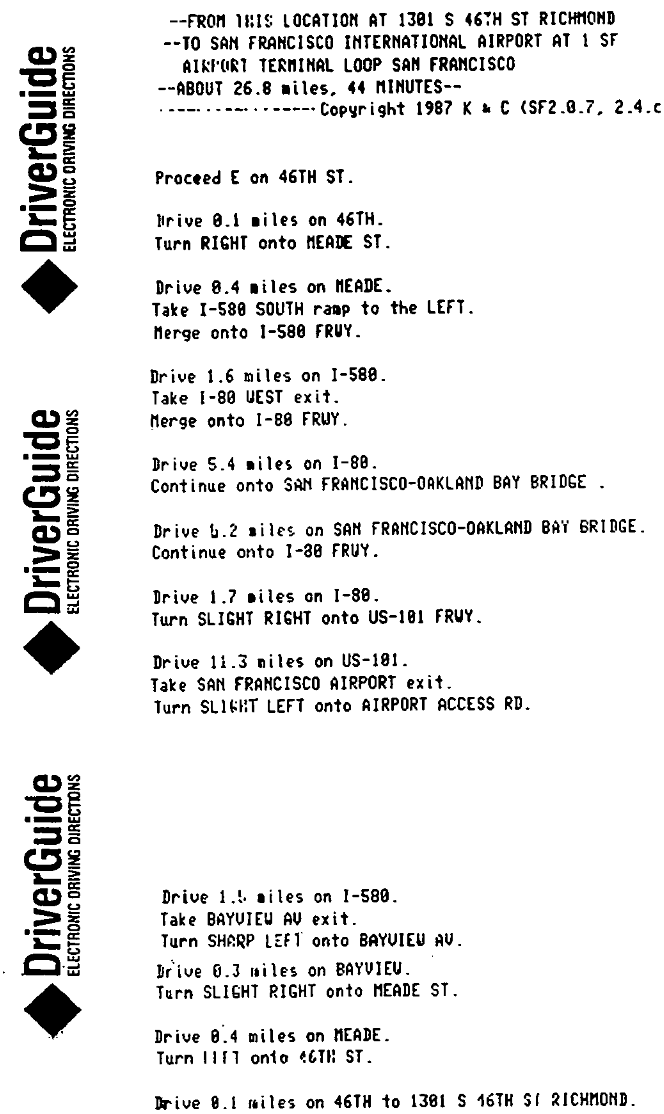
In the United States, an electronic route planning system has been developed by Navigation Technologies, Inc. (Figure 1). The system selects destinations from a structured database, using a look-up table. The system has been used by rental car firms to provide customers with directions to their destinations.

Electronic route planning facilities are also receiving attention in Europe (*8, 9*). The French TELETEL videotext system (*10*) comprises many interactive services including a route planning service called ROUTE. The service is accessed through remote videotext terminals that are connected by telephone to service suppliers. The database for ROUTE contains network information, together with current data on highway maintenance and construction activities, and road and weather conditions.

Also in France, the ANTIOPE service provides up-to-date traffic information that can be used by motorists in planning routes. ANTIOPE is not an interactive system, but collects and displays 30 to 40 pages of traffic information on a regional basis via a teletext TV service. ANTIOPE contains maps, showing the congestion on major roads in selected areas, that are updated at hourly intervals based on data collected by the highway patrol.

The U.K. Automobile Association (AA) has developed a similar service, called ROADWATCH (*11*), that provides traffic information to radio stations, TV, and teletext services. This networked system operates around a database that is kept up-to-date with the latest details of variations in road conditions due to weather, highway maintenance, or accidents.

At a pan-European level, there is a developing system known as ATIS (*12*) that aims to provide pretrip information, both on road traffic conditions and on other aspects important to tourists. ATIS is based around the existing ERIC (European Road Information Center) facility, which is coordinated by the AIT (Alliance Internationale de Tourisme) in Geneva, Switzerland. Important traffic information is reported by the police and motoring organizations in each of 12 European countries to the Geneva center. Here, it is processed and the resulting information transmitted back to each country, for dissemination via the motoring organizations.



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--FROM THIS LOCATION AT 1301 S 46TH ST RICHMOND
--TO SAN FRANCISCO INTERNATIONAL AIRPORT AT 1 SF
  AIRPORT TERMINAL LOOP SAN FRANCISCO
--ABOUT 26.8 miles, 44 MINUTES--
-----------------Copyright 1987 K & C (SF2.0.7, 2.4.c)

Proceed E on 46TH ST.

Drive 0.1 miles on 46TH.
Turn RIGHT onto MEADE ST.

Drive 0.4 miles on MEADE.
Take I-580 SOUTH ramp to the LEFT.
Merge onto I-580 FRWY.

Drive 1.6 miles on I-580.
Take I-80 WEST exit.
Merge onto I-80 FRWY.

Drive 5.4 miles on I-80.
Continue onto SAN FRANCISCO-OAKLAND BAY BRIDGE .

Drive 6.2 miles on SAN FRANCISCO-OAKLAND BAY BRIDGE.
Continue onto I-80 FRWY.

Drive 1.7 miles on I-80.
Turn SLIGHT RIGHT onto US-101 FRWY.

Drive 11.3 miles on US-101.
Take SAN FRANCISCO AIRPORT exit.
Turn SLIGHT LEFT onto AIRPORT ACCESS RD.

Drive 1.[illegible] miles on I-580.
Take BAYVIEW AV exit.
Turn SHARP LEFT onto BAYVIEW AV.

Drive 0.3 miles on BAYVIEW.
Turn SLIGHT RIGHT onto MEADE ST.

Drive 0.4 miles on MEADE.
Turn LEFT onto 46TH ST.

Drive 0.1 miles on 46TH to 1301 S 46TH ST RICHMOND.
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Figure 1. Electronic route planning in San Francisco. (Source: Navigation Technology, Sunnyvale, California)

2.3 TRAFFIC INFORMATION BROADCASTING SYSTEMS

Traffic information broadcasting systems can potentially play an important role in keeping the motorist updated on current network traffic conditions, enabling him to adapt and replan his route as necessary. Systems can be used to warn drivers of various conditions including recurring congestion, short-term hold-ups caused by a traffic incident, or preplanned activities liable to cause congestion, such as highway construction and maintenance.

In the United States and Japan, traffic information broadcasting is provided by highway advisory radio (HAR). HAR (*13, 14*) is a short-range broadcast service provided to the motoring public through standard AM car radios. In the U.S., travelers' information stations (TIS) have been authorized to provide this service since 1977. HAR is operated by local and federal government agencies under rules that limit location, extent of coverage, and message content. This authorization and the rules covering HAR services are contained within Docket 20509 of Part 90 of the Federal Communications Commission (FCC) Rules and Regulations.

HAR stations can be authorized to broadcast on either 530 kHz or 1610 kHz, which are just below and above the standard AM broadcast band. Transmissions on these frequencies can be received by most standard AM car radio receivers; the system, therefore, has the advantage that motorists do not have to purchase any special in-vehicle equipment. However, because of the localized nature of the service, motorists must be notified by appropriate signing when approaching an area serviced by HAR in order to tune their radios to the appropriate frequency (Figure 2).

In 1980 the Federal Highway Administration (FHWA) initiated a program to develop automatic highway advisory radio (AHAR) (*14*). The AHAR system prototype was developed to the stage where it is technically proven. AHAR avoids the need for roadside signing and manual tuning by using a subsidiary FM receiver which automatically mutes the car radio and tunes to the AHAR frequency (45.80 MHz) on entering the coverage area of the AHAR transmitter. The radio is returned to its normal state after the message has been repeated and received twice. Institutional barriers have so far prevented the transition from HAR to AHAR.

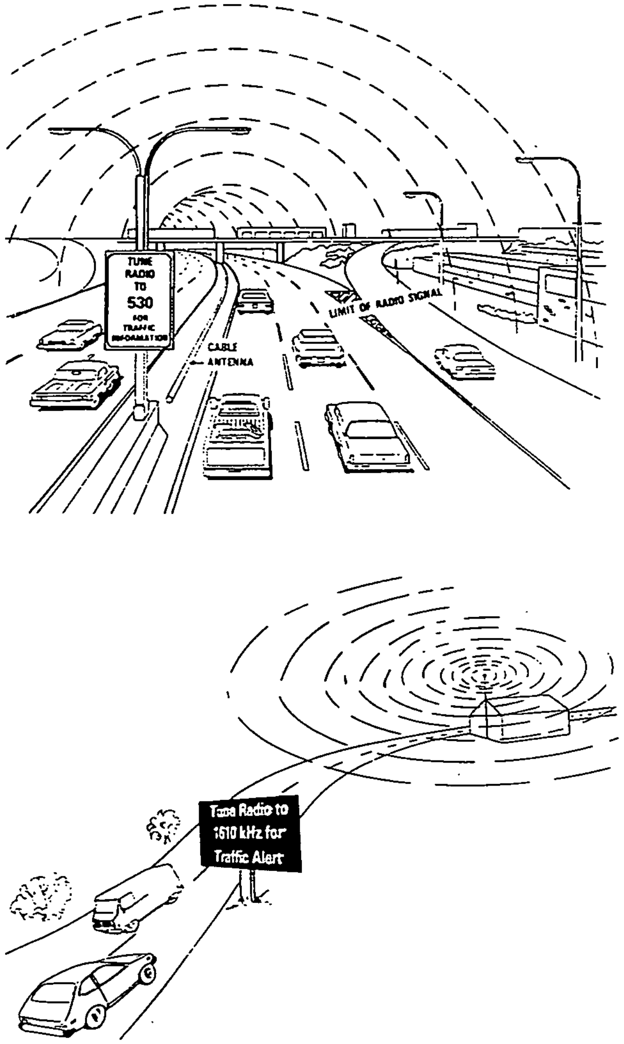

Figure 2. The Highway Advisory Radio Broadcast Service System. (Source: Ref. 14)

Other traffic information broadcasting systems include the West German system known as ARI (Autofahrer Rundfunk Information) (*16, 17, 18*), developed by Blaupunkt. ARI is widely used in Germany and parts of Austria, Switzerland, and Luxembourg. A modified version known as ARI-2 has also been implemented in parts of the U.S. (*18*).

In West Germany, traffic information is broadcast at specified times over a network of about 40 conventional FM radio stations, each transmitting on its own frequency. Because of the characteristics of FM transmissions, the range of each station is limited. With such a system using a large number of short range stations, it is important to provide a tuning aid to select the frequency of the station covering the area in which the motorist is traveling. The principal function of the ARI system is therefore to assist the motorist in tuning to a station which is providing traffic information, and to alert the driver when a traffic broadcast is imminent. To decode and utilize these ARI signals, vehicles need to be fitted with a specialized form of receiver. In West Germany, more than 80 percent of car radio receivers have an ARI capability.

The sources of traffic information for ARI are mostly observations by police and highway agencies. The information flow process necessarily involves detection of a major change in traffic conditions and its cause, transmission to a radio station, and broadcasting to the motorist. This inevitably involves a significant delay, which can result in the information being out-of-date by the time it is received.

In an attempt to reduce this delay, an enhanced version of ARI has been developed called ARIAM (*19, 20*). ARIAM stands for "ARI aufgrund Aktueller Messdaten," which can be translated as ARI with Actual Measurement. The objective of ARIAM is to automate the process of detecting changes in traffic conditions, and disseminating information on changes to the public using the established ARI network. ARIAM uses automatic incident detection equipment as the main basis for detecting these changes. Initial tests of the system have shown that information about road and traffic conditions can be made available to the traffic control center and the motorist around 10 to 15 min earlier than a system relying on nonautomated information collection.

A system that will eventually supersede ARI is the RDS of the European Broadcasting Union (EBU). This is a system that enables digitally encoded data to be inaudibly superimposed on the stereo multiplex signal of a conventional FM broadcast. These data are decoded by a suitably adapted car radio, which can automatically select the strongest of several traffic announcement programs when a driver leaves the reception area of one transmitter (*21*).

The RDS has been under development by the EBU since 1974. It provides a unified standard for automated tuning, station identification, and other receiver functions. The RDS Specification (*22*) was finalized in 1983, after consultation with radio receiver manufacturers confirmed that RDS objectives had been achieved. The standardization efforts of the EBU have also led to an agreement being reached on RDS within the CCIR. Recommendation 643, which covers the main characteristics of the system, was adopted at the Plenary Assembly of the CCIR at Dubrovnik in May of 1986, establishing RDS as a world standard.

International efforts are currently taking place to develop standards for the RDS Traffic Message Channel (TMC). A specialized receiver is required to decode the traffic information, which can then be displayed either as text or synthesized speech. Such a system is particularly attractive from a European perspective because digital transmissions can be interpreted in the language of the driver's choice.

Studies are also being undertaken in countries outside Europe, including Canada and Hong Kong, to investigate the possibilities of implementing RDS-TMC. In the U.S., Chrysler has been carrying out trials of RDS traffic information in the Detroit metropolitan area.

2.4 ONBOARD NAVIGATION SYSTEMS

Onboard navigation and location systems are another area of motorist information technology. These systems provide the motorist with information on his current location and how this relates to his destination. In some cases, onboard navigation systems also provide advice on the best route to take. This information is calculated and presented by a self-contained vehicle unit, which does not require any external link to a roadside infrastructure.

Onboard navigation systems are generally of most use to the motorist in conducting the route following task. Systems providing actual guidance information can also be used for the route planning task. However, without any information about real-time conditions on the traffic network, onboard navigation systems can only reduce motorist inefficiency which occurs under steady-state conditions.

A large number of self-contained vehicle navigation systems have been developed by manufacturers in the U.S., Europe, and Japan. Several of these have passed through development stages but have not yet been implemented. Others have been tested on the highways, and some are currently commercially available to motorists. The systems can be divided into three main types (*23*), described in the following sections.

1. *Directional aids.* Directional aids typically use dead reckoning (DR) to provide navigational information to the motorist. DR utilizes measurements made by distance and heading sensors to continuously compute a vehicle's progress from a known starting location. Several different technologies (*24*) can be used to monitor both distance traveled and vehicle heading. The odometer is the most common means used for distance measurement. Heading sensors for DR include the magnetic compass and the gyrocompass.

Even the most precise DR systems accumulate error with distance traveled and, therefore, require periodic reinitialization. Accuracies of around 2 percent of distance traveled are normally achieved. Reinitialization can be achieved in a number of ways, such as through a network of roadside proximity beacons or by manual adjustment.

Proximity beacons work by local transmission of a location code, which enables a vehicle to learn its true current position. In practice, it may be uneconomic to deploy large numbers of such beacons purely for compensation of DR errors, and this approach is therefore not generally favored. Manual correction of the system position is required by some systems and has the advantage of being a low-cost approach. However, it reduces the utility of the system to the driver.

In-vehicle equipment for directional aids (*9, 23*) generally consists of a microcomputer, a keypad, and a display unit. The motorist is required to enter position coordinates for his trip origin and destination. The vector connecting the two positions is then calculated and its characteristics (direct distance and heading) are displayed in the vehicle. Heading is usually displayed as an arrow symbol which identifies the direction the motorist should take in order to reach his destination.

The system continuously updates the vehicle position and recomputes the vector as the vehicle progresses on its journey, and displays new headings and remaining distances to the motorist. Therefore, as the motorist approaches each intersection on his journey, he has available both a measure of how near he is to his required destination and the direction he should take to reach it.

2. *Location displays.* Location display systems show the motorist his current position on an in-vehicle display unit, frequently in the form of a point on a map display. These systems have the distinct advantage over directional aids, in that the actual road network is indicated by the system. However, location display systems only show the driver where he is in relation to an intended destination, and do not offer advice on the best route to take.

Vehicle position in location display systems is calculated using initial coordinates updated through use of DR or trilateration techniques. Trilateration involves the detection of radio frequency (RF) transmissions from three or more fixed points. Ranges to those fixed points are then calculated, effectively fixing the position of the vehicle.

Land-based trilateration techniques include use of systems such as Loran-C (*25*) and Decca (*26*). Loran-C has shown potential for vehicle navigation systems in the U.S. However, problems with Loran-C for this application include lack of coverage of the central United States (known as the mid-continent gap), illustrated in Figure 3. Also, problems are encountered in receiving Loran-C transmissions in urban areas because of multipath reflections and obscuration of the deflection of the signals.

Satellite trilateration techniques are currently based around the U.S. Navy TRANSIT system or the Navstar Global Positioning System (GPS). The TRANSIT (or NNSS) system (*27, 28*) is a radio positioning system based on four or more satellites in approximately 600 nautical-mile polar orbits, together with four ground-based monitoring stations. Ford's prototype TRIP-MONITOR (*29*) system, fitted in the "Concept 100" car in 1983, used TRANSIT, with a receiving antenna located in the trunk of the car.

TRANSIT, however, will soon be superseded by Navstar GPS (*30*). Navstar GPS is a space-based radio positioning, navigation, and time-transfer system that will become fully operational in the early 1990s. GPS has the potential for providing highly accurate three-dimensional position and velocity information along with Universal Coordinated Time (UCT) to an unlimited number of suitably equipped users.

However, GPS is not without drawbacks (*31*). First, GPS receivers are complex and costly. Second, signal disruption, caused by tall buildings, tunnels, and bridges, leads to positioning discontinuities, particularly in built-up urban areas. Augmentation of GPS-based systems with DR capability is therefore necessary for a continuously effective onboard navigation system.

GPS has been considered as the basis of onboard location display systems by several manufacturers, including Chrysler, General Motors, and Ford. Chrysler demonstrated its CLASS prototype system, based on GPS, at the 1984 World's Fair (*32*).

At present, however, the market place for location-display onboard navigation systems is dominated by systems that are based primarily on DR. One of the earliest successful attempts at producing a DR-based location display system is the Japanese Honda ELECTRO-GYROCATOR (*33*). This device relies on a helium rate gyro to sense heading and an electronic odometer to dead reckon the position of the vehicle.

More sophisticated DR-based location display systems include the ETAK NAVIGATOR system and Philips CARIN. The ETAK system (*34, 35*) is the only onboard navigation system that has been actively marketed in the U.S. This uses DR augmented by map-matching to track vehicle location on a CRT map display. The ETAK system incorporates a flux-gate magnetic compass as well as differential odometry for DR inputs, and uses tape cassettes to store digital map data.

The map-matching augmentation of the DR system is based on the fact that vehicles are generally constrained to travel on the highway network. This makes it possible for algorithms to

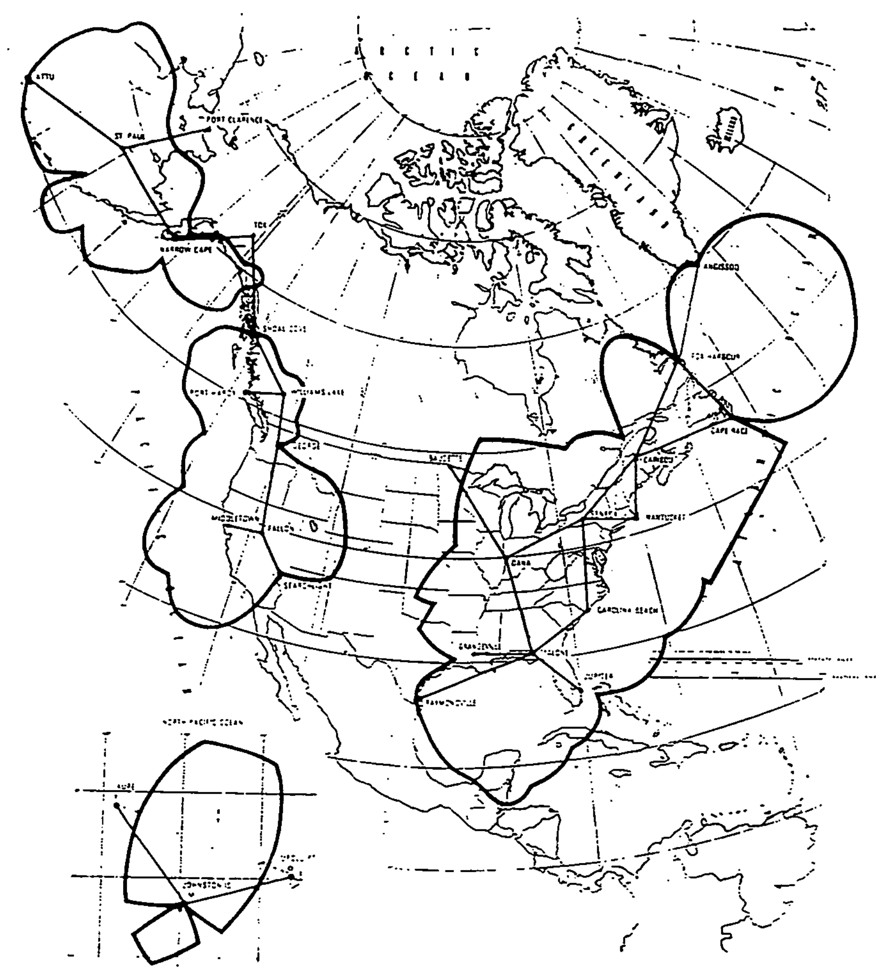

Figure 3. U.S. LORAN-C coverage. (Source: Ref. 25)

use a map as the basis for matching the pattern of the vehicle's indicated path (from DR) with that of the feasible path on the map and, thus, determine vehicle position at specific points where the pattern clearly changes, such as at a turn in the road.

The Philips CARIN system (*36, 37*) currently exists as a prototype version. This system uses a compact disc capable of storing 600 Mbytes of data, sufficient to hold a digital map of a very large area. For the future, Philips proposes that the system will provide actual routing instructions, and will be capable of using GPS for positioning as well as its current DR capability. Further development of CARIN is being undertaken as part of the European CARMINAT project within the Eureka framework, in a cooperative effort between Philips, Renault and Sagem of France.

3. *Self-contained guidance systems.* Self-contained guidance systems provide the motorist with actual routing advice, as well as vehicle location information. To provide this routing advice, a more comprehensive description of the road network must be stored in the vehicle unit, together with an algorithm which can compute an optimum path through the network.

In some systems, such as ROUTEN-RECHNER, EVA, and ROESY, a description of the highway network is stored in memory in terms of the intersections (nodes) and the impedance of the road links that connect them. A suitable algorithm can then be used to compute the minimum impedance path between any two intersections. Distance is most commonly used as a measure of impedance, because it is the easiest to establish, but time or cost can be used as criteria for route selection if sufficient data are collected.

In other systems, the network description is precompiled to provide signpost data for each intersection, with the resolution needed to give guidance to every other intersection in the network. This precompilation process can employ a distance, time, or cost criterion.

Self-contained route guidance systems can again use dead reckoning or a trilateration technique as the basis for fixing the vehicle location. In each case the motorist must initialize the system by keying in codes for his required destination using a keypad. The system then computes the best route through the network using an appropriate minimum path algorithm.

Presentation of the routing advice to the motorist may be achieved through a variety of interfaces. These include alphanumeric displays, graphic displays, speech synthesis units, or other audio signals. Visual displays may either be located at dash panel level or may take the form of head-up displays, similar to those used in aircraft.

One of the earliest successful attempts at providing routing instructions to motorists via an in-vehicle system was ARCS

(Automatic Route Control System), developed in the U.S. by French (*38*) during the early 1970s. This used DR augmented with map-matching to track the vehicle location. Routing advice was provided by preprogrammed audio instructions that were developed off-line during a pretrip route planning process.

ROESY may have been the first system to develop routing instructions in the vehicle. This prototype allowed the user to specify a network of up to 300 nodes and 450 links, and to specify both the lengths and impedances of the links. Origin and destination codes were then entered on the keyboard, and a speech synthesis unit was used to give routing instructions to the driver as he progressed on his journey. The device was not developed beyond the demonstration phase.

A similar principle was used by the German ROUTEN-RECHNER from Daimler-Benz (*39*). This was primarily aimed at providing route guidance on the German autobahn network. ROUTEN-RECHNER used minimum distance as its criterion for optimum route selection and stored details of intersections and connecting roads in memory. The routing advice was presented to the motorist via audio messages or on an alpha-numeric display. As with ROESY, it was assumed that the driver followed the instructions implicitly, as measurement of distance traveled dictates the timing for displaying instructions.

Also in Germany, the EVA (Electronic Traffic Pilot for Motorists) system developed by Bosch-Blaupunkt (*40*) was developed specifically for metropolitan areas. EVA used DR and digital map-matching techniques to determine the vehicle position, and utilized this positioning information in giving appropriate instructions. Instructions are presented aurally via a speech synthesizer unit and also visually by a liquid crystal display unit.

Finally, Plessey has developed a self-contained route guidance system known as PACE (Plessey Adaptive Compass Equipment). PACE (*41, 42, 43*) is based on DR using an electronic compass to sense vehicle heading. This is coupled to a map database and minimum path software, with routing instructions presented on a small visual display panel. Plessey claims an accuracy of 1 percent of distance traveled.

2.5 EXTERNALLY LINKED ROUTE GUIDANCE SYSTEMS

Externally linked route guidance systems comprise all electronic route planning and route following aids that have a communications link from in-vehicle guidance equipment to an external system providing network or traffic information. The advantage of these systems over self-contained onboard navigation systems is that they can potentially take account of real-time traffic conditions, providing additional benefit to the motorist in conducting his route planning and route following functions. The extent and usefulness of the real-time information provided depend on the particular system configuration under consideration.

Externally linked route guidance systems can be divided into two main categories: those linked by a long-range communications or broadcasting channel to a traffic information service; and those with a short-range communications link to a roadside infrastructure. Each of these is described in the following discussion.

Long-range communications systems are limited to receiving information about major traffic incidents or delays reported by police or highway agency personnel. They would be unlikely to take account of normal variations in traffic conditions because of the absence of an effective monitoring network in recording transient traffic conditions. Possible approaches in this first category are route guidance systems that utilize mobile cellular radio, systems that are linked with the RDS, and systems using digital broadcasting such as the Advanced Mobile Traffic Information and Communication System (AMTICS).

Cellular radio (*44*) provides a mobile radio telephone service using a modular coverage plan. A cellular radio could be used in conjunction with a modem and onboard computer unit to interrogate a traffic condition database held on a remote computer. This database could be used to update versions of the digital map information held by an onboard route guidance unit, reflecting known changes in network conditions. Alternatively, the information could simply be presented to the driver to supplement information supplied by an onboard route guidance unit.

Coded network traffic information broadcast using the RDS system could also be used to update map databases held in memory by an in-vehicle unit, or again could be presented separately to the motorist as additional information. With RDS, the driver would not need to take any specific action to interrogate an information source, but would simply have to have the RDS receiver switched on. Information received from RDS would be stored in memory, updating previous data records.

A current Japanese initiative in long range, externally linked route guidance has been set up by the Japan Traffic Management Technology Association. Proposals for AMTICS have been developed in cooperation with the Japanese Ministry of Posts and Telecommunications (MPT) and a number of private corporations.

AMTICS is an integrated traffic information and navigation system. Traffic information is collected by Traffic Control and Surveillance Centers managed by the police and located in 74 cities. The information collected is reprocessed at the AMTICS data processing center and then broadcast to vehicles. The broadcasting system is a radio data communication system called teleterminal. The equipment in vehicles will consist of a display screen, a compact disk read-only memory (CD-ROM) reader for retrieving map information, and a microcomputer to calculate the vehicle's position and to superimpose it on the display.

In 1987, a Conference on the Practicability of AMTICS was organized in which 59 private corporations participated. Twelve groups of companies have since joined together to develop elements of the system within an overall, coordinated framework. Within this framework, however, each group of companies is pursuing its own system development program. An experimental system was started in Tokyo in 1988, and the first commercial system will be available in Tokyo and Osaka in 1990.

Short-range communications systems, the second category of externally linked route guidance systems, also include several different approaches (*8*). These approaches are responsive to traffic conditions to varying degrees, and include both one-way and two-way vehicle-roadside communications. Some of these systems have been tested in the field, while others have not progressed beyond the conceptual development stage.

Data received by the in-vehicle unit from the roadside infrastructure are usually location parameters enabling the vehicle's position to be determined, and updates of road network and traffic conditions that are used for route guidance purposes. In two-way systems, data sent from the vehicle may comprise vehicle type, destination, and journey times over previous links of the network. This latter information is the essential feedback needed to realize the possibility of fully responsive, real time route guidance.

At the simplest level, a basic "beacon" system configuration with low data rate roadside-vehicle communication provides similar benefits to a self-contained onboard route guidance system. This configuration operates by equipping key points on the highway network with data transmission beacons, which continuously emit unique codes identifying particular locations. Techniques include use of inductive loop, RF, microwave or infrared transmissions.

Vehicles must be equipped to receive and decode the beacon transmissions, and also need an in-vehicle unit comprising a keypad, a microprocessor, a display unit, and a map database. If beacons are very closely spaced, no DR or other onboard subsystem is needed. Alternatively, with less frequent beacons, a self-contained onboard route guidance system is required, with beacons serving to correct accumulated positional errors.

A second level of system complexity provides a limited degree of responsiveness to traffic conditions. In this configuration, rather than simply transmitting a location identifier code, each beacon transmits part of an electronic map, at high data rates. This is used by in-vehicle equipment to calculate route guidance advice, and avoids the need for each vehicle to carry a detailed map database for the whole network.

The highest level of route guidance system complexity provides a two-way communications link between the vehicle and the roadside infrastructure. The two-way link enables each vehicle to supply the infrastructure with journey time information on the section of network it has just traveled, as well as receive information on alternative routes ahead. This floating car information is used by a central computer to update a continuously changing model of network conditions. This model is used as the basis for supplying routing advice to motorists.

Systems that utilize two-way communications links in this manner are potentially able to operate in a fully responsive mode, taking full account of changing traffic conditions. The advantage of this type of system over an onboard navigation system is shown in Figure 4. A self-contained onboard navigation system treats determination of the optimum route between two points as a two-dimensional problem, since the impedance along each link between the two points is assumed to be fixed. However, a fully responsive route guidance system treats the journey between the two points as a three-dimensional problem, whose link impedances vary with time as network conditions change. Therefore, at each decision point on the journey, optimum routing advice is provided that is up-to-date and takes account of real-time variations in traffic congestion.

Route guidance systems have been a topic of research and development in several countries for over 20 years. Some of the earliest work was carried out in the United States in the late 1960s, with the investigation and development of a prototype Electronic Route Guidance System (ERGS) (*45, 46*). The system concept was investigated by several organizations, including General Motors (*47*) and Philco-Ford (*48*), under contract to the Office of Research and Development of the Bureau of Public Roads.

The ERGS concept was based around two-way communications between vehicles and a roadside beacon network infrastructure via in-pavement inductive loops and vehicle-mounted antennas. An in-vehicle console with thumbwheel switches permitted the driver to enter a selected destination code. The code was transmitted when triggered by an antenna as the vehicle approached key intersections. The roadside unit immediately analyzed routing to the destination and transmitted instructions for display on an in-vehicle panel.

In the ultimate system concept, ERGS was envisioned with each roadside beacon connected to a central computer, monitoring feedback on traffic conditions from the loop antennas to update a network database. The ERGS project was terminated in 1970 because of the high projected costs of the roadside infrastructure.

Japanese investigations into short range, externally linked

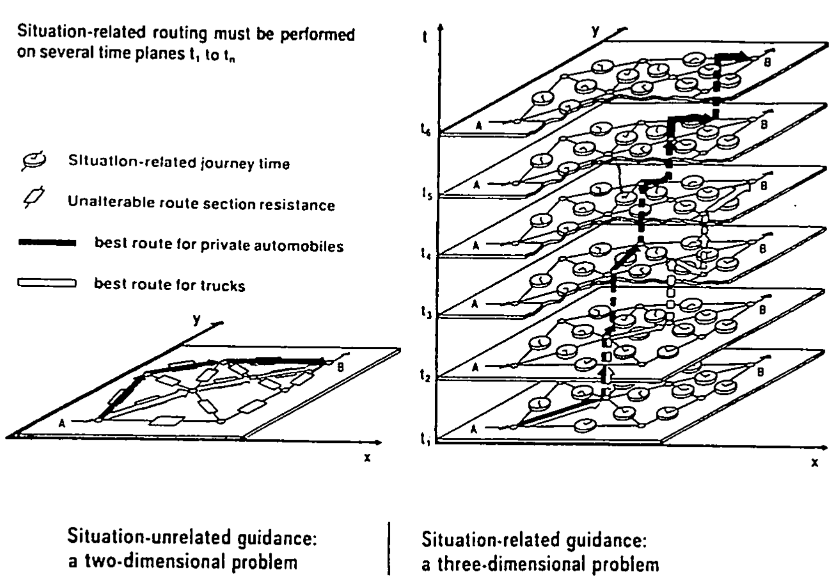

Figure 4. Situation-related guidance. (Source: Ref. 60)

route guidance with two-way communications have been in progress since the early 1970s. The Comprehensive Automobile Traffic Control System (CACS) project (*49, 50, 51*), sponsored by the Japanese Ministry of International Trade and Industry (MITI), began in 1973 and ran for a 6-year period.

The prototype CACS system demonstrated in Tokyo used inductive loop antennas for two-way communications between the vehicle and the roadside. As an equipped vehicle approached a CACS intersection, the vehicle type, an identification number, and its coded destination (entered via an in-vehicle unit) were transmitted from the vehicle to the roadside. Routing and driving information were sent from the roadside to the vehicle. The roadside equipment was connected to a communications control center which processed travel time information derived from vehicles to continuously update a network condition database. Routing information updates were sent periodically from the control center to the roadside equipment.

The CACS project was completed in 1979, at which time the results of the project were given to a number of organizations concerned with traffic management. In order to carry out further development, building on CACS, the JSK Foundation (*52*) was established under the direction of the MITI. JSK involves 27 Japanese manufacturers of electronic equipment and motor vehicles.

In 1985, JSK organized a trial of an updated route guidance system in Tsukuba (*53*) to test out the most recent technologies. The system tested used overhead antennas, and the travel time between equipped intersections was computed by the in-vehicle unit. Full results of the evaluation have not been publicly released.

Other Japanese organizations are also active in the field of externally linked route guidance. These include the Public Works Research Institute (PWRI) of the Japanese Ministry of Construction (MOC) and the Highway Industry Development Organization (HIDO) (*54*). HIDO is a consortium of vehicle and electronics manufacturers. A 3-year study of externally linked route guidance involving PWRI and HIDO members started in August 1986 (*55*), entitled RACS (Road-Automotive Communications System).

RACS involves further investigations of inductive beacon systems, together with experiments on microwave beacons. Trials conducted in 1987, utilizing inductive beacons and a prototype in-vehicle unit with DR between beacons, were of limited value in that only one-way communication was used. The advantage of the microwave approach over the earlier inductive systems lies in its high data transmission rate, which allows significant quantities of information to be passed between roadside beacons and vehicles. Further trials are planned which will incorporate two-way communications and will utilize the more recent microwave-based technology.

European investigations into short range, externally linked route guidance have been principally carried out in West Germany. A number of West German manufacturers worked on developing both onboard navigation systems and externally linked route guidance in the late 1970s and early 1980s. Route guidance systems of particular interest developed around this time were ALI (Autofahrer Leit und Informationssystem) and AUTO-SCOUT.

The ALI system (*56, 57*) was developed by Blaupunkt. Like ERGS and CACS, it used inductive loops for vehicle-roadside communication. It was designed principally for use on the German autobahn network. In the ALI system, the motorist keys in his destination as a seven-digit figure using a small keypad. As an equipped vehicle approaches a freeway intersection, the destination code is transmitted via the inductive loop antenna to a roadside unit, which returns routing advice based on current traffic conditions.

Network conditions are monitored in ALI using the inductive loops and roadside units, which act as traffic volume counters over the freeway sections. This information is transmitted every 5 min to a central control computer, which calculates the current traffic situation and forecasts future flows on the various highway sections from the incoming data. Appropriate routing advice is then sent back to the roadside units, ready for transmission to equipped vehicles.

The AUTO-SCOUT system (*58*) was developed by Siemens and used infrared technology for roadside-vehicle communications. AUTO-SCOUT was designed to include a more sparse network of beacons, with only around 20 percent of all significant intersections equipped. At each beacon, travel times on previous highway sections are transmitted from the in-vehicle unit to the roadside equipment, and then to the central computer. A description of the local road network and the recommended route to the next beacon are then transmitted back to the vehicle. Vehicle location and route following between the beacons is achieved by a navigational computer using DR.

More recently, the ALI-SCOUT system (*59*) has been developed in a cooperative effort by Bosch/Blaupunkt and Siemens, using experience gained from ALI and AUTO-SCOUT. ALI-SCOUT (Figure 5) is an infrared-based system which uses a roadside infrastructure consisting of post-mounted infrared transmitter/receivers. It has many similar features to AUTO-SCOUT, including an in-vehicle DR unit for navigation between beacons. The basis for providing guidance information is travel time data, which are received from equipped vehicles at each beacon. These data are analyzed in a central computer, which updates map information giving relative impedances of alternative routes held by the roadside equipment.

A large-scale demonstration of the ALI-SCOUT system, known as LISB (Berlin Navigation and Information System) (*60, 61*) began in 1988 and is due to continue for at least 12 months. Around 1,000 vehicles will participate in the project, which is sponsored by the West German federal government and the State of Berlin. In Berlin, 230 urban intersections and 10 freeway variable message signs will be fitted with beacons.

In Britain, the Transport and Road Research Laboratory (TRRL) has taken an active interest in externally linked route guidance systems since the early 1980s, when TRRL undertook a study (*62*) in association with Plessey Controls. Demonstration systems (*63*) using inductive loop technology were set up on the TRRL test track and were used to show the practical feasibility of externally linked route guidance.

This work formed the initial basis of proposals for a London AUTOGUIDE system (*64, 65*). AUTOGUIDE will use a network of strategically located roadside beacons, a central computer and two-way communications with in-vehicle transceiver units, to provide drivers with real-time information on the best route to take between any two points. The elements of the AUTOGUIDE proposal are shown in Figure 6.

During the initial investigation of AUTOGUIDE (*66*), a choice was made between inductive loops and infrared beacons for the roadside equipment to be used to receive and transmit

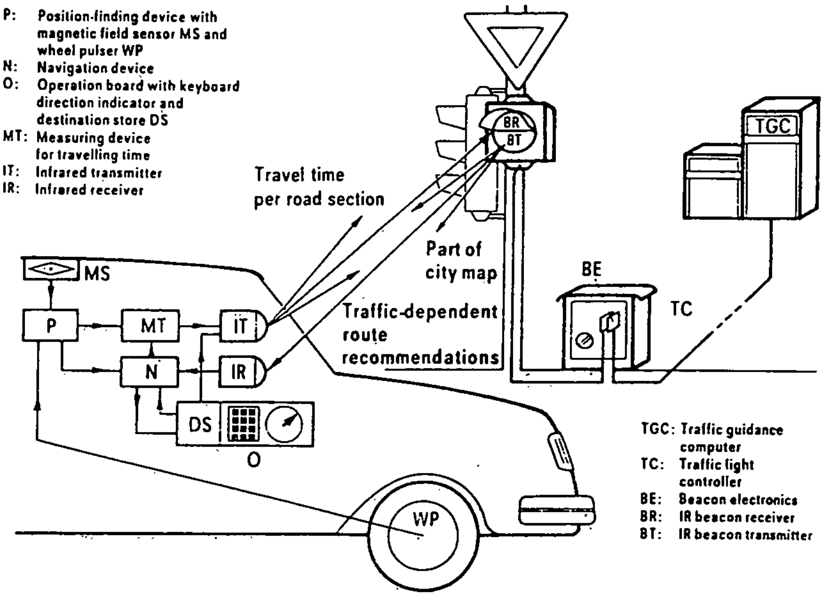

Figure 5. The ALI-SCOUT system. (Source: Ref. 59)

information. The main determining factors were data transfer rate, cost, and reliability. Post-mounted infrared beacon systems are less expensive to install than loops and allow more information to be handled, with a potential data transfer rate of 500 Kbaud. A decision was made that further development and demonstration should concentrate on the infrared approach, with a final commitment dependent on the results of field trials.

Work has also progressed on the implementation of an AUTOGUIDE demonstration scheme in London (*67*). The initial demonstration started in 1988 and utilizes five beacons, sited along a corridor between Westminster and London's Heathrow Airport. In the demonstration, however, beacons are not connected to a central computer. A large-scale pilot system is now being installed, involving the deployment of several hundred beacons linked to a central computer, with two-way communications between vehicle and roadside and a full real-time routing capability.

2.6 AUTOMATIC VEHICLE IDENTIFICATION

Automatic vehicle identification (AVI) is the term used for techniques that uniquely identify vehicles as they pass specific points on the highway, without requiring any action by the driver or an observer. AVI systems (*68*) essentially comprise three functional elements: a vehicle-mounted transponder or tag; a roadside reader unit, with its associated antennas; and a computer system for data processing and storing. At the simplest level, information which identifies the vehicle is encoded onto the transponder. This information normally consists of a unique identification number, but can also include other coded data. As the vehicle passes the reader site, the transponder is triggered to send the coded data via a receiving antenna to the roadside reader unit. Here, the data are checked for integrity before being transmitted to the computer system for processing and storage.

Two-way communication is also possible with some AVI systems. Here, data flow occurs in both directions, with coded messages being transmitted between the reader unit and vehicle-mounted transponders. More sophisticated technology is needed for this type of system, with additional capabilities required in both the roadside and vehicle-based equipment.

AVI can potentially contribute to relief of urban traffic congestion in a number of ways through its vehicle-roadside communications link. One of its potential applications lies in providing real-time travel speed information, which can then be used as an input to traffic information systems such as HAR, RDS, or AMTICS. At the simplest level, a coded vehicle identification number can be passed from the vehicle to the roadside each time a reader unit is passed. This identification data can be processed by a central computer to obtain journey times between the various distributed reader units in an AVI network, giving an indication of traffic conditions between these points.

AVI systems with full two-way vehicle-roadside communication allow messages to be passed back from the roadside reader station to the vehicle. Vehicles could potentially be warned of congested areas, accidents, or adverse weather conditions, enabling drivers to take alternative routes. The network condition information forming the basis of these messages would be derived by the central computer from journey time information computed from the AVI data passed from vehicles to the roadside.

A significant project currently underway in the field of AVI is the Heavy Vehicle Electronic License Plate (HELP) program. The \$7.5 million HELP program (*69, 70, 71*) is funded and directed by a group of 13 states, as well as the Port Authority of New York and New Jersey, the federal government, and various motor carrier organizations. The aim of the program is to develop an integrated truck traffic information and management system combining AVI, weigh-in-motion, and automatic vehicle classification technologies with a networked data communications and processing system, comprising roadside stations linked to regional and central computers.

AVI systems can be used as a tool for implementing traffic restraint policies aimed at reducing congestion levels. Road pricing is one approach to traffic restraint for which AVI is an ideal implementation tool. The theory of road pricing (*72*) is that road

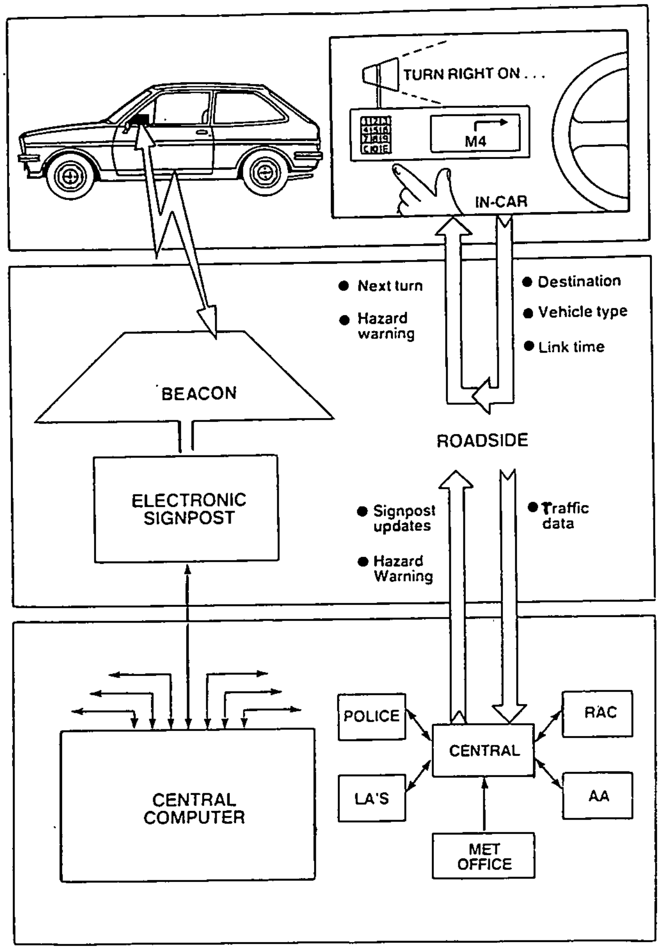

Figure 6. The AUTOGUIDE concept. (Source: Ref. 64)

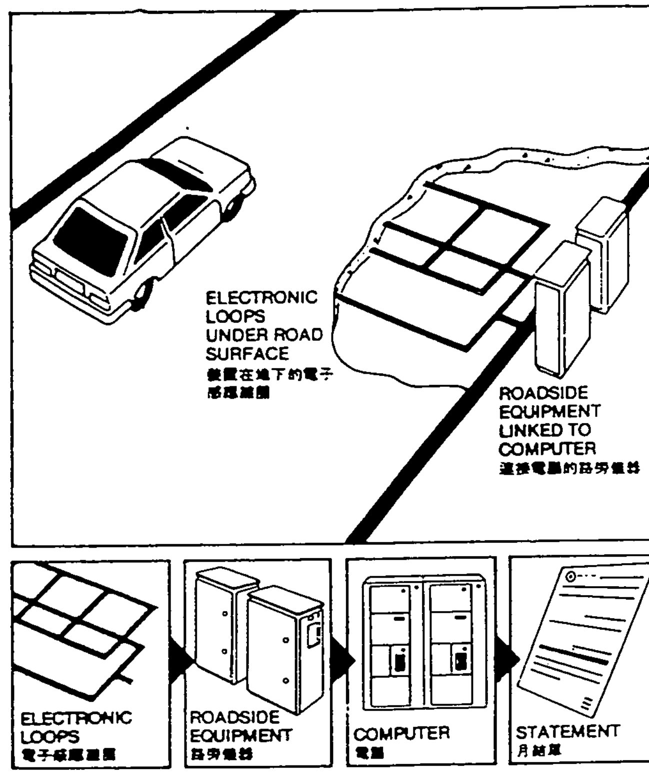

Figure 7. The Hong Kong electronic road pricing system. (Source: Ref. 74)

users should pay for their use of road space according to how much they are contributing to congestion. It therefore depends on charging vehicles for being in a particular place at a particular time. AVI systems linked to a computer network can be used to set up toll sites on the highway network using AVI readers. Road user charges can be varied by time of day and location, according to congestion levels. Vehicles equipped with AVI transponders debit an account each time they cross a toll site, and users are subsequently billed for their road use.

AVI has been demonstrated for road pricing in Hong Kong on a trial basis (*73, 74*), and has been shown to be technically feasible (Figure 7). However, there are significant issues of public acceptability concerned with using AVI for this purpose which need to be considered. First, traffic restraint policies in themselves tend to be controversial and unpopular with a significant proportion of the population. Second, use of AVI for road pricing requires that all vehicles which enter the congested area are fitted with an AVI transponder or "electronic license plate." This mandatory fitting of electronic license plates raises privacy objections that contribute to the difficulties of implementing AVI systems for this particular application.

Finally, AVI systems may alleviate congestion where they are used for automated toll collection. AVI-based automatic toll collection facilities have been under consideration for several years, with experiments carried out by the New York and New Jersey Port Authority, Caltrans (*75*), and the Golden Gate Bridge Authority. An operational system is currently being implemented on the Dulles Toll Road in Virginia (*76*). In this application, regular users of toll bridges, tunnels, or turnpikes opt to have their vehicles fitted with AVI transponders, so that they do not need to stop to hand over cash when driving through the toll plaza. AVI-fitted vehicles are automatically identified, and the appropriate charges are calculated by a computer system. These are either automatically deducted from a prepaid account, or users can be billed at regular intervals. Use of this type of system should increase the throughput of toll facilities, reducing the level of congestion at the toll plaza and on the approach roads.

A number of approaches to AVI have been developed since the first investigations of AVI were carried out in the 1960s. Recent advances in vehicle detection and data processing techniques have made the application of AVI systems both technically and economically feasible. AVI systems can be divided into four main categories, described as follows.

Optical systems formed the basis of the earliest AVI technologies developed in the 1960s in the United States and Europe. However, optical systems require clear visibility, performance being seriously degraded by snow, rain, ice, fog, or dirt. They are also sensitive to reader/tag misalignment, focusing problems, and depth of field limitations, although improvements in performance have been achieved in recent years. A recent project undertaken at the University of Arkansas carried out investigations into bar-code optical AVI systems. The results suggest that, even with modern technology, the level of reliability of optical AVI is too low for most highway transportation applications.

Infrared systems were tried during the 1970s as a substitute for the earlier optical approaches, but were found to share many of the problems of the earlier optical systems, being similarly sensitive to environmental conditions. AVI applications usually require very high read reliability levels; the fundamental nature of these problems is such that both optical and infrared approaches have been largely abandoned by AVI manufacturers.

Inductive loop AVI systems use conventional traffic detection and counting loops in the highway pavement to detect signals from transponders mounted on the underside of vehicles. These approaches can be divided into active, semi-active, and passive systems, according to the source of power used by the vehicle-mounted transponder.

RF and microwave systems generally use roadside-mounted or in-pavement antennas, transmitting or receiving on a wide range of frequencies in the kilohertz, megahertz and gigahertz ranges. These systems can also be divided into active, semi-active, and passive approaches.

One advantage of microwave systems is that they can transmit data at much higher rates than inductive loop systems because they operate at higher frequencies. However, a potentially serious problem associated with microwave passive systems concerns the power levels that must be transmitted in order to energize the vehicle-mounted tags. In many countries these may violate limitations on accepted safe operating levels for microwave systems. Semi-active systems offer a compromise, using a sealed unit transponder with an internal lithium battery. These allow radiated power levels to be greatly reduced, while providing for a transponder design life of several years.

Surface acoustic wave (SAW) technology is the basis of another AVI approach (*77, 78*). A SAW tag consists of two elements, an antenna and lithium niobate SAW chip that serves as a multitapped electronic delay line. The SAW chip receives an interrogating signal through the attached antenna, stores it long enough to allow other reflected environmental interference to die out and then returns a unique phase-encoded signal. The key operating characteristic of the SAW chip is the ability to convert the electromagnetic wave into a surface acoustic wave. SAW tags overcome concerns over high microwave power levels but are limited to purely fixed-code applications.

2.7 AUTOMATIC VEHICLE LOCATION SYSTEMS

Automatic vehicle location (AVL) systems are the final system category considered in this chapter. These systems are similar in many respects to onboard vehicle location systems described earlier. However, the emphasis in AVL systems is on providing vehicle location information to a central control rather than to the driver himself.

AVL systems allow fleet managers to use their vehicles more efficiently, thereby reducing vehicle-miles traveled. In particular, they allow the fleet manager to schedule complex trips with multiple destinations in real-time, as orders are received or circumstances change. This reduces excess mileage caused by vehicles making multiple single-destination trips.

There is a significant degree of overlap between the location technologies used in AVL systems and those that form the basis of onboard navigation systems. Indeed, some systems can be used both for vehicle monitoring and management at a central point, and for providing positional and navigational information to the vehicle driver.

The location technologies used as the basis of most AVL systems involve DR, beacon proximity, or radio-determination, as described previously. The computed location information is then displayed to personnel in the control center either on a map display or as a coordinate listing. Fleet management software can also be used to manipulate the computed location data.

Several current AVL systems use LORAN-C radio determination as their basis. Motorola Inc. currently manufactures and markets a LORAN-C system known as TRACKNET AVL-200 (*79*). II Morrow Inc. (*80, 81*) also produces a LORAN-C-based AVL system called the Vehicle Tracking System (VTS).

A third example of a U.S.-manufactured AVL system is the METS TRACKER system (*82*) produced by METS Inc.. The METS system is not reliant on one locational technology. LORAN-C is currently the preferred method for vehicle positioning, but METS will also interface to the GPS and to units with DR capability.

An example of an AVL system which combines a central vehicle monitoring function with provision of location advice to individual drivers is the GEC TRACKER system. GEC's system (*83*) uses DR augmented by updates from proximity beacons as the basis for location computation, and is linked to a control center by a mobile radio link.

Finally, there is great potential for AVL through use of the new Radio Determination Satellite Services (RDSS) recently licensed by the FCC (*84, 85*). The FCC authorized three firms (Geostar Corporation, MCCA American Radiodetermination Corporation, and McCaw Space Technologies) to construct, launch, and operate RDSS in August 1986. A fourth firm (Omninet Corporation) received authorization in early 1987.

RDSS will provide commercially operated, satellite-based location services, together with the capability to send and receive short data messages. However, RDSS is not able to support traditional voice communications.

A major difference between RDSS and other satellite systems, such as GPS, is that the location determination takes place not at the vehicle, but at a stationary central location processor. This makes RDSS also well-suited as the basis of an AVL system, because the need for communication of position data from the vehicle to a central point is eliminated. Because RDSS also allows for data communication, it can provide location coordinates to an on-vehicle unit, with greater accuracy and using a much lower cost receiver than GPS.

2.8 SUMMARY

In summary, a range of systems is being developed and demonstrated that can provide drivers with information on highway conditions and route availability. Driver information systems have potential to assist motorists in the three key activities of route planning, route following, and trip chain sequencing. In particular, electronic route planning systems offer pretrip advice, potentially reducing the proven inefficiencies in driver route selection. New traffic information broadcasting techniques offer greatly increased coverage and selectivity, to alert drivers to ever-changing traffic situations. On-board navigation systems help drivers find and follow a preferred route, while electronic route guidance seeks to combine route choice with real-time response to congestion within a truly dynamic system. Finally, two related technologies, AVI and AVL, complement the on-board information systems and offer particular benefit in specific situations such as toll roads and commercial fleet management.

The next two chapters continue this initial review of advanced technologies with potential for relieving traffic congestion by focusing on advanced traffic and vehicle control systems.

CHAPTER 3

TRAFFIC CONTROL SYSTEMS

3.1 INTRODUCTION

Control of traffic in time as well as space adds a fourth dimension to traditional highway engineering solutions to the congestion problem. The coordination of road space and road time on a particular ramp or intersection can be extended to wide-area schemes capable of securing major traffic benefits at relatively modest cost. The proven benefits of traffic control include freer traffic flows, shorter journey times, substantial fuel savings, and generally reduced congestion. Because the benefits can be great, the use of these techniques is already widespread in the United States and overseas (*86, 87, 88*).

Operational objectives of traffic control systems include making the best use of existing highway network capacity and cutting journey times, without creating adverse environmental effects (*89*). By reducing congestion and delay, some systems have been used to produce fuel savings or to reduce traffic noise and vehicle emissions. Linked with other systems, urban traffic control (UTC) can provide the basis for an expanded control philosophy incorporating features such as variable message signs, congestion monitoring, emergency vehicle priority, and other intervention strategies. In the longer term, current techniques could be extended into areas such as expert system traffic control and interaction with driver information systems, such as the route guidance techniques described in the previous chapter (*90, 91*).

Traffic control systems can also be used to influence the pattern of route choice in pursuit of policy objectives such as protection of residential environments, increasing safety, assisting pedestrians, or giving priority to public transit vehicles. As well as being reduced, congestion can be redistributed between geographic areas or between categories of the highway system to arrange for queuing to take place in areas where it can best be accommodated. Warnings can be directed from traffic control centers through variable message signs or in-vehicle information systems to help prevent secondary accidents and to direct vehicles away from congested areas.

This chapter considers recent and ongoing developments in the field of traffic control systems. It includes fixed-time and traffic-responsive UTC strategies, incident detection techniques, freeway and corridor control systems, and future possibilities for integrated traffic control—combining these techniques with those described in the previous chapter.

3.2 TRAFFIC SIGNALIZATION

Traffic signals on urban highways allow vehicle movements to be controlled through time and space segregation, speed control, and advisory messages. Signal equipment and control techniques have evolved to deal with a wide range of highway situations and traffic demands. This section considers how available techniques may be better used, and examines some new and upcoming approaches with greater potential.

Coordination between adjacent traffic signals on arterials, ramps, or grids requires some form of plan or strategy to integrate individual signal timings on a wide-area basis. Both fixed-time and traffic-responsive strategies of control have been developed and are now applied in urban areas in many parts of the world. Fixed-time coordination is commonly used in most cities, while traffic-responsive techniques are becoming more widespread in some other countries (*92, 93*).

Although advanced technologies may have much to offer in the field of traffic control, it is also worth considering what could be accomplished by better use of existing approaches. Techniques already exist for the determination of optimal signal timings at isolated intersections and in fixed-time coordinated networks. A great deal could be achieved by widespread application of techniques that are already well established.

Isolated Intersection Control. Isolated intersections may be operated fixed-time, semiactuated, or with full vehicle-actuation. Whichever strategy is used, there is often scope for improvements in signal timings to reduce delays. The very simplest methods derive green splits manually, in proportion to expected traffic demand. More complex methods calculate signal timings according to a predetermined performance measure and involve some form of computer optimization (*94, 95, 96, 97, 98*).

SOAP84 is a computer program developed for the FHWA and used for optimizing isolated intersection settings. The model calculates optimum cycle time and green splits based on a modified Webster's method (*99, 100*).

Current developments in isolated intersection control are looking toward advanced control strategies to replace current methods of vehicle actuation. MOVA (Modernized Optimized Vehicle Actuation) works on a principle of approach occupancy, and trades off stopping approaching vehicles against holding already-stopped vehicles for a few more seconds. Two sets of loops are used on each approach at distances of 130 ft and 330 ft from the stopline (*101*). The LHOVRA algorithm adopts a similar approach (*102, 103*).

Improved Fixed-Time Coordination. In coordinated signal systems, as at isolated signals, much could be achieved through the wider use of established techniques. In 1982 it was estimated that there were about 130,000 sets of traffic signals in the United States which formed some part of coordinated systems (*104*). Cimento (*105*) described progress made during the 1960s and

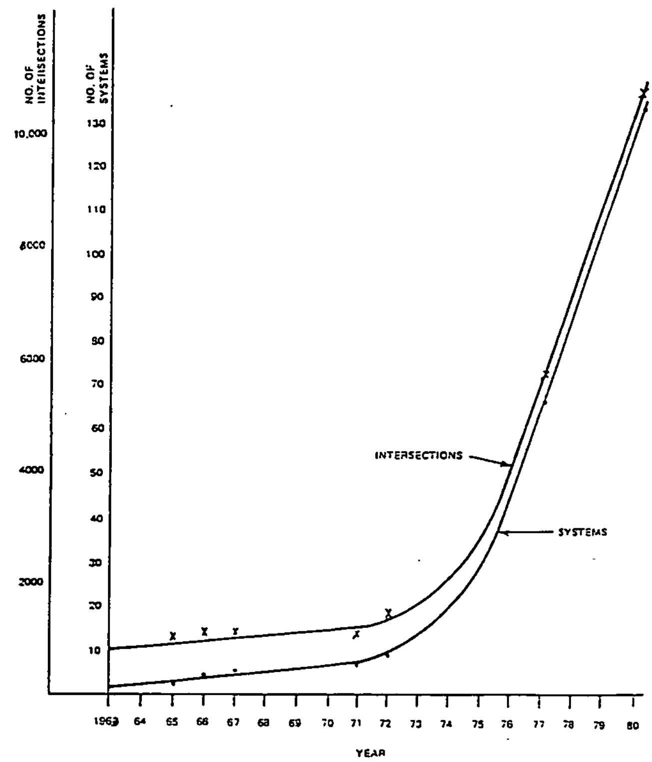

Figure 8. Number of computerized traffic control systems and controlled intersections in the United States. (Source: Ref. 105)

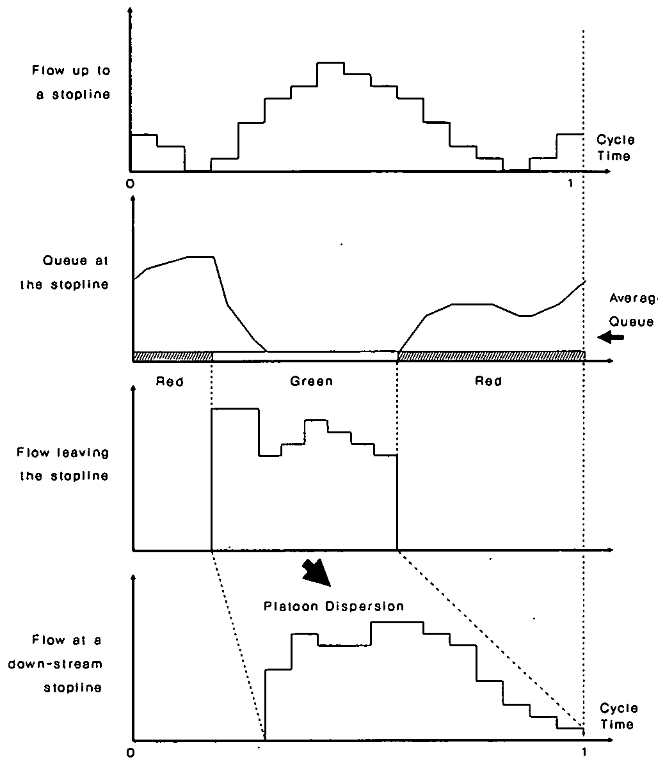

Figure 9. Cyclic flow profile in the TRANSYT model. (Source: Ref. 111)

1970s in bringing these systems under electronic computerized control (Figure 8).

The concept of coordination is to control the durations and offsets of green periods at adjacent sets of signals along an arterial or within a network. To maintain coordination from cycle to cycle, each intersection must operate with a common cycle time, or sometimes half the basic cycle. The green periods at each intersection are timed in relation to each other by specifying an offset for each set of signals, based on the average journey time along each link. The offset is the starting time of a specified phase, measured against a common time base of one-cycle duration.

Coordinated signal timings for arterials were first produced manually using time and distance diagrams. In many areas, signal plans are calculated using computerized versions of the time and distance concept, typically providing maximum bandwidth "green wave" progression on limited numbers of arterials. Examples of computer programs for maximizing bandwidth and progression along arterials include MAXBAND (*106*) and PASSERII-84 (*107*).

For grid networks, one of the first, national initiatives to develop efficient fixed-time coordinated traffic signal timings was the SIGOP program (*108*), produced in 1966 for the Bureau of Public Roads. The SIGOP optimization routine uses an algorithm that depends on two variables: ideal offset, calculated from speed, link length and queue discharge time; and link weighing, which can either be specified as input data or calculated by SIGOP in proportion to the competing approach volume demands.

More recently, a different approach has been used for coordinating fixed-time signals based on network optimization. The TRANSYT (Traffic Network Study Tool) program models traffic behavior, carries out an optimization process, and calculates the best signal settings for the network. The program also provides extensive information about the performance of the network including estimated delays, numbers of stops, journey speeds, and fuel consumption. TRANSYT has been extensively documented and only a few references are quoted here (*109, 110*).

TRANSYT models traffic behavior using histograms to represent the arrival patterns of traffic. The histograms are called cyclic flow profiles (*111*) because they represent the average rate of traffic flow during one signal cycle (Figure 9). The signal optimizer searches systematically for a good fixed-time plan by minimizing a performance index such as the weighted sum of delays and stops on all links of the network. Specific links can be further weighted to give priority to high occupancy vehicles (HOVs) or to guarantee green waves along arterials. Otherwise, TRANSYT seeks a global optimum, trading off the needs of arterials, side roads, and grid sections of the network to calculate efficient signal settings for the area as a whole.

One of the earliest evaluations of TRANSYT was performed in Glasgow, Scotland, in 1968 (*112*). TRANSYT, still in its developmental stages, was compared with existing uncoordinated vehicle actuation. The results of the Glasgow trial showed an average 16 percent reduction in vehicle delays using the TRANSYT method, compared with the existing system. The maximum benefits were observed during the morning and evening peak periods.

The current version of TRANSYT-7F was developed by the University of Florida Transportation Research Center, and evaluated in the NSTOP project (*113, 114*). Since 1981, TRANSYT-7F has gone through five releases. Initially, a fuel consumption model was added to allow for optimization of energy use. A platoon progression diagram (PPD) capability was subsequently included, showing traffic densities at all points in time along links in a time-space diagram format. Release 5 provides four new capabilities: (1) a gap acceptance model for permitted, opposed movements; (2) explicit treatment of "sneakers," who turn left at the end of a permitted phase; (3) explicit treatment of stop-sign control; and (4) modeling of shared left and through lanes. TRANSYT-7F has been widely evaluated and applied in programs such as FETSIM (*115, 116, 117, 118*), detailed in Chapter 6.

Enhancements to the TRANSYT program have also continued in Europe, with two recent versions providing increases in capability. TRANSYT-8 includes a fuel consumption model, explicit treatment of yield control, provision for modeling opposed turning movements, and inspection of a range of cycle lengths. More important, it incorporates a capacity-sensitive component in the performance index, limiting queue formation on short links by "gating" or metering traffic in the vicinity of critical intersections.

The recent TRANSYT-9 incorporates three further updates: (1) an interactive editing program for creating and modifying data input files; (2) a routine allowing users to examine the effects of different phase sequences; and (3) an interactive program for demonstrating queue and performance index graphs for individual links over one complete cycle.

The benefits offered by any new fixed-time signal plan will depreciate over time as traffic conditions change and the plan becomes less appropriate. Experience shows that signal plans degrade by about 3 percent per year, so that the initial benefit can be lost within 5 years. Actual rates of aging may vary significantly about this mean and will tend to be more acute in grids than along arterials (*119*).

The aging process arises from changes in traffic demands over the whole network, changes in traffic flows on specific links due to rerouting or demand shifts, or physical or regulatory alterations to the street network.

This aging process implies that retiming programs such as FETSIM need to be a permanent feature with all fixed-time signal coordination schemes. In practice, updates occur infrequently because of the time and costs involved, even though such actions would be highly cost effective. It is to avoid these problems that traffic-responsive coordination systems have been developed. These systems are described in subsequent sections.

Coordinated, Partially Adaptive Signals. Traffic-adaptive control systems monitor traffic conditions in a network using some form of detection, and react to the information received by implementing appropriate signal settings. In order words, systems of this kind adapt themselves to traffic patterns and respond to traffic demands as they occur.

A good fixed-time system will typically require four to eight changes of plan during a normal weekday. In some cities, controller equipment permits only a single plan to be operated all day, while other systems allow only separate plans for morning peak, inter-peak, and evening peak (*120*). In more advanced systems, libraries of eight or ten alternative plans are normally prepared and activated as required. Sometimes plan changes are carried out manually based on visual surveillance of traffic conditions using closed circuit television cameras (CCTV). The most common method is to change plans, at particular times each day, determined historically in the light of expected traffic conditions.

The simplest form of a traffic-adaptive system involves automated plan selection. In this method of control, the information received from on-street detectors at critical intersections is used to select the most appropriate signal plan from a predetermined library. Although this method provides a degree of self-adjustment to prevailing traffic conditions, it still requires the time-consuming preparation of signal plans off-line. Evaluations also suggest there is no convincing evidence that systems which select fixed-time plans on the basis of flows and congestion measurements perform any better than the simpler procedure of changing plans by time of day (*112, 121*).

The major U.S. initiative in this area was undertaken within the Urban Traffic Control System (UTCS) project initiated by the FHWA. The first-generation UTCS control system began operating in 1972 at a test facility in Washington, D.C. In this system, detector data were used automatically on-line to select appropriate cycles, splits, and offsets.

The first-generation software used prestored timing, plans developed off-line based on previously generated traffic data. Plan selection options included manual, time-of-day and automated plan selection based on recent volume and occupancy data. The results of the UTCS-1 test in Washington, D.C., showed improvements over previous control systems. Within the test, the traffic-responsive strategy of automated plan selection showed small, but generally significant, benefits over alternatives such as time-of-day selection. A further test in New Orleans showed larger benefits overall for UTCS-1 relative to previous equipment. However, in this case time-of-day was marginally ahead of automated plan selection.

At the present time, generation 1.5 UTCS's represent a step toward traffic-responsive approaches, potentially replacing wholly fixed-time operation. Work on the development and implementation of generation 1.5 concepts can be seen in the ATSAC (Automatic Traffic Signal and Control) system implemented in Los Angeles (*122*). In the ATSAC system, enhanced UTC equipment uses loop detectors for flow monitoring to identify when signal plan changes are required. Off-line plan development is also partially automated, based on data from the on-street detectors.

Development of a second-generation UTCS strategy was also undertaken. This approach represented a real-time, on-line system that computes and implements signal timing plans based on surveillance data and predicted changes. UTCS-2 retained many features of the first generation system. However, UTCS-2 results showed network-wide degradation in performance in every instance relative to the base case three-dial system. Increases in delay ranged from 1.1 percent to 9.3 percent, with the worst results occurring during the evening peak period. Slight improvements (2 percent) were measured on the arterial portion of the network, but it is not clear whether these gains were statistically significant.

The lack of success of the earlier second-generation vehicle-responsive systems led to investigation of the reasons for failure. Some of the problems of this adaptive systems approach are believed to be as follows (*123*):

1. *Frequent plan changing.* Most of the second-generation methods of control required that new plans be calculated on-line and implemented as soon as possible. Even the best methods of

plan changing cause significant transition delay; a new plan must operate for more than 10 min to achieve an overall benefit.

2. *Inadequate prediction.* From the above it is seen that a prediction for several minutes into the future is necessary. Random variations in traffic make this prediction very difficult. Historical data may be needed to help identify trends.

3. *Slow response.* When unexpected events occur, the response is delayed by the historical element of prediction and the need for a new plan.

4. *Effects of poor decisions.* Unexpected events or faulty detector data may cause poor plans to be implemented which cannot be corrected until the next plan update.

The SCATS system, developed and initially implemented in Sydney, Australia, is said to overcome the problems identified with early second-generation systems (*124*). SCATS combines several features of UTCS-1 and UTCS-2, using background traffic control plans selected in response to traffic demand. Signal timings within these plans are determined according to traffic conditions at critical intersections which control coordination within small subsystems.

The subsystems vary in size from one to ten intersections and, as far as possible, are chosen to be traffic entities which can run without relation to each other. As traffic demands increase, the subsystems coordinate with adjacent subsystems to form larger groupings. This "marriage" and "divorce" of subsystems is calculated using simple empirical rules based on traffic flows and intersection spacings.

Each subsystem requires a substantial database, including minimum, maximum, and geometrically optimum cycle lengths, phase split maxima, and offset times. Background plans are stored in the database for each subsystem. Cycle length and the appropriate background plan are selected independently to meet the traffic demand, using data from stopline detectors at critical intersections. Empirical relationships are used to decide whether the current cycle and plan should remain or be changed.

At peak periods, SCATS determines subsystem cycle lengths according to traffic demands at critical intersections, using Webster's method. Offsets are precalculated to suit the busier direction of travel. Progression is not guaranteed in the less busy direction at peak times (*125*). During off-peak periods, SCATS selects the minimum of two or three precalculated cycle times giving good two-way time-distance progression (*126*).

Coordinated, Fully Adaptive Signal Systems. Coordinated, fully adaptive signal systems represent a goal sought by researchers in several countries throughout the 1970s. In the United States, work on UTCS-3 was designed to create a fully responsive, on-line traffic control system.

UTCS-3 (*108*) uses two optimization algorithms: an approach with no fixed cycle times for undersaturated conditions, and congested intersection control/queue management control for use along congestion paths. In the former approach, signal coordination is accomplished by implementing a coarse simulation of traffic flow, and then systematically adjusting signal settings to minimize a weighted sum of delays and stops. The congestion algorithm aims to maximize throughput and manage queue lengths to avoid blocking adjacent intersections. Results of a UTCS-3 evaluation in Washington, D.C., showed increases in delay ranging from 3.4 percent to 15.2 percent over the base case three-dial system. Overall, the third-generation system produced about 10 percent more delay than the previous system used in Washington, D.C.

In Europe, a coordinated, fully responsive traffic control strategy was developed by TRRL. The system is called SCOOT (Split, Cycle and Offset Optimization Technique). SCOOT was developed in association with three electronics companies—GEC, Plessey, and Ferranti—who now market the software. SCOOT reacts automatically to changes in traffic flow, adjusting the cycle time, the splits, and the offsets in accordance with an on-line optimization process.

SCOOT monitors cyclic flow profiles in real-time for input to a TRANSYT-type optimization. The vehicle detectors are inductive loops, located well upstream of each intersection, usually close to the preceding signal (Figure 10). SCOOT uses this information to recalculate its traffic model predictions every few seconds, and makes systematic trial alterations to current signal settings, gradually implementing those alterations which the traffic model predicts will be beneficial. The principles of the SCOOT traffic model are illustrated in Figure 11.

The first trials of fully adaptive control were carried out in 1975 (*127*), at the end of an initial research and development phase. These encouraged the U.K. Department of Transport to develop the system for general use. Further research by TRRL led to an improved system which, evaluated in Glasgow during the spring of 1979, was compared with up-to-date, carefully optimized fixed-time TRANSYT plans. In this evaluation, and in subsequent trials in other cities (reported in Chapter 6), SCOOT has consistently improved upon fixed-time TRANSYT control by significant margins.

Research suggests that adaptive control is also likely to achieve an extra 3 percent reduction in delay each year, relative to fixed-

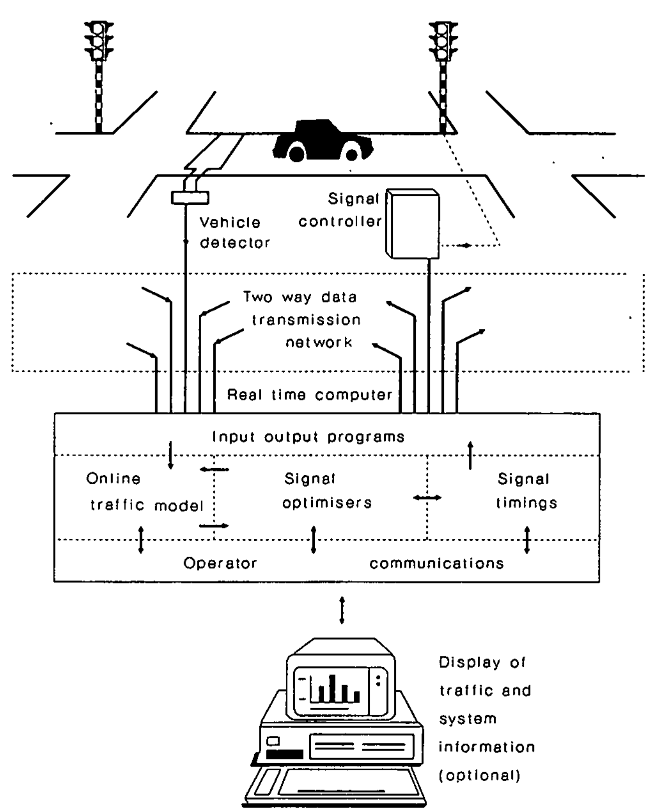

Figure 10. Flow of information in the SCOOT system. (Source: Ref. 127)

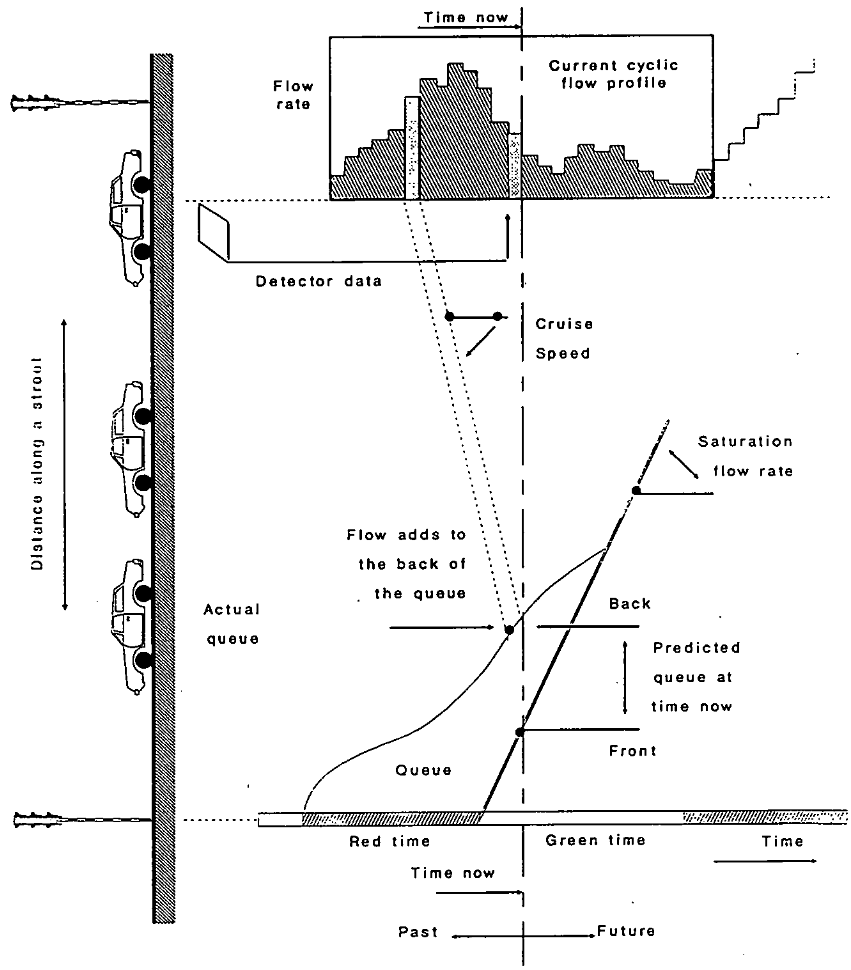

Figure 11. Principles of the SCOOT traffic model. (Source: Ref. 127)

time control, as fixed-time plans age and become less appropriate for current traffic flows (*119*). Over the 4 to 5 years between TRANSYT updates typically occurring in well-maintained systems, this would accumulate to an extra 12 to 15 percent. In many instances, where fixed-time plan updates are less frequent, the benefits of a traffic-responsive system could be larger.

Fourth Generation Signal Systems. SCOOT does not represent the end of the line in traffic control strategies, and is in a very real sense already a 15-year old technology. Some of the limitations of SCOOT that need to be addressed by future fourth-generation systems include the following:

1. The current policy of minimizing transients and allowing only "creeping" plan changes is beneficial in maintaining coordination but works against the objective of fast response when conditions change rapidly, for example because of an incident. A fourth-generation system would decide when to institute a remedial plan, which the system would then fine-tune, using an incremental optimization.

2. While TRANSYT's heuristic optimization technique is normally specified to try both large and small step sizes within the process of seeking a global optimum, incremental changes as well as limitations on processing power inherently restrict the scope of SCOOT to an essentially local optimization. Field evaluation shows that this is not a major problem. However, a fourth-generation system should be able to take occasional large steps to radically new plans, subject always to an evaluation of the resulting disruption against the eventual benefit.

3. By monitoring cyclic flow profiles at the beginning of each link, and necessarily smoothing out random fluctuations in traffic flow, SCOOT effectively optimizes for recently past traffic conditions, rather than the upcoming situation. The amount of lag differs in respect to split, offset, and cycle. A fourth-generation system would contain subsystems for short-term forecasting, based initially on historical data and real-time origin-destination (O-D) estimation, and perhaps later on feedback from externally linked route guidance systems.

4. The loop detectors used by third-generation technology give only limited information on network traffic conditions. Externally linked route guidance systems offer much greater feedback on signal plan performance, in the form of actual journey times and delays as they occur.

5. While in many ways the second generation SCATS system is a tool no better than the judgment of the engineers who set it up, SCOOT's use of an on-line traffic model makes it into a black box one either loves or hates. Recent development of SCOOT

Table 1. Summary of the advantages and disadvantages of different types of UTC systems.

Type of UTC system	Advantages	Disadvantages
Fixed time	* Cheaper to install and maintain. * Can be implemented using non-centrally controlled equipment. * Familiarity with settings for regular users. * 'Green waves' easily implemented.	* Needs large amounts of data to be collected and updated. * Signal plans will require updating. * Disruption of plan changing. * Requires operator reaction to incidents. * Cannot deal with short-term fluctuations in flow levels.
Partially adaptive	* Can deal with some day-to-day fluctuations. * Plan change time may be more appropriate. * Might be valuable on arterial routes. * May be cheaper than fully responsive control as fewer detectors required.	* Requires as much or more data to be collected as for fixed time sytems. * Detector failure possible. * Needs decisions on thresholds for plan change. * May plan change for wrong reason. * Difficult to foresee all plan needs.
Fully adaptive	* Less data need to be collected in advance. * Plan evolves so avoids problems with plan changing and updating. * Can deal with short and long-term fluctuations in flow levels. * Automatic reaction to incidents. * Monitors traffic situation throughout the area.	* Detector failure possible. * More expensive to install. * Requires central control. * Maintenance critical.

"procedures" has led to traffic management techniques which work essentially by fooling the model. A fourth-generation system would contain explicit, policy-related intervention strategies for use by highway agencies, or by a higher level expert system.

Table 1 summarizes the advantages and disadvantages of current approaches to UTC. Traffic adaptive systems are more costly to install than purely fixed-time systems. However, the additional benefits demonstrated by advanced systems can justify the cost within a short period. In the short-term, fixed-time and responsive systems can operate signals in adjacent parts of urban areas. Adaptive systems may give greatest returns in central business districts (CBDs) where congestion is high and flow patterns are complex and vary from day-to-day. Fixed-time control will work well where congestion is lower and flow patterns more consistent.

3.3 INCIDENT DETECTION SYSTEMS

Another category of advanced technology systems is automatic incident detection systems. Incidents such as accidents or queue formation behind slow-moving vehicles can rapidly cause significant congestion problems, particularly on freeways. Techniques are now becoming available that will automatically detect incidents, allowing adjustments to be made to traffic control strategies and enabling information to be passed to drivers through many other technologies.

Traffic delays can generally be attributed to recurrent and nonrecurrent problems. Recurrent problems occur routinely, particularly during peak periods, when traffic demand exceeds capacity, even for relatively short time periods. Recurrent congestion occurs daily and is reasonably predictable in both effect and duration. Nonrecurrent problems are caused by random, unpredictable incidents, such as traffic accidents, temporary freeway blockages, maintenance operations, oversized loads, and so on. Environmental problems, such as rain, ice, snow, and fog, also fall into this category (*128, 129*).

Automatic incident detection systems typically consist of a small computer or distributed microprocessor system that monitors signals from vehicle detectors spaced along the highway. Special algorithms are used to detect incidents by looking for particular disturbances in traffic flow patterns.

A number of operational automatic incident detection systems have been implemented in the United States. The most important of these is in use on the Chicago freeway system. In the Chicago area, loop detectors are provided in each lane every 3 miles along the freeway. Flow is also sampled in one of the center lanes at half-mile intermediate points. All ramps are monitored to produce a closed subsystem every 3 miles. The actual field location of detectors usually depends on the availability of utility service, often most readily available around urban interchange areas. All surveillance and control points in a particular service area are brought to a roadside cabinet, through aerial or underground interconnect systems (*130*). These, in turn, are connected to a surveillance center.

In Europe, different algorithms have been developed for incident detection. For example, HIOCC operates by identifying the presence of stationary or slow-moving vehicles over individual induction loop sensors. This is achieved by looking for several consecutive seconds of high loop occupancy. An alarm is activated when this is detected.

In the U.K., an experimental incident detection system was initially installed on the M1 and M4 motorways. Seven monitoring loops were cut into the pavement surface at intervals of 1,600 ft. Preliminary investigations enabled improvements to be made in the system (*131*). Based on these trials, a commercial system based on HIOCC is now available from the Golden River Corporation known as GRID (Golden River Incident Detection) (*132*) (Figure 12). Since these initial developments, the scheme has been extended to cover 50 miles of the congested M1 motorway (*133*) (Figure 13).

Systems for detecting adverse environmental conditions are a second type of automatic incident detection system, which could also potentially be linked into a computerized monitoring network. There are a number of commercial sensor systems available, such as those manufactured by SCAN in the United States, SFG in West Germany, and ELIN Electronics in Austria (*134, 135, 136*).

The most significant implementation of an integrated system to date has taken place on the Dutch freeway system. Here, electronic roadside sensors that automatically detect dangerous road conditions likely to cause accidents and congestion were installed in 1985 (Figure 14). These are capable of remotely detecting pavement slickness due to rain, snow, ice, sleet or commodity spillages. Variable message signing is linked to the sensors to direct drivers to slow down as necessary (*138, 139, 140*).

3.4 FREEWAY AND CORRIDOR CONTROL

Freeway management techniques fall into two main catego-

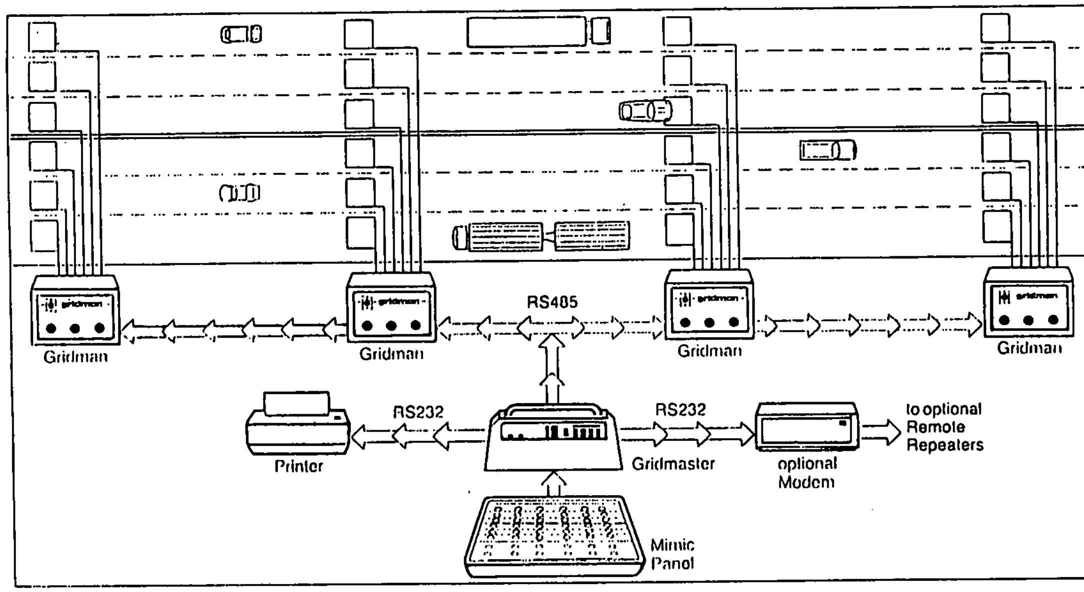

Figure 12. The Grid incident detection system. (Source: Ref. 132)

ries: capacity management and demand management (*141*). Capacity management seeks to maximize throughput and improve the level of service, while demand management attempts to reduce the vehicle-miles traveled. Examples of capacity management are ramp closures, ramp metering, variable speed control, lane control, express or reversible lanes. Demand management techniques include staggered or flexible working hours, ridesharing, and improved public transit.

Ramp control aims to limit the rate at which vehicles enter the freeway in order to avoid overloading the facility. Ramp closures are the simplest and most drastic form of ramp control. However, because of public opposition, ramp closures are not widely used in the United States (*142, 143*), although they are in routine use in Japan (*144, 145*).

Ramp metering (*146*) is more widely used, and may have greater potential for interfacing with advanced traffic control technologies. A standard traffic signal is used to control entry to the mainline. In the United States, a single vehicle is commonly released per green period, while in Europe, the operation resembles conventional signals with longer green and red periods. Chicago was the first metropolitan area to practice ramp control, in 1963 (*147*). Ramp metering signals now control traffic at 91 locations along various Chicago-area expressways. Centrally timed by the traffic systems center computer at Oak Park, the ramp signals are varied continuously as measured ramp and mainline flows are monitored in real-time. The total instrumented network covers 110 highway miles, with 1,650 loop detectors.

An earlier report describes the Chicago system's implementation and its operational evaluation (*148*). Ramp metering was found to reduce peak period congestion by up to 60 percent and accidents by up to 18 percent (*149*). Benefits will vary according to the level of congestion prevailing before the implementation of controls (*150*). On Houston's Gulf Freeway, for example, ramp metering reduced travel times by 25 percent and accidents by 50 percent, with little adverse effect on adjacent arterials. Many other North American cities report favorable experiences from implementing ramp control (*151, 152, 153, 154*).

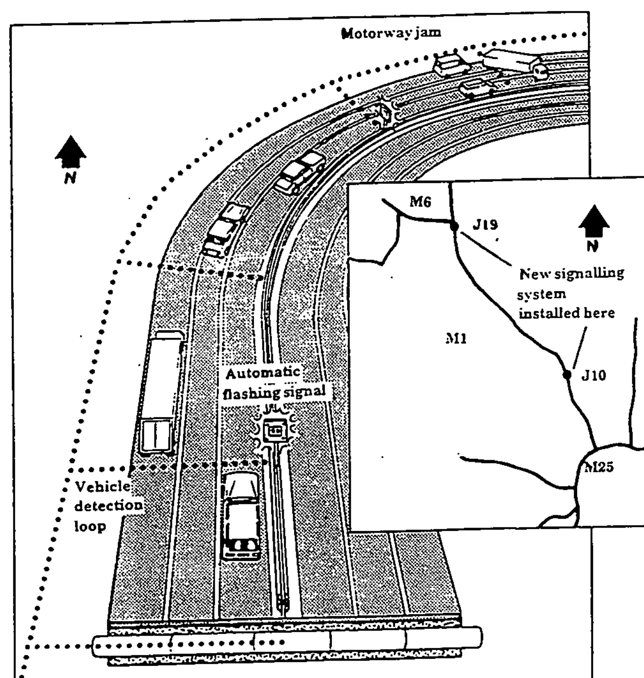

Figure 13. Incident detection system on the M1 motorway. (Source: Ref. 133)

Mainline control of speeds using variable message signs has been implemented in Britain, the Netherlands, Germany, Italy, Japan, and the United States. Speed advisories can be used to give advance warnings of traffic incidents or fog ahead. In Holland, they are also used to help smooth peak traffic flows. Elsewhere, they have been less successful as a capacity-enhancement measure; drivers in both Britain and the United States commonly ignore advisory speed limits (*155, 156, 157*).

Lane reversal for tidal flow operation is implemented on freeways and arterials in many countries. In the United States, re-

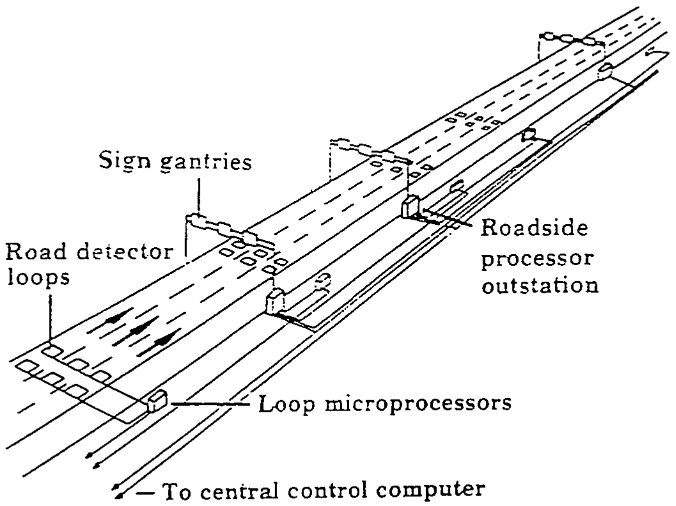

Figure 14. Rotterdam's motorway control and signalling system. (Source: Ref. 140)

versible lanes are often indicated by permanent signs and lane markings alone, relying on drivers to observe time-of-day limitations. In Europe, variable message signs are almost always used for permanent tidal flow control, with overhead gantries and advanced warning signs that are electronically switched at the appropriate times.

Traffic control centers are a vital requirement for integrating advanced technologies to improve conditions on urban freeways. The Washington State Department of Transportation, for example, has had a freeway control center in operation for more than 10 years. This is capable of monitoring flows, through a system of traffic detectors and data links. The Virginia Department of Transportation (VDOT) also has a freeway control and monitoring system in operation. The Traffic Management System (TMS) is a computerized freeway surveillance and control system that monitors and regulates traffic flow along Interstate 395 and Interstate 66. Traffic flow data are gathered by 550 traffic counters imbedded in the pavement of interstate lanes and entrance ramps. Using ramp metering, current mainline traffic and incoming demand are balanced with the known capacity of the freeway. The VDOT system also includes variable message signing for communicating with drivers.

Typical European practices in control center and communications design, including closed-circuit television, emergency telephone and radio systems, signaling, and maps, have been set out in a U.K. Home Office publication (*158*). British freeways are controlled from five regional computer centers over the National Motorway Communications System (NMCS-2), which links emergency telephones every mile and variable message signs at least every 2 miles. Traffic speeds and flows are continuously recorded and meteorological conditions monitored from roadside outstations (*159*).

Corridor control is a concept that seeks to treat urban freeways and adjacent arterials as a single system. The purpose of corridor control is to optimize the use of corridor capacity by diverting traffic from overloaded links to those with excess capacity. Currently, several corridor control projects are being developed, tested, and evaluated (*152, 160, 161, 162*).

3.5 INTEGRATED TRAFFIC CONTROL SYSTEMS

Interactive signal coordination is a new concept that may constitute the next generation of traffic control systems. It would go further than adaptive traffic control, in that it would be fully responsive to the actual pattern of short-term future travel demand, and would integrate traffic control systems with other advanced technologies. For example, an integrated system could be linked with real-time traffic monitoring, short-term forecasting and electronic route guidance. Using data on actual vehicle destinations, it would then simultaneously optimize signal coordination and vehicle route choice within the urban highway network.

Interactive signal coordination is still at the stage where ideas and concepts are being synthesized. Therefore, a definitive concept for an integrated traffic control system has not yet been developed. However, a series of objectives have been identified, including: minimize vehicle delays, minimize passenger delays, minimize variability in transit times, minimize user costs, minimize negative environmental impacts, minimize unnecessary travel, maximize safety of the system.

In order to accomplish these objectives and address the shortcomings of existing control systems, a series of features that could be included in the fourth-generation traffic control systems have been proposed. These include integration of traffic signal control systems with other advanced systems, leading to coordinated control of a number of different systems; prompt detection of and response to events; ability to predict and respond to origin-destination information; integration with vehicle location/identification/classification systems; inclusion of artificial intelligence/expert system features; accommodation of demand control and congestion pricing options; flexibility to accommodate different control objectives in different parts of an urban area or during different time periods; real-time communications with motorists; inclusion of visual surveillance; variable speed control to determine appropriate speeds during periods of congestion and inclement weather; and provisions for integration with automatic vehicle control.

3.6 SUMMARY

Advanced traffic control systems are more developed than the information technologies reviewed in Chapter 2. Control of traffic in time as well as space adds a fourth dimension to conventional highway engineering solutions to the congestion problem. The proven benefits of these systems include freer traffic flows, shorter journey times, substantial fuel savings, and generally reduced congestion.

Signalization strategies include improved methods of isolated intersection controls and fixed-time coordination; partially and fully adaptive coordination; and new concepts for fourth-generation, expert systems control. In the future, incident detection systems may be integrated with other advanced traffic control techniques, within freeway corridors and, in due course, throughout entire metropolitan areas. Finally, interactive traffic control concepts seek to integrate the driver information systems discussed in Chapter 2 with the traffic control systems of this chapter.

The next chapter concludes this review of IVHS technologies by describing system developments which aim to support the driving tasks directly. These systems are less developed than those of Chapters 2 and 3, and would have to overcome greater barriers before implementation. Their potential for relieving urban traffic congestion, however, may be substantially more than that of any other approach.

CHAPTER 4

AUTOMATIC VEHICLE CONTROL

4.1 INTRODUCTION

Automatic vehicle control (AVC) systems can help drivers perform certain vehicle control functions, and may eventually relieve the driver of some or all of the control tasks. The use of AVC technologies is likely to result in greater safety, more consistent driver behavior, and improved traffic flow characteristics.

Vehicle control is complex because of the large number of interactions that exist between the driver and the vehicle. The driver's key roles can be defined as: (1) to observe the outside environment, including highway geometry, vehicles and obstructions; (2) to operate the vehicle's control system; (3) to feedback observations and compensate for changing situations; and (4) to make decisions and select an appropriate trajectory ahead.

On a journey, a driver is constantly required to assess vehicular lateral position, speed, and distance to vehicles ahead, and judge gaps for merging and passing. Additionally, the driver must anticipate the actions of other road users and make decisions on opportunities for getting through lane changes, merges, and intersections by achieving smooth braking and acceleration.

At the most basic level, AVC systems can provide the driver with useful information and warnings, based on data collected by onboard sensors. The next level is to assist the driver with the control process, by automatically adjusting the control system characteristics to the operating conditions and helping to avoid situations that give rise to loss of control. The third level is to allow the control system to intervene and manage critical situations. The highest level is for the system to completely take over the driving tasks.

This chapter provides an overview of AVC concepts. It examines the AVC technologies currently available, and considers the more widespread uses of these systems in the future. It outlines the systems that are currently under development and considers the feasibility of implementation of these technologies.

4.2 ANTILOCK BRAKING SYSTEMS

The antilock braking system (ABS) assumes control of the braking function during periods of excessive braking or cornering. ABS differentially pumps the brakes to ensure rapid, nonskid braking. This is performed by a solenoid valve unit which connects the master cylinder and the wheel cylinder, and is controlled by an electronic control unit (ECU).

To the driver, the benefit of ABS is the ability to remain in full control of the vehicle under every type of road condition and during emergency stops. Without ABS, once the front wheels lock in an emergency stop it becomes impossible to steer the car. Similarly, if the rear wheels lock, the car becomes unstable and is prone to skidding. Wheel lock also reduces the effect of the braking action. There are several proprietary antilock braking systems now available, such as those marketed by Scania (*163*) and Alfred Teves (*164*).

The widespread implementation of ABS could reduce the number of accidents involving skidding. In one survey, 13.5 percent of all injury accidents involved some form of skidding (*165*). Investigations suggest that over 7 percent of all road accidents might have been prevented if ABS had been fitted to the vehicles involved (*164*).

Another technology that can be incorporated with ABS is electronic traction control (ETC), also known as slip-spin control. This uses the same sensors and computer that prevent the wheels from skidding during braking to prevent the wheels from slipping during acceleration.

When a vehicle is accelerating on a surface with a low coefficient of friction, opening the throttle too wide will cause the wheels to spin. The wheels are then no longer able to transmit lateral force, causing the vehicle to become unstable. Using ETC, sensors detect when the wheels are about to start spinning, and prevent this from happening by reducing engine torque or partially applying the brakes.

4.3 SPEED CONTROL SYSTEMS

Speed control systems are an essential component of AVC technology. Two types of speed control systems are available on present generations of vehicles—cruise control and governors.

Cruise control (*166*) is one form of speed control technology that is already in widespread use in the United States. In normal operation, cruise control maintains the speed of the car, set by the driver, until a new speed is selected or the brake pedal depressed. Cruise control can also permit controlled acceleration/deceleration, and can resume a speed stored in the memory following a braking incident.

PROMETHEUS (Program for European Traffic with Highest Efficiency and Unprecedented Safety) is currently examining the feasibility of developing cruise control systems capable of responding to external vehicle sensing devices. This concept, called "Intelligent Cruise Control," aims to develop techniques to process sensory information for the control of vehicle speed (*167*). In the most sophisticated form, it may be feasible to interpret sensor information on road and traffic conditions, speed of other vehicles, obstacle detection and forward visibility, and to adjust the speed accordingly. Preliminary research indicates that a prototype system capable of operating in a well-structured environment could be demonstrated presently, given required progress with sensor technology research.

A second speed control technology already available, though not widely used, is the speed governor. Governors are limiting devices that prevent a vehicle from exceeding a preset speed limit. They have been used mainly on heavier vehicles, such as trucks and buses, powered by diesel engines. When the vehicle exceeds the preprogrammed speed, a signal is triggered which acts on the fuel injection pump to prevent further acceleration.

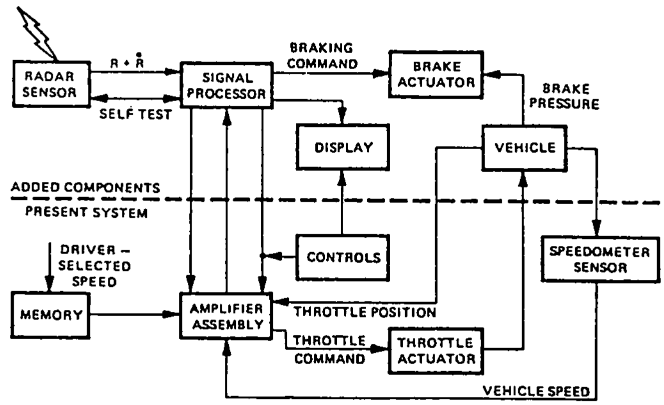

Figure 15. Block diagram of an AHC system (Source: Ref. 168)

4.4 VARIABLE SPEED CONTROL

A natural extension of current speed control technologies would be variable speed control (VSC), for which the technologies largely exist. Systems that vary vehicular speed automatically or provide the driver with information for optimal speed adjustment have the potential to reduce speed differentials and minimize the frequency of vehicle stops.

The simplest form of VSC would program conventional cruise controls or governors with mandatory fixed speed limit information appropriate to each section of highway. This could be readily accomplished using existing AVI technology (described in Chapter 2). Another option is to locate reference markers, such as small permanent magnets, at variable spacings in the traffic lane so as to indicate safe speed by marker spacing.

In a second stage of application, variable-message speed control signs similar to those widely used on European freeways could be linked by AVI to an onboard VSC. Equipped vehicles would automatically select the safe operating speed for each section of highway, which could be optimized to suit capacity considerations or lowered under adverse weather conditions.

The aim of VSC at traffic signals would be to assist the driver in selecting a suitable approach speed to the intersection so that the vehicle would not need to stop. Advisory roadside speed control signs have been used for many years in West German traffic control systems, informing drivers of the optimal cruise speed to reach the next signal at green. These controls could be automated by AVI links to onboard cruise controls.

Each of the three applications of VSC outlined in this section could be operated in an advisory mode or an automatic mode linked to cruise or governor systems controlling the vehicle's throttle setting. The automatic mode could be user-selectable, allowing drivers to override the system, or could be mandatory, requiring vehicles to comply at all times. The mode of operation could also be varied on different types of highway, so that mandatory speed control might be required for drivers to be allowed to use certain high-capacity, limited-access facilities comparable to current HOV lanes.

4.5 AUTOMATIC HEADWAY CONTROL

A natural extension to intelligent cruise and VSC is the addition of sensors to automatically maintain a constant headway or gap between vehicles. The essential elements of an automatic headway control (AHC) system are a distance monitoring system, signal processing, control logic, and speed regulation through throttle and brake control. The block diagram in Figure 15, from a paper by Grimes and Jones (*168*), shows a radar headway control system based on cruise control technology. When fitted with an AHC device, a vehicle would automatically slow when approaching a vehicle, and remain at a safe distance until such time as it was appropriate to resume the original cruise speed. This feature would be particularly useful for urban freeway driving.

Papers by Hahn (*169*) and Belohoubek (*170*) concentrated on AHC systems with automatic throttle control only. Belohoubek describes a system that utilizes a microprocessor to monitor ground speed and radar signals reflected from the vehicle in front. Throttle control is achieved by means of a linear direct current (DC) motor connected by a chain, which receives instructions from the microprocessor in the form of variable-width pulses. The system does not incorporate automatic brake control, deceleration being achieved by air friction and engine drag when the throttle is released. If more rapid deceleration is required, an audible warning advises the driver to brake manually.

The European PROMETHEUS program has defined several relevant research topics within the AHC area. Lissel (*171*) outlines the development of a headway control distance sensor to enable drivers to maintain a safe driving distance in front of the vehicle. Cloup (*172*) describes another research topic within PROMETHEUS to analyze and interpret sensor outputs for an anticollision radar. The objective is to calculate the relative speed and distance of the object and, using the vehicle's speed, to determine the likelihood of a collision. The output can then be fed to a decision system for appropriate action to be taken.

PROMETHEUS has also defined a research project aimed at improving the reliability of radar sensors (*173*). The project will involve the use of a video camera as well as a radar system to enable headways to be deduced. Another project within PROMETHEUS is outlined by Bray (*174*). The objective is to determine and track the presence of a leading vehicle, using a pair of stereo cameras.

4.6 RADAR BRAKING

The major cause of collisions, on all types of highway, is the inability of some drivers to correctly judge speeds and distances. This is especially true in bad weather conditions and at night. A system which warns drivers that they are driving too fast or too close, or, in the event of an impending collision, automatically applies the brakes, could significantly reduce this type of accident, and provide an associated reduction in congestion.

One such collision avoidance system that has been extensively investigated is automatic braking using radar detection. Brinton (*175*) describes an early system which used Doppler radar. Further work has been carried out in this area by researchers such as Flannery (*176*), Troll (*177*), and Grimes and Jones (*168*).

Radar braking operates by detecting the presence of an obstacle in front of the vehicle, such as another vehicle or a pedestrian, using a radar head fitted to the front of the vehicle. From these raw data, a signal processor calculates the range and relative velocity of the vehicle and the object. Various processing techniques have been developed to perform this function.

Long-range radars use one of two methods for range calculations: pulse modulation or frequency modulation. Short-range radars may use one of the techniques described above. Alternatively they may be based on the diplex Doppler method, or sinusoidal frequency modulation.

Having received and analyzed the range and relative velocity, the signal processor is fed further data relating to the vehicle's ground speed and the present state of braking. This is analyzed and compared with the range and relative velocity. The processor uses internal logic to decide if the target is real or false and, in the event of a collision being deemed probable, actuates the brakes.

One of the main problems of radar braking is false alarms. False alarms may be caused by roadside obstacles, such as trees, signs, fences or parked cars, or by vehicles traveling in different lanes or in different directions. Obstructions in the roadway must be separated into major items and inconsequential items. Systems are particularly vulnerable to false alarms at corners or bends, where a roadside obstacle or vehicle may appear to be in line with the direction of travel. This problem may be reduced by limiting the range of the radar, although this would also reduce efficiency at high speeds.

Another major problem with radar braking is that of "blinding." This occurs when radar signals from vehicles traveling in the opposite direction block out the return signals from potential obstacles. There are also certain problems with radar braking systems caused by poor weather conditions, the most serious being backscatter from rainwater.

4.7 AUTOMATIC STEERING CONTROL

Automatic steering control (ASC) systems linked to power-assisted steering can ensure that vehicles will follow a predetermined path along dedicated highway lanes. ASC systems must possess three essential components: (1) a roadway reference system that can be sensed by a vehicle in order to ascertain its lateral position relative to the highway; (2) onboard sensors that measure the lateral displacement and determine any necessary remedial action; and (3) a steering control system that acts automatically on command signals to maintain or adjust the lateral position as required.

Techniques for achieving lateral position control can be categorized into two groups: (1) those systems requiring passive roadway reference systems, and (2) those using active reference systems.

A passive reference system is an inert structure or component of the guideway, such as a metalized strip, a painted stripe, passive reflectors, or a sidewall. Each vehicle obtains its own

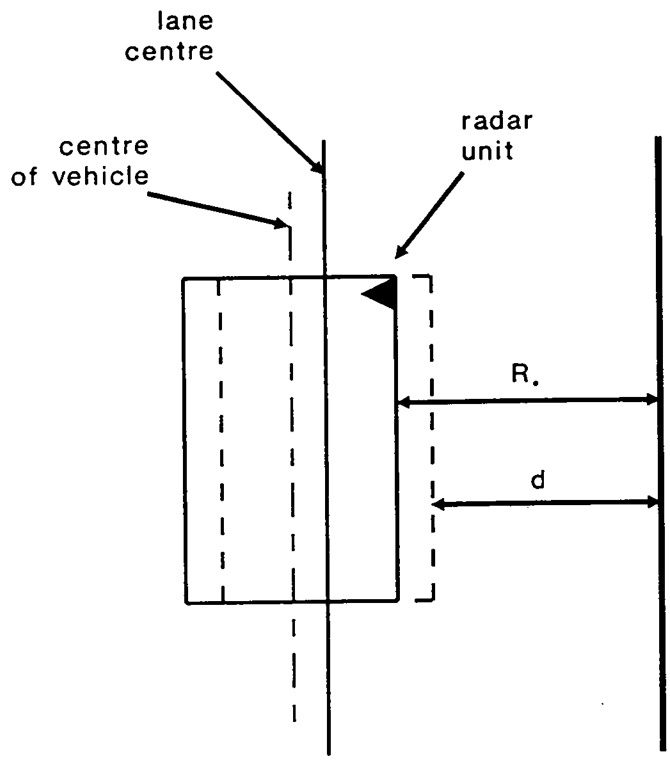

Figure 16. Vehicle-borne radar for lateral control. (Source: Ref. 178)

positional information using onboard equipment. One particular type of passive system that has been considered by Mayhan and Bishel (*178*) uses radar and a reference system in the form of a fixed barrier at the side of the roadway to obtain the necessary information for lateral control. A possible configuration is shown in Figure 16.

An active reference is used in the second type of ASC system to provide the information required for lateral position control. This typically involves the use of an energized cable running along the desired vehicular path, usually buried below the pavement surface.

During the late 1950s, General Motors and RCA developed and demonstrated automatic control of steering and longitudinal spacing of automobiles (*179*) for what was called the "Electronic Highway." By 1962, the first university research on ASC of automobiles was reported from Ohio State University (OSU) (*180*), under the sponsorship of the Ohio Department of Highways and the Bureau of Public Roads. This led to a later, long-term control study, under the sponsorship of the Ohio Department of Transportation and the FHWA between 1965 and 1980. The first broad-scale investigation of the application of automation technologies to urban transportation problems appears to have been in the M.I.T. Project METRAN, in the spring of 1966 (*181*).

The basis of this type of system was that a buried energized cable created a magnetic field that was sensed by equipment under the vehicle (*182*). Deviations from the cable centerline produced a positive or negative DC error signal (depending on the direction), which was approximately proportional to the lateral displacement (Figure 17). The error signal was fed into a

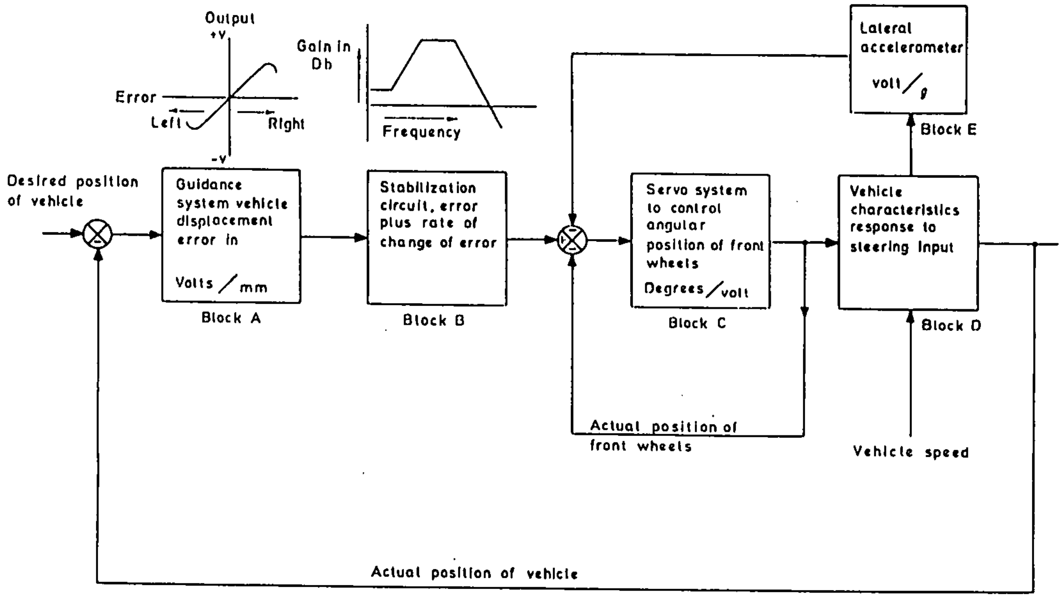

Figure 17. Operating principle of a steering control system. (Source: Ref. 182)

stabilizing circuit and the resulting signal was used to operate the vehicle's steering.

A major problem with energized wire reference following systems is interference on reinforced concrete pavements, where steel reinforcement causes the magnetic field to be weakened and distorted. This leads to a disturbed ride, and in extreme cases could result in a total loss of lateral control.

4.8 AUTOMATED HIGHWAY SYSTEM

This final section deals with the most complex and most ambitious form of AVC, the automated highway system (AHS). The technologies discussed previously assisted or assumed the role of the driver in performing one particular function, such as steering or braking. On an automated highway, however, vehicles would be totally automated in all aspects of control by a combination of these technologies, suitably adapted to an environment of total vehicle control.

The basis of the AHS system is essentially vehicle control in two directions—longitudinal and lateral (*183*). Incorporated with this must be an ability to merge streams of vehicles, allowing vehicles to enter and exit the AHS at appropriate intersections, as well as providing for breakdown and emergency facilities.

Two approaches for achieving longitudinal control have been advocated: synchronous and asynchronous. The synchronous concept, also referred to as Synchronous Longitudinal Guidance (SLG) or point-following, may be compared to a conveyor belt divided into equal-sized slots (*184*). Each controlled vehicle is assigned a slot, and obtains reference information in order to determine its position relative to that slot. Reference information may be provided by one of two methods: either through roadway or roadside position reference benchmarks, or through a continuous signal moving at synchronous speed.

The asynchronous technique, sometimes referred to as the car-following approach, does not confine a vehicle to a moving slot, but rather controls a vehicle on the basis of its state and that of the other traffic (*185*). An example of the asynchronous concept, in which the control of a following vehicle is determined with respect to a leading vehicle only, is AHC.

Although basic lateral and longitudinal control systems constitute the essential elements of an AHS system, equally important is the ability to successfully merge vehicles into a controlled traffic situation. This might be achieved using the lateral and longitudinal control systems, and has two major aspects: the macroscopic or systems aspect, and the microscopic aspect.

The macroscopic aspect is concerned with the simultaneous merging of a large number of vehicles at many intersections, and the resulting effects on system performance. The microscopic aspect is concerned with the control of a particular vehicle during an automated merging maneuver.

Another important consideration is the control of vehicles entering and exiting the automated stretches of highway. An entering vehicle would be operated in the manual mode on the approach to the AHS, until the entry point was reached. The vehicle would then be merged into a suitable gap and would continue under automatic control. Exiting the AHS would occur in the reverse fashion, with manual control being restored during the final stage of the exiting procedure.

More recently, studies have been undertaken to further examine the system concept and to define system development implementation (*186*). Given the substantial alterations necessary to the present vehicle population and roadway infrastructure, rapid implementation of a full AHS may not currently be practical. A more promising approach could be a staged implementation, in which total automation would be achieved following the introduction of several less radical changes. While gradual implementation was taking place, vehicles both equipped and unequipped with the new technologies would still use the same highways. This "evolutionary" approach could essentially consist of three stages of deployment.

The first stage would be the development and introduction of driver aids on a commercial basis. These would generally be vehicle-borne systems, requiring little or no support from roadside equipment.

Several automobile manufacturers have already produced concept cars that incorporate collision avoidance radar. Metzler et al. (*187*) described the features included in the Mercedes-Benz research vehicle in 1981. Ford's Continental Concept 100 in 1984 also incorporated a sonar detection system (*188*).

After a testing period, there may be sufficient acceptance or demand to permit the introduction of the second stage. This would involve the phased introduction of subsystems for partial automation. The adaptation of an existing highway lane in each direction, for example, could allow the introduction of ASC. Suitably equipped vehicles would now be able to use steering control in the modified lane, whereas those not equipped would still be able to use the other lanes.

Eventually, given the successful execution of stages one and two, there could come a time when most vehicles are fitted with automatic longitudinal and lateral control facilities. When this is the case, the third stage, the phased introduction of fully automated highways, could begin. This would be the most radical step of the implementation process, requiring major development and construction of control center systems and intervehicle communications.

4.9 SUMMARY

AVC systems seek to assist drivers in performing some or all of the driving tasks. Widespread use of AVC technologies could result in greater safety, more consistent behavior, and improved traffic flow characteristics. At the most basic levels, AVC can provide the driver with useful information and warnings. The next level is to assist the driver directly, helping to avoid potentially dangerous situations. The third level would provide for system intervention through emergencies, and the final level would completely take over the driving task. Although AVC systems are least developed of the IVHS technologies, their potential for relieving urban traffic congestion could be very high.

CHAPTER 5

TRANSIT INFORMATION SYSTEMS AND HIGH OCCUPANCY VEHICLE MANAGEMENT

5.1 INTRODUCTION

Perhaps one of the most promising ways in which urban congestion can be reduced is through the improvement and increased use of transit and rideshare facilities. These facilities offer the potential to move large numbers of people in fewer vehicles. This is in contrast to the present situation, where a high proportion of urban travel is made by single or low-occupancy private vehicles. Increased use of transit and rideshare facilities would therefore serve to reduce the number of private automobiles on the highway network, bringing about safety and environmental benefits, as well as reduced congestion.

This chapter examines the application of advanced technologies within the transit and rideshare environment. Advanced technologies can be used to encourage the use of transit and rideshare facilities, by improving their attractiveness and accessibility to travelers. In addition, advanced technologies can increase the efficiency of transit and rideshare operations, reducing operational costs while offering higher levels of service to the public.

Section 5.2 examines the use of advanced traveler information and service systems. These can be used to disseminate transit and rideshare information to the traveler. The section also covers pretrip planning information, trip reservation and payment, in-terminal information and in-vehicle information systems.

Section 5.3 focuses on the use of advanced traffic management systems (ATMS) in transit and rideshare operations. ATMS technologies have already been discussed earlier in this report, in the context of reducing congestion through the optimal coordination of road space and road time. When specifically applied to transit and rideshare schemes, ATMS can be used to encourage transit use and improve efficiency by giving priority to selected vehicle types.

The third category of advanced technologies discussed in this chapter is fleet management and control systems (FMCS) (Section 5.4). These can be used by fleet supervisors to monitor and coordinate the operation of their vehicles. FMCS technologies may therefore have potential to enable the most efficient use to be made of vehicle fleets in response to the needs of the general public.

5.2 ADVANCED TRAVELER INFORMATION AND SERVICE SYSTEMS

This section discusses some of the advanced technology developments that have taken place for disseminating transit and rideshare information to the traveler. New concepts are also proposed making use of current or imminently available technologies to improve the accessibility and attractiveness of the various aspects of transit systems. The services covered by this section include: schedule and fare information; route planning information; real-time schedule information; ticket purchase and seat reservation; and rideshare participant selection and location.

A variety of alternative technologies are introduced as ways of best providing these services. It should be noted that to provide maximum utility and increase the added value, many of these

Table 2. Pretrip planning.

Technologies \ Services	Route & schedule data	Trip itinerary	Rideshare participant selection	Rideshare participant profile	Rideshare route planning	Realtime departure schedules
Automatic tone/ dial telephone	●	●				●
Telephone & voice recognition	■	■				■
Computer & modem	▲	▲	▲	▲	▲	▲
Standalone computer & software	▲	▲	▲	▲	▲	
Facsimile	▲	▲	▲	▲	▲	▲
Teletext	●					▲
Videotext terminals	●	●	▲	▲	▲	●
Telephone to computer operator	●	●	●			

KEY: ● Currently applied ■ Near-term potential application (within 5yrs)

▲ Potential current application ▽ Possible future application

systems and technologies should be combined with others described in this report. Implementing a management information system using automatic vehicle monitoring (AVM) technology, for example, should be used as the basis for a real-time passenger information system using some of the techniques described within this section.

Pretrip Planning Information. This section covers the application of advanced technologies to meet the information requirements of travelers or prospective travelers prior to embarking on specific journeys. The application of advanced technologies in this area has potential to provide significant advantages to the transit authority and traveler alike. Table 2 provides a summary of these systems and the applicable technologies.

The initial technology considered in this section is the automation of telephone enquiry services. The telephone has for a long time been a popular mode of information retrieval, allowing convenient selection of travel route, schedules, and itinerary. The automation of the telephone enquiry service can be divided into three levels of technology application: (1) computerized information access, manually recalled by the service operative who answers the telephone; (2) fully automatic system making use of touch tone or other remote terminal facilities to select the required options; and (3) a fully automatic computerized system with voice recognition.

The airline industry has often led the way in areas relating to computerized information access and reservations. This review, however, limits itself to transit bus and rail applications, of direct potential relevance to addressing urban congestion issues.

The use of a computerized database to improve the speed and accuracy of information retrieval was successfully demonstrated by the Washington Metropolitan Area Transit Authority (WMATA) Automated Information Directory System (AIDS) (*189*). After an agent answers the call, a terminal is used to obtain detailed individual schedule and route information that is then relayed to the customer.

The Hamburg Automatische Fahrplan Information (AFI) is another example of a fully automated system (*190*) using voice synthesis and the telephone dial as its mean of communication. The AFI system uses codes input through the caller's telephone to describe the trip origin and destination and to select items from menus. Detailed optimum route information is generated and presented to the caller together with fare information via a speech synthesizer. A Teletrip system recently installed for the Long Island Railroad, N.Y., similarly provides automatic answering and fare schedule information selected by the telephone tone dial keys.

A real time automated telephone transit schedule system was demonstrated in Salt Lake City, Utah (*191*). The real time information on schedule variations was entered manually by the bus dispatchers. The Telerider system (*190*), successfully implemented in a number of U.S. and Canadian cities, also offers automated real time bus schedule information to the transit user. Each bus stop in the system has an individual telephone number associated with it. Travelers calling the number are told the time of arrival of the next one or two buses by a digitized speech system. The "GoTime" system (*192*) implemented in Halifax, Nova Scotia, also provides these real time bus enquiry facilities as part of a computer-based monitoring and information system. A project was also carried out in Erie, Pennsylvania, in the early 1980s (*193*), combining computer technology and voice response units to provide information on the arrival time of the next bus at any stop within the system.

A different approach is currently demonstrated through the French Teletel Videotex system, described in Chapter 2. Subscribers use a simple remote terminal called the "Minitel" to access a wide range of commercially sponsored information services. Data communication is by telephone and displays use conventional television screens. Real-time travel information for rail, bus, and air modes is available through Teletel from several information providers. Initial launch of the system was promoted by the French government which financed the distribution of some four million Minitel terminals to subscribers throughout the country.

Technology for true voice recognition is rapidly becoming a feasible alternative to the number dialing or button pushing methods described above. Offering the traveler a more acceptable automated interface is the AT&T voice recognition system, developed for airline industry bookings, with a 20,000 word vocabulary and running on part of a CRAY computer. Systems such as this will in due course allow fast and accurate information retrieval at high service levels without complicated O-D coding by the traveler.

The methods of telephone enquiry described are potentially applicable to any mode of transit including ridesharing and dial-a-ride facilities. The coverage provided by such an enquiry system is essentially governed by the administering organization. A central agent could act for all transit authorities and modes, providing the traveler with alternative routes and catering for special needs and wishes. The main issue here is system finance, for example through cost-sharing by transit operators, or through direct user fees.

Many systems providing remote general transit information have been implemented throughout the world. Typically, these systems are installed at activity centers such as shopping malls, and use keypads or touch screens with video displays and occasionally printing facilities. Two examples of these systems are the self-service computer terminals installed in some Washington, D.C., suburban shopping centers and the system implemented by Technology for People (TFP) for the Central Ohio Transit Authority (*194*). The computer terminals offer bus route, schedule and fare information along with useful telephone numbers in response to selection from a list of choices including restaurants, stores, theaters, and services. The Central Ohio Transit Authority system uses full motion picture video with text and voice and is activated through a touch sensitive screen. The system also includes a built-in printer to allow the user to take away helpful information.

A more versatile service can be provided by allowing the traveler remote access to the database via a terminal and modem in the home or workplace. Using a system such as this, potential travelers can interactively obtain full details of schedules and routes along with personalized itineraries for their chosen journey. Users would then be able to print hard copies of the information as required.

This same technology can be applied to the selection and allocation of rideshare participants. The traveler would again describe his journey in terms of an origin and destination. The central database computer would respond with suitable passengers or drivers and could also plan the route for collecting passengers. These technologies are presently more applicable to the workplace where computer/modem facilities currently have a higher usage rate. Such facilities in the home environment are still relatively uncommon.

A more widely available technology able to provide interactive enquiry facilities with the capability to produce hard copies is the facsimile machine. Facsimile machines are currently available for microcomputers which enable computer-generated text or graphics to be output directly to a remote fax machine. This equipment would be of particular use to those with impaired hearing and has the attractive feature of being a reasonably widely accepted technology, not requiring special skills or programs to operate.

In a simple application of this technology, communication with the database computer would be achieved via the tone keypad associated with the fax machine, and prompts and questions would be output audibly or via the facsimile printer. A more innovative use of this technology would combine the database computer with automatic character recognition or other form of "fax reading" equipment. To use this, the traveler would complete an information or itinerary request form, by hand. This would be faxed to the central computer system where the form contents would be interpreted and the information generated for transmission to users.

The final technology considered in this review applicable to pretrip planning are teletext-based information systems. Teletext services are provided by invisibly encoding pages of alphanumeric data onto conventional TV station carriers, which are then read by a special decoder built into the television receiver. Most Western European countries include information on real-time transit schedules and delays within their normal teletext services. Commuters using the service consult a teletext TV set before leaving home in the mornings, and can adjust their travel plans in the event of unusual service delays or disruptions.

Trip Reservation and Payment. The application of advanced technologies to the reservation and payment aspects of transit range from the widely used dial-up booking facilities to conceptual post-trip billing requiring no action from the traveler. Many of the technologies identified in the previous section, for trip planning and itinerary generation, are also capable of providing facilities for reservation and payment using conventional credit card procedures. The interactive systems suitable for remote booking can also be used to generate tickets if hard copies can be produced. A summary of trip reservation and payment systems is presented in Table 3.

The generation of tickets or confirmation of firm bookings typically requires a reasonably high degree of security, i.e., positive identification of the individual purchasing the ticket. Systems such as those installed by VISA in several railroad stations achieve this automatically by using specialized ticket dispensing machines equipped with a magnetic card reader and a keypad for remote selection and PIN entry. Hundreds of these systems are currently being installed by the French National Railway (SNCF) with data entry by touch screen and response in French, English, or German. Where charge amounts are lower, credit cards are currently accepted without any individual identification, for rapid processing of users, needed to help relieve urban congestion. A number of toll roads overseas rely on automated recognition and retention of stolen cards in order to achieve high throughput levels in congested urban environments.

In the future, voice pattern recognition technology could be used to positively verify the identity of the person making the reservation, allowing remote, confirmed bookings with minimal risk to the operator. However, for many applications, the remote entry of card number, expiry date and PIN, using telephone tone dial or computer/videotex terminal, will be satisfactory as an immediate solution. The cards used may be conventional credit cards or specially supplied charge cards unique to the transit operating organization.

Table 3. Trip reservation and payment.

Technologies \ Services	Remote reservation, seat allocation & payment	Automatic post-use billing	In-terminal automatic payment & ticket dispensing
Automatic tone/ dial telephone	▲		
Telephone & voice recognition	■		
Computer & modem	●		
Fax & automatic character reader	▲		
Videotext terminals	●		
Smart cards		▲	▲
Interactive auto credit card machine			●
Automatic personal identification		▽	▽

KEY: ● Currently applied ■ Near-term potential application (within 5yrs) ▲ Potential current application ▽ Possible future application

Another option for the future, currently under development within the airline industry, would eventually eliminate the need for hard copy tickets entirely. Passenger ticket details would be stored electronically on airline system computers, together with a digital image of the traveler's fingerprints. On check in, the fingerprint image would be verified using an electronic scanner, permitting full details of the passenger's reservations and payment status to be retrieved.

A leading edge technology particularly suitable for the automated payment application is the smart card. Smart cards are approximately the same size as a conventional credit card but contain both microprocessor and memory elements allowing them to perform calculations and manipulate data independently of the device with which they are communicating. Cards are available for which power and read/write data links can be provided in a contactless manner, giving a robust and secure method of data processing and information portability.

One scenario for the application of smart card technology is the replacement of current multijourney card punch or magnetic strip based pretrip purchase schemes. It has been demonstrated that bus passengers suffer their greatest inconvenience at the fare paying stage of their journey (*195*). Improvements in speed of entry and passenger processing will be of additional benefit to the transit operator, providing time and, hence, cost savings.

Passengers using transit on a regular basis would pay for a smart card with a predetermined number of fare units held in memory, instead of a season ticket, travel permit, or multitrip card. The smart card would communicate the passenger identification and remaining balance to an onboard computer (OBC) on entering and leaving the transit vehicle. The two-way communication link will allow the card balance to be decremented by the correct fare amount on exit from the bus. This system avoids the need for real-time communication between OBCs as all the information is stored securely on the card.

Contactless ID cards could also be used to implement post-use payment for transit systems, similar to the application of AVI for toll collection described in Section 2.6. The fare charged would be based on information stored on the passenger's card, but this would be recorded in an on-vehicle unit rather than on the card itself. Statements would be mailed out periodically to system users outlining the amount of travel and the required level of payment.

Smart cards also show potential for use as secure personal identification devices, to replace photographic identification currently used on some extended travel passes. A potential application for personal ID within transit operations comes in reducing driver and passenger assault. Crime is a major problem on many transit systems, deterring legitimate users and intimidating transit company personnel. Apart from reducing or eliminating cash handling by drivers, the smart card could record information on all passengers at any instant, including their name, address, social security number, or other details.

The final technology application to be considered under this section is that of automatic personal identification (API). This could consist of a microwave or RF tag carried by the traveler, similar to the already proven AVI technology. The tag would be read as the travelers entered and exited the transit vehicle, thus allowing their fare to be calculated and bills generated or an associated in-credit account debited with the relevant amount. Several vendors have undertaken the development of such systems (*196*) using tags, as little as 1 inch across, that can be carried in the holder's pocket or purse.

An API system could in the future be extended to cover trip reservation. The traveler would give an API identification number and obtain route and time information for which a seat could be automatically reserved. On arrival at the transit terminal the API system could identify the passenger to the guidance systems which would then direct them from the terminal entrance to the previously reserved seat.

In-Terminal Information. Many of the pretrip information services and advance reservation and payment facilities described in the previous two sections are immediately applicable at the transit departure and arrival terminals. The high volume of passengers using a terminal should also allow more elaborate specially designed equipment to be used. For the rideshare services, the terminal is taken to be an out-of-town parking lot where riders may leave their cars prior to meeting up with their drivers for the ridesharing portion of the journey. The additional information provided at the terminal includes timeliness information, real-time connecting service information and transit boarding points. The systems and technologies described in this section are summarized in Table 4.

In some countries, railroad stations have featured the use of state-of-the art passenger information technology for many years. Much of the innovation has focused on visual displays for stations and platforms. One of the most valuable facilities is the automatic real-time display of the destination and arrival of the next train. Ideally, the facility will be linked to a larger transit control system using automatic identification of transit vehicles and transit vehicle tracking.

A system of this type has been implemented in the Oslo, Norway Bus Terminal using technology based on Omega Electronics and Philips PREMID system (*197*). The display technologies include 19 departure display boards and 33 video monitors at various points within the terminal. The buses are automatically identified on entry to the terminal by their programmable windshield tag and given directions, displayed on monitors, by a central computer to an empty parking bay. The system automatically combines real-time arrival and departure information with stored timetables to update the departure information boards and video monitors.

A similar system utilizing the Dowty Videobus system has been installed at the Heworth interchange station on the Tyne and Wear Metro network (*198*). The system uses AVM equipment and video displays for flexibility. The system displays the following information on six display units: an alphabetical list of destinations possible in a series of services and appropriate bus numbers; real-time information for the departures of the next four vehicles with ultimate and intermediate destinations; special messages and announcements with advertising displays; and an extended route profile of the next vehicle to depart. Passenger surveys of the Heworth interchange system indicated that the information helped to plan journeys, allowed selection of alternative routes, and reduced perceived waiting times.

Systems have been operating on urban metro systems for many years, providing real-time information on dot matrix displays located on the platforms. Systems have been provided by vendors such as Thorn EMI Electronics, GEC General Signal and Westinghouse signals that can identify the current status of the network and display information on the destination and arrival times of the next few trains at that platform.

Although display technologies are continually advancing, the current state of the art provides a wide variety of options. Flap displays, possibly one of the oldest changeable display technologies, require little maintenance and are being made more mechanically reliable. Matrix displays can be provided by light emitting diodes (LEDs), liquid crystal displays (LCDs), or flip dots; each technology has its merits and must be chosen carefully to suit the application.

As discussed earlier, many of the pretrip planning services will share common technology with the facilities described above. However, one system worthy of mention here is the Situ equip-

Table 4. In-terminal information.

Technologies \ Services	Schedule	Route plan	Auto itinerary	Time-liness	Departure point location	Connect. service info.	Dynamic rideshare info.
Matrix displays	●	●		●	●	▲	
Flipover displays	●	●			●		
Video displays	●	●					
Interactive video terminal		●	●		▲	▲	
Interactive audio terminal	▲	▲	▲	▲	▲	▲	
Smartcard terminal	■	■	■	■	■	■	▽
Dynamic rideshare routing terminal							■
Voice synthesis	▲	▲	▲	▲	▲	▲	■

KEY: ● Currently applied; ■ Near-term potential application (within 5yrs); ▲ Potential current application; ▽ Possible future application

ment manufactured by Societé d'Etude pour l'Information sur les Transports Urbains (SEITU). This system provides a high functionality self-help passenger enquiry service. The user may enter an address, a location, a public monument, or a name of an activity, such as opera. Situ will produce a printout detailing the best way to get there and the approximate journey time. Travelers may also choose their preferred transport mode, including "least walking." Transport authorities in Paris, Caen, Nantes, Valenciennes, and Nimes have adopted Situ.

Several methods of data entry are currently available. The Situ system uses a keypad, while others facilitate entry by touch screen. The voice recognition technology discussed earlier would be suitable for providing an interactive audio terminal when combined with synthesized speech generation. A facility such as this could provide all the trip planning facilities previously described along with directions to the departure point, particularly benefitting those travelers with sight difficulties.

The API concept discussed in the previous section could also be used within the terminal to direct travelers to their point of departure. A more advanced application of the system may allow passengers to be individually called or paged when their transit vehicle is preparing to leave. This would be achieved by making the identification tags part of a two-way communications system or by linking the system to a portable telephone network.

The final in-terminal technology application discussed in this section relates to providing relevant rideshare information at a parking lot or collection point. A concept is envisioned using a computerized ride allocation system and other currently available technologies. The rideshare participants would enter their details, that is, destination and personal preferences, into the system on arrival at the rideshare "terminal." This could be achieved automatically through the use of AVI, API, or smart card technology. The traveler would then be matched with waiting passengers or drivers or asked to park and wait for suitable participants to arrive. Maximum waiting times could be specified after which the driver may wish to leave the system. In-car equipment or variable signing could be used to direct the driver around the lot or terminal so that riders would not have to leave their own cars until they knew they had a ride. The system could also interface to a telephone line to allow rides to be booked in advance and waiting time estimates to be generated.

The potential for improving the attractiveness of ridesharing using a dynamic system is evident from this brief review. A system such as this would be capable of minimizing delays to participants and overcoming the necessity for keeping to fixed time schedules. Telephone, videotex, or any of the other communication links described earlier could provide remote access to the system for return journey ride allocation.

In-Vehicle Information Systems. This section discusses the types of information required within the transit vehicle, as well as methods of presenting it to passengers. The discussion focuses mainly on information systems that address particular needs associated with this mode of travel. Basic driver information and route guidance systems have been dealt with in detail elsewhere in this report and are therefore only referred to where they provide facilities over and above those previously described. These systems are summarized in Table 5.

The first item of information required by a traveler entering a transit vehicle is where to sit. In the case of a passenger who has not booked a seat, directions are required to a suitable empty seat. On small transit vehicles, the use of information technology in this area will obviously provide little benefit. On large vehicles, a seating plan display could be provided to show which seats are empty and where reserve seats are located. A system developed by Focon Electronic Systems for Danish State Railway's IC3 (*199*) uses a dot matrix display at the train's boarding point to display the destination, departure and arrival times, and the seating plan. Further dot matrix displays are located in railcars that give more detailed reservation data.

Once the passenger is seated correctly, information on the timeliness of the service, the current location and distance and time to destination will be of most interest. Any of the conven-

Table 5. In-vehicle information.

Services / Technologies	Seating plan	Next stop announce.	Timeliness	Rideshare route guidance	Connect. service info.	Incident info.	General info. & advertising	Communications	Future trip planning/ reservations	Route info.
Matrix displays	●	●	●		▲	▲	●			●
Flap displays		▲								▲
V.D.U.	▲	●	●		▲	▲	▲			●
Voice synthesis		●	▲			▲				
Mobile phone								●		
Onboard terminal & comms link					■	■		■	■	
Route guidance system				■						

KEY: ● Currently applied; ■ Near-term potential application (within 5yrs); ▲ Potential current application; ▽ Possible future application

tional display technologies discussed in earlier sections could be used to provide this facility. For example, a dot matrix display is used to provide in-bus information in Panasonic's Bus Operation Improvement System. The display gives details of the next stop, current time, and time until next stop, and is also used to provide topical information such as news, weather, and advertisements. Synthesized speech has also been used for stop announcements in a system developed at Sweden's Lund Institute of Technology, which is being implemented on a number of buses belonging to a local transportation authority.

Video displays have been chosen by Mitsubishi Corporation for their MARIA (Mitsubishi Advanced Realtime Information Autosystem) system, one of the applications of AMTICS described in Chapter 2. In addition to supplying location and stop information to passengers, this system can point out tourist sights and other places of interest using information stored on compact disc read-only memory. These systems should also be capable of providing more detailed incident information or reasons for delay to the passengers to help reduce some of the frustrations associated with unexplained or unquantified hold-ups.

Real-time information on connecting services would be of use to travelers in determining how much time they have at the interchange. Ideally, this would be provided by an interactive system, although this would be difficult to achieve on a moving vehicle without installing some form of terminal at each seat. This type of information would generally be provided as a small part of larger communication systems such as those described for AVM and location technologies.

Providing communications facilities for passengers should also help to make the use of transit more attractive. Pay telephones have been available on many airlines and on several rail systems throughout the world for a number of years. Facsimile facilities or data communication links could also be considered in attracting the business person to the transit network.

Most of the technologies and facilities described above are applicable to bus or taxi based transit services rather than rideshare. One technology that would be of particular benefit within the rideshare vehicle is that of route guidance. A route guidance system such as those described in Chapter 2 would allow carpool drivers to locate riders in unfamiliar locations. Externally linked systems would also allow incidents to be avoided. Third party cars or vans for pooling show promise as an ideal test bed for these types of technologies. By linking the route guidance and rideshare participant selection system, full automation could be achieved, making single trip sharing more accessible.

5.3 ADVANCED TRAFFIC MANAGEMENT SYSTEMS

In applying Advanced Traffic Management Systems (ATMS) to transit and rideshare schemes, the goals are essentially different from those of the same technologies when used in other traffic control applications. As described in Chapter 3, the overall aim of traffic management is to achieve the optimal coordination of road space and road time, leading to freer traffic flows, shorter journey times, fuel savings, and generally reduced congestion. When specifically applied to transit and rideshare schemes, however, the intention is to bias the highway environment to give priority to selected vehicle types.

The use of ATMS technologies for transit vehicles and other HOVs can therefore have two principal effects which may encourage the wider use of these travel options. First, the implementation of priority measures in a traffic management system can reduce the variability of transit and HOV travel times, and will assist in avoiding areas of congestion. This serves to enhance travel by these means, where similar benefits are not available to private or low-occupancy vehicles.

Second, the introduction of priority schemes for transit and HOVs may actually have an adverse effect on nonpriority traffic, in some cases. Single occupancy vehicles, for example, may experience increased travel times through being denied access to more direct or freer flowing HOV facilities. Whether reduced convenience of travel for low occupancy vehicles is seen as an undesirable side effect or as an acceptable disincentive is a question for debate. Nevertheless, this may encourage travelers to participate in transit or rideshare schemes.

The following six areas have been identified for the application of ATMS technologies: traffic signal priority, reserved highway lanes, ramp metering bypass lanes, toll highways, parking areas, and enforcement.

Traffic Signal Priority. Chapter 3 considered the use of traffic signalization techniques for general congestion reduction. The same methods, in combination with other advanced technologies, can also be used to preferentially operate traffic signals in favor of transit and rideshare vehicles. This can be achieved for individual intersections or for a coordinated network. In addition, systems can be operated with either fixed-time or traffic-responsive signal-timing plans. The different applications and technologies involved are summarized in Table 6.

For isolated intersections, traffic signal timing programs such as those described in Section 3.2 could be used to optimize signal settings to achieve minimum person delays, rather than minimum vehicle delays (*200*). This would bias signal timings in favor of traffic streams containing transit vehicles. Given an appropriate knowledge of HOV routes and vehicle occupancy data, it should also be possible to use a similar approach for rideshare vehicles.

More effective traffic signal priority can be obtained using selective detection techniques. These involve the identification of individual vehicle or vehicle types, on the approach to an intersection, and the adjustment of traffic signal timings in their favor. With transit vehicles, identification can generally be achieved using automatic vehicle classification techniques, making use of inductive loops or piezoelectric axle sensors. These methods are advantageous in that no on-vehicle equipment is required.

An alternative to automatic vehicle classification for signal preemption involves the use of AVI technology, described in Section 2.6 of this report. A schematic of this approach is illustrated in Figure 18. Significant work has already been undertaken in this area, particularly in Europe. By 1976, for example, research on AVI conducted at the U.K. Transport and Road Research Laboratory had led to the development of a selective vehicle detection system for bus priority at signalized intersections (*201*). This was initially installed on 110 buses in Swansea, U.K., enabling them to initiate a priority call on the approach to 12 intersections and 8 signal-controlled pedestrian crossings in the city center.

Elsewhere in Europe, one of the earliest applications of AVI for public transit took place in Delft, Holland, in 1971 (*202*). Buses between the Hague and Delft were given local priority at

Table 6. Signalized intersections.

Technologies \ Services	Transit-pref signal control	HOV-pref. signal control	Transit-pref network control	HOV-pref. network control	Transit responsive network control	HOV responsive network control
Automatic vehicle classification	●				▲	
Automatic vehicle identification	●	▽			■	▽
Smart cards		▽			▽	▽
License plate scanners	▽	▽			▽	▽
Isolated intersection control software	●					
Fixed-time signal coord. software			●	▲		
Adaptive signal coord. software					■	▽

KEY: ● Currently applied ■ Near-term potential application (within 5yrs)

▲ Potential current application ▽ Possible future application

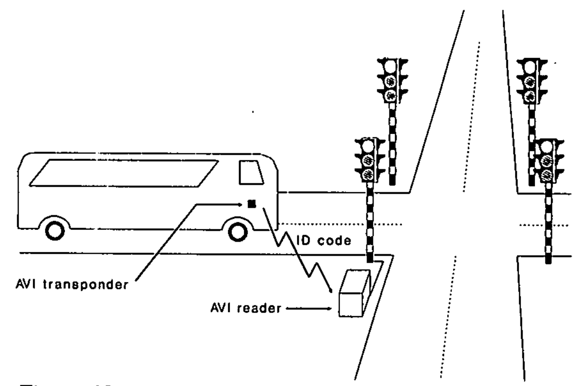

Figure 18. AVI for signal preemption.

signalized intersections using a simple form of inductive AVI known as VIPS (Vehicle Identification and Priority System). This was reportedly successful in reducing travel times and delays, and similar systems have since been implemented in a number of other Dutch cities.

Transit-preferential signal priority schemes have also been implemented at a number of locations in the United States. These have included experimental systems installed in Kent, Ohio, Louisville, Kentucky, and Washington, D.C., in the mid-1970s (*203*). In addition, a project carried out in Philadelphia in the early 1980s provided signal preemption for trolley buses in the city, as well as adding overhead wires for express trips during the peak period (*204*).

It may also be possible to implement a scheme for traffic signal preemption for other HOV vehicles using AVI technology. Conceptually, AVI transponders would be distributed for installation on vehicles registered to participate in a rideshare scheme. To prevent signal preemption by registered vehicles that were not carrying the required number of occupants, some form of passenger identification could be used. This could be in the form of individual smart cards, with the AVI transponder only becoming active after the insertion of the required number of smart cards into a reader unit. A number of other issues would need to be dealt with in setting up such a system, which would probably best be initially implemented as part of a third-party vanpool program.

Another technology that could be used for selective vehicle detection is license plate scanners. These are capable of automatically reading the characters on vehicle license plates. In the United States, the 3M Company has developed a commercial automatic license plate reader, based on earlier research and development by the Perceptics Corporation (*205*). The system is used to extract the characters from reflective license plates, which are imaged by a video camera and illuminated by an infrared strobe lamp. A shuttered image of the camera's field of view is captured and analyzed to determine if a license plate exists in the image.

The use of license plate scanners for traffic signal preemption would involve the comparison of license plates read by the system with a database of preferred vehicle records. Detection of a license plate included within the database would serve to preferentially trigger the traffic signal. A possible advantage of using license plate scanners over conventional AVI is that no additional on-vehicle equipment is required, potentially leading to significant cost savings. However, this must be weighed against the lower accuracy levels achieved by license plate readers caused by dirty, obscured, or damaged plates.

Techniques are also available for the preferential treatment of transit vehicles over a network, rather than simply at isolated intersections. In the U.K., for example, the TRRL has examined the use of TRANSYT for bus priority in Glasgow (*206*). This experiment involved the modification of signal timing plans in the city to optimize the movement of people, rather than the more conventional passenger car units (PCUs). The average occupancy of a bus was assumed to be 28 passengers for the purposes of calculating signal timings, with 1.4 occupants assumed for other traffic. This represented a significant weighting toward buses, which would normally count as two PCUs.

The Glasgow experiment resulted in increases in bus speeds of 9 percent, 8 percent, and 7 percent during the morning peak, off peak, and evening peak periods, respectively, with an overall reduction of 16 percent in the time spent delayed by signals. Significant redistribution in car journey times were also noted. Cars traveling along a bus route experienced a 5 percent reduction in journey time, while those traveling off bus routes faced a 15 percent increase in journey time. Overall, however, journey times for cars on the network did not change significantly.

At a more advanced level, it should also be possible to achieve

Table 7. Specialized highway environments.

Technologies \ Services	Transit-reserved lane access	HOV-reserved lane access	Preferential transit toll charges	Preferential HOV toll charges	Transit preferential ramp control	HOV-preferential ramp control	HOV-preferential parking control
Automatic vehicle classification	▲		▲		▲		
Automatic vehicle identification	▲	■	▲	■	▲	■	■
Smart cards		■		■		■	■
License plate scanners	▽	▽	▽	▽	▽	▽	■
Video/CCTV monitoring	▲	▲			▲	▲	▲

KEY: ● Currently applied; ■ Near-term potential application (within 5yrs); ▲ Potential current application; ▽ Possible future application

transit-preferential responsive network control. This would involve the use of the full adaptive signal timing techniques described in Chapter 3. The recalculation of traffic model predictions would be based on the movement of transit vehicles, possibly including an assumed average occupancy such as that used in the Glasgow TRANSYT experiment. Detection of transit vehicles could be achieved using classification systems, such as inductive loops, or could use AVI technology.

Reserved Highway Lanes. Outside of traffic signal control, there are a number of other specialized highway environments where advanced technologies could be used to give some form of priority or preferential treatment to transit vehicles and HOVs. These are described in this section and in Sections 5.3.4 through 5.3.6. The systems and technologies involved are summarized in Table 7.

In the United States, a variety of schemes have been implemented involving the reservation of certain highway lanes for preferred vehicle types. These have included separated and non-separated concurrent flow lanes, as well as contraflow reserved freeway lanes (*207*). Some highways, such as Interstate Highway I-66 in Northern Virginia, are reserved exclusively for buses and HOVs during peak periods.

The use of advanced technologies in implementing and operating priority schemes can have two alternative goals: access control and violation enforcement. Access control is discussed in the following paragraphs, while enforcement is considered later in this section.

In general, the use of advanced technologies for access control would be applicable to schemes involving physical separation of the reserved facility and the other highway lanes. An example of this is the Shirley Highway Express-Bus-on-Freeway demonstration project of the early 1970s (*208*). This project used an 11-mile, two-lane reversible busway in the median of an existing freeway in the Virginia suburbs of Washington, D.C., to increase efficiency of transit operations.

In implementing an access control system, the objective would be to identify preferred vehicle types and to permit their entry into the controlled area. For buses, this could be achieved using some form of vehicle classification device, such as inductive loops or piezoelectric axle sensors, or AVI equipment. AVI could also be used to regulate access to HOV facilities, for car or van pool vehicles possibly by a smart card system confirming the required number of passengers.

In developing a scheme of this nature, some type of physical control may be desirable to prevent unauthorized vehicles from entering the facility. This could be in the form of a barrier, for example, which would be raised on detection of an authorized vehicle. The use of this technique for a separated HOV lane, with registered vehicles equipped with AVI transponders, may also require video or closed circuit television monitoring of the entry point. This would permit manual activation of the barrier for compliant but unregistered vehicles which did not possess the necessary on-vehicle equipment.

Ramp Controls. Another area in which advanced technologies could be used for access control is in bypass lanes at metered ramps. These bypass lanes for HOVs have been installed in several U.S. locations, particularly in California, and have been shown to be effective, safe, relatively inexpensive, and publicly acceptable (*207*). In addition, the Blue Streak Bus Rapid Transit project, carried out in Seattle, Washington, in the early 1970s, demonstrated an express bus service with exclusive use of a reversible ramp in the CBD (*209*). However, problems have been experienced with violations of reserved bypass ramps by low occupancy vehicles. These could be prevented by installing barriers that would be activated by transponders on registered HOVs. Buses could again be detected using vehicle classification techniques, requiring no additional on-vehicle equipment.

A principal drawback of physical access control for HOVs is the need for a manual activation capability. Without this, infrequent HOVs which did not possess the required equipment would not benefit. This would therefore act as a disincentive to drivers who only had occasional cause to use the HOV facility, or to those who did not wish to fit AVI transponders to their vehicles. An alternative to physical access control would involve increased monitoring and enforcement seeking to deter potential violators without physically preventing their entry. The use of advanced technologies for this application is described later in this chapter.

Toll Highways. Another environment in which preferential access control for transit vehicles or HOVs could be implemented is reserved lanes at highway toll plazas. One way in which HOVs and transit vehicles could be given preferential treatment at toll plazas is through charging lower tolls than for other vehicles. This could be achieved relatively simply using a nonstop automatic toll collection system based around AVI technology, as described in Chapter 2. Vehicles equipped with AVI that were identified as registered HOVs would be charged a lower toll. An in-vehicle smart card system could again be used to verify the number of passengers, while some form of enforcement technology could be used to detect any vehicles violating the system. Preferential toll charging would provide a financial incentive that could be as important as other priority techniques in encouraging participation in an HOV scheme.

Parking Areas. Advanced technologies could also be used to implement HOV-preferential schemes in parking areas. This could involve giving priority or reserved access into parking lots for HOVs, or charging reduced rates. Methods for implementing these schemes could essentially be the same as those described above for toll road applications. Again video or CCTV monitoring could permit entry of unregistered vehicles.

In the United Kingdom, a system has been developed which makes use of license plate scanners for parking lot entry control and charging (*210*). License plates of vehicles entering the lot are read by a scanner and transmitted to a central computer. If license plates are obscured or broken, an attendant is alerted and the license plate is input manually. When vehicles exit the parking lot, the license plate is again read, and the appropriate charge displayed to the driver. Such a system could equally be applied to HOVs using a local database of registered vehicles license numbers.

Enforcement. A significant problem with many current priority schemes for transit and rideshare operations is violation by other vehicles. This is operationally undesirable, in that the illegal use of the facilities by low occupancy vehicles reduces their utility to legitimate users. In addition, persistent and unpenalized violations cause frustration among HOV users. This may ultimately lead to the public perception that a priority scheme has failed, despite any operational benefits that may have been achieved. An HOV scheme in Miami, for example, was reduced in scope because of a high violation rate in combination with under use of the facility and a lack of police commitment to the project (*207*). Enforcement systems and technologies are summarized in Table 8.

As described in the previous section, one method of overcoming the problem of violations involves physically restricting access to the facility. However, this probably requires some form of barrier, reducing vehicle speeds and needing manual activation for some vehicles. Additionally, this method is not applicable in unseparated, concurrent-flow reserved lanes, which constitute a significant proportion of HOV facilities in the U.S.

An alternative solution would apply advanced technologies for compliance monitoring and violation enforcement on restricted facilities. In general, enforcement systems used in transit and rideshare schemes would operate remotely and unmanned. Some technology configurations would be capable of automatically identifying violators, while others would require manual assessment of the records produced.

At the lowest level of complexity, selected points along a transit or HOV-reserved facility would be monitored using video or CCTV equipment. Violators would need to be detected manually, either in real-time or through subsequent assessment of taped footage.

Table 8. Enforcement systems.

Technologies \ Services	Transit-reserved violation detection	HOV-reserved violation detection	Traffic signal violation detection	Banned turn violation detection	Violation recording equipment
Automatic vehicle classification	▲		●		
Automatic vehicle identification	▲	■	■	■	▽
Smart cards		■	■	■	
License plate scanners	▲	▲	▲	▲	▲
Video/CCTV	●	●	▲	▲	●
Conventional/electronic stills camera					●/▲
Video image processing	▽		▽	▽	▽
Dial-up schemes	▲	●	▲	▲	

KEY: ● Currently applied; ■ Near-term potential application (within 5yrs); ▲ Potential current application; ▽ Possible future application

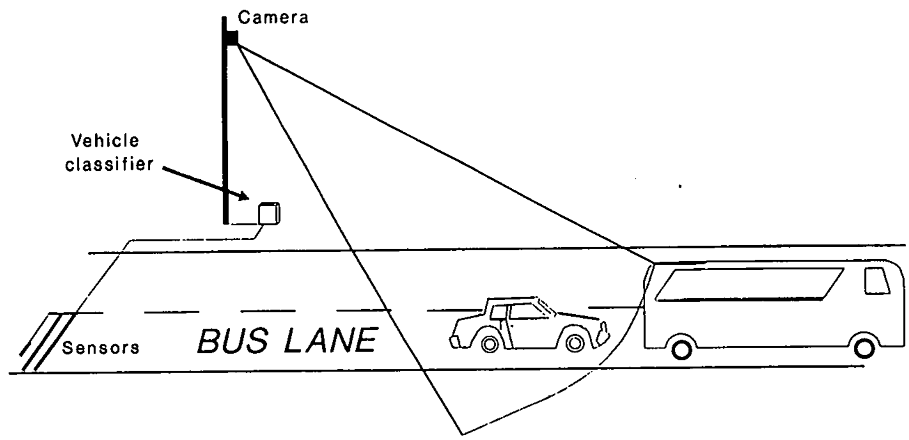

Figure 19. Bus lane violation enforcement.

A survey of HOV compliance monitoring methods published in 1989 revealed that video or CCTV equipment was generally not used for enforcement purposes (*211*). The California Department of Transportation (Caltrans) uses video cameras to monitor traffic and to provide images of license plates for O-D studies, but not to determine vehicle occupancy. Recently, however, Caltrans has been testing a system incorporating three high resolution cameras and sophisticated VCR playback equipment (*212*). The three cameras are positioned at different locations and angles to obtain a detailed view of a vehicle's interior. Manual assessment is subsequently used to determine the occupancy level.

Work has also been reported on the investigation of stills camera equipment for HOV violation monitoring (*211*). A prototype system consisting of a 16-mm camera, a flash unit, and an optical vehicle sensor was developed by the Naval Surface Weapons Center in 1977. Tests on the Shirley Highway I-95 HOV facility in Virginia indicated that the number of vehicle occupants could usually be determined, though in some cases light from the flash unit was absorbed by the car windows.

A similar technology that could potentially be used for HOV compliance monitoring is electronic stills cameras. These are similar in appearance to conventional stills cameras, but use a solid state imaging device to record the image on a magnetic disk rather than on film. Stored images can be transmitted over a telephone line for display on an ordinary television monitor eliminating the need for time-consuming retrieval and processing of photographic film.

A more complex level of enforcement would involve selective detection and recording of violations. For some applications, this could be achieved using automatic vehicle classification techniques. Violations of bus reserved lanes, for example, could be detected using piezoelectric axle sensors based on recorded wheelbases, or through vehicle "signatures" monitored by inductive loops, as shown in Figure 19. In the United Kingdom, a prototype system for the enforcement of truck prohibited zones has been demonstrated that could potentially be reconfigured to perform this function (*213*).

When implementing transit preferential signal control schemes it may also be desirable to incorporate red light enforcement to deter potential violators. An example is the Nottingham Zones and Collars experiment implemented in the U.K. in the 1970s. This sought to encourage the wider use of buses by giving priority at traffic signals while imposing artificial delays on private vehicles. Without a suitable deterrent, however, motorists were not prepared to wait for long periods at red signals and incur the time penalties. The Zones and Collars experiment was eventually abandoned, due in part to the high violation rates, as well as public opposition to the scheme.

A further level of automatic enforcement systems would involve unique vehicle identification rather than identification of certain vehicle types. This could be achieved using the AVI or license plate scanning technologies described previously. Automatic monitoring of HOV facilities would probably require this unique identification capability, because vehicle classification techniques would be unable to differentiate between HOVs and other vehicles of the same type. One possible equipment configuration for enforcement of HOV violations would involve the use of AVI equipment as well as conventional sensors for vehicle classification. Registered vehicles would be equipped with AVI, and would be identified by roadside equipment at monitoring points. Other vehicles illegally using the facility would not be detected by the AVI readers, but would be sensed by the classification equipment, which would trigger an enforcement camera.

A final enforcement option is that of telephone hotlines for the public to report restricted facility violators. These were initially introduced for HOV monitoring in Washington State in 1984, in a system known as the HERO. This allows Seattle area motorists to report the license plates of HOV violators by telephone, with violation data stored in a HERO program database. Reduced violation rates in Washington have subsequently led to adoption of the technique in other parts of the country. Recent research into the HERO program has called for greater encouragement of the use of car phones for reporting violations, possibly through a call-collect payment facility (*212*). In addition, the installation of an interactive telephone answering service during nonwork hours was advocated, which would be capable of prompting callers through a series of questions to obtain complete information on violators.

5.4 FLEET MANAGEMENT AND CONTROL SYSTEMS

The category of FMCS incorporates a range of technologies that are used to improve the operation of vehicle fleets. Some of these technologies have already been described in the context of

Table 9. Fleet management and control systems.

Technologies \ Services	Planning & scheduling	Data collection	Security	Vehicle dispatching	Location monitoring	Vehicle monitoring/ management
Operations software	●			●		
Electronic ticketing		●				
Onboard computers		●				●
Smart cards		▲	▲			▲
Automatic vehicle identification		●		●	●	●
Automatic vehicle location		●		●	●	
Automatic vehicle monitoring		●	●	●	●	●
Passenger counting systems		●				●

KEY: ● Currently applied ■ Near-term potential application (within 5yrs)

▲ Potential current application ▽ Possible future application

their application to individual vehicles. This chapter therefore focuses on their application to fleet vehicles and, in particular, to transit and rideshare vehicles. In addition, other technologies that may potentially be integrated with FMCS are also discussed.

Technologies that are currently being applied or have the potential for application within the area of FMCS include the following: transit operations software, electronic ticketing, OBCs and smart cards, AVI, AVL, AVM, and paratransit dispatching systems. The various applications and technologies involved are summarized in Table 9.

Transit Operations Software. One of the most widely used FMCS technologies is computer software for transit operations design and planning (*214*). This has included the following uses: network and operations planning, vehicle and crew scheduling, marketing, and management and administration.

A software package called BUSMAN has been developed for these activities (*214, 215*). BUSMAN is an on-line interactive minicomputer system which supports a wide range of computer programs for use by public transit operators. Among the facilities included in BUSMAN are: ROUTEPLAN, used for the development of new or revised routes based on known travel demands; TASC, designed for the scheduling of regular service vehicles based on user-defined routes, which may be obtained from ROUTEPLAN, and required levels of service; VAMPIRES, a network-based program designed for the scheduling of complete networks, which enables the user to define a target number of vehicles, and can be used either individually or integrated with TASC; COMPACS, used for scheduling crews in coordination with TASC vehicle schedules; and IMPACS, which provides input to, and receives output from COMPACs, and is used to produce an estimate of the number of duties required for a given schedule.

BUSMAN is by no means the only software currently in use for transit operations planning. Other widely used systems have included the Swedish VIPS (Volvo Interactive Planning System), and the North American RUCUS, SAGE, and HASTUS systems (*214*). The West German Ministry of Research and Technology has also funded research and development of transit operations software in the BISON (Betriebsfuhrungs und Informationssyteme fur der Offentlichen Nahverkehr—or Operational Control and Information Systems for the Public Transit Sector) project (*216*). Applications of the BISON software include route planning and scheduling, duty rostering, performance analysis, production and spare part control, and administration.

Electronic Ticketing. Another technology that may be applied to fleet operations is electronic ticketing for transit vehicles. The benefit of this technology lies in its ability to capture detailed information on in-vehicle transactions, as passengers enter the vehicle and pay their fare (*196*). Conventional mechanical ticket machines collect only a limited amount of data, such as a revenue summary and passenger count. Depending on the complexity of an electronic ticketing system (ETS), data that may potentially be collected include the following: revenue information disaggregated by route, by ticket type, or by passenger type; passenger information by ticket class, by route, or by time of day; passenger boarding/alighting information by stage; and partial O-D data.

Data collected using ETS technology can be used for a variety of management information applications. Marketing of transit services can be improved through the analysis of travel patterns of particular passenger groups. Continuous monitoring of demand can also be undertaken as a basis for considering changes in a transit network. Data collected using electronic ticketing machines can also be used as input to transit operations software packages discussed in the previous section. A further benefit of ETS is increased speed and ease of operation over conventional ticketing systems. The ETS concept is shown in Figure 20.

Electronic ticketing systems have been widely applied in a number of countries since their initial introduction in the late 1970s. Most common are in-vehicle systems for use in buses, although systems have also been developed for railroad booking offices and on-train use. The use of electronic ticketing machines in these environments provides a source of data that must otherwise be obtained through manual surveys.

The principal limitation in the use of ETS technology for data collection is its inability to deal with non-cash paying passengers. These can include holders of prepurchased travel cards or concessionary permits for free travel. The inclusion of these travelers within the collected data requires some form of action by the vehicle driver, which may be impractical on high density routes. The next section of this chapter considers the use of smart card technology to provide a solution to this problem.

Onboard Computers and Smart Cards. Recent advances in microprocessor technology have led to the introduction of computers in cars, trucks, and public transit vehicles. These have been used to monitor vehicle and drive behavior and to assist the driver in performing the driving function in an economical and safe manner.

OBCs are also being increasingly used to improve the efficiency of vehicle fleet operations. These include express courier, taxi, public transit vehicle fleets, and truck fleet operations. OBCs for fleet management (sometimes referred to as vehicle management systems or VMS) generally comprise a computer linked to a number of electronic sensors. These are attached to various vehicle components to provide information on vehicle performance and driver behavior. Information from the sensors is converted to digital form and can be stored in memory by the computer, together with time and date information from an internal clock.

OBCs may also have a facility for the input of parameters by the driver. Currently this facility usually consists of a simple keyboard. However, developing voice recognition technology may also be applicable in this area.

A number of fleet management systems are currently available, varying in capabilities and cost. These range from simple tachographs through taximeters to full computer-based management systems. Typical examples of each type of system are described in the following paragraphs.

The tachograph is an instrument designed to indicate driving time, speed, and distance covered by the vehicle. The information is recorded on a special chart against a time scale by means of several styluses. The charts produced can be examined to obtain information about driver and vehicle activities. Generally, this examination must be performed manually, although software is available which can interpret the data collected. Analysis of tachographs is therefore time consuming and often inaccurate.

Taximeters, originally developed to calculate taxi fares, have been advanced using new technology to measure and record many vehicle/driver characteristics. The latest taximeters are now capable of monitoring distance, time, speed, fuel consumption, engine rpm, and other operating variables.

There are many different manufacturers of taximeters, producing a wide range of devices from the basic "traditional" taximeter up to the "vehicle supervisor system" capable of monitoring fleet operations. Some of the fleet systems are radio-based, with information on the status of the vehicle transmitted to a central location whenever the radio is set to talk mode.

Computer-based vehicle management systems represent the highest level of current technology. A wide range of vehicle

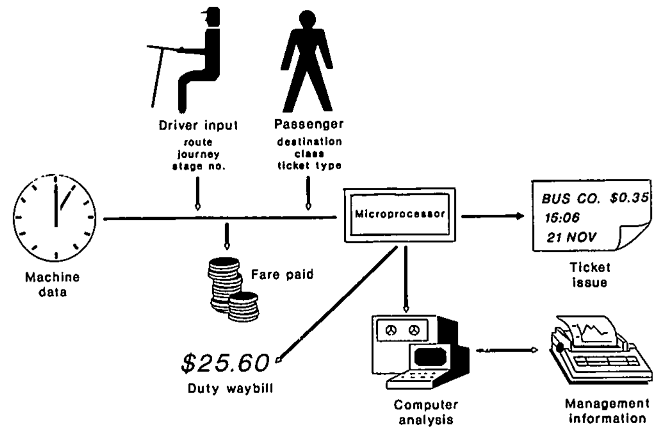

Figure 20. The ETS concept. (Source: Ref. 196)

management systems are currently available, varying in levels of sophistication and cost. Typical vehicle parameters monitored by the systems include engine rpm (revolutions per minute), speed, total trip miles, ignition on/off, water temperature, and oil pressure. Information is fed continuously from the sensors to the computer, as shown in Figure 21. Some systems make provision for manually entering additional information such as fuel purchases or other expenses.

A principal use of OBCs, in the context of fleet management, is for data collection. In these applications, information is collected, stored, and downloaded to a control center. It is then generally used to compile historical records which give an indication of driver and vehicle performance, for example: reports showing vehicle speeding, excessive idling periods, and the like, for individual vehicle or driver trips; summary reports, giving details of vehicle use and driver productivity; and database reports, giving life-cycle equipment and operating information. These are useful at many levels, enabling maintenance effectiveness to be determined, manpower and equipment needs to be assessed, and long-term fleet performance to be evaluated.

Smart card technology has already been discussed earlier in this chapter for use in traveler information systems, particularly in the area of trip reservation and payment. However, because smart cards are essentially miniaturized computers, they can also potentially perform many of the same functions as OBCs but in a much more portable form. Although the technology has not previously been widely applied to transit operations, some possible uses are described in the following paragraphs.

One potential fleet management application of smart cards within the transit industry is to improve data collection for operations management. Scheduling of transit services currently relies largely on historical trip data gathered by labor-intensive manual methods. Smart cards could provide many of these data, leading to cost and time savings and providing a more reliable basis on which to plan transit services. A reader system mounted at the entry and exit doors of a bus could be used to interrogate smart cards carried by passengers and determine origin and destination information. This would provide a trip database for planning purposes.

Other statistical data could also be carried on the card, providing information on the user such as age, sex, and frequency of travel. An important factor in public transportation marketing is price discrimination, through which different market sectors

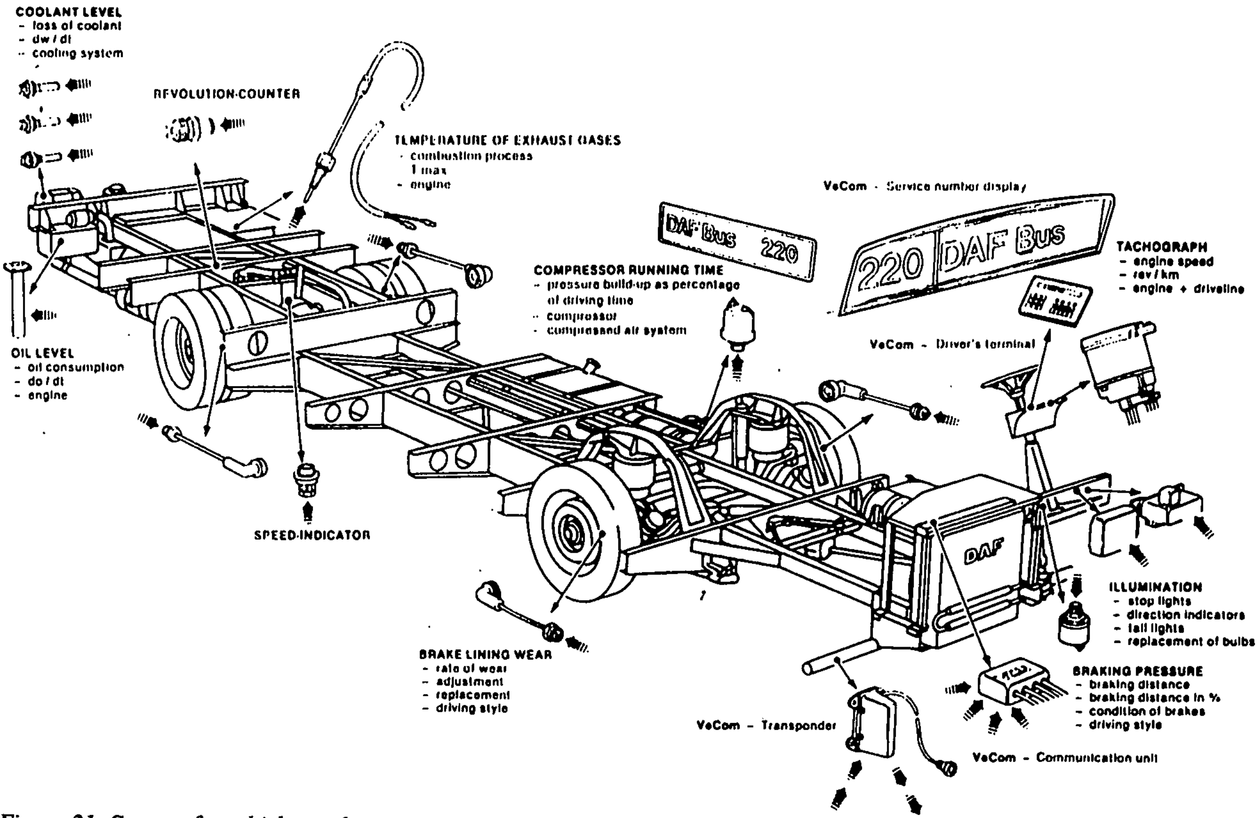

Figure 21. Sensors for vehicle condition monitoring.

are identified and charges set reflecting different elasticities of demand. Airlines use this approach in their complex pricing structures aimed at maximizing business revenue while permitting leisure travel at much lower fares. The smart card could open up similar potential for transit price discrimination by time of day, age, or route.

A further use of data collected from smart cards would be in supporting organizations that provide services to certain groups of travelers. This could include employers that distribute travel passes to their employees and request post-billing from a transit authority, for example. Additionally, social service groups which permit concessionary travel to those undergoing hospital treatment could provide smart cards to the traveler. This application would automatically produce documentation of concessionary pass use for subsequent audit by the social service organization to establish when and where subsidized travel is occurring. In addition, smart cards could be programmed to restrict the routes or times of day in which they may be used, as defined by the issuing agency. These applications would support the Urban Mass Transportation Administration's (UMTA) current Mobility Manager initiatives.

Smart cards could also be used for transit driver and fleet management. Drivers could be issued with a personal smart card, which would be placed on a reader in the vehicle during each journey. The smart card could then interact with other vehicle sensors to keep a log of driving hours, speeds, trip origins and destinations, and other data. The card could also be used to clock drivers in and out and, thus, record working and overtime hours for subsequent salary calculations.

Vehicle maintenance management is a further possible application of smart cards in transit operations. Here, a smart card would be allocated to an individual transit vehicle within a fleet to maintain records of the vehicle's operational status on an hour-to-hour, day-to-day, and month-to-month basis. Each smart card would be allocated to its vehicle at the start of the day and would be encoded with data from on-vehicle electronic sensors to provide information on performance and maintenance characteristics throughout the day. This information could be downloaded by maintenance crews via a card reader at the end of the day. This would provide a log of information which could form the basis of vehicle maintenance planning.

Automatic Vehicle Identification. AVI technology has already been discussed in some detail in this report, both in the context of providing driver information services for private vehicles, as well as in implementing priority schemes for transit and ride-share vehicles. This section discusses a further application of AVI to transit vehicles; that of vehicle location monitoring for fleet management purposes.

The use of AVI for fleet monitoring involves the installation of transponders on transit vehicles in the fleet, and the siting of reader equipment at selected monitoring locations. This configuration can be used as a management tool to display the route number, location and identity of vehicles at a central control point. Monitoring of services in relation to a planned timetable can then be undertaken allowing early remedial action to be initiated where problems are identified (*217*).

In Europe, the implementation of AVI for fleet monitoring purposes has often been combined with signal preemption measures and, to a lesser extent, with passenger information services. The Philips VETAG system, for example, has been used for these purposes in the town of Almere in the Netherlands (*218*). As well as providing for traffic signal priority, the system enables an operator in the control center to establish the positions of individual buses, to trace failure reports, and to initiate test programs for individual components. Data collected and stored by the central computer can also be used for economic and statistical analyses, and for maintaining logbooks and failure records.

Other fleet management applications of VETAG in Europe include the use of the system in France to facilitate automatic location display of 250 buses and streetcars in Grenoble, and to identify vehicles as they enter a bus station in Lyon (*219*). In this latter implementation, the identification of vehicles is used to automatically direct them to the appropriate platform, ensuring optimum use of platform space and maximum convenience for passengers and crews.

More recently, in the United States, AVI has been applied to the management and control of taxicab fleets. In particular, a number of airport authorities have implemented or are considering the use of AVI as a means of improving license control, automating dispatch functions, and monitoring vehicle access at their facilities (*220, 221*). Airports are frequently congested because of parked private vehicles at passenger exit points and unlicensed taxi cabs. The use of AVI to combat these problems therefore has significant potential benefits at these locations.

Automatic Vehicle Location. Perhaps the most widely used category of technologies and systems that has been applied to transit operations is AVL. As described in Chapter 2, the emphasis in AVL systems is on providing vehicle location data to a central control, allowing fleet managers to make more efficient use of their vehicles. A typical AVL system configuration is shown in Figure 22.

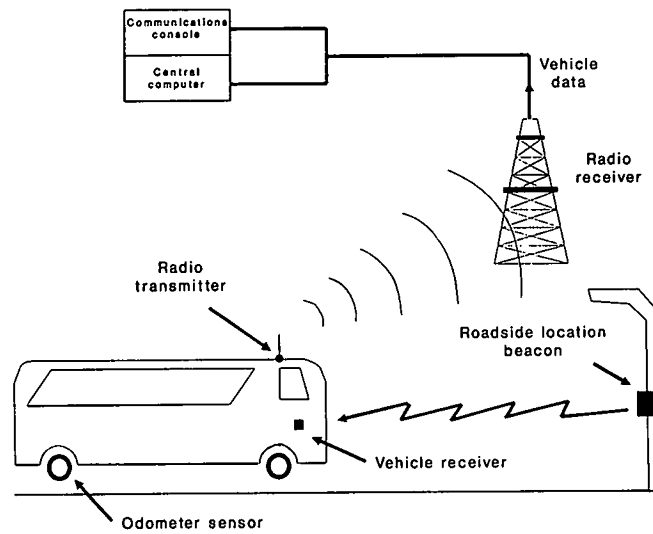

Figure 22. Typical AVL system configuration.

One possible AVL technology configuration is similar to the use of AVI for vehicle location monitoring, discussed in the previous section. In the United Kingdom, for example, a microwave-based system is being used to track midibuses along two downtown routes in London (*222*). The system works in conjunction with conventional radio communications between bus drivers and the operating base. A network of ten microwave beacons along the routes is used to identify vehicles and provide unique location data to a control center. A similar system has also recently been implemented in Ottawa, Canada (*223*).

Although the configuration described above is adequate for the task of providing a broad indication of vehicle movements, an inevitable drawback of the approach is that location data cannot be accurately established while vehicles are between beacons. Some AVL systems therefore use more frequent radio communications between the vehicle and the control center to overcome this problem. In these systems, location data are usually established on the vehicle, using either radio navigation or DR techniques.

Where DR is used to calculate vehicle location, the information is often supported by data transmitted from roadside beacons. These serve to correct errors that may accumulate during location calculations. An example of this type of system has been developed in West Germany and installed in the cities of Hannover and Wiesbaden (*224*). Onboard equipment is used to calculate vehicle location and other data, which are transmitted to the control center at 15-sec intervals. Infrared beacons installed at regular intervals along the bus route are used to calibrate the data stored on the vehicle. The system is used to compare the planned schedule with the actual state of the vehicle fleet, enabling timetable deviations and potential connection problems to be identified and handled at an early stage.

Radio navigation technologies have already been discussed earlier in this report, in the context of their application to onboard navigation systems and AVL for general vehicle use. Among those that can potentially be used for transit fleet monitoring are LORAN-C, GPS, GEOSTAR, and OMEGA systems (*225*). To date, however, there are no major implementations of radio navigation systems for transit applications known to the study team. A principal reason for this can be attributed to the high cost of radio navigation compared with beacon proximity or DR systems. In addition, accuracy problems have been reported with some radio navigation systems, particularly in built-up urban areas (*225*).

Automatic Vehicle Monitoring. A review of AVI and AVL systems reveals many similarities between the two technology areas. Some AVL systems make use of AVI-based equipment to establish a vehicle's identity at a known location, while others use what may be thought of as "AVI in reverse" to transmit location data from a roadside beacon to the vehicle. AVM takes the use of AVI and AVL a step further by integrating identification and location data with other vehicle-specific information. This provides for more detailed vehicle monitoring applications on a continuous or semicontinuous basis.

As well as schedule adherence and location, other information that can potentially be monitored using AVM includes passenger counts, fare information, vehicle condition data, and emergency status messages. A typical AVM system configuration is shown in Figure 23.

Passenger counting technologies have been incorporated into a number of fleet management systems in North America and Europe. An example was General Motors' transit information system (TIS), demonstrated on Cincinnati's Queen City Metro transit system (*226*). This produced data on passenger boardings and alightings, as well as travel times, per bus trip or bus route segment. The TIS was developed as an off-line system, however,

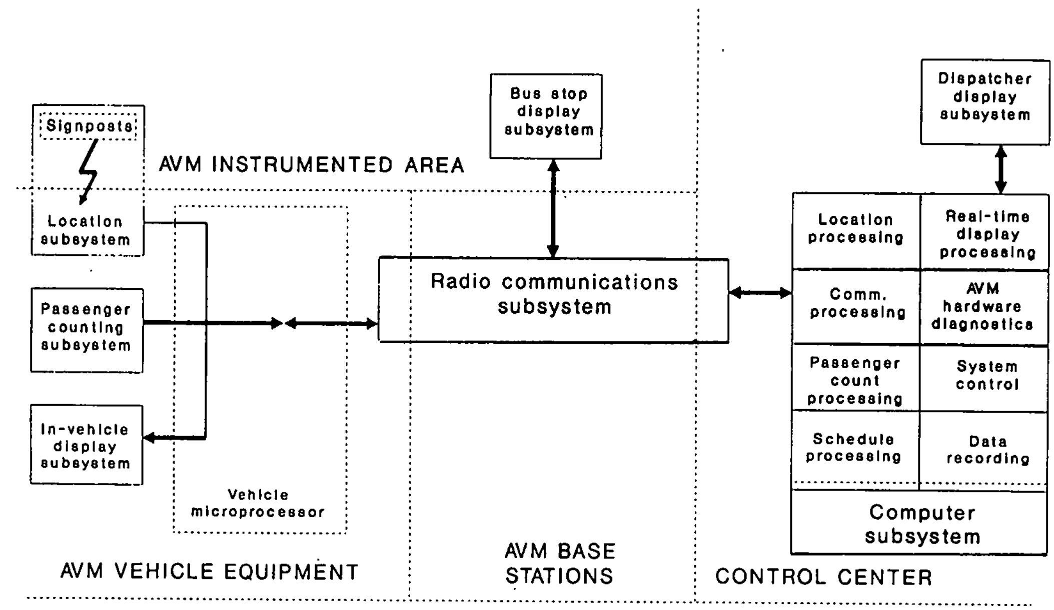

Figure 23. Typical AVM system configuration. (Source: Ref. 226)

and was therefore used for trip scheduling and route planning rather than real-time vehicle monitoring.

Elsewhere, examples of passenger counting systems have demonstrated real-time communication of count data to a control center. In Ontario, Canada, passenger counting is achieved through the interruption of an infrared beam as travelers enter and leave the bus (*227*). Count data are transmitted to a control center via roadside beacons, along with other information such as dwell time and location. The system has been designed as a planning tool, aiming to provide realistic schedules and fewer service irregularities.

An alternative to infrared technology for passenger counting involves the use of treadles at each door of the vehicle. This has been demonstrated in Turin, Italy, with data transmitted via a radio data channel to the control center (*228*). The system also includes a facility for automatically estimating the load on the bus using air spring pressure sensors.

Fare information can be collected by electronic ticketing machines, as described earlier in this chapter. As well as providing financial data, this could serve to offer an alternative method of passenger counting to the infrared beam or treadle technologies discussed above. At a further level of sophistication, smart cards distributed to passengers could be used to supply a variety of data to support AVM systems.

Vehicle condition information collected by onboard sensors could represent a further category of data used for AVM. The use of OBCs and smart cards for the continuous monitoring of vehicle or component performance and driver behavior has been discussed earlier. The addition of a real-time communications link to a control center as part of an AVM system would therefore enable operating problems to be identified at an early stage and dealt with appropriately.

AVM systems can also include a facility for the transmission of emergency messages to a control center. An example of this has been incorporated in the Toronto Transit Commission's communication and information system (CIS) (*229*). The Toronto CIS enables bus drivers to contact the control center by pushing a button when an automobile accident or similar situation is witnessed. Control center personnel are alerted by a buzzer, and can direct emergency services to the location of the accident which is automatically transmitted from the alerting vehicle. The CIS also has a silent alarm that can be activated when the driver is in danger, automatically opening a voice channel.

A review of progress in AVM was carried out by UMTA in the early 1980s (*230*). This reported on UMTA's program to evaluate the application of AVM in transit operations. A number of AVM systems were discussed, including the Bus Electronic Scanning Indicator (BESI), developed in London in 1959, through to more recent projects such as the Radio-Data-Locator system implemented in Queens Village, New York.

AVM has continued to develop since the UMTA study findings were published in 1981. This has been due in part to technological advances in AVI and AVL systems, which provide the communications network for many AVM systems. In Japan, for example, the development of RACS has been seen as a powerful tool to support AVM systems (*231*). In Europe, the two-way communications capability of the Veçom AVI system developed by Philips has been used to implement a modular vehicle monitoring and management system known as TRANSMATION (*232*). An example printout of data collected by the TRANSMATION system is presented in Figure 24.

Among the more recent examples of AVM implemented in the United States is a system developed for transit operations in the city of San Antonio, Texas (*233*). The system tracks the location of transit vehicles, automatically warns dispatchers of delays, and provides two-way voice and data communications between dispatchers and drivers. In addition, it has the capability to monitor vehicle operating characteristics such as oil pressure and coolant temperatures, as well as operational information such as passenger counts. The system was put into full use in San Antonio in early 1989, following more than a year of successful testing in the city.

Paratransit Dispatching Systems. Demand-responsive transit,

VISDRS50 DRAAIDATUM : 14-03-1990 TIJD : 11:04 BLADZIJ : 3

VIS-OVIS125 - OVERZICHT : GEHELE GEHEUGENPAKKET

(Date) DATUM : 13 (March) MAART (Tuesday) DINSDAG

BESTAND : I0797400
CBE-NUMMER : 12
(Fleet number) GROOTWAGENNUMMER : 450

(Line) LIJN	(Run) DIENST WAGEN	(Distance) AFSTAND (Current) HUIDIG	(Distance) AFSTAND (Total) TOTAAL	(Time) TIJD (Arrival) AANKOMST	(Time) TIJD (Departure) VERTREK	(Stop) HALTE TIJD (SEC)	(Door) DEUR OPEN (SEC)	(Speed) RIJSNELHEID (KM/UUR)	(In) IN (Current) HUIDIG	(Out) UIT (Current) HUIDIG	IN (Total) TOTAAL	UIT (Total) TOTAAL	(Occupancy) BEZETTING	(Remarks) OPMERKING
0023	27	380	24130	08:10:35	08:11:02	27	24	16,5	9	10	118	98	20 +	
		340	24470	08:12:23	08:12:58	35	32	15,1	7	2	125	100	25 +	
		430	24900	08:14:03	08:14:16	13	10	23,8	0	1	125	101	24 +	(Delay)
		160	25060	08:15:27	08:17:30	123	0	8,1	0	0	125	101	24 +	OPONTHOUD
		270	25330	08:18:24	08:18:43	19	15	18,0	6	11	131	112	19 +	
		440	25770	08:19:42	08:20:04	22	10	26,8	1	2	132	114	18 +	
		440	26210	08:21:06	08:21:17	11	7	25,5	0	2	132	116	16 +	
		190	26400	08:21:45	08:22:06	21	18	24,4	1	2	133	118	15 +	
		470	26870	08:22:57	08:23:07	10	7	33,2	0	4	133	122	11 +	
		320	27190	08:23:47	08:24:59	72	64	28,8	13	4	146	126	20 +	
		190	27380	08:25:33	08:25:56	23	22	20,1	1	2	147	128	19 +	
		580	27960	08:27:40	08:27:51	11	8	20,1	1	2	148	130	18 +	
		660	28620	08:29:07	08:29:31	24	23	31,3	6	2	154	142	12 +	
		590	29210	08:31:23	08:31:37	14	13	19,0	6	1	160	143	17 +	
		480	29690	08:32:28	08:33:10	42	40	33,9	4	1	164	144	20 +	
		300	29990	08:34:00	08:34:49	49	47	21,6	19	7	183	151	32 +	
		190	30180	08:35:33	08:35:45	12	11	15,5	4	1	187	152	35 +	
		370	30550	08:36:27	08:36:52	25	23	31,7	9	1	196	153	43 +	
		300	30850	08:37:35	08:37:51	16	14	25,1	3	4	199	157	42 +	
		860	31710	08:40:03	08:40:18	15	14	23,5	5	5	204	162	42 +	
		440	32150	08:41:48	08:42:05	17	16	17,6	1	12	205	174	31 +	
		620	32770	08:43:04	08:43:15	11	8	37,8	0	3	205	177	28 +	
		470	33240	08:44:03	08:44:21	18	15	35,3	1	23	206	200	6 +	
		930	34170	08:45:57	08:46:07	10	7	34,9	1	3	207	203	4 +	
		990	35160	08:47:42	08:47:50	8	6	37,5	0	1	207	204	3 +	
		400	35560	08:48:42	08:48:50	8	5	27,7	0	2	207	206	1 +	
		340	35900	08:49:58	08:50:01	3	3	18,0	1	0	208	206	2 +	
		280	36180	08:50:43	08:50:48	5	3	24,0	1	0	209	206	3 +	(Beacon) (Loop #)
		0	36180	08.50.50										ZENDER : 0245
		70	36250	08.51.03										ZENDER : 0245
		240	36490	08:51:37	08:51:41	4	2	22,8	0	1	209	207	2 +	
		400	36890	08:52:25	08:52:32	7	4	32,7	0	0	209	207	2 +	
		530	37420	08:53:25	08:53:38	13	10	36,0	1	3	210	210	0	
		100	37520	08.53.58										ZENDER : 0076
		200	37720	08:54:30	08:54:42	12	9	20,8	1	5	211	215	4 -	
		200	37920	08:55:12	08:55:29	17	13	24,0	2	1	213	216	3 -	
		660	38580	08:56:37	08:56:45	8	5	34,9	1	0	214	216	2 -	
		400	38980	08:57:58	08:58:09	11	8	19,7	1	4	215	220	5 -	
		550	39530	08:59:06	08:59:18	12	10	34,7	0	3	215	223	8 -	
		330	39860	09:00:08	09:01:16	68	13	23,8	0	3	215	226	11 -	
		30	39890	09:01:43	09:22:40	1257	44	4,0	0	1	215	227	12 -	
		20	39910	09:22:52	09:24:28	96	49	6,0	5	3	220	230	10 -	
		970	40880	09:26:46	09:26:54	8	8	25,3	4	0	224	230	6 -	
		350	41230	09:27:34	09:27:39	5	2	31,5	0	1	224	231	7 -	
		610	41840	09:28:34	09:28:41	7	7	39,9	3	0	227	231	4 -	
		420	42260	09:30:29	09:30:40	11	7	14,0	3	3	230	234	4 -	
		670	42930	09:32:12	09:32:20	8	6	26,2	2	1	232	235	3 -	

Figure 24. TRANSMATION data printout.

or paratransit schemes have somewhat different needs from those of more conventional transit schemes. This has therefore led to the development of advanced technology systems specifically for paratransit operations.

In the United States, for example, the Cape Cod Regional Transit Authority (CCRTA) has implemented a computerized management information system (MIS) for its b-Bus program (*234*). When the MIS was first introduced in 1980, the b-Bus program represented a 25-vehicle regional advance reservation, demand responsive service. Annual ridership exceeded 150,000, with a significant proportion of elderly and handicapped passengers.

The computerized MIS was introduced by CCRTA as a replacement for the labor-intensive manual management procedures used previously. The MIS was developed to provide on-line scheduling and various operational, managerial, and statistical reports. In addition, data gathered and maintained by the MIS enabled CCRTA to add a billing and payment system to support an innovative fare collection system. This replaced the previous fixed quarterly fee payment system with monthly automated invoicing, based on client type, trip purpose, and distance traveled.

Paratransit scheduling was not fully automated by the MIS, but the process was simplified by providing the receptionist with all necessary information in response to a trip request and the automatic transfer of relevant information to the trip file. This service also provided data to support other MIS services such as maintenance reporting, client billing, cost accounting and allocation, and statistical reporting. An evaluation of the cost effectiveness of the MIS, carried out following its implementation in 1980, indicated that the system had reduced the information management cost from $0.43 per trip to $0.30 per trip.

Another system developed for paratransit is the West German Ruf-Bus system (*235*). Ruf-Bus enables travel requests to be entered by passengers into computer terminals at bus stops. Data entered into the computer include the number of passengers in the party, so that a standard-sized bus, a minibus or a microbus can be dispatched in response to the request. The city of Friedrichshaven in West Germany has reportedly reduced annual transit operating costs by 20 percent following implementation of the Ruf-Bus system, and has also increased ridership, particularly in suburban areas.

5.5 SUMMARY

This chapter has investigated the application of advanced technologies within the transit and rideshare environment. Transit and rideshare schemes show particular promise in the area of congestion reduction, because they offer the ability to move large numbers of travelers using a limited number of vehicles. Advanced technologies can be used to encourage the use of transit and rideshare facilities, by improving their attractiveness and accessibility to travelers. In addition, the operational efficiency of transit and rideshare vehicles can be increased, offering reduced management costs and improved levels of service.

The chapter has considered three specific application areas for the use of advanced technologies in transit and rideshare operations. Advanced traveler information and service systems can be used to improve the convenience of travel, by providing travelers with a variety of data and service options. Advanced traffic management systems provide the ability to redress an historic imbalance in the highway environment, in favor of transit and rideshare vehicles. Finally, fleet management and control systems will allow controllers to achieve the optimal use of vehicle fleets, through increased monitoring and management.

Some of the technologies examined within this chapter can be used for several different purposes. The implementation of advanced technologies for transit and rideshare can therefore be undertaken within an integrated framework, designed to support complementary systems from each of the three application areas outlined previously.

CHAPTER 6

IMPLEMENTATION ISSUES

6.1 INTRODUCTION

This chapter presents a preliminary assessment of issues associated with the implementation of advanced technologies and systems. These include financing options; jurisdictional concerns; public/private sector roles; and consumer/user issues, such as the economic effect of widespread system implementation. The assessment considers current policies and infrastructure limitations that could present barriers to the implementation of advanced technologies.

6.2 FINANCING OPTIONS

This section examines potential funding sources available for developing the advanced technologies described in this report. It considers whether these developments would best be supported by the public or private sector. Additionally, it describes the sources of funding available to each.

Where advanced technologies involve new infrastructure development, the funding sources for the technologies may not differ significantly from those for other urban traffic and transit system improvements. Some of these new technologies offer a significant opportunity for private investment, but the majority of transportation infrastructures will rely on public funding of one kind or another for both initial capital costs and for ongoing operation and maintenance.

Where advanced systems involve a major in-vehicle component, private funding is the more likely approach. Almost all components of current motor vehicles have been developed and funded by the private sector, albeit with significant levels of government regulation and control. Government has also played a part in promoting various private sector developments through legislative processes and standardization.

The difficulties in funding new transportation improvements lie in determining who will benefit from the new system and in developing a method for distributing the costs of the system in an equitable manner among the users. Ideally, this distribution of costs should take into account both the amount of benefit gained by individuals and the ability of those individuals to pay.

The next consideration for funding is to determine where it can be obtained, and what is the potential size of each funding source. The most applicable sources for funding new transportation technologies are summarized in the following.

Public Sector Funding

The potential sources of funds for new technology system construction and operation can be categorized as public and private funding. Public funds can be obtained at several levels of government and can either be allocated from existing sources or be created through a variety of tax increases. Each potential source is discussed separately.

Federal Funds. Federal money is always a popular choice of potential users of a new transportation system. There are, however, several difficulties with the use of federal funds. First, they are difficult to obtain, precisely because they are so much in demand. Also, they usually require relinquishing some control over the system's design to the federal government. However, for new technologies, federal support may be crucial in order to provide consistency among cities, technical guidance, national exposure to important technologies, and large-scale funding for large-scale systems.

Four categories of federal funds are included in this section. All federal assistance discussed is controlled by the U.S. Department of Transportation (U.S. DOT), with the exception of so-called "set aside" funds.

1. *Grants and demonstration funds* are usually discretionary funds appropriated to demonstrate the potential for new and

innovative transportation projects. Funds are either allocated directly by Congress as part of a national funding bill allocated by the U.S. DOT administration to promote and test new technologies or practices, or set aside from other federal agencies to achieve a stated objective.

U.S. DOT demonstration money could play a critical role in the first application of many of the candidate new technologies. However, these funds are almost always limited to one project, and do not cover continuing operations and maintenance costs. Such costs must be borne by the operating agency. Also, the agency receiving demonstration funds must usually supply matching funds of an amount determined through negotiation.

2. *Federal pass-back funds* are used extensively by state transportation departments to fund the construction, maintenance, and operation of highway systems. FHWA officials indicate that high technology, traffic control improvement projects would qualify for some categories of these funds, depending on the technology and the specific application. However, competition for these funds is already strong within all states.

3. *New taxes*—almost all federal funding for road transportation is based on the federal gas tax. It is possible that this tax may be increased at a future date to provide more funds for transportation improvements. It is also possible that a fund similar to the interstate construction fund can be created. However, such a special nationwide tax increase or major reallocation of existing funds could only occur if the technology to be funded provided substantial benefits to the nation as a whole, required implementation on a national scale, and involved a fundamental change in the existing highway infrastructure.

4. *Set-aside funding* is support from an agency other than U.S. DOT that can be used to provide transportation improvements. Potential set asides include areas such as environmental improvement, energy conservation, and the development of alternative fuels. The exact nature and size of such funding sources are difficult to estimate in advance of the special circumstances which create them. Most set-aside funding is available one time only. This covers initial capital costs, but not on-going operations and maintenance.

The most important set aside currently available comes from oil rebate funds. In this instance, a series of lawsuits made by the federal government on behalf of the nation's energy consumers against oil companies resulted in several very large fines or out-of-court settlements against those oil companies. The fines have been placed in trust funds under the control of the U.S. Department of Energy in collaboration with the various state energy offices, with the stipulation that they must be used for reducing energy consumption.

State Funds. As with federal funds, state money for implementing high technology solutions to traffic congestion can come from either existing sources or from new taxation. Unlike an increase in federal taxes, the possibility that a state might pass additional taxes to pay for transportation improvements is more realistic.

To fund the state portion of statewide transportation system capital, maintenance and operational needs, most states use some combination of the following: state general funds, state fuel tax, vehicle registration fees, drivers' license fees, vehicle excise taxes, and personal property taxes.

It is likely that new technology solutions would compete with new construction or other projects for existing state resources. If estimated costs and benefits from new systems are compared with those of new construction, new technology systems may prove to be more cost beneficial.

However, there are several limitations to the reallocation of existing funds. State DOTs may have a natural preference toward building and maintaining roads. Some new technologies and their improvements to traffic operations may not be as "visible" to the public as new highways, leading to poor public perception. The public has a strong reaction to the need for more roads. Some new technologies may be perceived as being underutilized. Some systems may initially be too expensive for all drivers to afford, so public funding may be viewed as discriminatory.

Local Funds. Local jurisdictions have the authority to assess taxes in addition to state and federal taxes. Many urban areas use taxes within their jurisdiction to fund transportation improvements. Among the most common taxes that have been assessed by localities are local fuel taxes, sales taxes, and property taxes.

The greatest difficulty with local taxation comes from what is called the "border effect." This means that increases in taxation tend to cause the services being taxed to move outside of the borders of the taxed area. These border problems reduce the expected income from the tax and can create new transportation problems by fueling growth in areas without sufficient transportation infrastructure.

Sublocal Funds. Improvements for geographic areas smaller than a local entity are often funded through a fee for development within the area. For areas with significant transportation problems but little new development, special assessment districts can be set up either by government action or by cooperation among private developers. Such privately developed taxes are more commonly called "associations" and usually work in conjunction with public agencies.

Special assessment districts are intended to fund improvements to an area through taxation of the value added to the land after the improvements have been made. The concept is again one of equity: those who benefit from the improvement pay taxes to support the improvement. The difficulty in this approach is in first determining who will actually benefit from the proposed improvements and then in finding an equitable method for taxing those who gained.

In most cases, special assessment districts use one of the following methods for assessing additional property taxes within an improvement district. (1) *Ad valorem* taxes are paid on increases in the assessed value of the property due to the improvement made. (2) *Post-betterment* taxes are based on improvements to land values measured after an improvement is installed. And (3) *Tax increment financing* freezes taxes at a given date. Any increases in taxes paid as a result of increasing land value after that date must be used for a particular purpose, such as redevelopment.

To summarize, public financing of advanced technologies will most likely be appropriate where infrastructure costs analogous to current highway investments are concerned. A wide variety of funding sources are available based primarily on taxation imposed at any of the different levels of government. While taxation is almost always unpopular, and can readily be criticized on grounds of equity, border effects or low correlation with facility use, it will remain a major source of support for advanced technology demonstrations and applications.

Private Sector Funding

Private sector financing of advanced technologies will be more appropriate than public sector financing, where markets for equipment are associated primarily with individual motorists and automobiles. Private funds can be obtained from a number of sources, described in this section.

User Fees. User fees involve a direct charge to the public for the use of advanced technology systems. They are most appropriate for the technologies that require interaction between motorists and a central facility, but can also take the form of a rental charge for equipment. User fees are also widely accepted in the transportation area, forming the basis of funding for toll roads, and making a major contribution to funding for public transit.

User fees can be collected in several ways. The primary user fee structures are usage charges and subscriptions. Usage charges are applied as a motorist accesses the system. Subscription fees allow use of a system without specific user charges.

User Purchase. User purchase involves the motorist buying advanced technology systems for personal or business use. Where advanced technologies require the traveler to acquire special equipment for personal use in the home, workplace, or vehicle, private funding through user purchase is the most likely method of finance.

To purchase equipment for advanced technology systems, a motorist will need to determine that the benefit he will gain will comfortably exceed the purchase price and operating cost over a reasonably short period. This may be difficult in situations where systems are relatively untried and untested, as perceptions of the benefits will be generally inaccurate. Further problems arise where a technology has to be quite widely used before individual users gain major benefits, or where doubts exist over the commitment of a public agency to establish or operate a supporting infrastructure.

Despite these reservations over user purchase, for many advanced technologies there will be no practicable alternative for widespread system implementation. Although public funding or other forms of private finance may have a role to play in developing and demonstrating the potential of the technologies, the ultimate test of their success will lie in the marketplace.

Advertising. Information dissemination systems are particularly effective mediums for advertising. Audio-message systems used for driver information are a possible source of revenue from advertising. Videotext systems in the home or workplace might be supported by advertisers. Operation of such systems could be maintained either privately or publicly.

In a private system, the operating company might purchase, or be given, highway and traffic information from a transportation authority and it would dispense the information to motorists through a variety of media. Advertising would be presented between motorist information broadcasts, and the fees for advertising time would be used to offset the cost of information gathering and message transmission. A public agency might also perform the same function by directly broadcasting information.

Share Subscriptions. In some countries, governments are currently selling major public utilities and industries, primarily to small investors. The success of these sales is indicated by the large number of applications for each share issue. Shares can also be used to raise funds for new systems.

In the area of new construction, the buoyant private investment marketplace has directly led to the construction of the Channel Tunnel between England and France. Eurotunnel is a private sector Anglo-French consortium, which has been granted a concession to construct and operate the Channel Tunnel. Eurotunnel has arranged total finance of some \$11 billion, of which approximately \$9 billion is in the form of credit facilities and \$1.8 billion is equity finance. A share issue in November 1987 raised three-quarters of the \$1.8 billion equity finance.

Public/Private Cooperation. In recent years, diminishing revenues and increased demand for expenditures have resulted in federal, state, and local governments seeking alternative methods of financing major projects. One example of the change in funding emphasis in the transportation sector is the introduction of private sector financing of toll roads. While traditional toll road schemes were financed and operated by government agencies, new schemes are being proposed involving the private sector in financing, construction, and operation.

For the investor, these schemes involve large quantities of "up-front" capital, but with potential for significant returns. There is a risk element involved, however, as the usage level is unknown in the preimplementation stages. The advantage to the community is that more money is generated for road construction than would normally be available from public funds. Commercial toll road ventures may also have reduced lead times and construction periods, as all financing is available from the outset, and quick returns are needed. The major disadvantage to the government agencies and possibly the community is that with reduced financial involvement, government agencies may lose some control as policy makers.

One other example of major public/private cooperation lies in the European EUREKA projects. EUREKA is a framework for promoting collaborative projects in fields of advanced technology, which was agreed between 18 European governments and the Commission of the European Communities (CEC) in November 1985. The aim of EUREKA is to improve European competitiveness in world markets through civil applications of new technologies, by encouraging industrial and technological collaboration.

Industrial participants in EUREKA projects are eligible to apply for financial support from their national governments under existing economic development programs. In Britain, for example, the Department of Trade and Industry's Support for Innovation (SFI) scheme covers up to 50 percent of applied research costs and up to 25 percent of development costs. It is expected that EUREKA projects, having a commercial purpose, will obtain the remainder of their funds from the capital markets or from commercial sources.

Impact Fees. Some local jurisdictions have recently raised funds by the imposition of impact fees. These fees are paid by property developers in return for development concessions. Impact fees are usually used for the funding of all features of the developed infrastructure, such as highways, schools, utilities, and shops. They might also reasonably be used for funding certain types of advanced technologies.

The main advantage of impact fees is that they are private funds that do not affect government spending programs. There are, however, significant disadvantages to the use of impact fees. In particular, developer contributions to the infrastructure are inevitably passed on to the consumer in the form of higher rents and property prices.

Private Donations. Private donations for transportation improvements are usually related to specific business objectives or are realized because a company is extensively linked to the welfare of a particular town. While there are many reasons why a business might contribute toward a transportation system improvement, a desire to expand the density of development is usually the overriding factor.

Developers and land owners may voluntarily contribute to expanded transportation systems in order to increase the value of their property. In several recent instances, a business or group of businesses have formed transportation improvement associations to improve travel conditions into a major development. Tysons Corner in Virginia is one of the better known of these associations. At times, a developer may offer to make improvements as part of a negotiation with local government to allow development of a particular site.

In some cases, equipment manufacturers will provide equipment at reduced rates, or free of charge, to demonstrate their technology, or even as part of their final system development. This lets the company "debug" a system it wishes to market, provides a functioning product that can be viewed by potential clients, and gives the company access to a state-of-the-art transportation system. The costs of the initial demonstration to the company are recouped from future sales of the product being demonstrated.

6.3 FUNDING SPECIFIC TECHNOLOGIES

This section describes funding methods potentially appropriate for the technologies examined in this report.

Driver Information Systems

Electronic route planning systems would most likely be predominantly private enterprises. Revenue would be from user fees in the forms of either subscription services, purchase of self-contained systems, or single-use charges, comparable to a long-distance telephone bill.

Traffic information broadcast systems could be operated by a public agency or a private firm working in conjunction with a public agency. In both cases, the public agency would provide the traffic information using existing data collection techniques. The physical means for broadcasting this information could be operated by either a public or a private organization. Possibilities include commercial radio stations, public broadcasting, or specially operated DOT channels. The cost of the broadcast system would include analyzing the collected information, determining the messages to be transmitted, and physically transmitting those messages.

An alternative funding option would be for the broadcasting organization to be required to pay a fee for access to the traffic information. This fee would reduce the amount of public sector funding required for collecting traffic information. The broadcasting organization could recoup its costs through increased advertising attracted by the additional listeners making use of the traffic information.

Onboard navigation systems would most likely be developed and marketed by private firms. The cost of these systems would be borne by the user who purchased a system.

Externally linked route guidance systems would most likely require a combination of public and private support to be implemented. The public sector may be the most appropriate choice to develop the traffic monitoring and data analysis tools. The private sector is the logical choice for developing and marketing the in-vehicle systems for route guidance.

AVI systems could automate toll collection by identifying vehicles and entering the appropriate information into a database for later billing. Such systems would be built and run by the toll authorities, most of whom are currently public sector agencies. In this type of system, the toll authority would provide the capital for constructing the system. One exception to this might be vehicle transponders, which could be financed by either the user or the operating authority.

AVI systems could also be used to provide data for traffic monitoring. These systems would provide no direct benefit to individual users and, thus, would not be likely candidates for private operation or for user fees.

AVL systems include those systems that track fleet vehicles from a central location. These systems are primarily aimed at public fleets, such as police vehicles, and private fleets, such as delivery trucks. The costs of these systems would be borne by the users who purchase them.

Traffic Control Systems

Traffic control systems consist of a series of vehicle detectors, computers, software, and traffic control devices to monitor and control vehicular traffic. Traffic control systems will be operated and maintained by a public agency. None of these systems present a significant opportunity to charge user fees or present advertising. In addition, none of these technologies require new equipment within the automobile that a user might need to purchase. Consequently, each of these systems will require funding almost exclusively from the public sector. All of the systems are eligible for some kinds of federal, state, and local highway funds.

Fixed-time and adaptive traffic control systems can be run locally, within city or county limits, or run by state DOTs. Funds for these systems are most commonly based on some combination of state and federal (FAUS) monies. Some jurisdictions would be able to raise funding for these systems through special assessment districts and development fees, but at best the money available from these taxes would only provide a local match to state or federal funds.

Freeway control systems and automatic incident detection are almost always on state-operated facilities. As such, funding for their construction and operation would most likely be restricted to state and federal sources. When corridor control is included alongside the freeway, complex interjurisdictional funding issues will arise involving all levels of government.

AVC Systems

This category (automatic vehicle control systems) is divided into two parts, currently available systems and future systems. Currently available systems can be readily implemented on new vehicles. Future systems are still in the development stage.

Currently available systems include ABS, cruise control, speed governors, trip computers, and vehicle condition monitors. Each of these technologies is available on new cars in the United States. The costs of these developments are borne by the automobile industry and by consumers that purchase these vehicles. No public funding is currently used.

Future systems include a range of new technologies that are primarily private sector oriented, but several of them require public sector systems to work correctly. Many of the systems being investigated are intended to function independent of the roadway. Such systems might be developed and implemented within the private market, or could be the subject of joint public/private sector initiatives, as in the European PROMETHEUS program. Systems that require interaction with roadside electronics, or with sensors installed in the road, are likely to require public funds for installation of that equipment.

Given these assumptions, the most likely sources of funds will be national programs based on fuel taxes or other user fees. As with current highway funding programs, state participation in the funding of these projects would be essential. State funds will have to be either allocated from existing budgets or developed from increased in-state transportation taxes. If AVC leads to the development of automated highways, very large commitments will be needed from public sources. A major national program might be required, analogous to the interstate construction program.

6.4 JURISDICTIONAL ISSUES

This section discusses the jurisdictional issues surrounding the planning, implementation, operation, and maintenance of the various advanced technology systems discussed in this report. Included in this section are discussions of who should build, maintain, and operate the systems; how the potential traffic impacts of each system affect the selection of the operating authority; and when agreements are required between agencies or jurisdictions to create an appropriate operating authority.

Potential Operating Authorities

There are several potential jurisdictional structures for building and operating the various high technology systems. Most of the technologies can be built and operated successfully under more than one of these structures. The structure that is best for one particular application of a specific system will depend primarily on local conditions.

Single Jurisdiction Operation. Single jurisdiction operation is where one existing agency, other than a regional agency, operates the system for an area, whether or not that agency has jurisdiction over the entire area.

Single jurisdiction, or agency, operation is most appropriate when one agency already has control over all, or the great majority, of the roads to be covered by a new technology system. If a system is to be implemented entirely within one jurisdiction, that jurisdiction will obviously want and need to operate and control the system. If the system is then expanded slightly to cover a minor portion of another jurisdiction's roads, it is probably cost effective for the new jurisdiction to allow the first agency to operate that extension.

Single jurisdiction operation is also warranted when the system to be used is so large or complex that only one agency has the resources or capabilities to operate and maintain it. For example, it may not be within the resources of a small city to obtain the trained personnel necessary to operate such a system. A third reason for operation by a single agency is the need for centralized control of a system.

The biggest difficulty with this form of operation is that the single agency is not always sufficiently sensitive to the impacts of the system on the jurisdictions that surround the system. For example, local jurisdictions may not want the agency which operates the urban freeway system to route traffic onto specific arterials during incidents.

Multijurisdiction Operation. Multijurisdiction operation involves different jurisdictions operating their own systems independently of other jurisdictions. Coordination between systems of neighboring jurisdictions is done at the staff level, with or without interconnection between the systems themselves.

The advantage of multijurisdictional control is that each local jurisdiction retains control over its own system. This may lead to the best use of that system within each jurisdiction. However, it does increase the potential for conflicts between jurisdictions.

Another advantage of this type of operating structure is that it ensures that each jurisdiction that helps pay for a system receives benefits from that system. Because each jurisdiction operates its own system, it has control over how the benefits of that system are obtained, and how the system is used to shape the flow of traffic and influence surrounding land uses.

Regional Operation. Regional operation is much like single agency operation, except that a specific multijurisdiction agency is created to control the system. Such an agency can be specifically created to build, operate, and maintain a new system, or an existing agency can be empowered to take over those functions.

Regional authorities are appropriate when a system will span many jurisdictions, there is a need for a regional outlook toward system operation, and there is a need to reduce the impact of jurisdictional disputes on the day-to-day operation of the system.

By separating the operation and control of the system from individual jurisdictions, the staff that operates the system is given more freedom to provide transportation improvements to the region as a whole. A difficulty with regional authorities, however, is that they must have legislative approval to take on new tasks. Furthermore, if a regional authority does not already exist, it must be set up by legislation.

Private Operation. Private operation of the system has been divided into two parts, described as follows:

1. *Private monopoly.* In the first structure, a monopoly, legislation must be passed that will allow a single operator to serve a particular urban area or portion of an urban area without competition from other private concerns. In return, the private corporation gives up a measure of its rate-setting freedom and provides for substantial input from the public on how much money the company can make and what fees it can charge. Use of the monopolistic structure provides a more stable base for the company providing the service, and may give a more consistent service to the user. It helps ensure that the system's components will operate as a group and that improvements and parts to the system will be added in a coherent, cohesive, and compatible manner. On the other hand, private monopolies may be remote and nonresponsive to customer service issues, in comparison with private competitive firms.
2. *Private competitive firms.* The second type of private operation is the normal open competitive market. In this structure, any private company may make and sell products or services. Each company is responsible for meeting any specified standards, for setting prices, and for limited coordination with other companies, cities, and agencies.

The private, competitive structure is appropriate where competitive pressures will improve the quality and price of the system being promoted. It is also the least troublesome for local government, and probably the most cost effective for the consumer. However, if the competitive market structure is used, the government must be prepared to set standards to ensure system compatibility.

Jurisdictional Structures for Specific Technologies

Operating structures for the various categories of advanced technology systems are discussed below.

Driver Information and Communication Systems. Electronic route planning systems could be operated under any of the five basic structures outlined previously. The most likely choices would be private, competitive systems, or single agency systems.

Electronic route planning is a function that could be performed by the private sector. Keeping the market open to competition will allow market forces to select the appropriate type of service required by the users, resulting in a better match between service offered and price.

A private, monopolistic structure might be more appropriate if the basic route planning capabilities were only the first step toward an externally linked route guidance system. In this case, the need to provide incentives to a private firm (in the nature of a noncompetitive market) may be necessary to allow the accumulation of sufficient capital to construct the more complex system at some later date.

The provision of route planning systems could be undertaken by a variety of local agencies in an attempt to reduce total vehicular travel. If operated by a government agency, the single agency structure is most appropriate. This agency could be either the local transit authority, the state DOT, or a regional agency.

Traffic information broadcast systems could be operated equally well as either public or private entities. In addition, such a system may well be operated as a joint public/private venture, in that the traffic data needed to determine broadcast messages may come primarily from public agencies.

Commercial radio stations already perform the vast majority of traffic information broadcasting in the U.S. during peak hours, and it is likely that they will continue to perform that function. With dedicated traffic information broadcast systems, the installation and operation could easily be accomplished by private companies. The cost of traffic broadcasts could be paid for with advertising revenue or through a subscription fee. In either case, there is little warrant for a monopolistic structure for a private company.

As with route planning, if no private company wishes to undertake this type of project, a public agency may perform this function. A single agency structure, or single regional agency, appears to be the logical public sector alternative. The agency responsible for collecting and analyzing traffic information could also be responsible for controlling the broadcast function.

The difficulty with a single agency structure is that routing decisions made by the operators on the basis of optimum system performance may not be acceptable to the jurisdictions that are impacted by those decisions. It is likely that interjurisdictional agreements concerning preferred traffic routings would be needed before such a system was installed.

Onboard navigation systems will most likely be developed in the private competitive market. Several companies are working on systems that will soon be available to the public. Onboard systems within this category do not need to communicate directly with the highway infrastructure and, therefore, are not required to interface with public sector systems.

Externally linked route guidance systems will most likely be either a public/private venture or operated entirely within the private sector. The most promising technologies for electronic route guidance collect their own traffic data on journey times or equipped vehicles, before sharing that information to provide real-time routing advice.

Because of the complexity of the system, a private organization may require a monopolistic structure. The cost to the public vendor of installing the necessary communication equipment may be sufficiently high that without the incentives of a monopoly position, no private companies would be willing to enter the market. Additionally, the development of externally linked systems should be undertaken in accordance with a federal standard to ensure compatibility of systems between cities.

AVI systems can be used in several ways. Toll collection systems will best be operated with a single agency structure. These systems require strict control for accounting purposes. The agency operating the toll facility would build, operate, and maintain the system.

One-way systems for provision of journey time data and in conjunction with traffic broadcast systems will most probably be operated by public agencies. Any of the three public structures could be used for such a system, depending on who controls the broadcast and AVI systems.

Traffic Control Systems. Fixed-time control and isolated intersection control are currently operated using a multiagency structure. While this structure does not assist in the linkage of signal systems between jurisdictions, it does minimize conflicts created over funding and system operation. In European countries, traffic control systems are more commonly operated by regional jurisdictions responsible for whole metropolitan areas. This is considered to have management and coordination advantages that outweigh the benefits of local control.

Adaptive traffic control requires a strong interaction between signal systems, and a significant amount of centralized processing. While it would be possible to operate such a system under a multiagency structure as with fixed-time signals, a preferable method would be either regional or single-agency operation.

If a single agency or regional approach to this system is taken, it is desirable that each local jurisdiction have a significant input into the prioritization of movements within the highway system. It is important that the local level of government retains a large measure of control over the basic objectives of the traffic signal system within its jurisdiction.

Freeway control, including *automatic incident detection,* will be best performed by a single operating authority responsible for operating the freeway system. However, because the decisions made for managing the freeway control system invariably impact the surrounding arterial system, the operator of the freeway control system should have an input mechanism for the concerns of the local jurisdictions. Alternatively, a regional authority could be established to operate traffic systems within an urban area. Such a structure would be appropriate where a regional authority has been created to operate large interjurisdictional traffic signal systems or other wide-area systems that might feed information to the traffic monitoring process.

A multiagency structure may be more appropriate where data collection for traffic monitoring exists as a secondary purpose of the sensors. In this case, a single agency would provide the central processing capability to determine where the incidents were located, and would most likely fund, operate, and maintain the communication links between sensors and the central computer. Individual jurisdictions would be responsible for maintaining the sensors as part of their routine signal maintenance function. The arrangement would require written agreements between the involved agencies to clarify the responsibilities of the participating agencies and ensure system compatibility.

Automatic Vehicle Control. Current systems are all being developed by the individual vehicle manufacturers. These systems are, therefore, within the private competitive structure. Future systems are being investigated which require different degrees of highway/vehicle interaction.

The private competitive structure will be most appropriate to develop and implement those systems that are self-contained in the vehicle. For those systems that make use of technology built into the infrastructure, a combination of private, competitive, and single-agency or multiagency structures will be necessary to build, operate, and maintain the system.

It is likely that the development of these systems will take place primarily as a joint venture between private companies, U.S. DOT, and the various state DOTs. Initial installations will probably take place on state DOT highways, so the public sector portions of the systems will be operated by those agencies using a single-agency structure. As the number of roads equipped with these technologies increases, the public sector portion of the system will likely take on a multiagency structure.

6.5 CONSUMER/USER ISSUES

This section examines how people react to new technologies. Their perceptions of a technology are naturally very important in determining whether it will be adopted. One issue is the question of who benefits and how to allocate costs. Analysts may determine, from a societal point of view, that the benefits of the new technology outweigh its costs. The political process will then determine how costs are allocated. Whether or not this allocation corresponds to the public's perception of the distribution of benefits affects acceptance of the system. Some technologies' benefits may be widespread in the population, but people may not recognize the benefits they receive. Alternatively, benefits may be concentrated on the few who can afford the new technology. Public perception of fairness is important.

The problem of cost allocation is particularly difficult with many of the technologies described in this report. The savings or benefits obtained are generally spread thin and may not be perceived by the average motorist. People may not, therefore, be willing to support investments in these types of systems either individually or through public subsidy. Information on these benefits must be communicated to the consumer or public official in order to develop the required support.

A second set of issues in the acceptance of a new technology involves the secondary effects that people expect from a new technology. If they do not trust that it will work, they will not accept it. If they feel that it changes their lives too much, they may not accept it. If the new technology threatens them in any way, they will resist it. These barriers to change will need careful consideration in the development and implementation of advanced technology systems.

CHAPTER 7

TECHNOLOGY ASSESSMENT

7.1 INTRODUCTION

This chapter presents a preliminary evaluation of selected advanced technologies which show promise for relieving urban traffic congestion. Following this introductory section, the results of the initial assessment are presented for each of the major technology areas described in the report.

This initial assessment sought to identify benefits that may accrue from the technologies, in addition to purely relieving urban traffic congestion. Many of the systems under consideration may also give significant benefits in other areas, such as accident reduction, fuel saving, or driver comfort and convenience. The following areas were therefore included in the assessment: capacity gains, vehicle travel times, vehicle mileage traveled, air quality, noise pollution, traffic safety, driver comfort and convenience, and provision of additional traffic data.

These impacts and benefits are summarized in three assessment frameworks covering the broad technological areas described in previous chapters, and are discussed in Sections 7.2, 7.3, and 7.4. In the initial evaluation, the research team also determined quantifiable benefits for the selected technologies and compared these with available cost data. The results of this process are included in the assessment frameworks, and are summarized in the discussion.

The assessment frameworks also show implementation time-scales for each of the selected technologies. Within the context of this project, the primary focus was on technologies which could be implemented in the short- to medium-term. Realistic time-scales for widespread implementation were therefore determined for each technology in the following ranges, as an important input to the initial evaluation process: immediately available; short-term availability, 0 to 5 years; medium-term availability, 5 to 15 years; and long-term availability, > 15 years.

The results of the assessment presented in Sections 7.2, 7.3 and 7.4 were used to select three technologies for further detailed investigation in this project. All the items included in the assessment frameworks were considered in making this selection. A summary of the selected technologies is included in Section 7.5, together with other interim conclusions and recommendations reached at the end of the first project phase.

Finally, it is emphasized that the results given in this initial analysis are tentative in nature. In many instances, there is a significant shortage of existing information on which to base estimates because of the new and untried nature of the technology. More detailed examination of benefits and costs of the three selected technologies is presented in Chapter 8.

7.2 DRIVER INFORMATION SYSTEMS

This section presents an initial assessment of driver information and communication systems. Four advanced technologies and system options were selected for preliminary assessment in this area. These were chosen on the basis of appearing to have the greatest probability of being implemented in the short- to medium-term, and offering the most potential for having a significant effect on congestion levels.

Conceptually, driver information systems may provide benefits under two distinct sets of conditions. The first set represents "average" traffic conditions, with minimal real-time variations in the relative merits of alternative routes. The second set represents "real-world" traffic conditions, where changes in the traffic, highway, or environmental situation cause significant real-time variations in the merits of alternatives.

Systems that only provide information on average traffic conditions can be classified as "static" systems, while systems that also provide real-time network information are often referred to as "dynamic" systems. The extent to which dynamic systems provide real-time information depends on their degree of responsiveness to network conditions. Some systems provide limited real-time information, taking account only of major incidents or delays, while others are able to provide a much higher degree of responsiveness to all real-time changes in the network affecting the driving task. Potential benefits associated with each of the selected driver information technologies are summarized in the assessment framework of Table 10.

RDS-TMC Traffic Information Broadcasting System. During the course of the state-of-the-art review, a number of dedicated traffic information broadcasting systems were identified: HAR, AHAR, ARI, ARIAM and RDS. Of these, the RDS-TMC appears to show the greatest probability of bringing significant benefits in relieving urban congestion, and was therefore selected for evaluation in the preliminary assessment. Based on European experience, it was estimated that RDS-TMC could be implemented in the short-term, within a timescale of 3 to 5 years.

In assessing the RDS traffic information broadcasting system, two areas were identified in which major benefits would be achieved immediately, as indicated in the assessment framework of Table 10. The first is reduced travel times for motorists. RDS-TMC will allow drivers to be better informed in the event of an incident. Motorists receiving these warnings will have the opportunity to divert to avoid the incident and will thereby reduce congestion build-up at the scene of the incident. Reducing congestion in this way may help to minimize lost time to both vehicles equipped and those not equipped with RDS-TMC receivers.

Second, there may be improvements in comfort and convenience to drivers using RDS-TMC. These benefits would result because the in-vehicle RDS-TMC receiver is a highly selective device. Only information which is pertinent to a driver's route or corridor will be provided by the system. This allows the driver to rely on receiving only relevant traffic messages. Additionally, RDS-TMC is capable of operating in conjunction with normal car radio and audio-cassette equipment, muting the radio program or tape when a message is broadcast. This avoids the need for the driver to constantly retune the radio to ensure he receives the messages.

A third important area of potential benefit from RDS-TMC messages will relate to weather conditions, or warnings of traffic accidents ahead. Where drivers are unable to divert, or reschedule their trips, they will arrive at incidents better informed, and therefore better able to avoid being surprised. Although the road safety benefits of these advance warnings are very difficult to quantify, there is reason to suggest that gains could be worthwhile.

The effect of RDS-TMC on vehicle-miles traveled is uncertain. When drivers divert to avoid a problem, some will incur extra mileage, while others will find the arterial route more direct. This also relates directly to potential fuel savings. Air quality and noise pollution impacts could similarly go either way, but both are likely to be small overall. Environmental impacts on particular diversion routes could be significant, however, and care will need to be taken in specifying alternatives.

The capital cost (including installation) of an RDS-TMC receiver was estimated to be around $150 greater than that of a comparable normal car radio. This estimate is based on an assumption of substantial production volumes and an established market for the equipment, which may only be achieved a number of years after initial system implementation. Infrastructure costs of the system are detailed in the next chapter. Because the system builds on existing traffic control centers and conventional FM radio stations, these costs are expected to be as low as $275,000 for an entire metropolitan area. Annual operating costs would also be low because few or no additional staff would be needed.

Potential benefits, on the other hand, could be high. The interim project report presented results of an initial appraisal of the system based on computer modeling, in which quantifiable annual benefits of $65 million were estimated for the Seattle Metropolitan Area. More detailed computer analyses are presented in Chapter 8 of this report, which examine a wide range of applications scenarios. Benefits arise from drivers switching routes to avoid traffic incidents, a significant cause of congestion in major metropolitan areas.

Finally, RDS is gaining widespread acceptance in Europe, and has already generated considerable interest in the United States, Canada, and other countries. It has the advantage of being an internationally standard system, ensuring essential economies of scale for manufacturers. RDS uses low implementation barriers in conjunction with existing FM transmitters, and can cover much wider areas than systems such as HAR and AHAR. It also has the automated tuning capability at the basis of the AHAR and ARI systems.

Onboard Navigation Systems. The second technology evaluated in the broad area of driver information systems was onboard navigation systems. As discussed in Chapter 2, these can be divided into simple directional aids, location display systems, and self-contained guidance systems. Of these, self-contained guidance systems offer the greatest potential benefits because they provide actual routing advice to the motorist. This type of system was therefore selected for evaluation in this preliminary

Table 10. Assessment framework for driver information systems.

	Full Implementation	Capacity Gains	Travel Times	Total Miles Travelled	Fuel Savings	Air Quality	Noise Pollution	Traffic Safety	Comfort and Convenience	Real-time Traffic Data	Quant. benefit / year	Extra cost/ vehicle	Extra running costs	Infra-struc. costs
Radio data system	3 to 5 years	Nil	Substantial reduction for equipped vehicles	Uncertain	Uncertain	Uncertain	Uncertain	Substantial benefits	Major improvement for equipped vehicles	None	$ 65 m	$ 150	$ 175 k	$ 275 k
Navigation systems	Within 5 years	Nil	Significant reduc. mainly for equipped vehicles (7%)	Small reduc. (2%)	Small benefit	Some benefit	Some benefit	Benefit may be signif.	Substantial gains to equipped vehicles	None	$ 60 m	$1000	$ 3 m	Nil
Externally linked route guidance	4 to 6 years	Nil	Significant reduc. mainly for equipped vehicles (9%)	Small reduc. (2%)	Small benefit	Some benefit	Some benefit	Benefit may be signif.	Substantial gains to equipped vehicles	Major	$142 m	$ 250	$ 4 m	$ 27.5 m
AVI for toll collection	Within 2 years	Up to 300% increase	Reduced delays at plaza	No change	Some savings	Slight	Slight	Uncertain	Significant gains to equipped vehicles	Major potential benefit	$ 3.4 m	$ 50	$340 k	$ 1.5 m

analysis. Again, these onboard navigation systems were estimated to be available for implementation within the short-term timeframe of 5 years.

Self-contained guidance systems can assist drivers in both route-planning and route-following tasks under essentially steady-state conditions. They can take account only of average traffic and are unable to cope with dynamic real-time variations in traffic conditions. In order to provide the maximum benefits, the map databases on which these systems work need to reflect network characteristics such as travel cost and time, as well as distance.

One of the major benefits of onboard navigation equipment will come from reductions in vehicle travel times and mileage. This results from the system's ability to direct drivers along optimal routes, thereby reducing navigational wastage. The main benefits due to this reduced navigational wastage will accrue to the individual drivers who have bought and used the system. However, because of the reduction in congestion caused by the elimination of some excess travel incurred by fitted vehicles, there will also be secondary benefits to all traffic.

Additional benefits will arise in the area of driver comfort and convenience. These result from the ability of onboard navigation systems to provide drivers with routing advice which can help reduce uncertainty. This is particularly true at unfamiliar intersections where specific guidance will reduce or eliminate driver hesitation. Secondary benefits in terms of improved road safety may also be possible when driver uncertainty is reduced. Finally, to the extent that travel times and vehicle-miles traveled (VMT) are reduced, there may be reduced fuel consumption, improved air quality, and reduced noise pollution. These, however, would probably be small and are difficult to quantify.

A study of the extent of navigational excess travel in the United States was completed in 1986 by KLD Associates for the FHWA (*2*). This study estimated the proportion of all travel that is unnecessary under steady-state conditions, as follows: proportion excess distance = 6.4 percent proportion excess time = 12.0 percent.

In reality, a self-contained guidance system would be unlikely to recover all of the excess time because of difficulties in establishing minimum-time routes and other system imperfections. In order to take account of this, a factor of 80 percent was applied to the 12 percent proportion giving a figure of 9.6 percent for the maximum proportion of total travel time that could reasonably be reclaimed under steady-state conditions.

Having established the proportion of total journey time or distance that could be saved, an assumption was made of the criterion drivers would use to optimize their travel. This is necessary because in many cases the minimum-distance route between two points does not coincide with the minimum-time route. Drivers will therefore, on average, choose a route which uses some trade-off between time and distance, saving a proportion of excess time and a proportion of excess distance.

Experience in both the Japanese CACS project and European investigations into route guidance suggests that most people would normally use something approaching a minimum-time criterion for route selection. The estimates developed for this preliminary analysis are therefore that, typically, a driver will save 75 percent of the attainable journey time saving and 24 percent of the attainable journey distance saving. These figures are reflected in the assessment framework of Table 10 as initial estimates of travel time and distance savings.

The main cost item associated with onboard navigation systems is the in-vehicle equipment. The only onboard navigation system currently commercially available in the United States is the ETAK NAVIGATOR, which is marketed for $1,500. However, competition may grow in the future, causing price levels to fall. Therefore, a cost of $1,000 per system may be realized within a few years.

The operating and maintenance costs of an onboard navigation system are very low. These essentially consist of costs of periodic system repairs and regular updates of the digital map database. These costs have previously been estimated as $30 per year (*2*). If the system-wide costs are calculated for an estimated 100,000 users, the total running cost is therefore $3 million per year.

Potential benefits were assessed using data from the London AUTOGUIDE system appraisal (*66*). The static route guidance benefits were estimated as around $500 to $600 per vehicle per year (*66*) for usage within a typical large metropolitan area. For the Seattle area this corresponds to a system-wide annual benefit of around $60 million.

Externally Linked Route Guidance. The third technology evaluated in this initial analysis was externally linked route guidance. The most advanced point of the current state of the art in this area is a system with a two-way communications link between in-vehicle equipment and a roadside infrastructure. It is believed that this type of system would potentially provide the highest level of benefits, providing dynamic routing information that is fully responsive to network conditions. This type of system is exemplified by the ALI-SCOUT system currently undergoing major trials in Berlin, the AUTOGUIDE system being evaluated in London, and the Japanese route guidance systems which are being developed in the RACS project.

An externally linked route guidance system would help eliminate inefficient route choice to the greatest degree possible. It would not only reduce excess travel under steady-state conditions, but would also reduce suboptimal route choice which occurs because of real-time changes in traffic, highway or environmental conditions. The degree of responsiveness to these changes in network conditions would be the highest possible, with the system reacting to incremental changes in conditions as well as the occurrence of major incidents.

The system would, therefore, aid in reducing both recurring congestion and spontaneous congestion caused by incidents, by rerouting a proportion of the traffic away from congested areas. This would benefit both individual vehicles fitted with appropriate in-vehicle equipment, and all other traffic, which would benefit from the reduction in congestion caused by the rerouting of equipped vehicles.

Additional benefits would also accrue in other areas. Unlike the two systems described previously, implementation of an externally linked route guidance system would provide a very good source of traffic data. The vehicle-to-roadside communications link will allow information on traffic flows, journey times, and trip origins, and destinations to be determined. This will be very valuable for transportation planning and traffic management.

Drivers whose vehicles are fitted with appropriate in-vehicle units to receive real-time route guidance information would receive the greatest benefits from a route guidance system. These benefits would take the form of reductions in excess miles traveled and reductions in journey times. The first stage in evaluating these user benefits involved quantifying the extent of the problem of excess travel in terms of a proportion of total vehicle travel.

For evaluating the benefits of route guidance under essentially steady-state conditions, it was assumed that the maximum recoverable waste is the same as for an onboard navigation system—6.4 percent of total distance traveled and 9.6 percent of total journey time.

However, it is emphasized that these estimates are restricted to trip planning and route following under steady-state conditions. The excess travel time caused by deficiencies in route choice due to real-time dynamic variation in network conditions are not included. In order to assess this additional benefit, the results of major trials conducted in Japan were examined (*50, 51*). These involved comparisons of journey times between test vehicles equipped to receive dynamic route guidance information, and nonequipped vehicles. The trial results showed that the attainable time savings using real-time route guidance information in dynamic traffic conditions ranged from 9 percent through 15 percent with a mean time saving of 11.5 percent. This average suggests that provision of real-time route guidance in dynamic traffic conditions may have only a small additional impact over and above the time savings achievable through static route guidance information in steady-state conditions. The figure is believed to be conservative, however, because the real-time information available in the CACS trials was limited by the relatively small number of equipped vehicles.

The small reduction in vehicle-miles traveled will lead directly to a similar small benefit in fuel savings. Also, where travel time and VMT are reduced because of traffic redistribution, further benefits may accrue through improved air quality and reduced noise pollution. Reduction in VMT and the ability of the system to provide timely and accurate hazard warning information to drivers will also lead to a possible benefit in net accident savings.

The value of the quantifiable benefits was estimated in the interim project report as $142 million per year. The majority of this benefit results from journey time savings, with a smaller proportion resulting from excess distance savings. Over 90 percent of the benefits were accrued by equipped vehicles, the remaining gains being attributed to general reductions in congestion.

Consultations with system manufacturers suggest that the in-vehicle unit could be significantly less complex than the on-board navigation system, and may cost around $250 per vehicle in large volume production. Operating and maintenance costs could be similar. Infrastructure costs would be significant, however, and were estimated as $27.5 million to equip a large metropolitan area with an infrared beacon system. These estimates are refined in Chapter 8.

AVI for Toll Collection. The final technology evaluated in the area of driver information and communication systems was AVI. AVI can be used for a number of applications, but the particular application selected for evaluation in the preliminary analysis was the automation of toll collection, as described in Chapter 2 of this report.

In these specialized highway situations, congestion levels at toll plazas and on the approaches to plazas could be significantly reduced. This potential is currently being recognized by a number of toll authorities, including VDOT and the Texas Turnpike Authority, who are in the process of implementing AVI-based toll collection systems. Therefore, this technology application again falls into the short-term timeframe, with implementation possible within 2 years. The specific benefits which could result from use of AVI for automatic toll collection include the following: no cash or prepaid ticket handling by drivers, leading to increased convenience for the motorist; increased toll plaza capacity and throughput, leading to reductions in vehicle delays and/or avoidance of the need for construction of extended facilities; time and vehicle operating cost savings at the toll plazas and on the approaches to the plazas; administrative and security benefits for vehicle fleet operators, in not having to deal with tickets or cash; reduction in cash handling at toll plazas, giving increased security to the toll authority; staffing reductions for the toll authority through automation; and major potential source of real-time travel speed information for use in driver information and traffic management systems.

Table 10 summarizes potential benefits in the context of the framework evaluation.

A particularly important additional application of AVI for toll collection is to provide a valuable source of real-time traffic congestion data. Real-time travel times can be calculated as vehicles are uniquely identified at the toll plazas. Initially, these data will only be available for the toll facility. However, the system provides scope for easy expansion, with the provision of additional AVI readers at other sites off the toll facility, potentially providing wide-area data on traffic delays in real time.

Of the benefits outlined within the assessment framework of Table 10, the most significant are likely to be the time savings and capacity gains at the plazas. The scenario used to evaluate these benefits was modeled on a future facility similar to the Dulles Toll Road. This facility will consist of a 3-lane divided highway, with one main toll plaza with six toll booths in each direction. The facility also has toll booths on the six 3-lane eastbound entrance ramps and six westbound exit ramps. It was assumed that two of the six lanes in each direction at the main toll plaza are fitted with AVI readers, while one of the three lanes at each ramp plaza is fitted with an AVI reader. This scenario was compared with one where conventional toll collection methods are retained in order to evaluate the system benefits.

For this preliminary analysis, it was taken that queues develop at the toll booths only during the morning and evening peak hours in the major flow directions (eastbound in the morning and westbound in the evening). It was assumed that queues develop at the main plaza in each direction during 250 peak hours each year, when traffic volumes on the approach to the plaza are forecast to reach around 5,000 vph. Queues on each ramp plaza were assumed to be much less frequent, occurring during 30 peak hours per year, when approach volumes reach around 2,200 vph.

Under these assumptions, outside peak hours, delay incurred without AVI is simply due to the process of decelerating, stopping at the booths to pay the toll, and accelerating away. With AVI lanes, the time spent in this process can be reduced as fitted vehicles need not stop. In this analysis, it was taken that vehicles passing through an AVI lane can do so at around 30 mph.

Assuming that vehicle approaching the main toll plaza are initially traveling at around 50 mph, a suitable deceleration distance of 370 ft was calculated from American Association of State Highway and Transportation Officials (AASHTO) design criteria (*236*) for a vehicle without an AVI tag to stop at the toll booth. Traffic surveys performed in Hong Kong during a feasibility study of AVI-based automated toll collection (*237*) suggested that the average time spent at a toll booth is around 5 sec. The required distance to accelerate away from the toll booth back to the initial approach speed was also assessed from AASHTO design guidelines as 1,300 ft.

These figures give an overall time of approximately 51 sec spent in decelerating, paying a toll and accelerating, over a distance of 1,670 ft. Assuming that a vehicle fitted with an AVI tag decelerates to 30 mph going through a nonstop AVI lane, a travel time of 27 sec to cover the same distance can be calculated. The average time saving for each vehicle using an AVI lane at the toll plaza would therefore be 24 sec. A similar calculation can be performed for the ramp toll plazas showing a potential time saving of approximately 18 sec for each vehicle using an AVI lane.

Projected traffic flows for the Dulles Toll Road main plaza are on the order of 50,000 vpd in each direction. If the assumed peak flows of 5,000 vph are deducted from this figure, 45,000 vpd would pass through the main toll plaza in each direction outside the peak hour. If one-third of these vehicles use the AVI lanes, the potential total time saving to those vehicles is 36,500 hours per year. Applying the value of time and average vehicle occupancy figure used previously gives a monetary benefit of $613,000 for both directions of travel.

For the ramp toll plazas, the projected traffic flows are around 12,000 vehicles per ramp per day. If the 30 peak hours per year during which congestion occurs are excluded, the annual average off-peak throughput of each ramp would be around 4.3 million vehicles per year. If one-third of these vehicles are again assumed to use the AVI lanes, the total annual saving for all ramps would be 86,280 vehicle-hours, which equates to a monetary benefit of $725,000.

The time saving benefits during peak-hour congestion merit separate evaluation, since the use of AVI in toll lanes increases the plaza capacity. If this additional capacity is fully utilized, time savings will result not only for vehicles equipped with AVI, but also for nonequipped vehicles, through a reduction in congestion at the toll plaza.

For this analysis, it was assumed that traffic flow levels on the approach road to the main plaza are around 5,000 vph during each peak hour. The measured capacity on the Dulles Toll Road averages approximately 700 vehicles per booth per hour. Six conventional booths would therefore have a throughput of 4,200 vph, causing queues and delays to traffic at the plaza. Under a scenario without AVI, it was assumed that vehicles would spend an average of 3 min queuing at the main plaza during the peak hour.

If AVI was used in two nonstop toll lanes, the capacity of the facility would rise significantly. Observations undertaken during the Hong Kong Autotoll study suggest that an estimate of the capacity of an AVI toll lane of at least 1,400 vph is reasonable. During peak hours, a high proportion of drivers would be commuters who would have AVI tags fitted to their vehicles. For this analysis, it was therefore assumed that 50 percent of peak-hour vehicles would use the AVI lanes. This would eliminate queuing delays at the plaza because traffic demand for AVI lanes and conventional toll lanes would fall below the available capacity.

The total time saving benefits to all peak-hour traffic would therefore comprise time savings to all vehicles through the elimination of toll plaza queues, plus time savings to AVI-equipped vehicles through reduction in time spent passing through the plaza. The magnitude of the time savings to all vehicles would be 3 min per vehicle, which amounts to 250 vehicle-hours in each peak hour, in each flow direction. The annual time savings would therefore be 125,000 vehicle-hours in both directions, corresponding to a monetary benefit of $1.05 million. AVI-equipped vehicles would also benefit from an additional 24-sec time saving, equivalent to a total annual benefit of $70,000.

The peak-period benefits for the ramp plazas were similarly evaluated for the 30 peak hours per year when congestion was assumed to occur without any AVI lanes. The queuing delay in this case was assumed to be much shorter, with each vehicle delayed 30 sec on average without any AVI lanes. With an AVI toll collection system in operation, it was assumed that 50 percent of the peak-hour vehicles would use the AVI lane on each ramp. This would eliminate queues at the ramp plazas, resulting in time saving benefits to all vehicles.

Using calculations similar to those used for the main plaza, these benefits were evaluated as 6,600 vehicle-hours per year, for all ramp plazas, which corresponds to a monetary benefit of $55,400. The additional time savings to AVI-equipped vehicles were also evaluated as $16,600 per year during the 30 peak hours of interest. Totalling the calculated benefit figures, the annual value of potential time savings achievable through use of AVI for automatic toll collection on a specific toll road facility was estimated as $2.5 million.

Vehicle operating cost savings associated with use of AVI for toll collection would result from the reduction in congestion, delays, and stops. A conservative estimate was made that the value of vehicle operating cost savings would be around 10 percent of the value of time savings. This proportion gives an annual benefit figure of around $250,000.

Finally, operating staff cost savings represent a significant further benefit area of using AVI for automated toll collection. Benefits can accrue in this area from savings in staff required for the following functions: manual toll collection at the toll booths, collecting cash from toll booths and distributing change, and counting and processing cash.

For this preliminary analysis, it was assumed that the benefits in reduction of staff involved in collecting, distributing, counting, and processing cash might be offset by new administrative staff required to operate an automated toll collection scheme. However, benefits from reduction in the required number of toll collectors could be substantial. It was estimated that among toll collection staff, eight less main plaza collectors and twelve less ramp plaza collectors could be required. Taking the fully burdened cost of a toll collector as around $30,000 per year, the potential annual staffing cost savings would be $600,000. The total value of all system benefits quantified in this analysis would therefore be $3.38 million per year.

The estimated capital and installation costs of an AVI-based automatic toll collection system suited to the evaluation scenario are included in the figures given in Table 10. These can be divided into the central costs of AVI readers, computers, and communications equipment; and the costs to system users of AVI transponders. In developing these estimates, the number of vehicles fitted with AVI tags required to achieve the projected benefit levels was estimated to be 50,000.

The average operating life of all components of a toll collection system is likely to be approximately 10 years. If the total capital and installation costs are distributed over this period, the annual cost was shown to be around $500,000. The operating cost for a system of this type principally comprises the cost of data communications between the central computer and the toll lanes. For this preliminary analysis, it was assumed that data communications leased lines would be used for communications purposes. These were estimated to cost around $25,000 per year.

The maintenance costs for an AVI-based system are difficult to estimate because of the lack of long-term experience with such a system. The transponders should be maintenance-free throughout their operating life, and therefore incur no costs in this area. Annual maintenance costs for other equipment were assumed to be 10 percent of the capital and installation cost of AVI readers, processors, and computers. This was assessed as $140,000 per year. Combining these cost estimates, a total annual system cost was calculated at around $690,000. Of this total, $350,000 would be attributable to the transponders and $340,000 to the central system equipment.

In conclusion, the use of AVI equipment has considerable potential for improving toll collection procedures. Within the specialized toll road environment, automation could provide very worthwhile benefits. Within the scope of this project, however, primary emphasis was on those technologies that can be applied to a wider range of highway situations.

7.3 TRAFFIC CONTROL SYSTEMS

This section examines potential benefits of advanced traffic control systems. Five advanced traffic control technologies were selected for preliminary assessment from the technologies reviewed in Chapter 3, on the basis of proven performance or assessed potential from actual field experience. In this respect, the information base for traffic control systems is much better than that of other advanced technologies, where hands-on experience is harder to find. The benefits are summarized in the assessment framework of Table 11.

Optimized Vehicle Actuation. Optimized vehicle actuation could be beneficial in reducing unnecessary stops and delays at isolated intersections. This would lead to reductions in fuel consumption, noise, and air pollution. Some important gains include capacity increases because of more efficiently optimized actuation and reductions in lost time. Comfort and convenience should also be increased through the elimination of unnecessary and frustrating delays (see Table 11).

New microprocessor-based signal controllers are available that can be programmed to carry out more sophisticated vehicle activation strategies. In response, the MOVA strategy has been developed which allows demand-responsive control at isolated intersections. An evaluation study (*101*) of MOVA was performed at four signal-controlled intersections. This study demonstrated significant benefits of MOVA over gap-seeking vehicle actuation, showing significant delay reductions at all sites, with an average reduction of 15 percent during off-peak hours. These benefits were evaluated as $7,000 per intersection per year, for a projected infrastructure cost of $75,000 per intersection.

Although perhaps less exciting than some other new developments, optimized vehicle actuation may contribute more to highway efficiency than other alternatives considered in this report. This is due to the very large number of isolated intersections, which constitute a majority of all signalized intersections. Isolated control will remain predominant in all areas where signal density is low, as linking often is not a viable option.

Improved Fixed-Time Coordination. Improved fixed-time coordination is another option which could be pursued within a short-term timeframe. The primary benefit areas of improving fixed-time coordination will be the same as those of optimized vehicle actuation, namely reductions in congestion, travel times, stops, and delays. However, with coordination between signalized intersections there will be additional benefits through improvements in traffic flow over a wide area. It is also likely that secondary benefits will accrue in the areas of reduced air pollution, reduced fuel consumption, and improved driver comfort and convenience. These are summarized in the assessment framework of Table 11.

Through the FETSIM (Fuel Efficient Traffic Signal Management) program (*115, 116, 118*), the State of California has provided grants to local agencies for retiming of their traffic signal systems, using TRANSYT 7-F, in order to reduce fuel consumption, stops, and delays. In the 3 years of the FETSIM program (*118*), substantial savings in fuel costs, vehicle operating costs and traveler's time have been identified. Additional, unquantified benefits also include a decrease in air pollutant emission products through reduced delays and stops; benefits to transit operators and passengers because of reduced bus operating costs and higher average speeds; possible vehicle and pedestrian safety improvements because of smoother, more rational traffic flow; improved data for use by city governments and the private sector; and benefits of training provided to staff and consultants.

The cost of updating signal timings to provide improved fixed-time coordination is itemized as follows:

1. *Signal timing (labor)*	
Data costs (per signal)	$384 to $410
Modeling costs (per system)	$700
Implementation and fine tuning (per signal)	$36 to $40
2. *Other labor costs*	
Reports	$1,120
Secretarial	$48
Workshops	$1,460
Before and after studies	$1,920

Based on a network of 30 intersections, an estimate of total cost for updating signal timings would be $21,294, with an average cost per signal of $745.

In the 3 years of the FETSIM program (*118*), the costs and benefits for updating signal timings were as indicated in Table 12. Records of improved operating efficiency resulting from programs to retime traffic signals in states other than California are summarized in Table 13. These support the California experience and similar programs elsewhere. Improved fixed-time coordination plans can be highly cost effective, giving rates of return which will justify the investment in a very short period.

Partially Adaptive Coordination. Partially adaptive traffic control systems select signal plans from a predetermined library in response to changing traffic conditions. Of the many partially adaptive systems that have been developed worldwide, two systems—ATSAC in the U.S. and SCATS in Australia—are in current use, and have been the subject of field evaluations.

Previous evaluations of partially adaptive signal coordination have suggested that benefits achieved do not differ significantly from those of fixed-time coordination. Within the assessment framework of Table 10, therefore, the primary benefits of reduced congestion, travel times, stops, and delays for partially adaptive coordination replicate those of the fixed-time alternative. Again, secondary benefits of reduced noise and air pollution and improved comfort and convenience are predicted. In addi-

Table 11. Assessment framework for traffic control systems.

	Full Implementation	Capacity Gains	Travel Times	Total Miles Travelled	Fuel Savings	Air Quality	Noise Pollution	Traffic Safety	Comfort and Convenience	Real-time Traffic Data	Quant. benefit / year	Extra cost/ vehicle	Extra running costs	Infra-struc. costs
Optimized vehicle actuation	2 to 3 years	Signif. increase	Significant delay reductions (15%)	Nil	Some benefit	Slight benefit	Slight benefit	Minimal effect	Significant gains to all drivers	Optional feature	$ 7 k	Nil	Nil	$ 75 k
Fixed time coord.	Within 2 years	Some increase	Significant delay reductions (15%)	Nil	Signif. benefit	Some benefit	Some benefit	Minimal effect	Significant gains for all drivers	None	$ 20 k	Nil	$350	$ 1000
Partially adaptive coord.	Within 2 years	Some increase	Significant delay reduction (15%)	Nil	Signif. benefit	Some benefit	Some benefit	Minimal effect	Significant gains for all drivers	Major benefit	$ 66 k	Nil	$1500	$ 50 k
Fully adaptive coord.	2 to 5 years	Signif. increase	Substantial delay reductions (up to 27%)	Nil	Subst. benefit	Some benefit	Some benefit	Minimal effect	Significant gains for all drivers	Major benefit	$110 k	Nil	$1500	$ 50 k
Ramp control	Within 2 years	Signif. increase	Significant delay reductions	Nil	Some benefit	Some benefit	Some benefit	Minimal effect	Gains to mainline drivers	Optional feature	$ 30 k	Nil	$ 250	$ 45 k

Table 12. FETSIM program benefits.

Item	1983	1984	1985
Savings in fuel costs	$7,700,000	$6,700,000	$4,600,000
Savings in operating costs:			
due to reduced delays	$600,000	$400,000	$250,000
due to reduced stops	$13,400,000	$7,700,000	$5,100,000
Value of time saved due to reduced delay	$10,200,000	$6,200,000	$3,950,000
Total benefit	$31,900,000	$21,000,000	$13,950,000
Cost of program	$2,000,000	$1,100,000	$850,000

tion, major benefits are included in Table 10 for the provision of additional traffic data, obtained through real-time monitoring of traffic flows.

Only one evaluation of SCATS has been reported to date, carried out in 1980 at Parramatta (*126*), a regional center near Sydney. This site included 14 signals in a grid network, adjoining an arterial system of eight signals. Four signal control modes were evaluated in the trials. In the isolated control mode, the 22 signals operated without any form of coordination. The SCATS mode used all the normal features of SCATS available at that time. The TRANSYT and Linked Vehicle Actuated (LVA) modes operated with fixed-cycle, time-of-day selected plans optimized off-line by means of TRANSYT-7. The performance difference (PD) between the two main control modes (SCATS and TRANSYT-7) was calculated for the journey times and delays. A performance index difference was also calculated to combine the effects of journey time and delays. The results of the evaluation for the three areas covered are summarized in Table 14.

In the CBD, the difference between SCATS and TRANSYT-7F was not significant at the 5 percent level. SCATS was unable to achieve a reduction in delay even when compared with isolated signal operation, reducing stops by only 8 percent. SCATS was 10 percent worse than LVA on journey times in the CBD. On the Great Western Highway (GWH), SCATS was again unable to attain a significant improvement in journey times over fixed-time TRANSYT or LVA operation. SCATS did reduce stops by 25 percent when compared with the TRANSYT plans used in this study, but was not significantly better than LVA at reducing stops. Finally, on Church Street, SCATS was 26 percent worse than TRANSYT on journey times and 43 percent worse in stops. These highly significant results were attributed to a software error in SCATS producing grossly suboptimal progression for both directions of travel on Church Street. These results were therefore discounted.

To summarize, although the Parramatta study has been quoted as proving the success of SCATS in minimizing stops, delays, and fuel consumption (*125*), the results actually indicate that SCATS may be no better than a good set of fixed-time TRANSYT plans. More evaluation would be needed to support any conclusion that the system offers worthwhile benefits over fixed-time coordination, or over other second-generation traffic-adaptive systems.

The Los Angeles Automated Traffic Surveillance And Control (ATSAC) system was implemented in the Coliseum area in July 1984, 1 month before the summer Olympic Games. The installation involved 118 signalized intersections and 396 detectors covering an area of 4 square miles, some 5 miles to the southwest of the ATSAC Control Center in City Hall East. Over the following 3 years, important enhancements were made to the system, and the staff at the control center gained much operating experience. The ATSAC system represents the current state of the art in computer control of traffic signals in the United States.

The advantages of the ATSAC system include automatic adjustment of signal timing plans to reflect changing traffic conditions, identification of unusual traffic conditions caused by incidents, override of special event plans, short-term traffic timing changes in response to incidents, and automatic equipment malfunction detection.

The ATSAC system can accommodate 64 separate timing plans. Currently, 14 plans are resident in the computer. All timing plans have been developed off-line using TRANSYT-7F and "fine-tuned" through 3 years of actual operation. Critical Intersection Control (CIC) allows signal timing modifications within the constraints of the overall network plan selected. Decisions are made based on traffic volume and congestion level.

An evaluation study of the ATSAC system was carried out (*238*), limited to the northwestern quadrant of the Coliseum area. In all, 28 signals (7 operating under CIC mode) and 80 detectors were involved. Four arterials were evaluated with between 5 and 9 signals along each route of about 1 mile in length. The study included both morning and afternoon peak periods, 7:00 to 9:00 a.m. and 4:00 to 6:00 p.m., during a typical weekday.

Overall, the study showed significant improvement over the previous mode of control. Table 15 is a summary of the daily and annual network-wide savings to the motorist, based on an extrapolation of the Coliseum study, to cover the whole ATSAC area. The annual benefits from the Coliseum ATSAC system based on the figures presented in Table 15 were estimated as $7.84 million, itemized as follows:

	Amount ($)
Reduction in stops ($0.03/stop)	4,411,500
Reduction in fuel consumption ($1/gal)	1,337,000
Reduction in travel time ($2/hr)	2,091,000
Total annual benefit	7,839,500
Average annual benefit per intersection	66,400

The benefits shown are those resulting from operation under time-of-day plans with 25 percent of signals under CIC mode. Benefits not included were those due to operating under traffic responsive mode, nonrecurrent incidents, disabled vehicles, construction activities, manual override capability, other economic benefits because of reduction in emissions and in accidents due to smoother flow.

The total estimated cost of the ATSAC system was $5.6 million for construction, including equipment engineering and field work. The annualized cost was itemized as follows:

	Amount ($)
Construction and engineering	654,200
Operating and maintenance	148,400
Total annualized costs	802,600
Averaged annualized cost per intersection	6,800

The annualized construction cost of $654,200 was compiled using an 8 percent interest rate over 15 years expected life. Because this is higher than the current cost of money, and the system life is expected to be about 20 years, these cost estimates can be considered conservative.

Table 13. Updating signal plans in the United States.

Location	Programs used	Number of districts/cities/ signals	Given benefits or cost	Comments
Florida (1983-1984)	TRANSYT PASSER SOAP	6/30/511	cost: $594,000	only signals not requring new equipment were retimed
(1985-1986)		-/30/700	cost: $960,000	
Illinois	-	6/-/110+	to be determined	pilot demonstration
Maine (1982-1984)	SOAP TRANSYT NETSIM	-/30/150-160	improved signal timings, updated inventory	review of operating efficiency excluded new signals signals
Michigan (1984-1986)	-	-/26/1,000	budget: $750,000	funded by Department of Energy, Amoco Oil
Minnesota (1984-1985)	-	5 grants, of $155,000	budget limit: $15,000/project	Department of Energy grants
Missouri (1982-1984)	TRANSYT	-/8/161	cost: $800,000	TRANSYT runs free of charge at central location
New Hampshire	-	-/-/234	cost: $50,000	used state Dept. of Public Highways grants
New Mexico	PASSER			using controllers, then returning
New York	-	-/-/424	cost: $150,000	
project 1 project 2	-	723 eligible	cost: $47,000	within Nassau- A Statewide program similar to California will follow
N. Carolina	SOAP	-/-/300	cost: $400,000	isolated intersections used manual techniques
Pennsylvania	-	roughly 70 projects/year	savings in energy, congestion and improved safety	ECONS project upgrade throughconges construction, signal timing signing, geometric improvements, installation/ upgrade timings control devices
Washington	TRANSYT	City of Tacoma: 13 signals	cost: $15,000	Transportation Research Center at University of Washington demonstration project

Table 14. Results of the Parmetta SCATS/TRANSYT comparison. (Source: Ref. 121)

		CBD	GWH	CS
Journey Time % Diff.	Total	2.6	4.4	-26
	Lunch	-6.3	0.4	-31
	Peak	0.3	2.4	-31
	Late	-0.9	8.6	-8.6
Stop % Diff.	Total	1.2	25	-43
	Lunch	1.5	27	-66
	Peak	1.8	21	-34
	Late	9.1	26	-50
Performance Index	Total	-5.4	19	-24
	Lunch	-15	8.0	-19
	Peak	2.3	19	-35
	Late	3.1	20	-7.9

Table 15. ATSAC's network savings to the motorist.

Measure of effectiveness	Daily Savings	Annual Savings
Travel time (veh-hr)	4,182	1,045,500
Intersection delay (veh-hr)	2,199	549,800
Number of stops	588,205	157,051,100
Fuel consumption (gal)	5,348	1,337,000
Hydrocarbons (kg)	364	91,000
Carbon monoxide (kg)	3,273	818,300

The ATSAC evaluation quoted above does not examine whether similar benefits could have been derived by a wholly fixed-time system. Also, the quantified return does not consider how bad the system was before ATSAC, and may reflect this as much as how good it is now. Evaluations of similar systems in the UTCS program noted in Chapter 3 suggest that partially adaptive control does not necessarily produce significant benefits over and above wholly fixed-time, TRANSYT-optimized signal plans selected by time of day alone. These studies suggest that the additional complexity involved in partially adaptive control may not necessarily be cost effective.

Fully Adaptive Coordination. As with previous types of traffic signal coordination, the principal benefits of fully adaptive control are in the areas of reduced congestion, travel times, stops, and delays. With the increase in effectiveness over other signal control techniques offered by fully adaptive control, the benefits in these areas will be high. Resulting secondary benefits might also be assumed to be greater than those for the earlier alternatives, as shown in Table 11. In addition, major benefits are expected through the provision of additional data from the comprehensive network of traffic sensors used in fully adaptive signal control systems.

One fully adaptive control system without predetermined background plans has been shown to be more effective than recently optimized TRANSYT fixed-time control, selected by time of day. This is the SCOOT system described in Chapter 3. Benefits that adaptive control has achieved over TRANSYT in several cities have been extensively documented by TRRL.

In summary, the first trial was performed in Glasgow which compared SCOOT with up-to-date, optimized fixed-time TRANSYT plans during a 5-week period. Averaged over a day, there was a 6 percent reduction in journey time, equivalent to a 12 percent reduction in delays at signals. It is not certain why benefits varied during the day, but adaptive control appeared to be most effective during the afternoon and the evening peak when traffic demand in downtown Glasgow is highest. All of the major delay savings were statistically significant.

In order to test the system further, SCOOT was installed in Coventry, a much smaller city of some 300,000 people. Two subareas in Coventry, having a total of 27 sets of signals, were chosen to complement the experience gained in the central business district of metropolitan Glasgow. The results of a 5-week trial in the Foleshill Road area are shown in Table 16. The average reduction of 5.5 percent in journey time corresponds to a saving in delay of about 27 percent during the working day. The ratio of delay to journey time was higher along the Foleshill Road than in Glasgow because the link lengths were longer (1,000 ft on average, against 350 ft). Subsequent appraisal of SCOOT in other cities has confirmed its advantages over purely fixed-time control.

Initial estimates of fully adaptive signal coordination costs and benefits (detailed in the interim report for this project) are refined in the next chapter.

Ramp Control. The final technology considered in this section, ramp control, has been more widely used in the United States than in other countries. Evaluations have been carried out in many cities (*239, 240*), which have been widely disseminated and are summarized in this project's interim report.

The major benefits which can be obtained by the control of vehicles at freeway on-ramps include reduced travel times and significant capacity gains for mainline traffic. Although some delays are incurred by vehicles entering the freeway, ramp control promotes smooth traffic flow along the mainline freeway and increases fuel efficiency. Secondary benefits in the areas of reduced noise and air pollution can also accrue. There may additionally be improvements in comfort and convenience to mainline motorists through metering the rate at which merging vehicles enter the facility.

Table 16. Results of the Coventry SCOOT trials.

Period of the day:	Journey Time Saving using SCOOT:
Morning peak	5%
Between peaks	5%
Evening peak	8%

7.4 AVC

This section presents preliminary estimates of the potential of AVC technology. AVC systems were described in Chapter 4; they include currently available systems through to long-term options such as the AHS concept. This section examines a range of possible systems, and gives an indication of the potential of each system for relieving urban congestion. The results of this assessment are summarized in Table 17.

Antilock Braking Systems. ABS is a technology that could undergo widespread implementation in the medium timeframe, being already fully developed and demonstrated. The main benefit of ABS lies in improved traffic safety through a reduction in the number of accidents. In particular, the use of ABS may substantially reduce the risk of accidents due to poor application of vehicle brakes. Investigations outlined in Chapter 4 (*164*) have suggested that approximately 7.5 percent of all road accidents might be prevented if ABS was fitted to the vehicles involved.

In addition, there may be small additional benefits through the reduction of congestion that occurs around traffic accidents. A more important benefit, however, could be the increased comfort and security a driver experiences when using a vehicle fitted with ABS. These factors are reflected in the assessment matrix. Initial estimates of system costs and accident saving benefits per vehicle are also included in the assessment matrix. With widespread implementation, the cost per vehicle of ABS was estimated at $800, while the accident saving estimate shown is detailed in the project interim report.

Speed Control Systems. Two currently available speed control systems are described in Chapter 4: cruise control and governors. These are each discussed below.

Speed control systems offer benefits in two main areas: reduced fuel costs, and improved comfort and convenience to drivers. Operating cost savings are achieved through a reduction in acceleration and deceleration cycles and, in the case of governors, through a limit on speeds. This benefit is potentially substantial, with a small secondary reduction in air and noise pollution. Substantial benefits were also estimated for a reduction in accidents through the use of governors on heavy trucks.

Consultations with manufacturers suggested that the cost of supplying and fitting a governor is currently between $600 and $900. With widespread implementation in the long term, this could fall to around the same price level as cruise control. A long-term price estimate of $300 per truck was therefore developed, and is included in the assessment matrix.

In its present form, the main benefit of cruise control lies in improving driver comfort and convenience by simplifying the task of driving. This benefit is particularly hard to quantify, as individuals' perceptions of its importance, or even its desirability, are diverse. Additional benefits may also be gained from cruise control through a reduction in vehicle operating costs. Specifically, the transition from manual control to cruise control can result in a decrease in acceleration and deceleration cycles, leading to smoother engine running and, consequently, more efficient use of gasoline and oil.

Although cruise control systems presently offer little potential for reducing accidents or increasing capacity, this may not always be the case. The PATH and PROMETHEUS programs include the concept of "intelligent cruise control," in which systems would be capable of responding to external vehicle sensing devices. Systems could interpret sensor information on road and traffic conditions, vehicle speed, obstacle detection, and visibility, and would potentially have implications in the areas of safety and congestion reduction. Preliminary research suggests that prototype systems may be ready for demonstration soon. This option is considered further in the next section.

Variable Speed Control. VSC systems are another near-term possibility, allowing vehicle speeds to be automatically optimized. The main potential benefits of these systems are increased safety and improved fuel efficiency, particularly at approaches to traffic signals. Overall, vehicle speeds might be optimized to prevent collisions, maximize throughput, and minimize stops.

The main potential benefits of VSC are savings in fuel costs and reduced accident rates. The optimization of speeds may also result in some small-capacity increase. Control of speeds should result in the reduction of speed-related accidents. Additionally, removing the task of controlling speeds from the driver will have some comfort and convenience benefit.

To allow VSC systems to become a practical reality with widespread implementation, a low-cost infrastructure will be needed which could reasonably be installed on most roads. The option of installing small permanent magnet reference markers at differential spacings in the traffic lane, outlined in Section 4.4, could meet the low-cost infrastructure requirements and be deployed almost everywhere.

The safety benefits of a system which automatically slowed up traffic approaching reduced speed zones or adverse highway geometry could be substantial. Like current cruise controls, intelligent cruise would not force drivers to comply with limits, but it would help them to do so by making compliance easy. The safety gains and comfort/convenience advantages could well be sufficient to promote widespread acceptance of the system.

A more advanced option would transmit variable speed guidance using AVI technology, for example, in approaching intersections. Fuel savings and improved throughput achieved by such a system at traffic signals would be similar to those of the German "funnel." This system, described in Chapter 4, helps drivers select the optimum speed for approaching signals. Significant benefits have been claimed for the funnel technique, which is implemented using variable message signs. An automated system based on VSC might do significantly better than the variable message signs at funnelling traffic into signalized intersections.

A further potential use of VSC technology would be on freeways, to meter traffic into congested freeway sections and prevent breakdown of flow. This would be analogous to ramp metering, except that speeds would be automatically controlled on the mainline through VSC technology.

To summarize, initial review of VSC technology indicated that its implementation may lead to benefits in a number of areas. For maximum benefits to be achieved, all vehicles would need to be equipped. Considering the current state of development, a research effort is now required before the system could be fully implemented. VSC systems seem likely to offer potential for demonstration and implementation in the medium term.

Radar Braking. Radar braking is more complex than any of the AVC technologies previously discussed, requiring longer term development prior to widespread implementation. In this assessment, a timeframe of at least 10 years was estimated for this to occur. A number of major obstacles still need to be overcome in these development stages.

The main potential benefit of a radar braking system would be in reducing accidents. In particular, radar braking could help

Table 17. Assessment framework for automatic vehicle control systems.

	Full Implementation	Capacity Gains	Travel Times	Total Miles Travelled	Fuel Savings	Air Quality	Noise Pollution	Traffic Safety	Comfort and Convenience	Real-time Traffic Data	Quant. benefit / year	Extra cost/ vehicle	Extra running costs	Infra-struc. costs
Antilock braking system	Within 10 years	Nil	No change	No change	None	No change	No change	Substan. benefit	Uncertain	None	$ 37	$ 800	Nil	Nil
Speed governors	Within 10 years	Nil	Uncertain	No change	Substan. benefit	Some benefit	Some benefit	Substan. benefit	Some benefit	None	May be subst.	$ 300	Cost	None
Variable speed control	5 to 10 years	Some increase	Uncertain	No change	Substan. benefit	Some benefit	Some benefit	Substan. benefit	Some benefit	None	Uncer-tain	Under $1000	Cost saving	Low to medium
Radar braking	10 to 20 years	Nil	No change	No change	None	No change	No change	Substan. benefit	Uncertain	None	$ 700	Uncer-tain	None	None
Automatic headway control	5 to 10 years	Some increase	Small reduction	No change	Some benefit	Slight	Slight	Signif. benefit	Some benefit	None	May be signif.	Uncer-tain	Poss. cost saving	None
Automatic steering control	10 to 20 years	Some increase	Small reduction	No change	Slight	Slight	Slight	Some benefit	Some benefit	None	Prob. low	Uncer-tain	Low	Medium
Automated highway	20 to 30 years	Increase may be substan.	May be re-duced sub-stantially	No change	Uncertain	Some benefit	Uncertain	Benefit may be substan.	Major benefit	Major benefit	May be very substan.	Uncer-tain	Low	High

eliminate a significant proportion of rear-end collisions, together with a smaller proportion of head-on accidents. These accounted for 24 percent of all accidents in 1985. Fixed object and intersection collisions are also possible candidates for effective system use.

An associated secondary benefit would be that of reduced congestion occurring at the scene of traffic accidents. The system may also lead to some small benefits in terms of driver comfort through increased confidence in having the radar braking system. Benefits in other areas considered in the assessment matrix framework are expected to be negligible.

In order to achieve the greater part of the quantified level of benefit shown in the assessment matrix, all vehicles would need to be equipped with radar braking systems. This might become feasible in the long-term future, if radar braking becomes an accepted standard feature on new vehicles.

The likely cost of radar braking systems is difficult to estimate. Past experience gives little indication of system costs. Research and development in the late 1960s resulted in the market launch of a simple radar braking system in 1970 (*175*). This Doppler-based radar system was not wholly successful, however, and was later withdrawn from the market. More recent systems are currently projected to cost between $5,000 and $10,000 per vehicle, but the cost may decrease substantially with volume production.

Automatic Headway Control. AHC would provide benefits through relieving the driver of the car-following task and maintaining constant headways between vehicles. This could bring benefits in reduction of accidents, reduction in fuel consumption, and reduced congestion through the possibility of increased highway capacity. Accident savings could result in a similar way to those achieved through radar braking. Improved driver comfort and convenience could also accrue from the system's additional capabilities over conventional cruise control.

AHC may have the potential to reduce headways and optimize vehicle speeds, thereby cutting congestion, travel times, operating costs, and pollution. The extent to which this may be realized will depend on the nature of the system implemented. As an initial estimate, these benefits were assumed to be feasible for modest capacity increases, associated with small reductions in journey times.

An AHC system's ability to increase highway capacity will depend on the headway it allows between vehicles. A system that allows for "brick wall" stopping—in which it is assumed that a lead vehicle may stop as if it has hit a brick wall—is safer, but much less effective in providing throughput than a system that follows less severe stopping criteria. Indeed, such a system could result in much lower highway capacities than those currently experienced.

Opinions vary on the determination of a set of criteria for AHC close-following distances (*186, 241*). The brick wall stop may be unnecessarily severe in an automated highway situation, where it is hoped that catastrophic accidents will become extremely infrequent occurrences. If AHC is first implemented in mixed traffic, in order to achieve incremental acceptance, then rapid stopping capabilities may need to be retained. Product liability concerns also tend to mitigate against the reduced headways needed for capacity increases.

Realistic costs for AHC equipment are again difficult to estimate because of the lack of available data. However, the cost of AHC would probably be of a similar magnitude to that of radar braking because the systems are similar technically.

Automatic Steering Control. ASC is technically a near-term possibility. Wire-following systems have been proposed for many years, and new concepts of point systems based on small permanent magnets now offer substantial infrastructure cost advantages. The differential-spacing magnet system proposed for VSC could also provide affordable automatic steering for use as a driver support system on a wide range of road types. As with intelligent cruise, first-generation ASC systems would assist the driver's lane-following task without removing his ultimate responsibility for vehicle control.

Once ASC becomes accepted and deployed, a second phase will be to establish exclusive ASC lanes. The main potential benefit of ASC for relieving traffic congestion lies in use of narrow lanes. The tight limitations imposed on a vehicle's lateral position by ASC will potentially allow use of traffic lanes much narrower than normal. This allows an increase in capacity to be obtained without the need for new construction. Possible secondary benefit areas include reduction of accidents and increased driver comfort and convenience, but these may be relatively minor in comparison to the main benefit area.

The full-capacity benefits of using ASC in narrow traffic lanes would accrue only in certain specialized highway situations, such as construction zones and congested freeway sections. The narrow lanes would need to be restricted to suitably-equipped vehicle use, and would need to be segregated from each other without barriers. Under these circumstances, the benefits of ASC could be quite substantial.

Automated Highway System. The eventual implementation of full highway automation with an AHS could potentially have far-reaching benefits in the relief of congestion, as well as in areas such as safety, time-savings, comfort and convenience, and operating cost reductions. The main benefit for congestion relief lies in increasing highway capacity above the normal levels attainable on conventional highways. The extent to which this may be possible will depend on the nature of the system deployed.

In the long-term scenario of full highway automation, major benefits could be achieved in many important areas of interest, as shown in Table 17. The AHS could have a major impact in reducing congestion, giving reduced travel times and less pollution. Accident occurrences might be greatly reduced on automated sections, while driver comfort and convenience could be enhanced by eliminating many of the driving tasks. Land-take requirements could be less than those for conventional highway construction through the use of automated steering systems. In addition, an automated highway would provide large volumes of real-time traffic data which could be used for a variety of other purposes.

Journey time savings would result in scenarios where capacity flow levels were achieved with speeds maintained at 55 mph, compared to a conventional highway which would typically operate at capacity around 30 to 35 mph. An AHS incorporating AHC and VSC elements would also allow for more optimal fuel use. Accident reductions on an AHS facility could be expected through elimination of many accidents due to driver error. According to a recent General Motors AHS study (*186*), two-thirds of all accidents result from driver error. For this preliminary analysis it was assumed that almost all of these accidents could be avoided by an automated facility. The total accident reduction would, of course, be dependent on the scale of conversion from conventional to AHS.

The AVC technologies, which in combination would form an AHS, are, however, still in the early development stages. The fully automated highway system is therefore possibly the most long-term system concept examined, combining several of the other emerging technologies. An AHS facility would probably best be implemented through a major long-term R&D effort. This may reveal that the currently unquantified benefits of an AHS associated with substantial increases in highway capacities will be greater than those of any other technology assessed in this study.

7.5 INTERIM CONCLUSIONS

At the end of the first project phase, a number of interim conclusions and recommendations were formulated. These were based on the technology reviews presented in Chapters 2 through 4, the investigation of implementation issues described in Chapter 6, and the initial assessment of technologies presented in this chapter. The main features of these conclusions were as follows:

1. There was found to be a very wide range of advanced technologies that could help alleviate urban traffic congestion to a greater or lesser extent. Many of these technologies were also found to have other potential benefits. Some technologies appeared more likely than others to be successfully implemented in the short- to medium-term because of their state of technological advancement and their greater probability of social and institutional acceptance. Certain technologies were seen to be more applicable to general highway situations, while others are suited to specialized situations such as toll collection.

2. Three advanced technologies were recommended for further, more detailed investigation in the second project phase. These were externally linked route guidance, the RDS for traffic information broadcasting, and adaptive traffic control; the results of this second-phase investigation are detailed in Chapters 8 and 9.

3. It was strongly recommended that other advanced technologies should also be investigated and developed further within the framework of a coordinated national program. In particular, longer term AVC technologies, ultimately resulting in an AHS, were seen to have the potential for major impacts not only on congestion and safety, but also on society's whole perception of automobile travel. AVI technology was seen to offer potential for reducing congestion in the short term, where it is implemented in the specialized highway situation of ATC. In addition, improvements to fixed-time traffic signal coordination were seen to be a highly cost-effective strategy, which could provide immediate benefits in many cities where widespread congestion occurs. This recommendation formed the basis of work carried out in the second project phase on the development of an outline plan for a national IVHS program. This work is reported in Chapter 10.

CHAPTER 8

BENEFIT AND COST ANALYSIS

8.1 INTRODUCTION

This chapter presents a summary of detailed assessments of the three technologies selected through the initial evaluations contained in Chapter 7. The three technologies under examination are externally linked route guidance systems, the RDS for traffic message broadcasting, and adaptive traffic control systems. Details of the computer modeling techniques used, specific parameters used in the analyses, and the quantified results obtained from the assessments are contained in the Task 5 working paper of this project (*242*). This chapter contains a discussion of the results and presents conclusions drawn from the evaluations.

8.2 EXTERNALLY LINKED ROUTE GUIDANCE

The detailed assessment of externally linked route guidance was performed using Seattle as representative of a "typical" U.S. metropolitan area. The assessment considered the benefits of a self-contained route guidance system, the overall benefit of externally linked route guidance during freeway incidents, and the costs of implementing and operating an externally linked route guidance system. Benefits accruing in other situations were judged to be secondary and were omitted from the analyses.

The potential benefits available to individual users of a self-contained route guidance system are summarized in Table 18. These are the savings to drivers who use systems without a link to an external infrastructure. These systems provide route guidance advice without taking account of real-time traffic variations. The analysis indicates that very substantial benefits may be gained by helping drivers select and follow efficient routes.

Table 19 summarizes the additional benefits of externally linked route guidance. This appraisal considered not only the benefits directly available to system users but also the benefits provided to nonusers. In an externally linked system, users are directed along optimal routes based on real-time data obtained from roadside-to-vehicle and vehicle-to-roadside communication channels. In the event of an incident, an externally linked system can divert equipped vehicles along alternative, less congested routes. As vehicles are diverted from congested areas by the system, traffic flow will improve, and drivers of vehicles not equipped for route guidance will also benefit.

To analyze the overall benefit of externally linked route guidance, a modeling approach was adopted, using a computer model developed for this project. The model was designed to assess the potential benefits for all vehicles when a proportion of drivers use traffic information to alter their travel plans. The main findings of this analysis are summarized in Table 19.

Analysis of Benefits. For the analysis, the Seattle metropolitan area was divided into 20 sections (Figure 25). Each section comprised a length of freeway, with most sections also offering alternative parallel arterials.

The detailed analysis considered the three types of incident severity which occur in the area modeled. These are a one-lane blockage (type 1), a two-lane blockage (type 2), and a three-lane blockage (type 3). These incident types are based on work by Lindley (*243*).

Examination of results on the basis of incident type (Table 20) for all sections of the Seattle metropolitan area showed that total savings resulting from externally linked route guidance systems during type 1 incidents are significantly greater than those accruing during type 2 incidents. Similarly, savings achieved during type 2 incidents are greater than savings during type 3 incidents. The principal reason for this is that type 1 incidents are much more common than type 2, which, in turn, are more common than type 3. Because the number of incidents is a major factor used in calculating benefits, the total of benefits will naturally increase with number of incidents.

The benefits by incident type are also divided into peak and off-peak periods. Again, the main factor affecting benefit totals is the relative incidence of incidents (overall) during peak and off-peak times.

Adjusting the benefits to calculate an average benefit per incident revealed that peak period savings during type 1 incidents are almost 10 times greater than those achieved during type 2 and type 3 incidents. In the off-peak period, the benefits gained at type 1, type 2, and type 3 incidents are similar to those gained at type 1 incidents in the peak. This indicates that route guidance equipment is well suited to dealing with type 1 incidents, and is better suited to dealing with type 2 and type 3 incidents at off-peak periods than during peak periods.

Type 1 incidents are generally of low severity, creating direct capacity reduction on the 20 sections in the range of 18 percent to 50 percent. Generally, therefore, there is sufficient spare capacity on adjacent arterials to assist with this type of incident, even in peak periods. Incident types 2 and 3, however, are more serious, with direct capacity reductions ranging from 36 percent to 100 percent and 55 percent to 100 percent respectively. At peak periods, when there is typically only limited space capacity, there is simply insufficient road space to accommodate the diverted vehicles in the event of a major incident. Under these scenarios there is less that route guidance equipment can do to improve the situation.

The results of the analysis were also examined on a section-by-section basis. It is possible to identify corridors in which substantial savings are achieved during peak and off-peak periods. The corridors in which route guidance equipment is of major benefit in the event of traffic incidents are generally those in which travel demand on the freeway is close to capacity, or incidents are of high severity (i.e., the section has few lanes), and the alternative routes have significant reserve capacity, expressed as a proportion of freeway travel demand. These factors lead to situations where there is insufficient capacity to accommodate all vehicles on the freeway during an incident, and yet there are alternative, less congested routes to which vehicles can be diverted.

Conversely, the sections in which route guidance equipment provides low overall savings are those in which at least some of the following factors hold: low freeway volumes in relation to capacities, low incident severities (i.e., the section has many lanes), no available alternative routes, and alternative routes with very low reserve capacities.

In the first two cases, incidents are of insufficient severity or flows of insufficient volume to cause congestion. The traffic continues to flow uninterrupted in the event of an incident, and dynamic route guidance is unnecessary. In the other cases, the system is unable to reroute enough vehicles to make an impact on the problem, and total benefits are small.

The effect of increasing the proportion of equipped vehicles varies from corridor to corridor. In some cases, increasing the proportion of equipped vehicles increases the number of drivers able to divert around the incident and, thereby, benefit from the system. In other cases, where an optimum proportion of diverted traffic has already been achieved by the route guidance system, further increases in the proportion of equipped vehicles have no effect. A benefit ceiling prevents any additional dynamic gains.

This appraisal of externally linked route guidance can be summarized as follows: (1) substantial benefits of route guidance result from "static" information which can be achieved by onboard navigation equipment without external linking; (2) dynamic route guidance is most effective when the diversion of

Table 18. Potential annual savings for users of self-contained route guidance equipment (Seattle metropolitan area).

Proportion of vehicles with route guidance equipment (%)	Total annual user benefit ($ millions)	
	Annual mileage 10,288	Annual mileage 19,400
7	21 - 38	41 - 68
14	43 - 76	82 - 136
25	78 - 135	146 - 243

Table 19. Additional annual savings from externally linked route guidance for all vehicles during incidents (Seattle metropolitan area).

Proportion of vehicles with route guidance equipment (%)	Annual benefit ($ millions)		
	Peak periods	Off-peak periods	Total
7	4.4	34.0	38.4
14	8.6	47.3	56.0
25	9.8	57.6	67.4

Table 20. Breakdown of potential annual savings during incidents.

Percentage of vehicles with route guidance equipment (%)	Incident type #	Peak Benefits ($)	Off-peak Benefits ($)	Total Benefits ($)
7	1	4,393,116	32,828,651	37,221,767
	2	25,001	1,022,785	1,047,786
	3	3,508	128,868	132,376
14	1	8,580,326	45,668,124	54,248,450
	2	52,285	1,490,610	1,542,895
	3	7,392	177,145	184,537
25	1	9,740,976	55,445,572	65,186,548
	2	73,623	1,917,729	1,564,233
	3	7,808	200,191	207,999

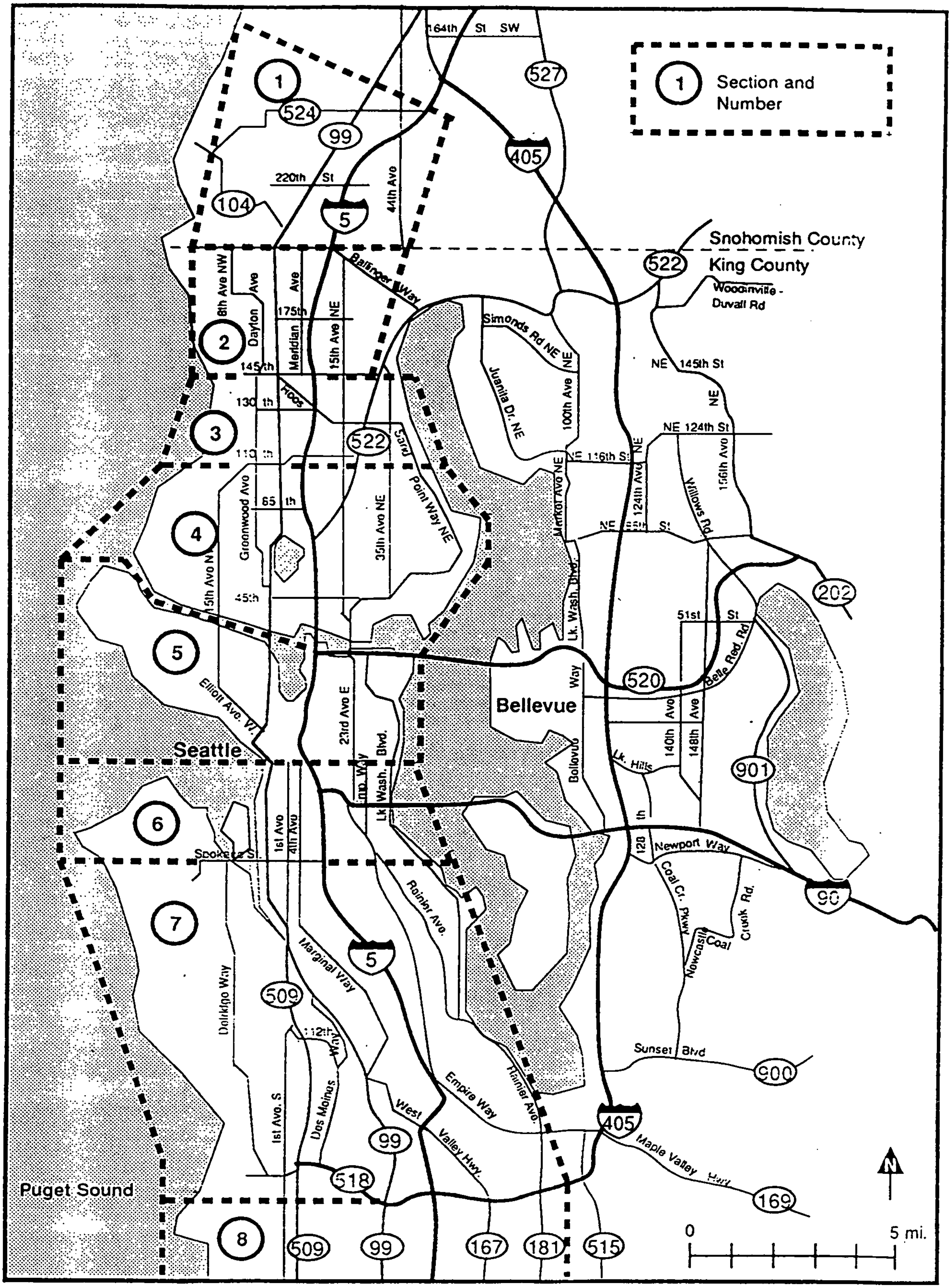

Figure 25. Section locations.

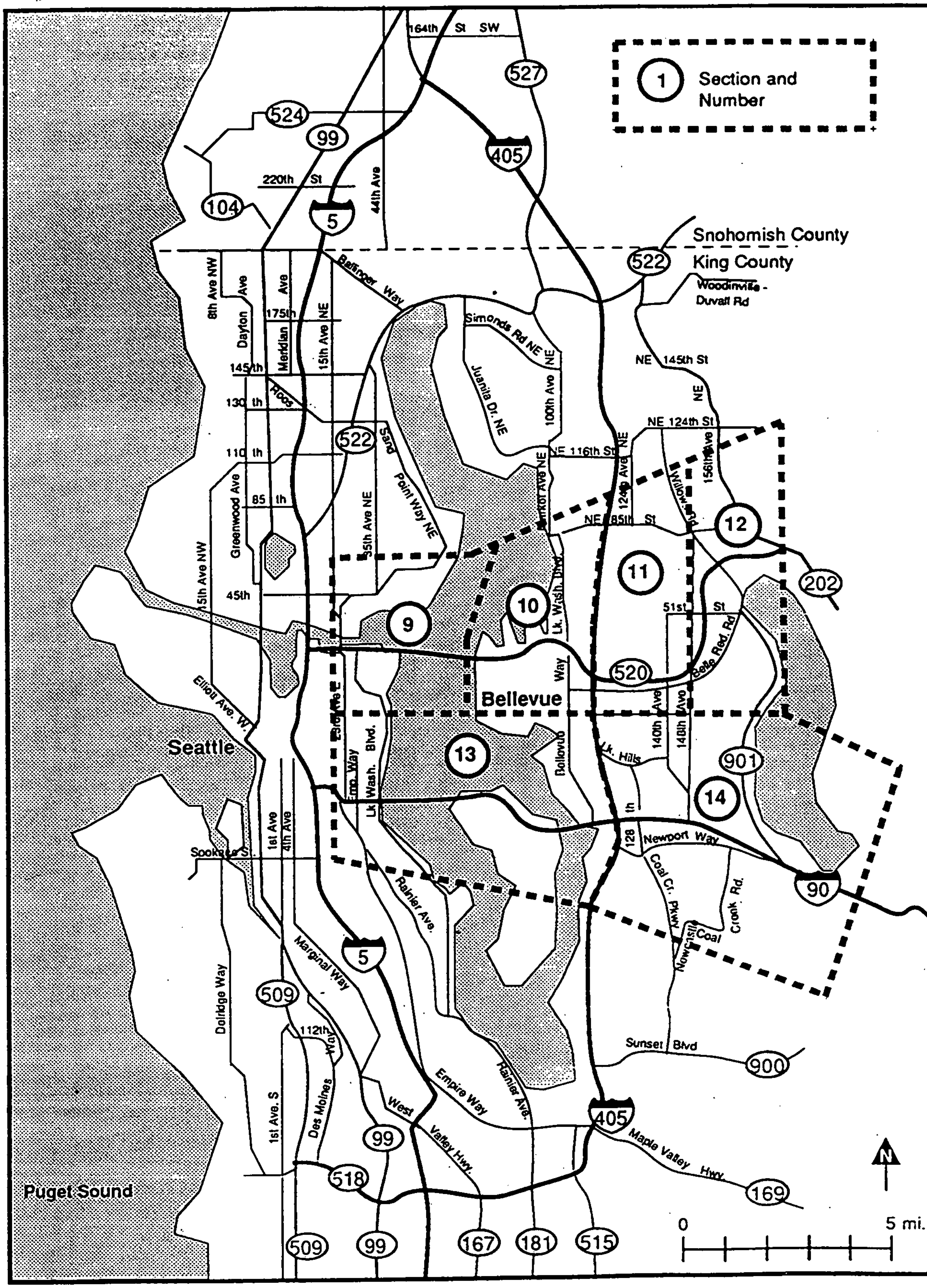

Figure 25. Continued

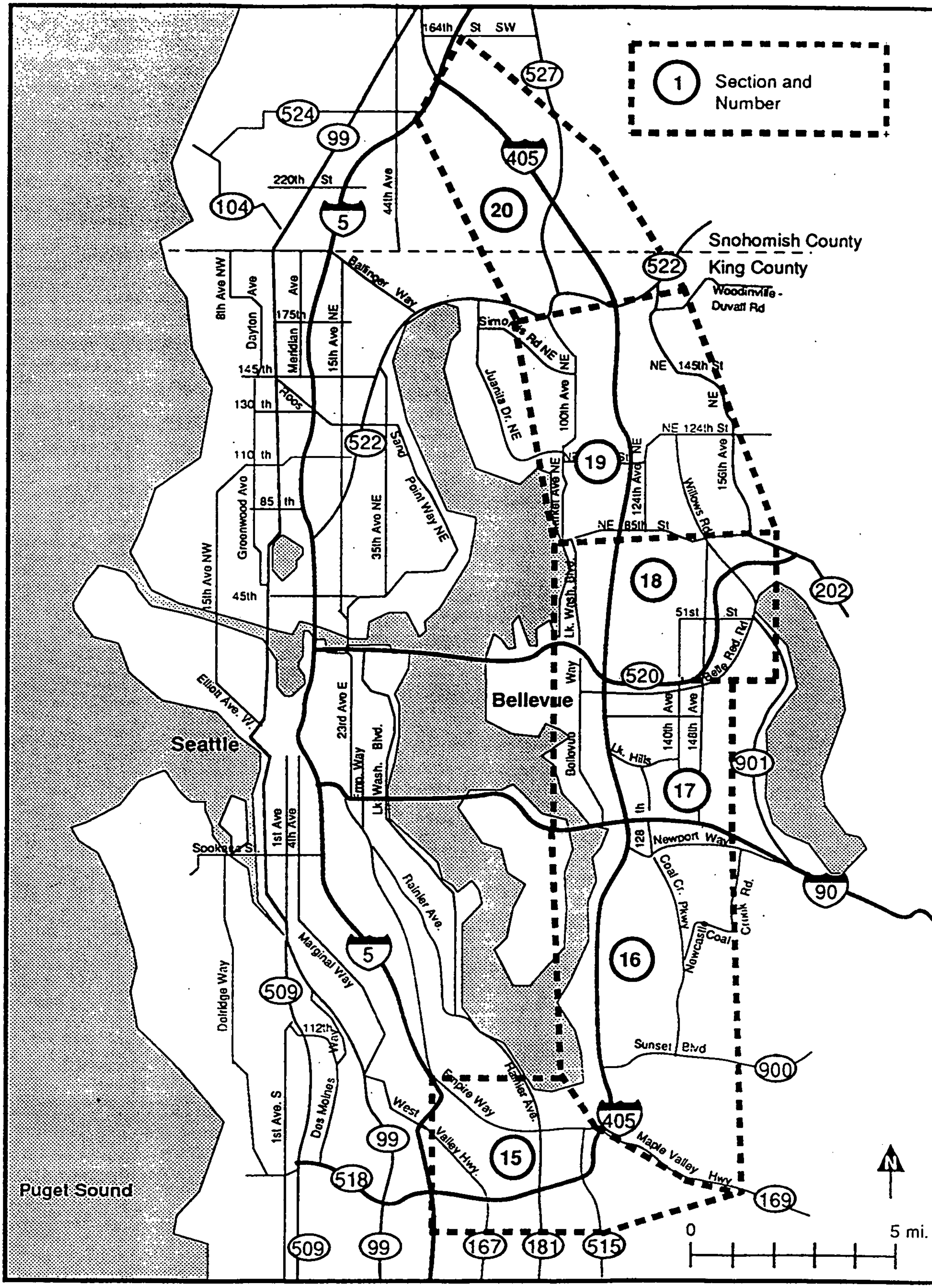

Figure 25. Continued

traffic is sufficient to prevent demand from exceeding capacity, and is able to keep demand balanced on all the facilities (these cases are not universal, but can lead to substantial savings); (3) dynamic route guidance is not of great benefit when there is little spare capacity on alternative routes; and (4) dynamic route guidance may not be needed when there is a large reserve capacity on the route affected by an incident.

Costs of Externally Linked Route Guidance. The costs associated with implementing and operating an externally linked route guidance system in the Seattle metropolitan area are incurred in two main areas (the derivation of system costs is described in detail in the Task 5 working paper (*242*)). The first area relates to the in-vehicle equipment. Table 21 summarizes the cost of this system element assuming high, medium, and low unit costs and associated market penetrations. The market penetrations have been applied to the known registered vehicle population of Seattle of 1.2 million automobiles and 330,000 trucks to produce total system costs under three scenarios.

The second area covers implementation and operation of the route guidance system infrastructure. This can be further divided into two categories: capital and installation costs, and operating costs. Capital and installation costs will be incurred only during the implementation stage of a scheme, or when equipment has reached the end of its operating life and requires replacement. These costs include purchase and installation of roadside beacons, purchase and installation of central computer equipment, purchase and installation of display units and interfaces, provision of the control center building, software development, and coding of network data.

Operating costs will be incurred over the lifetime of the system. These costs can be calculated over a fixed time period, annually, for example. Operating costs include staff salaries, updating of coded network data, spare parts and maintenance, communication and power requirements, and control building overheads.

The capital and installation and operating costs for an externally linked route guidance system are summarized in Table 22.

Summary. Table 23 presents an overall summary of costs and benefits for the example implementation of an externally linked route guidance system in the Seattle metropolitan area. The savings resulting from the system depend on traffic demand, capacity, incident severity, and proportion of equipped vehicles on the network section under consideration. These benefits can range from zero to millions of dollars per year for individual sections of highway.

The appraisal of system costs shows that the cost of in-vehicle units (which would be borne by individual users) makes up between 80 and 95 percent of total system investment.

Even in this partial analysis of potential benefits, the overall picture is very favorable. Quantified annual benefits are of the same order of magnitude as total system capital costs, suggesting that the fully implemented system would pay for itself within a year. Returns on the public investment (the roadside infrastructure) are even greater, with investments returned within months of full implementation. The case for a full-scale demonstration project in the United States matching similar projects in London, Berlin, and Tokyo, is therefore very clear.

Table 21. Costs of in-vehicle units in an externally linked route guidance system.

	High	Medium	Low
a) In-vehicle unit cost ($)	550	450	350
b) Market penetration (%)	7	14	25
c) # of vehicles equipped (1.2M + 0.33M * b)	107,000	214,200	382,500
d) Total cost of in-vehicle units (a * c) ($M)	58.9	96.4	133.9

Table 22. Estimated capital, installation, and annual operating costs for externally linked route guidance infrastructure (Seattle metropolitan area).

Information lag (minutes)	Capital and installation costs ($ millions)			Annual operating costs ($ millions)		
	High	Medium	Low	High	Medium	Low
5	19.2	14.4	9.6	3.7	2.8	1.8
10	12.3	9.2	6.2	2.3	1.7	1.1
20	8.9	6.7	4.4	1.6	1.2	0.8

Table 23. Overall summary of quantified benefits and costs for externally linked route guidance (Seattle metropolitan area).

Cost scenario	High	Medium	Low
Assumed market penetration	7%	14%	25%
Static guidance benefit $M*	39.5	79.0	140.5
Dynamic guidance benefit $M	38.4	56.0	67.4
(Annual operating cost $M)	(2.3)	(1.7)	(1.1)
Net annual benefit $M	75.6	133.3	206.8
In vehicle equipment cost $M	58.9	96.4	133.9
Infrastructure and installation costs $M**	12.3	9.2	6.2
Total capital cost $M	71.2	105.6	140.1

*Median values.
**for 10 minute information lag.

8.3 RDS TRAFFIC INFORMATION BROADCASTING

This study also considered the assessment of the RDS-TMC, again based on Seattle as being representative of a typical U.S. metropolitan area. The assessment dealt with the quantitative benefits of RDS-TMC in reducing delays caused by traffic incidents, as well as the costs of implementing and operating a system under various operating scenarios. The outcome of the assessment is summarized in this section.

The results show that a major benefit of RDS-TMC will accrue through a reduction in delays caused by traffic incidents. The overall delay due to an incident can be reduced if a proportion of the traffic approaching the affected area is diverted onto alternative arterials. This has been analyzed using computer modeling techniques. Other potential benefits of RDS-TMC, outlined in Chapter 7, are more difficult to quantify.

Three incident types were defined for the externally linked route guidance analyses presented in the previous section. The same incident types were used for the RDS traffic information system appraisal, combined in different ways to form two scenarios. The first scenario assumes that all types 2 and 3 incidents, but none of the type 1 incidents, will be reported by the traffic

Table 24. Annual savings for users of an RDS traffic information broadcasting system.

Info. Lag (mins)	% Vehs. Diverted	INCIDENT SCENARIO ONE		
		Peak	Off-Peak	Total ($)
10	10	- 87,000	+1,554,000	+1,466,000
10	20	-193,000	+1,915,000	+1,722,000
10	40	-399,000	+2,372,000	+1,973,000
15	10	-82,000	+1,379,000	+1,297,000
15	20	-163,000	+1,803,000	+1,640,000
15	40	-310,000	+1,965,000	+1,655,000
20	10	- 8,176	+1,324,000	+1,316,000
20	20	- 94,000	+1,741,000	+1,647,000
20	40	-249,000	+1,654,000	+1,406,000
Info. Lag (mins)	**% Vehs. Diverted**	**INCIDENT SCENARIO TWO**		
		Peak	Off-Peak	Total ($)
10	10	+1,640,000	+20,419,000	+22,058,000
10	20	-1,585,000	+27,194,000	+25,609,000
10	40	-6,592,000	+32,978,000	+26,386,000
15	10	+1,039,000	+19,242,000	+20,281,000
15	20	-1,313,000	+25,122,000	+23,809,000
15	40	-4,702,000	+30,171,000	+25,468,000
20	10	+1,328,000	+17,866,000	+19,194,000
20	20	- 52,000	+23,375,000	+23,323,000
20	40	-3,831,000	+27,423,000	+23,592,000

information broadcasting system, with recommended diversions. The second scenario assumes that half of all types of incidents are reported. These assumptions reflect the fact that unlike the externally linked route guidance technology, the RDS-TMC scenario evaluated here makes no new provision for detecting and monitoring the extent of traffic incidents.

Analysis of Benefits. For this analysis, as for externally linked route guidance, the Seattle metropolitan area was divided into the same 20 sections for which benefits have been determined (Figure 25).

The annual savings to users of RDS-TMC are summarized in Table 24. The information lag defined in the table is the time elapsing between the start of an incident and the receipt of traffic information by drivers. This is dependent on the particular method of incident detection deployed in the area covered by RDS-TMC. The table also presents different percentages of vehicles diverting from the freeway in the event that information about an incident is broadcast. This is assumed to be equal to the proportion of vehicles equipped with RDS receivers.

This assumption of a fixed percentage diverting is responsible for a major difference between the RDS-TMC results and those of externally linked route guidance. Externally linked route guidance was assumed to use its inherent traffic monitoring capability together with intelligent, predictive software to avoid setting up diversions that add to overall delays. RDS-TMC is taken to be a less-refined tool that is sometimes capable of recommending diversions resulting in more delay overall, instead of less.

It could be argued that RDS-TMC need not be used by traffic authorities in circumstances where traffic diversions are expected to make things worse. Another viewpoint is that drivers would not continue to divert around problems in fixed proportions if that tended to add to their delays. A learning process would help to ensure a certain response equilibrium, preventing significantly negative outcomes.

Comparing results of the two incident scenarios in Table 24, the benefits accruing under the second scenario are on average 15 times larger than those under the first scenario. This is because the first scenario assumes no reporting of type 1 incidents. Because there are many more type 1 incidents than other incident types, it follows that the second scenario will yield much higher benefits. A second reason is more complex. An incident blocking one lane causes a smaller reduction in capacity than an incident blocking two or three lanes. Particularly during off-peak periods, therefore, traffic can be diverted from the freeway more easily when a type 1 incident occurs, resulting in substantial benefits. It is during the off-peak that the large differences between the two scenarios is most apparent.

Analysis of the peak flow results in Table 24 shows negative results as higher proportions of vehicles divert from the freeway on hearing a traffic information broadcast. Only the second scenario with 10 percent traffic diversion gives predominantly positive results. Data for the 20 highway sections of Seattle show the peak demand is high on most freeway sections and the corresponding parallel arterials. Therefore, during any incident in the peak which causes a loss of capacity on the freeway, either the freeway becomes congested, causing substantial delays, or some fixed proportion of the traffic is diverted onto the parallel arterials, which may cause delays on those facilities. Unless the percentage diverting is small and finely tuned, the effect on delays can be adverse. This is particularly true under the first scenario, where only major incidents are assumed to be carried on RDS-TMC.

Off-peak flow analyses reveal more predictable findings. Table 24 shows that off-peak benefits generally increase with the percentage of vehicles diverting. Also, benefits increase as the information lag decreases. The analyses show that parallel arterials offer substantial reserve capacity during off-peak periods. This spare capacity can accommodate substantial diversions of the off-peak freeway flows, allowing potentially large savings from RDS-TMC.

Overall values, detailed in Table 24, can be derived for the total annual savings of RDS-TMC. These values show trends similar to the off-peak savings. In general, the benefits increase as the percentage of vehicles diverting increases, or as the information lag decreases. For the two scenarios examined the total annual savings are bounded by a maximum value. In the case of the first scenario, the ceiling is around $2 million per year. For the second scenario, the upper bound is around $26 million.

A section-by-section analysis has also been undertaken. Sections 1 and 2 almost always produce positive benefits under each scenario. Both are nearing capacity on the freeway during the peak period. However, the corresponding parallel arterials are operating at less than half capacity. Consequently, the network in this area can cope with a more than 50 percent reduction in capacity on the freeway by diverting traffic to the alternative arterials. RDS-TMC can therefore provide considerable benefits.

Section 6, 7, and 8 produce similar benefits, particularly during off-peak.

More generally, benefits in the off-peak periods are high. However, there are cases where disbenefits can occur. For example, Sections 10 and 16 produce disbenefits when the information lag is large and the proportion of vehicles diverting is small. In both cases, the parallel arterials have low capacities and cannot accommodate vehicles diverted from the freeway, even during off-peak periods.

The potential benefits of the RDS-TMC traffic information broadcasting system evaluated in these scenarios can be summarized as follows: (1) RDS-TMC has highly beneficial effects when the freeway demand is approaching capacity and the alternative parallel arterials have sufficient surplus capacity to accept the diverted traffic; (2) depending on recommended diversions and driver reactions, RDS-TMC could potentially have adverse effects when the entire network is approaching capacity, or when the parallel arterials have limited or no spare capacity, (3) benefits accrued through RDS-TMC during off-peak flows are significantly higher than those from peak periods; and (4) the largest potential for benefits from RDS-TMC comes from the reporting of incidents affecting only one lane of the freeway because these are most common and easiest to address by means of diversions.

Costs of an RDS-TMC Traffic Information Broadcasting System. The following discussion outlines the costs associated with the implementation and operation of RDS-TMC for traffic information broadcasting in the Seattle metropolitan area. Detailed derivations of system costs are provided in the Task 5 working paper.

To implement an RDS-TMC system, costs can be considered in two categories: capital and installation costs, and operating costs. The capital and installation costs will be incurred initially and recur as equipment reaches the end of its operating life and requires replacement. The main components included in these costs are in-vehicle receivers, encoders, and central computers.

Costs for these items are presented in Table 25 assuming high-, medium- and low-cost scenarios. Table 26 presents overall costs for different market penetrations.

Operating costs are those incurred continuously during the operation of the system, and can therefore be calculated for a fixed time period. The main elements included in the operating costs are staff salaries, communication charges, and maintenance. Annual operating costs are summarized in Table 27.

Summary. Table 28 summarizes total capital and operating costs and net annual benefits for three market penetration scenarios, under high-, medium-, and low-estimate headings. The total capital costs range from $27.8 million as a low estimate for 10 percent market penetration, to $73.5 million as a high estimate for 40 percent take-up of the system. As market penetration changes, the only variable cost is for the receivers. Because this cost element makes up from 97 percent to over 99 percent of the capital cost in each case, it follows that a change in the take-up level will have a considerable effect on the total capital cost.

The overall benefit assessment shows large net savings under all implementation scenarios. The level of benefits was shown to vary significantly between individual sections of the highway network and, in particular, between the peak and off-peak periods. Returns also diminish with increasing market penetration, the highest returns being gained by those who buy in to the system first. However, this main cost element of an RDS-TMC traffic information broadcasting system is borne by the individ-

Table 25. Unit capital and installation costs ($) for an RDS-TMC system.

	High	Medium	Low
Receiver	180	150	120
Encoder	30,000	20,000	10,000
Central Computer	30,000	25,000	20,000

Table 26. Total cost ($M) of in-vehicle receivers for an RDS-TMC system (Seattle metropolitan area).

Market Penetration	High	Medium	Low
10%	27.5	23.0	18.4
20%	55.1	45.9	36.7
40%	110.2	91.8	73.4

Table 27. Annual running costs ($) for an RDS-TMC system.

	High	Medium	Low
Operating costs:			
3 staff	180,000	150,000	120,000
Telephone charges	30,000	25,000	20,000
Maintenance costs:			
Encoders	30,000	20,000	10,000
Central computer	3,000	2,500	2,000
Total	243,000	197,500	152,000

Table 28. Overall summary of quantified benefits and costs for RDS-TMC (Seattle metropolitan area).

Cost scenario	High	Medium	Low
Assumed market penetatration	10%	20%	40%
Peak period benefit $M* Off-peak benefit $M* (Annual operating cost $M)	1.6 20.4 (0.2)	(1.6) 27.2 (0.2)	(6.6) 33.0 (0.2)
Net annual benefit $M	21.8	25.4	26.2
In-vehicle equipment costs $M	27.5	45.9	73.4
Infrastructure and installation costs $M	0.3	0.2	0.1
Total capital costs	27.8	46.1	73.5

*for 10 minute information lag

Table 29. Adaptive traffic control network data.

Network Code	Network	Total Number of links	Number of external links	Number of internal links	Number of adaptive nodes	Proportion internal links (%)
SS1AB	Saulte Ste. Marie	54	27	27	10	50
MN1PB	Menominee	19	12	7	3	37
CA1AM	Cadillac	81	40	41	12	51
HIGHST	High Street Hamilton, OH	74	43	31	8	42
GHN1AB	Grand Haven	62	34	28	13	45
SOCBDMD	—	107	27	80	26	75
YPO4AF	Ypsilanti Michigan Avenue	148	64	84	23	57
PH1AM	Port Huron	205	102	103	49	50
ARL15PM	Wilson Boulevard Courthouse Arlington, VA	27	13	14	7	52
DAYTONA	Daytona Beach, FL	99	26	73	12	74
FSMMD1	Fort Smith	69	22	47	21	68
MLPO	Midland System	198	57	141	99	71
MACKNIGHT	McKnight Road Pittsburg, PA	49	26	23	7	47
LAMARAM	—	23	15	8	5	35

ual system users. The cost to the system operating agencies is very low, with extremely large returns offered on the public investment.

8.4 ADAPTIVE TRAFFIC CONTROL SYSTEMS

Detailed investigations into the potential benefits and costs of adaptive traffic control systems were also performed. This analysis dealt with a benefit assessment for a fixed time, traffic control system, followed by a more detailed evaluation of the benefits of adaptive traffic control. The costs of implementing and operating an adaptive traffic control system were also investigated. The benefit analysis was undertaken through modeling a series of U.S. signalized networks. The costs associated with adaptive traffic control systems were derived from European experience. The results of the analyses indicate high returns on investment in adaptive traffic systems.

An adaptive traffic control system is able to adjust signal timings in response to changing traffic demand on a cycle-by-cycle basis. Therefore, adaptive systems can give additional benefits over fixed-time systems by responding to flow variations within a signal plan period, and by avoiding the delay caused by switching from one plan to the next. An adaptive system may not only demonstrate increased benefits during a 24-hour period, but will also respond to fluctuations in daily flow profile patterns that take place from day-to-day throughout the week. Additional benefits will be realized in networks experiencing significant cyclical and seasonal variations in traffic flow.

Benefit Analysis of Adaptive Traffic Control in U.S. Networks. The total benefit of an adaptive traffic control system over isolated intersection control was calculated as the sum of the benefits of fixed-time coordination over isolated control, and adaptive traffic control over fixed-time coordination. Evaluation of the benefits was undertaken using TRANSYT-7F data from 14 North American networks. These data are presented in Table 29 together with the number and proportion of internal links in each network. Network sizes studied range from 19 links to 205 links. On average, the networks contain 87 links.

Table 30. Average annual link benefits.

Network	Average annual link benefit ($)		
	fixed time/ isolated	adaptive/ fixed-time	adaptive/ isolated
SS1AB	1708	1050	2758
MN1PB	3647	2835	6482
CA1AM	4830	2086	6916
HIGHST	5432	2401	7833
GHN1AB	6167	3024	9191
SOCBDMD	6937	2730	9660
YPO4AF	6321	2660	8974
PH1AM	7567	3332	10906
ARL15PM	9492	4382	13867
DAYTONA	9793	3913	13706
FSMMD1	13279	5187	18452
MLPO	13048	5565	18613
MACKNIGHT	15855	7203	23058
LAMARAM	22036	9800	30436

To calculate the monetary benefits of an adaptive traffic control system, the software package COORDBEN was used.

COORDBEN was used to determine estimates of the benefits of fixed-time coordination over isolated intersection control; adaptive traffic control over fixed-time coordination; and adaptive traffic control over isolated intersection control. The distributions of link benefits were derived for all 14 networks. A summary of benefits is presented in Table 30.

Studies show that traffic using external links will experience a monetary disbenefit within a fixed time, coordinated traffic control system. Therefore, the higher the proportion of external links in a network, the greater the disbenefit these links contribute to the overall benefit assessment of a traffic control system.

More specific results drawn from the detailed network evaluations are as follows: (1) In general, the benefit distributions follow the same pattern. The benefit distributions of adaptive traffic control over isolated intersection control have a sharper, short-tailed distribution, with the mode shifted to the right when compared with the other two comparisons. This demonstrates a consistent, substantial additional benefit through the use of adaptive traffic control techniques. (2) The benefit distributions given in the Task 5 working paper *(242)* show level of benefits to be achieved through use of adaptive traffic control to vary substantially between networks. (3) The benefits of adaptive traffic control over isolated intersection control are always greater than the benefits of fixed-time coordination over isolated intersection control. (4) Very large benefits can be achieved with adaptive traffic control when there are only a small number of links in the network. These links are those that feed into critical intersections, tending to be short and to have high traffic flows. (5) The range of benefits achieved through adaptive traffic control is very wide. Actual average benefits per link are independent of the size of the network. Both large and small link benefits are found in any network. (6) The overall level of disbenefit in a network increases with the number of external links, for both fixed-time and adaptive control. (7) Certain benefit distribution diagrams do not exhibit a long tail. This suggests that the network in question does not contain critical nodes and links.

The network evaluations also show that the distribution of benefits is directly proportional to traffic flow, and inversely proportional to travel time. Comparison of these distributions clearly shows that benefits are dominated by traffic flow volumes. It can also be seen that the largest link benefits are achieved when large traffic flows are coupled with very short travel times for the link.

An additional benefit of adaptive traffic control systems is that they do not suffer from the problem of signal plan aging. In these control systems, signal plans are adjusted to respond to actual traffic conditions. This produces an additional benefit of adaptive traffic control over optimized fixed-time signal plans, which has been calculated as 3 percent per year, or around 9 percent in total for a typical 3-year-old signal plan.

Costs of Adaptive Traffic Control. The cost of implementing and operating an adaptive control system can be divided into two categories: capital and installation costs, and operating costs. Capital and installation costs are those incurred when a system is initially implemented or is replaced at the end of its operating life. These costs include purchase and installation of the central control equipment, purchase and installation of the data transmission equipment, and costs of optional system components.

Operating costs are incurred continuously during the operation of the traffic control system. These costs are evaluated over a fixed-time period, for example, annually. Operating costs include spare parts and maintenance, communications costs, and staff salaries.

Table 31 summarizes the cost elements for an adaptive traffic control system. This covers capital and installation costs, and operating costs calculated on an annual basis. High-, medium- and low-cost estimates are included, with two cost figures for components (a) and (b). The first value in each case represents the cost for a network with up to 64 adaptively controlled nodes. The value in parentheses is the cost figure for networks with up to 128 adaptively controlled nodes.

Three networks of different size have been used to develop total system costs. The size of each network, assuming high, medium, and low scenarios of the number of nodes under adaptive control, is shown in Table 32. The total combined capital and installation costs are presented in Table 33.

Summary. Table 34 summarizes the quantified benefits and costs of adaptive traffic control in three sample networks. The direct benefits of more efficient control represent a significant return on the immediate costs of traffic control system conversion.

Nonquantified benefits of moving to adaptive traffic control include reduced staff costs of data collection and signal plan updating. These must be traded off against the costs of system maintenance. Experience overseas suggests a further net benefit may be achieved in this area.

The most likely scenario for implementing adaptive traffic control will be when a traffic control system is, in any event, due for renewal. Under these circumstances, the marginal cost of adaptive control will be small, and the potential for substantial returns on investment will be greatest. Another particularly favorable scenario would be where new control systems are proposed in previously uncoordinated areas. Again, marginal costs of adaptive over fixed-time control will be low, with potential benefits of adaptive systems providing major return on public investment.

Table 31. Cost elements in an adaptive traffic control system.

	High ($)	Medium ($)	Low ($)
Central system			
a. Computer hardware, software 25 OTUS, 1 VDU, 1 printer, training	395,500 (467,250)	377,100 (446,250)	358,750 (425,250)
Data transmission			
b. Instation equipment	21,000 (42,000)	19,250 (38,500)	17,500 (35,000)
c. Outstation equipment	5,250 each	4,500 each	3,750 each
d. Maintenance training and documentation on outstations	8,750	7,850	7,000
e. Test equipment	29,750	28,850	28,000
f. Detector racks in outstation with four detector channels	1,300 each	1,050 each	800 each
Options			
g. Additional color VDUs	-	7,850 each	-
h. Software to allow use of IBM PCs	26,250	-	-
i. IBM PCs with color monitors	6,100 each	-	-
j. Lamp monitoring for OTUs	500 each	450 each	-
k. Weatherproof housings for OTUs	3,150 each	2,800 each	-
General			
l. 3 year maintenance for central computer equipment	52,500	47,250	42,000
m. Spares for central computer	7,000	6,100	5,250
n. Spare OTUs	5,250 each	4,500 each	3,750 each
o. Green wave control panels	6,550 each	6,100 each	5,700 each
p. Roving printers	4,375 each	-	-
q. Slot cutting	2,600 per OTU	2,200 per OTU	1,750 per OTU
r. Controllers	9,200 each	8,750 each	7,850 each
s. Telecommunication connections	35,000	28,000	21,000
t. Main works contract	1,137,500	875,000	700,000
u. Site supervision	52,500	42,000	35,000
Annual			
v. System maintenance contract	87,500	78,750	70,000
w. Telecommunications rental	35,000	28,000	21,000
x. Staff running costs	61,250	52,500	43,750

Table 32. Number of adaptively controlled nodes in the example networks.

	High	Medium	Low
Midland System (MLFO)	99	70	40
Port Huron (PHIAM)	49	35	20
Ypsilanti, Michigan Avenue (YPO4AF)	23	18	12

Table 33. Total capital and installation costs for an adaptive traffic control system.

	High	Medium	Low
Midland System (MLPO)	4,144,400	2,811,900	1,711,350
Port Huron (PHLAM)	2,984,100	2,057,350	1,431,950
Ypsilanti, Michigan Avenue (YPO4AF)	2,300,575	1,768,500	1,348,750

Table 34. Summary of costs and benefits of adaptive traffic control in sample networks.

Network	Midland System (MLPO)	Port Huron (PHLAM)	Michigan Avenue (YPO4AF)
Annual benefit (adaptive/fixed-time)	1,102,000	683,000	394,000
Ageing benefit (after 3 years)	233,000	140,000	84,000
Total annual benefit	1,335,000	823,000	478,000
Total capital & installation cost	4,144,000	2,984,000	2,300,000

CHAPTER 9

ILLUSTRATIVE TECHNOLOGY IMPLEMENTATIONS

9.1 INTRODUCTION

This chapter examines the practical problems of preferred technology implementation by choosing specific examples from the Seattle metropolitan area. Although these examples necessarily emphasize responses to the specific characteristics of the Seattle region, these choices would be similar in other localities. It is emphasized that the "decisions" discussed in this section are hypothetical.

The urban portion of the Central Puget Sound region is roughly 6,300 square miles in area, and includes much of the populated areas of King, Snohomish, Pierce, and Kitsap counties (Figure 26). The population of the combined urban areas is about 2.5 million.

The area's jurisdictions consist of more than 68 cities and towns, plus four counties. Within the area, 240 miles of limited access highway, 600 miles of major arterials, and 1,630 miles of minor arterials and collectors constitute the metropolitan highway network.

9.2 RDS-TMC

The Seattle RDS-TMC plan would be intended to provide significant improvement over available traffic reporting, at a minimum increase in cost to the Washington State Department of Transportation (WSDOT).

The RDS-TMC system in Seattle would be an incremental improvement to the existing traffic information system. WSDOT currently operates variable message signs and HAR on segments of the freeway system. In addition, both WSDOT and the Municipality of Metropolitan Seattle (Metro) provide traffic conges-

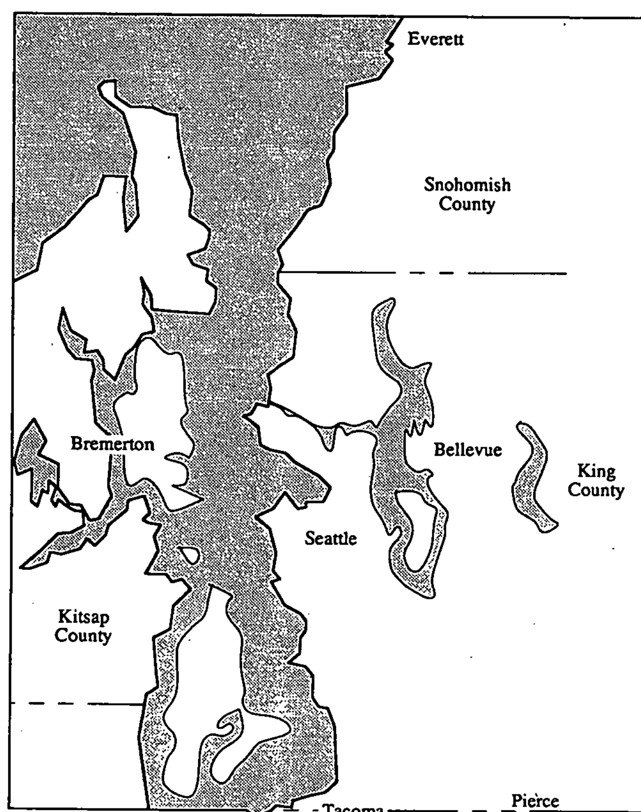

Figure 26. Seattle-Tacoma metropolitan area.

tion and incident information to the news media for broadcast to motorists.

The current system suffers primarily from a lack of off-peak coverage, and the fact that traffic broadcasts are not continuous on any channel but are interspersed among music and news broadcasts. This detracts from the usefulness of the data because many motorists do not hear essential information in time to avoid congested highways.

During peak periods, many radio stations assign personnel specifically to monitor a variety of information sources and develop traffic condition reports for broadcast every few minutes. In off-peak times, most radio stations are not staffed to collect and dispense traffic congestion information, and reports of traffic accidents are infrequent.

The RDS-TMC system envisioned would be able to broadcast continuously, cover the entire urban area, and be designed to broadcast both up-to-the-minute traffic information and upcoming construction activity announcements. Even routine congestion could be broadcast because channel capacity would be available and system selectivity would prevent information overload.

Implementation Issues

The success and use of the RDS-TMC system would greatly depend on the quality of the RDS messages. If the system is to fulfill its intended function, it will have to provide up-to-the-minute traffic information over a wide spectrum of highways. To do this, the system will preferably be supported by systems capable of gathering information on those roads and determining the location and extent of traffic congestion.

Traffic information is currently collected and processed by a number of organizations and individuals who use data from a variety of sources. These include the following:

1. *Airborne traffic watchers.* Cost is the primary drawback to expanding the use of information collected through aerial observation. However, some of the cost could be borne by radio stations, as is now the case.

Another problem would be off-peak data collection. It is unlikely that off-peak collection of traffic information through aerial observation would be cost effective. However, access to WSDOT and Washington State Patrol (WSP) dispatch calls could be used to supplement the airborne observations during the off-peak periods.

2. *Freeway loop detectors.* WSDOT maintains loop detector information for a large part of the freeway system. However, a number of freeway sections still do not contain detector loops. Increasing the number of loop detectors on the freeway system would provide WSDOT with considerably better information about traffic on freeways. To adequately monitor the entire urban freeway system would require a substantial increase in loop detectors being operated, and a commensurate increase in the maintenance staff required to keep the equipment in operation. Thus, the cost for the system would be high, both for initial capital construction and long-term maintenance.

3. *Arterial loop detectors.* The problem with existing arterial loops is that many are not designed to give traffic volumes but simply to detect the presence of vehicles for signal control. In addition, on many routes only side streets have detectors that are used as simple actuation devices. For RDS-TMC, arterials would ideally require detectors able to provide traffic flow and congestion data.

4. *Transit authority information from AVL.* Metro has implemented a system which indicates the current location of buses. With appropriate system upgrades, it would be possible to determine travel times between points on the major arterials in the region. However, use of the information would require translating bus travel times into automobile travel times.

Because Metro currently "sells" traffic information by getting free advertising on the radio stations that use it, Metro probably would require some compensation. This might take the form of relaying bus travel information via RDS-TMC in addition to car trip information. Use of AVL information provided by Metro would probably be the lowest marginal cost of any method for improving traffic information in the Seattle area.

5. *Private- or commercial-vehicle AVI techniques.* Automobiles can be outfitted with inexpensive transponders that can automatically identify the vehicles. Roadside equipment that would record the passing of a vehicle equipped with AVI could relay the information to a central processor and compute travel times between points in the system.

Without some incentive, owners of private vehicles would probably be unwilling to purchase even the most inexpensive equipment required for this method of traffic information acquisition. However, companies owning fleets of vehicles might be willing to do this if the information could be sold to facilitate an RDS-TMC system.

By themselves, the types of traffic information discussed above are not particularly useful to the general public. The data require interpretation and packaging into messages to which the public can respond. Considerable effort should be devoted to the development of an RDS-TMC coding structure representing types of conditions leading to congestion and for indicating the location of that congestion. Traffic reporters would then develop these messages using data from a variety of sources that fit the coding schemes.

The determination of which functional elements are necessary first in an RDS-TMC system is a difficult problem. Without in-vehicle electronic equipment capable of receiving and decoding traffic information, the collection of traffic data and development of messages for the RDS-TMC system would be superfluous. Without good data collection and the production of useful messages, in-vehicle equipment would be useless.

Inevitably, there would be a significant time lag between initial RDS-TMC broadcasts and the time when a substantial number of people actually had RDS-TMC receivers. The first users would be people with special needs or for whom the cost of the equipment was relatively insignificant. As the number of users grew, the cost of the equipment would decrease and more people could afford the equipment.

Because the cost and difficulty of obtaining good real-time traffic information are significant, initial implementation of RDS-TMC may be expected to provide information that was less useful than that at later stages. Therefore, as RDS-TMC matured, the messages that could be sent over the system would become more accurate. However, it would be important not to raise initial expectations and lead people to purchase equipment before the system could realize the attractive potential benefits.

There are certain advantages to a phased system implementation. First, it would allow WSDOT or other system operators to gradually expand the work force needed to install and maintain traffic information gathering equipment. It would also allow other data gathering technologies to become fully operational. As traffic data volumes increased and became more accurate, more vehicle owners would purchase the necessary equipment, and so the technology would become more attractive to radio stations interested in carrying the RDS-TMC broadcasts.

Jurisdictional Issues

The implementation of RDS-TMC in Seattle raises three primary types of jurisdictional question:

1. *Radio station involvement.* This issue is particularly significant, because RDS-TMC would be broadcast over existing radio station bands. Therefore, radio stations would need an incentive to broadcast traffic information over their frequencies in preference to other silent digital data services.

An RDS-TMC system could be implemented where either the radio station paid nothing or the radio station paid a portion of the total system costs. The system could be set up with either some or no competition from other radio stations at its implementation.

There would be little competitive impact from an RDS-TMC system in its initial stages. At first, traffic information would not be provided to a large number of drivers, and the quality of the information might not be very different from current traffic information. Continuous availability and selectivity of messages would be the main incentives to drivers to procure the system.

As the quality and prevalence of traffic information through RDS-TMC expanded, some competitive impacts could occur. These conditions might be attractive to radio stations, but could be problematic under some conditions. The new system might reduce the competitive advantage of stations that currently provide good traffic information if other stations had access to the information.

A main objective would be to avoid alienating stations that previously provided good traffic information, while still improving traffic information available to motorists in the Seattle area. One possible way to structure the system would be to make information available to only a few stations. This approach would limit the availability of information and might lead to legal problems.

The main question would be how a public entity could decide which stations would get the information. By restricting the information to only one or very few stations, public funds would be giving a competitive advantage to those stations. However, the station(s) could be chosen through a competitive bidding process, either in terms of direct financial contributions or through an assessment of "added value" offered by the total information service.

Probably the best approach would be to make the information available to all stations. In the early implementation stages of the system, WSDOT would provide the basic information. Stations would be free to embellish and broadcast their own reports. The stations spending money on traffic reporting would still have the "best" information, as in the current situation.

2. *Operating authority data provision.* Currently, WSDOT, Metro and private sources provide traffic information. Metro's traffic information is obtained from motorists during the peak hours. Drivers are assigned particular places and times to call in with local traffic conditions. This oral information is interpreted and summarized for use by radio stations. Since Metro currently gets free advertising time as compensation for the traffic information, some arrangement would have to be made to provide payment for any additional services Metro would provide for interpretation of the traffic information for RDS-TMC purposes. One solution would be to provide Metro with free time on the RDS-TMC data channel.

Information on arterial traffic volumes could be provided as part of a joint arterial/freeway control integration project. There are three important questions concerning the involvement of local jurisdictions in traffic information collection. The first relates to the cost of upgrading or buying new equipment capable of collecting traffic information. The second question concerns whether or not local jurisdictions have enough to gain from improvements in the system to help pay those costs. The third involves who would actually maintain the equipment and transfer the information necessary for the RDS-TMC system.

It would be difficult to separate the costs for new or upgraded equipment incurred through improving the control/integration system from those incurred in the collection of traffic data. The primary additional cost would be the transfer and interpretation of the data. It might be considered most appropriate that WSDOT should pay those costs.

Assuming that local jurisdictions found contribution to the development of a control/integration system advantageous, they would help fund the collection of data. They would probably not see an advantage in paying any extra costs for the interpretation and transmission of the data. In fact, if a significant amount of traffic was diverted to local arterials and streets as a result of RDS-TMC messages, local jurisdictions might have to invest additional funds in upgrading their facilities to handle the extra volumes of traffic. One incentive to contribute, however, could be to influence the specific traffic message routings broadcast by the system.

3. *Impact on parallel facilities.* The impact of RDS-TMC on local streets and arterials would depend on the content of the messages. If specific routes were advised, those routes would need to be cleared with local jurisdictions before they were broadcast. If these routes were determined in cooperation with local jurisdictions, then the question of who would pay for the improvements necessary to handle the additional traffic would arise.

If no specific route alternatives were recommended in the RDS-TMC messages, drivers would choose alternative routes as they currently do. If RDS-TMC messages did not contain specific routing alternatives, the issue of cost sharing for arterial improvements would have a different character. A local jurisdiction would have more difficulty in making the claim that the agency responsible for the RDS-TMC messages should participate in funding specific arterial improvements.

Integration of RDS-TMC into the Existing Infrastructure

RDS-TMC would integrate well with the existing infrastructure. The RDS-TMC broadcasting equipment will be a relatively small proportion of the cost of system implementation. Further, each of the necessary traffic information collection enhancements would be valuable to the agencies collecting those data, and could be introduced gradually as the system developed.

Smooth integration could be accomplished if the system was installed in a phased approach. An initial system that used existing traffic data could be implemented immediately. It would require only a limited amount of new equipment, permission to broadcast over at least one radio station, and perhaps one or two full-time staff in addition to the current WSDOT staff.

Potential Funding Mechanisms

The basic objectives of WSDOT would be to make the traffic information available in as broad a range as possible and to incur the least cost. These two objectives are somewhat incompatible and would have to be balanced. In order to get radio stations to initially participate in RDS-TMC broadcasting, WSDOT might have to pay for equipment at the radio stations. If WSDOT did not subsidize the equipment, many radio stations would probably not participate, at least in the beginning.

One way to achieve a balance would be to accept bids for RDS-TMC information. Stations would be offered basic traffic information messages if they would pay part of the cost of the encoding and broadcasting equipment. The radio stations offering to pay the highest percentage of the equipment costs would be the first to receive WSDOT messages. The stations would have an incentive to bid high, because they would be aware that no subsidy would be available later when the ability to receive RDS-TMC messages by motorists would be more widespread.

Another approach would be to leave RDS-TMC entirely in the private sector. A private company could produce RDS-TMC messages for a fee, and radio stations would purchase these broadcast messages. In this case, the private agency could be expected to help fund the purchase of broadcast equipment and pay any air time charges imposed by the radio stations.

Consumer Reaction

The basic reason for having better driver information systems is to allow drivers to choose more efficient routes. Even if only some of the drivers choose the most efficient routes, the entire system benefits. System benefits do not require that everyone have access to the RDS-TMC information. However, the most likely way that RDS-TMC would be introduced would be by having the cost of the RDS receiver borne by the user. Vehicle users without RDS receivers would benefit as a result of RDS-TMC users' decisions, but they would be unlikely to perceive those benefits. This might lead to concerns over the use of public funds to subsidize the system.

Another issue in cost allocation concerns the onboard equipment capable of receiving RDS-TMC signals. Motorists are likely to prefer buying the equipment along with the car, rather than adding it later. Making RDS receivers a standard part of vehicle radios would require participation by automobile and radio manufacturers, which is already occurring within the European DRIVE program.

9.3 EXTERNALLY LINKED ROUTE GUIDANCE

Externally linked route guidance is the most complex of the three technologies being investigated. It offers the most significant potential for reduction in traffic congestion, but it also requires the greatest amount of additional infrastructure before it can operate.

An externally linked route guidance system could be designed and implemented under several different system configurations. To illustrate in detail the issues inherent in the development and implementation of the technology, one likely configuration is described below as an example. The impacts of this system configuration on development needs, implementation issues, and other factors are discussed.

This section assumes that the externally linked route guidance configuration would include the navigation capabilities within the vehicle. Each vehicle would receive periodic updates of traffic information. This strategy would have a number of advantages, including the distribution of the computational load and the ability to use the navigation features of the system before widespread implementation of the external communication links.

The objective of the external link would be to provide real-time traffic information to the in-vehicle processor. A data collection procedure would also be needed to collect real-time information.

Implementation Issues

The first issue considered relates to system development needs. None of the system elements would require major new technological development. The development work that may be needed would involve adapting existing technologies to the highway and vehicle environment.

The highway environment is characterized by poor conditions. Conditions can change dramatically over time, from low to high temperatures and from low to high humidity. Equipment placed near a highway is subjected to high levels of pollutants, as well as heavy vibrations, noise, and electrical power variations caused by weather conditions. Roadside equipment is also subject to theft and vandalism. The automotive equipment shares several of these difficulties which will affect on-board equipment.

In-Vehicle Navigation. It is envisioned that the in-vehicle navigation system would be a module of the larger, externally linked route guidance system. In its simplest form the in-vehicle navigation system would contain the following subsystems: a database of the urban area street system, a position locate that would track the vehicle's location against the network database, an input device for telling the navigation system the destination for each new trip, a computer for determining the best travel path to take, given the vehicle's current location and the input destination, and an output device for informing the driver of the preferred path and any possible alternatives.

One specific development task would be to determine the method by which the system should give route guidance directions to the driver. Research is needed to determine whether such a system should be map oriented, text oriented, use synthesized speech, or some combination of these.

Development of electronic maps of urban areas would also be necessary for these devices. Such development might be possible by downloading data contained in GPS/DIME files, in the new Census TIGER files, or by digitizing street maps of the required urban areas. Standards for updating maps are highly desirable and should involve both public and private sector cooperation.

The most important additional functions needed to achieve full externally linked route guidance would be the following abilities: to provide communication to the central traffic database, to receive information from the central traffic database, to allow updates to the network travel time parameters contained in the on-board electronic highway network, and to provide for some type of notification so that drivers are aware that changing traffic conditions have altered their planned routing.

Traffic Data Collection and Monitoring. Current traffic monitoring systems would not provide sufficient detail on most urban roadways for the externally linked route guidance system to be fully implemented. Most existing systems cover only portions of the urban freeway systems and occasionally sections of major arterials.

Externally linked route guidance would, therefore, itself provide the means for inexpensively collecting traffic information. Beacons would be used throughout the urban area to broadcast traffic information updates to in-vehicle navigation systems. This communication link would work in two directions and could therefore serve as a major source of traffic information. The in-vehicle navigation system would calculate its travel time on the links it had just traversed and then transmit this information to the external system.

Use of this system to provide traffic information would also serve as a means of providing a return on the externally linked route guidance infrastructure investment to motorists who did not use the externally linked route guidance system. The traffic information available through the system described previously could also be broadcast over an RDS, or be provided to local media for broadcast over conventional radio and TV networks.

Communications Standards. Communications between the beacon system and the in-vehicle navigation systems would require a significant developmental task. At this time, the European Community is investigating the use of an infrared system to pass information. This system offers potential, but radio frequency systems might also be used for this communication link. In addition, communication protocols would be needed, and the specific information to be passed between the two subsystems would have to be determined.

Phasing. The implementation of an areawide externally linked route guidance system would be a capital-intensive undertaking. Reasonably large commitments of funds would be required from the system operator for infrastructure and from the users of the system for purchase of sophisticated electronics for their cars. Consequently, installation and operation of the system would need to be implemented in stages, as the system development was completed and the infrastructure was constructed.

1. *Technological phasing.* From the technology standpoint, some subsystems of the externally linked route guidance system could work independently of one another, and therefore might be implemented at different times. The most independent subsystem would be the in-vehicle navigation equipment. In that system, the initial device would provide basic route navigation information, and then functional additions would provide the external links as they became available.

The second subsystem that might be implemented prior to full implementation would be the beacon communication system. The advent of a two-way communication system to collect traffic information has sufficient merit that it could easily be implemented independently of the externally linked route guidance system.

In order to be effective, the beacon system would require that a reasonable number of vehicles be outfitted with communications capabilities. These vehicle fleets could be transit vehicles or commercial vehicles that were tracked by the operating agency for purposes of fleet or personnel management.

2. *Geographic phasing.* To provide an entire urban area with externally linked route guidance capabilities would require a substantial investment in infrastructure. This investment would be the responsibility of the operating agency and might not be possible during the initial stages of implementation.

Several options would be available for phasing the construction of the externally linked route guidance infrastructure. Placing the infrastructure on the freeway system first would allow the highway agency to replace the existing loop detection systems, preventing the need to duplicate traffic information and incident detection systems.

The drawback to this phasing methodology would be that information on actual congestion levels would be available for the freeways, but not for the parallel arterials. This situation may cause a disproportionate number of users to select arterial travel paths, a decision that might not be justified by actual conditions.

The alternative phasing system would be to instrument specific geographic zones within an urban area, and then progressively expand the geographic coverage of the system. The advantage of this strategy is that complete information would be available within the instrumented area, and drivers using this system would quickly gain confidence in its utility. The disadvantage of the subarea strategy is that benefits would not be spread evenly throughout the urban area. This would not be a significant issue if the system was built with private funding. It could, however, have significant political repercussions if the prime funding source was public.

Jurisdictional Issues

Any number of agencies or private companies could build and operate the infrastructure of an externally linked route guidance system. The most likely public authority would be a regional transportation agency of some kind. In the Seattle area, WSDOT would be the most likely instigator of an externally linked route guidance system. WSDOT has the greatest resources, and already performs many of the data collection and analysis functions that the externally linked route guidance system would require.

A private operator would also be a possibility for an externally linked route guidance system. However, a private firm would need to be confident that the system would actually generate revenue beyond the cost of building, maintaining, and operating the system. A major route guidance system is being installed in London, England, using entirely private finance. In this case, WSDOT's role could be to develop and promote appropriate legislation to authorize the private venture.

A private company could also construct or operate an externally linked route guidance system as a contractor to a public agency. Since DOTs are under restrictive staffing constraints, they may elect to subsidize private development of the system. The private company would be expected to contribute to the cost of building the infrastructure and operating the system. The DOT would also contribute to the construction costs, and would probably need to provide a subsidy or other payment to fund operating costs.

The operator would need agreements with each of the cities, agencies, and firms whose equipment or information they would share. For example, the operating agency may need to place beacons on signal poles. An agreement would be needed to allow access to those signal poles for routine and emergency beacon maintenance and repair. Other agreements would be needed to provide access to the information collected and maintained by different operating agencies. Agreements would also be needed for the communications portions of the system, such as a contract with the local telephone company for leased telephone lines, or an agreement to share conduit or power poles for running communications cable.

The in-vehicle systems should be designed and marketed by the private sector. The state or federal government should be involved in setting standards for the operation of in-vehicle navigation equipment or the interaction of that equipment with external data sources.

Opposition to externally linked route guidance would most likely come from jurisdictions that believed the system would divert a large amount of unwanted traffic onto their streets. Any public jurisdiction that participated in an externally linked route guidance effort would have to be prepared to answer questions concerning the rerouting of traffic as a result of system implementation.

Given the system configuration outlined above, however, the role of jurisdictions not operating the externally linked route guidance system would be fairly limited. With route selection performed in-vehicle, the local jurisdictions would not have significant input into the choice of alternative paths. The jurisdictions would need to be concerned with the operation and maintenance of the beacon system, if only to the degree of granting access to the beacons on the city arterials.

Integration into the Existing Infrastructure

The in-car navigation systems would function autonomously before the development of the external link. The two-way communication between the in-vehicle navigation system and the external system database would also provide traffic information to the system. These data would provide valuable information on traffic performance for output via RDS-TMC, commercial radio, or any one of a number of other media. Participating agencies could use these data in their continuing efforts to improve information on traffic conditions.

It would be possible and desirable to integrate the infrastructure required by the externally linked route guidance system with existing infrastructure requirements. For example, beacons would logically be placed on existing light standards or traffic signal poles, where power would already exist and where, in many cases, room would exist for additional equipment in signal cabinets.

Potential Funding Mechanisms

A variety of funding sources would most likely be used for different parts of the system. The in-vehicle navigation systems would undoubtedly be purchased by private individuals. No public funding would be required or warranted for this substantial portion of the externally linked route guidance system.

Funding for the infrastructure portion of the externally linked route guidance system could come from a wide variety of sources and would be dependent on the selection of the system operator or owner. If a private organization owned and operated the externally linked route guidance system, the cost of the infrastructure would be borne by the owner, and usage fees from the users would provide a return on the owner's investment.

If a public agency operated the system, some form of tax dollar would likely be used to pay for the infrastructure construction and subsequent operation. An externally linked route guidance system would be eligible for federal funding, in the form of federal aid funding with a required local match of 50 percent. Usage fees could be based on either a monthly charge or a charge for use, such as a fee-per-beacon-passed. The monthly charge would be the most simple accounting tool, but would be the least equitable of the usage fee arrangements.

If the usage fee was based on actual system use, the in-vehicle system would have to either transmit an identity code in passing each beacon, or maintain its own account balance on-board. The former accounting system would be more conventional, with the user receiving a monthly bill. Such a system would also have to address significant issues of security to ensure that erroneous charges were not made to accounts and that vehicle ID codes could not be duplicated or altered. The latter option would require the vehicle owner to periodically take the in-vehicle unit to a location for recharging the account or to pay off the accumulated balance.

Consumer Reaction

Like RDS-TMC, the externally linked route guidance system would help those people equipped with the system choose more efficient routes. Even if only some people chose those routes, the motoring public as a whole would benefit, because congestion on the worst routes would decrease as a result of those choices.

Externally linked route guidance would be likely to require some public funds for implementation. The nonequipped motorists may have difficulty in perceiving the benefits they obtain from reduced congestion because of choices other drivers make. Some controversies might therefore exist over the use of public funds for such a system.

9.4 ADAPTIVE TRAFFIC CONTROL

This section describes the issues involved in the development and implementation of an adaptive traffic signal control system for urban areas. It describes the factors that an agency would encounter in attempting to install such a system under conditions commonly found in the United States.

Implementation Issues

The most important issue surrounding adaptive traffic control is that such a system currently does not exist for implementation in the U.S. While truly adaptive control systems are in use in other parts of the world, they will not immediately work on signal controller hardware sold and serviced in the United States.

A fully adaptive signal control system could be made available for implementation in U.S. urban areas in three ways:

1. *Installation of imported equipment.* This would be the most straightforward method for installing an adaptive traffic control system. In this scenario, the U.S. jurisdictions would simply purchase controller hardware and central processor software from overseas vendors.

The advantage of this scenario is that the development work has already been done on these systems. The software has been debugged, and any improvements already made to the system could be readily implemented on the systems operating in the United States. Finally, overseas systems generally run on U.S. central computers such as DEC, which would be bought in this country.

The disadvantage of this scenario is that the system requires controller hardware components that are not commonly available in the U.S. marketplace. This may limit a jurisdiction's ability to obtain spare parts or to obtain assistance in the repair and maintenance of the signal control system. It would also require the jurisdiction to retrain the technicians that maintain the field equipment.

2. *Development of interface equipment.* This option would be selected if imported central software was desired, to be used in conjunction with existing signal controller hardware. In this configuration, an interface unit would be required to translate the messages designed for use by overseas signal control hardware into signals that U.S. hardware could properly interpret.

The advantage of this method is that the interface unit could be designed to match any type of U.S. controller. The memory and processing power inherent in the interface could be designed specifically to handle the combined needs of the adaptive control system algorithms and the controller capabilities. The approach would minimize both additional outgoings and the imported element, and probably constitute an effective short-term solution.

3. *Development of a new control system.* This option would require a national agency to sponsor a renewed effort to provide a new adaptive signal control system. Such a system could be a revision of the existing TRANSYT-7F software, an extension of the OPAC signal algorithm currently under development, or an entirely new algorithm. It could be specifically designed to take into account domestic signal control hardware, the increased processing power of modern microprocessors, and actual traffic conditions found in the United States.

There are two significant disadvantages to development of a new adaptive system. The first is that development effort will be expensive and entail a considerable amount of time and staff resources. The second disadvantage is that the development effort will be a research project, with an uncertain outcome. However, much more is now known about effective real-time adaptive system designs than when the UTCS project was abandoned in the 1970s. The chance of success is therefore high, and the potential rewards are considerable.

Installation

Cities wishing to upgrade traffic signal systems have a number of alternatives. Thus, the adaptive traffic control system would not only have to be cost effective, it would have to be more cost effective than the installation of a conventional signal system before an urban area would select it for implementation. In addition, because initial systems would be developmental efforts, their expected benefits would have to outweigh the cost associated with their uncertainties.

In order to select implementation of an adaptive control system, the system would have to outperform conventional systems in the following criteria:

1. *System performance.* It would be necessary to develop some simple means of demonstrating the benefits of improved traffic signal systems to public officials and the motoring public. Signal system improvements are often difficult to sell politically because the improvements are not as visible as alternative choices for that funding, such as new road construction. For example, a motorist has difficulty recognizing the average improvement in travel time through a signal system, whereas the presence of a new road is obvious.

2. *Costs and cost effectiveness.* The basic components of the adaptive system need be no more costly than the components of a conventional, centrally controlled, fixed time system. These components include a central computer, individual signal controllers, vehicle detectors, and communications capabilities. However, the cost of an adaptive system could be significantly impacted by the costs associated with adapting the system to domestic hardware, whether directly or through some type of interface system.

3. *Maintenance.* This requires a determination of how many additional loop detectors are needed by the adaptive system. Loops are an expensive part of any traffic signal system, in terms of both initial installation and subsequent maintenance. If the new system could use existing loop placements, the cost to install it would be minimized. A system that required extensive new detector placements would also increase the need for staff to maintain those detectors.

4. *Staffing.* Staffing will be a major portion of the cost of maintaining and operating the signal system. Operating and maintaining an adaptive signal control system will require a competent engineering staff. While an adaptive system should run without user intervention and the need for highly trained staff, a city must always maintain a staff capable of understanding, monitoring, and administering the signal system being used. Staff who become well trained on sophisticated signal systems are often heavily recruited by private firms because of their expertise. Cities should expect to have to pay their key employees wages comparable to what they could earn in the private sector.

Jurisdictional Issues

Adaptive signal systems would have little effect on traffic routings. Instead, the primary jurisdictional issues in adaptive arterial control would center on the determination of which signals to include within the boundaries of an adaptive signal system, and which agency within those boundaries would operate and maintain the system.

To avoid jurisdictional disputes and the need to create operating agreements, the most likely adaptive control implementation in the Seattle area, as in most metropolitan areas, would take place entirely within one jurisdiction or in those locations where jurisdictional boundaries were already blurred. For example, the state DOT, which operates signals at freeway ramp/arterial interchanges, might cede operating control over some of these signals to local municipalities or counties so that they could be incorporated into that jurisdiction's signal system. The municipality might also take over maintenance of those signals when it assumes operational control.

For the larger jurisdictions, the switch to adaptive traffic control would be relatively easy. Most larger cities in metropolitan areas have at least some central control over their signal systems, and maintain a technical staff that would be capable of operating an adaptive control system.

Integration Into the Existing Infrastructure

The adaptive signal control system would integrate into the existing urban signal systems as well as any new signal system. The control system would require increases in maintenance and operations expenses similar to the introduction of any similarly sized traffic signal system. The primary difference is that an adaptive signal system will maintain its signal coordination automatically. Therefore, collection and measurement of traffic volumes to periodically adjust the signal timings will be unnecessary.

Depending on the hardware configuration chosen for the system implementation, the jurisdiction may require additional training for its technical and professional staff. This would need to be included as part of the system price. The communications requirements of the new system may also be different from those of the older central control system being replaced.

Consumer Reaction

Consumer reaction would not be a factor in the development and implementation of adaptive signal control systems. Such signal systems would be publicly owned and operated, as are conventional signal systems. The role of private organizations would be limited to funding considerations, particularly as part of traffic mitigation plans for new developments. Consumer reaction to an adaptive signal system would be small. Operating correctly, a system will be transparent to the motorist. While the system would provide benefits to the motorist in terms of reductions in travel time through the network, as well as reductions in stops and improvements in air quality, the size of these improvements would be small for any given trip and, as such, would be typically imperceptible to the motorist.

Potential Funding Mechanisms

The primary funding sources for implementing adaptive signal systems will be those that municipalities currently use for funding traffic signal systems. These are generally a combination of local tax revenues, money provided by state government, federal gasoline tax pass-back funds, and private contributions from developers for traffic congestion mitigation.

In many cases, large developer contributions are used to leverage other state and local funds towards the purchase, installation, and operation of a signal system. These funds are then supported with federal aid urban funds, city resources, special development or transportation taxes, and miscellaneous funding sources such as the oil rebate funds.

9.5 SUMMARY

This chapter has described possible implementations of the three selected technologies. Seattle, Washington, was chosen as an example of a "typical" U.S. city, and the role and responsibilities of involved parties in this city have been outlined. Similar jurisdictional arrangements and equivalent agencies exist in most other metropolitan areas. Therefore, many of the issues described will be equally applicable to other cities across the United States.

CHAPTER 10

DEVELOPMENT OF A NATIONAL PROGRAM

10.1 INTRODUCTION

This chapter describes national and international efforts to prepare research, development and demonstration programs for advanced transportation technologies. Following this introduction, two major European initiatives in this area are described. Current efforts within the United States to develop a national program are then outlined. The chapter concludes with a description of a proposed IVHS program for the U.S. prepared within this research study.

10.2 PROMETHEUS

PROMETHEUS (*244*) is a major European research program which aims to define and develop road traffic of the future based on advanced technologies. Organized under the EUREKA umbrella, PROMETHEUS is a collaborative effort between European automobile manufacturers and their respective governments. The objective is to create concepts and solutions that will make vehicles safer and more economical, with less impact on the environment, and will render the traffic system more efficient.

The program was initiated by the Europeans in the face of increasing competition from Japan and North America in the field of information and communication technologies applied to automobile and traffic engineering. In addition to strengthening European competitiveness through coordination concepts, the program aims, using a top-down approach, to produce a totally integrated highway transportation system throughout Europe. By coordinating the parties involved in all facets of transportation, it is anticipated that synergistic gains can be achieved and that considerable advances will be made in the scientific sector.

Beginning in October 1986, 300 scientists and engineers in research institutes and research departments of automotive companies in Europe worked together to develop a framework for the research program. This Definition Phase is finished, and the program has moved into the Research and Development Phase. The time span for developments emerging from the program is expected to be more than 20 years.

The PROMETHEUS program combines both scientific research conducted by universities and research institutes, and applied research conducted by industry. This cooperation will be accomplished with the support of government agencies responsible for highway transportation and telecommunications. To ensure integration of national and European interests, a PROMETHEUS Council has been formed under the chairmanship of the Federal Ministry for Research and Technology in Germany.

PROMETHEUS has been subdivided into seven program areas. Three will be undertaken primarily by the automobile industry, and the remainder primarily by research agencies and government. The industry-related areas are as follows:

PRO-CAR: The objective of this program area is to develop systems which will assist or support the driver in performing the driving tasks. Using onboard computers, these systems will take inputs from sensors on the vehicle, interpret them and then take appropriate actions. Impending critical situations can be recognized, and the systems can instigate emergency action to prevent accidents.

PRO-ROAD: The second area of research for industry concerns the development of communication and information systems between roadside and onboard computers. This will enable drivers to receive information on which they can individually optimize their driving patterns.

PRO-NET: The final aspect to be performed by the industrial participants concerns the development of a communication network between vehicle computers. Among other benefits, the implementation of such a network would allow vehicles to be operated with "electronic sight," enhancing the perceptive range of the driver beyond his own range of vision.

The four remaining subprograms, concerning basic research, are outlined as follows:

PRO-ART: This subprogram will examine and develop the principles of systems which use artificial intelligence. Methodological investigations and studies of problem areas and experimental systems will be included.

PRO-CHIP: The aim of this area is primarily the development of microelectronics required for artificial intelligence systems, of a size and reliability for incorporating within vehicles. Other microelectronics required by PROMETHEUS will also be addressed in this subprogram.

PRO-COM: The field of communications is considered in PRO-COM. Architecture and general protocols will be developed to optimize data communication between vehicles, road, and environment.

PRO-GEN: The final subprogram of PROMETHEUS aims to develop scenarios in the area of traffic engineering, which adapt the road system to the technical developments.

PROMETHEUS is still at an early stage and it may be some time before its developments can be usefully implemented. Funding for the program is currently proposed at the $700 million level, to be provided jointly by governments and industry. The technological advancements in PROMETHEUS promise to be significant and could lead to substantial reductions in traffic congestion, as well as "unprecedented" improvements in traffic safety.

10.3 THE DRIVE PROGRAM

DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) is a $140 million research program of CEC linking information technology and transportation. CEC initiated studies into current and future developments in the area of road transport informatics (RTI) and their potential application to highway and vehicle safety during 1985. Based on this review, CEC made a proposal for a European Community R&D program (COM(87)351 final) in July 1987. DRIVE was formally adopted as a community research program in June 1988.

A DRIVE workplan (*245*) was developed by CEC in consultation with member nations of the European Community, industry, and various highway user organizations. The workplan formed the basis of a call for proposals published in July 1988. In October 1988, 189 proposals were received, of which some 60 projects were funded. These projects comprise an effort of around 11,000 man-months. A further round of funding has established additional projects from mid-1989, and detailed proposals have been developed for "DRIVE-2."

The general objectives of DRIVE are: (1) to enable the timely adaptation of the highway infrastructure and services to take advantage of the opportunities created by technological advance; (2) to exploit the opportunities for synergy between road and telecommunications infrastructure developments; (3) to promote the consistent development of RTI, so as to facilitate the development of an internal European market; (4) to contribute to the international competitiveness of the equipment and service industries; (5) to stimulate government-industry collaboration in analyzing opportunities and requirements, in basic R&D for developing the infrastructure technologies, and in the development of specifications and initial system testing; (6) to support international standardization in RTI and for related equipment and services; and (7) to contribute to the timely common adaptation of an appropriate regulatory framework for advances in RTI.

Within these general objectives, the overall goal of DRIVE is to make a major contribution to the introduction of an Integrated Road Transport Environment (IRTE) offering, by 1995, improved transportation efficiency and a breakthrough in road safety. Through the individual projects DRIVE seeks to achieve the following results: to identify the most promising technologies from an economic and technical standpoint and to develop a strategy for their implementation; to prepare performance specifications and compatibility standards to enable industry to develop the necessary equipment and systems; to develop directives and guidelines to which products and infrastructure should conform; and to design and implement pilot schemes to assess the performance of equipment and systems.

10.4 U.S. INITIATIVES

This section describes current efforts within the United States to promote research and development of IVHS. Work by federal and state governments, universities and research agencies, professional organizations, and other ad-hoc groups is described in turn.

U.S. DOT. During 1987 and 1988 the FHWA, through the taskforce on the Future National Highway Program, examined the role of the federal-aid highway program beyond 1991. This investigation included a consideration of the role of advanced technologies.

The current federal-aid highway program is authorized through September 30, 1991. If federal assistance to national highway programs is to be continued beyond that date, the U.S. Congress must enact new legislation. A consensus as to what that legislation should contain must therefore be achieved.

The primary goals of the FHWA taskforce were to determine the objectives of national highway programs and to define the role of federal government in ensuring those objectives are met. The interim report of the taskforce (*246*) concluded that involvement at the federal level was warranted where national uniformity was required and where cost-savings could be achieved by centralizing certain activities, such as long-term highway research and technological development.

Additionally, the Conference Report on the FY1989 Department of Transportation Appropriations Act (*247*) directed the Secretary of Transportation to report to Congress on IVHS technology. The objectives of the report were to assess ongoing European, Japanese and U.S. IVHS research initiatives; analyze the potential impacts of foreign IVHS programs on the introduction of advanced technology for the benefit of U.S. highway users and on U.S. vehicle manufacturers and related industries; and make appropriate legislative and programmatic recommendations.

In performing this study, the U.S. DOT was directed to consult with state and local governments, private sector transportation groups, and vehicle and electronic manufacturers. To assist in this process, the Office of the Secretary of Transportation prepared a discussion document (*248*), which was distributed to interested parties in May 1989.

The discussion paper did not finally commit to the need for a national IVHS program but summarized the potential goals and technology areas to be included in such a program. These were formulated as a set of six goals, which include program activities spanning short-term to long-term timeframes. The specific goals were as follows:

1. Increase traffic movement efficiency of urban streets and highways using ATMS including real-time traffic responsive control strategies, and integration with advanced information systems.
2. Enhance individual motorists' information on route choice, current traffic incidents, and other pertinent information through advanced in-vehicle driver information systems.
3. Improve safety of highway operations through the use of in-vehicle advisory warning systems or aids, and improve driver detection and response.
4. Increase the efficiency, safety, and reliability of trucks and other highway-based fleet operations using safety warning systems and driver control aids, communications, vehicle identification, and safety back-up systems.
5. Substantially increase future levels of highway service (higher speeds and increased safety) for intercity and rural highway travel using partially and (eventually) fully automated vehicle control.

Achieving these goals will require a program of research, development, demonstration, and deployment in four system technologies: ATMS, advanced in-vehicle driver information systems, freight/fleet operations systems, and AVC.

Finally, in July 1989 the Secretary of Transportation announced the development of a national transportation policy as a top priority (*249*). The key objectives of this effort are to ensure that the policy is flexible in responding to emerging transportation needs and promotes integrated solutions. In both respects, IVHS is cited as potentially contributing to these goals.

A national transportation policy statement, issued in early 1990, sets out the decision-making framework by which transportation infrastructure, services and related needs can be systematically assessed and implemented over the next 30 years. Development of this policy statement was achieved through an outreach program to elicit the views of state and local government and the private sector. This process was undertaken through six cluster groups, one of which focused on the role of innovation and human factors.

The innovation and human factors cluster examined the application of new technology, management, organizational structures, and information systems to transportation, as well as the interaction between the individual user and the transportation system. This was achieved through a series of open forums and policy issue seminars during the latter half of 1989.

Congressional Office of Technology Assessment. In February 1989, the Subcommittee on Transportation of the Senate Committee on Appropriations requested the Office of Technology Assessment (OTA) to assess how IVHS could contribute to improving transportation productivity and efficiency. The staff paper prepared by OTA (*250*) contained the following conclusions and recommendations:

1. IVHS technologies now available can increase roadway efficiency and throughput by 10 to 20 percent, make travel time more predictable, improve safety, and reduce vehicle emissions, although by themselves they will not solve urban traffic problems.
2. The multiple benefits from IVHS argue for their immediate further development and greater investment in research, development, and operational testing. More aggressive federal leadership in organizing and supporting research could assist states and localities in addressing urban transportation infrastructure problems.
3. Substantial short-term national advantages could come from federal policies and programs to encourage implementation of advanced traffic operations and control systems.

4. Federal participation in testing and demonstration programs of IVHS technology could encourage further technical development and avenues for reducing manufacturers' liability risk. Early government leadership in addressing standardization issues would also aid the development of these technologies.

5. Market incentives for private sector development of IVHS technologies are significantly dependent on public sector programs. Therefore, federal dollars invested in assisting state and local governments could provide assistance for programs to address urban congestion, as well as assisting industry by creating the public infrastructure necessary to communicate with products that are almost ready.

6. Attention to safety and human factors is a top priority, and active participation in these areas by federal agencies responsible for highway safety is warranted.

American Association of State Highway and Transportation Officials. AASHTO has a formalized mechanism for encouraging and promoting research, development, and technology transfer (RD&T) within its own committee structure. This is primarily achieved by the Standing Committee on Research (SCOR) created by the AASHTO Policy Committee in 1987. SCOR has responsibility for performing the following functions (*254*): to assist other AASHTO committees and subcommittees in identifying research needs and defining an overall research agenda for highway and transportation from the perspective of AASHTO's member departments; to review, observe, and encourage effective use of the federal-aid highway program's Highway Planning and Research (HP&R) funds and recommend an appropriate level of funding for research; to serve as a forum and coordinator for highway and transportation research by AASHTO and its member states; and to review, monitor, and coordinate each of the national programs of highway research within AASHTO, including HP&R, NCHRP, and the Strategic Highway Research Program (SHRP).

Starting early in 1989, SCOR undertook to evaluate the issues that will affect the future of highway and transportation research; to recommend positions for consideration by AASHTO; and to consider current and prospective programs of research, providing AASHTO with the information needed to determine priorities.

As a result of this effort, SCOR has proposed a number of policy recommendations for consideration by the AASHTO Policy Committee in the area of transportation research, development, and technology transfer (*255*). Of particular importance is a policy resolution adopted in July 1989 (*256*) which states that AASHTO:

1. Strongly endorses the concept of IVHS as an effective means of addressing many problems of the highway network.

2. Supports the initiation of efforts within the AASHTO member departments to pursue demonstration of advanced highway technologies, both as direct programs and as part of future federal programs.

3. Encourages the AASHTO member departments to explore various technological options with a view to establishing full-scale IVHS demonstrations in their areas.

4. Urges the FHWA and U.S. DOT to take the leadership with AASHTO in arranging demonstrations of IVHS equipment and facilities to transportation professionals and others.

5. Requests the new Special Committee on Transportation Systems Operations to include the subject of IVHS on its work program, and to serve as a focus within AASHTO for the consideration of such systems.

The AASHTO Special Committee on Transportation Systems Operation was established in 1988 to pursue the implementation of those strategies having practical value in alleviating congestion; demonstrate the potential of new techniques; and encourage intergovernmental and interagency coordination and implementation of these efforts on a systemwide basis.

Transportation Alternatives Group. The Transportation Alternatives Group (TAG) is the primary focus for consensus building within the Transportation 2020 program. TAG is a coalition of 12 national public and private sector organizations with involvement in surface transportation issues. The Transportation 2020 program was established in 1987 by AASHTO to develop a plan for dealing with transportation needs through the year 2020; to evaluate financial and program alternatives to meet those needs; and to develop a long-term program with specific goals and measurable results.

The first step in this effort was to gather information from highway and transportation officials and users on present and future transportation needs. This was accomplished through 65 public forums held throughout the United States (*257*). TAG is currently summarizing and synthesizing the data obtained and has developed policy themes that include the following (*258*): (1) future transportation programs should focus and coordinate research and development efforts on new vehicle and highway technologies; (2) U.S. technological leadership in surface transportation should be rebuilt through renewed emphasis on research, development and training through expanded federal and state programs; and (3) future transportation programs should encourage government (at federal, state, and local levels) and private sector cooperative projects and partnerships.

Mobility 2000. Mobility 2000 is an ad-hoc coalition of transportation professionals drawn from government, universities, and industry. The group is seeking to establish an agenda for research, development, and demonstration of advanced vehicle and highway technologies. Mobility 200 is promoting the need for a cooperative program involving federal, state, and local government and private sector organizations to increase mobility, improve safety, and meet the needs of international competitiveness (*259*).

Mobility 2000 has proposed a national organization to administer an IVHS program (*260*). This would place leadership of a national program with the U.S. DOT Office of the Secretary of Transportation, and would establish a council made up of government, industry, academia, and user representatives which would be responsible for establishing program goals and addressing policy issues. In turn, this council would be advised by a committee made up of FHWA, NHTSA, and UMTA. This committee would be responsible for program administration and the monitoring and coordination of individual program elements. The proposed structure is shown in Figure 27.

State of California. Since the mid-1980s, Caltrans has undertaken a series of studies and initiatives involving advanced technologies for transportation. During that period, other agencies and organizations became partners in these efforts. Current research and demonstration projects underway in California are described in the following paragraphs.

Caltrans is leading the implementation of the multi-state Crescent Demonstration within the HELP program. HELP is an integrated heavy vehicle management and monitoring system combining the technologies of AVI, weigh-in-motion (WIM), and automatic vehicle classification (AVC). The Crescent involves the installation of the fully developed HELP system in five western states.

PATH (Program on Advanced Technology for the Highway) (*261,262*) is a proposal from the University of California at Berkeley for a national R&D program including a multi-state consortium, costing several hundred million dollars over a 12-year period. The major themes of the program are highway electrification and automation, including many AVCS concepts. Approximately $5.0 million has been spent on the program in the past 10 years. More recently, Caltrans and U.S. DOT (UMTA and FHWA) funds have been earmarked for this advanced technology program, and a total of $6.3 million of new funding has been made available. Private sector funds are being sought from the California utilities. These funds will be applied to the development of electrification and automation technologies for the highway.

The Smart Corridor is a joint demonstration project under the leadership of the Los Angeles County Transportation Commission which includes Caltrans, Los Angeles DOT, California Highway Patrol, and Los Angeles Police Department. The corridor will cover a 15-mile length of the Santa Monica freeway and five adjacent arterials. Sensors installed on the freeway will provide information on current traffic conditions that will be used to make control decisions and to provide up-to-date information to motorists through a variety of media. Closely related to the Smart Corridor is PATHFINDER (*263, 264*), a cooperative field experiment involving Caltrans, FHWA and General Motors, which aims to perform an initial assessment of the feasibility and utility of a real-time in-vehicle navigation and motorist information system. The project will be performed within the Smart Corridor demonstration area.

State of Michigan. The University of Michigan Transportation Research Institute (UMTRI) is currently defining and organizing a research program within the State of Michigan on IVHS technologies (*265*). The main objectives of this effort are to develop a research agenda and an institutional framework in which to perform the research. UMTRI is presently engaged in a 12-month research planning study. The study is sponsored by public and private sector organizations, including Michigan DOT, FHWA, NHTSA, General Motors, Ford, and Chrysler.

State of Texas. Investigations of IVHS technologies in Texas are currently being led by the Texas A&M University System (*266*). This is being undertaken through the Texas Advanced Transportation Technology (TexATT) research project sponsored by the Texas State Department of Highways and Public Transportation (SDHPT). The key objective of this project is to keep SDHPT informed of the latest advances in technology and the best methodologies for the application of these technologies in reducing congestion and improving highway safety. The project also includes two specific technical studies. The first is a short-term effort to develop a real-time traffic signal control system; the second is longer term work to develop an autonomous vehicle system using stereo camera sensors.

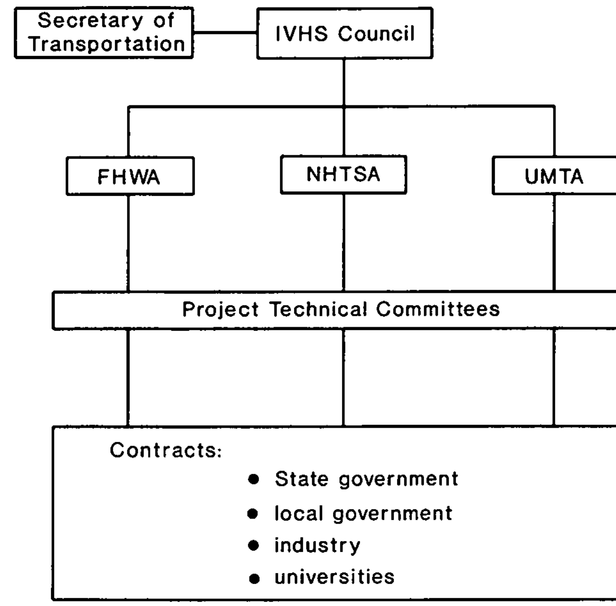

Figure 27. Proposed organizational structure for national program administration.

10.5 DEVELOPMENT OF A NATIONAL PROGRAM

This section describes the initial work undertaken in this project toward defining a national IVHS program for the United States. This effort has involved identifying and outlining projects or activities to be undertaken within such a program. These cover research, demonstration, standard-setting, implementation, and ongoing support, with most emphasis given to the first three. A preliminary timeframe for the program is also included.

The project and activity descriptions have been divided into five categories. A general category has been included to cover areas such as IVHS program management and coordination, policy formulation, and broad-based institutional issues. The remaining categories reflect four technological areas as follows: ATMS, advanced traveler information systems (ATIS), FMCS, and AVCS.

The program has been divided into three broad time horizons: short-, medium- and long-term. Short-term is considered to be the period up to 1995, medium-term is the period 1995 to 2005, and long-term is beyond the year 2005 through 2020. Project and activity outlines for the short-term time horizon have undergone the greatest amount of development.

For the general, ATMS, ATIS, and FMCS categories, no project descriptions have been prepared beyond the medium-term. Specific widespread implementation programs for systems and technologies in these categories can be developed at a later stage. However, recognizing the longer timescale associated with the development and demonstration of certain AVCS, some outlining of a recommended long-term AVCS program has been undertaken.

This section also addresses a number of issues relating to the organization, contracting approach, public and private sector cooperation, and funding relating to a national IVHS program.

Approach to Program Development. The initial step in developing an outline IVHS program was to identify specific individual projects, tasks, and activities that need to be considered. The approach followed involved examining each of the program areas in turn and defining the work needed to fully develop those advanced technologies and systems which show the greatest potential for a significant impact in terms of improving transportation system efficiency and safety.

It was recognized that the many technologies and systems are at different current levels of development. In some cases, basic or applied research is required on techniques and approaches which show particular promise. In others, systems are sufficiently developed to permit demonstrations in the near-term. Certain systems would also benefit from near-term standardization, and so standard setting activities have been identified. Finally, some advanced technology systems have passed through these early stages, so that widespread deployment and implementation are now needed to realize the benefits of the technologies. Therefore, each project activity identified has been categorized into the appropriate development category within its broad technological area.

Additionally, for a program of this magnitude, a series of general activities is also required. These activities include defining policy objectives, overall program management and coordination, developing project review and evaluation guidelines, and liaison with standardization bodies. Other issues are also addressed in the general activities, including antitrust concerns, impacts on society, behavioral responses, and the need for legislative changes to allow the implementation of certain technologies.

Finally, in developing an outline national program, two other areas were addressed. The first was to identify the interrelationships between projects or activities. Work has been undertaken to ensure there is a logical progression for each system or technological development from research through demonstration, standard-setting, and implementation. Additionally, the development of certain systems or approaches will rely on the completion of technological developments in other areas. The relationship of projects within and between individual technology areas has also been considered.

The second area covers the duration and timing of projects and activities. All activities have been placed within either the short-, medium- or long-term timeframes described above. Activities defined as short- or medium-term have additionally been assigned a specific duration representing an estimate of the level of effort involved. Finally, using the logical relationships between projects and their durations, all activities occurring through the year 2000 have been placed on an overall timeline.

Issues in Developing a National Program. This section addresses issues and questions that have been raised in the process of developing a national IVHS program. It seeks to provide answers to these questions wherever possible. It also suggests additional efforts to be undertaken in resolving these issues.

Objectives of a national program. It has been suggested that proponents of a national IVHS program could spend too much time developing technological solutions without first fully defining the problems that could be solved. However, existing levels of traffic congestion, continued growth in traffic volumes leading to reduced urban and rural mobility, increasingly serious air pollution levels, and predicted increases in accidents can be coupled with current technological opportunities and serious concerns about international competition and loss of technical leadership to constitute a convincing catalog of urgent motivations.

A major conclusion of this project is that IVHS technologies developed and implemented in the United States have the potential to help alleviate these problems. A well-organized and highly prioritized national research, demonstration, and implementation program is the only way to establish the actual value of these highly promising technologies.

The key goals of a national IVHS program are to make automobile travel safer, more efficient, more energy efficient, and more environmentally benign. The worldwide market opportunities for advanced technology systems also provide a major commercial incentive. Additionally, short-term benefits of implementing current IVHS technologies must be demonstrated in order to secure the necessary public and political support for longer term R&D on more long-term technological approaches.

Public and private sector cooperation. In the U.S., cooperative public and private sector technology development efforts raise concerns about proprietary interests, liability issues, privacy of information, and responsibility for standard-setting. The 1984 National Cooperative Research Act addresses antitrust issues by providing a framework for precompetitive joint research and development ventures. Such initiatives are permitted provided that there will not be anticompetitive effect from these ventures. At present, 125 joint ventures are registered under the act with the Federal Trade Commission.

In Europe and Japan, private sector companies (industry and consultants) are playing key roles in cooperative IVHS research programs. It is essential for industry, working closely with government, to take joint responsibility for research, demonstration, and standard-setting. Final implementation will, of course, remain fully competitive, with systems being privately operated as well as privately constructed wherever possible.

Institutional issues. The federal government has a number of important roles to play in a national IVHS program. However, if the program is to be a cooperative effort between government and industry, the federal government will not be best placed to give the detailed management or direction to the program, whose initiatives must come from a diversity of sources. The federal role in such a program is to encourage, promote, and persuade, not to direct or dictate. The federal government is also in a position to provide national priority to an IVHS program.

There is also a role for federal government in bringing together industries that provide vehicle-borne equipment, and state or local government, who generally provide the necessary infrastructure for advanced technology systems. The utility of many technological solutions will be determined by the interaction of these elements. Federal government influences the actions of both parties and so is in a good position to act as a facilitator in this respect.

Of particular importance is the role of the federal government in standard setting. There is a concern that the value of many IVHS technologies will be seriously limited if manufacturers adopt incompatible proprietary solutions, unable to interact with other systems or technologies.

State and local governments also have a role to play in a national IVHS program. Some states will want to support research in a similar manner to federal government. Many state and local governments must be encouraged to participate in demonstration projects, by providing locations, facilities, and support. They must also work together to develop an institutional framework that allows inter-jurisdictional operations. State and local government must show commitment to longer term implementation programs through continued maintenance, training, and support functions associated with advanced technology systems.

Foreign participation is the final issue discussed. International collaboration is a key issue in IVHS which cannot be addressed by taking a highly restrictive posture. While PROMETHEUS reflects the focused viewpoint of certain automobile companies, a more open approach is reflected in the European DRIVE and Japanese initiatives. Distinctions need to be drawn between research, development, and demonstration on the one hand and commercial implementation on the other. It would be self-defeating to pursue basic research and standard setting in isolation, given the international "one-world" market for traffic and automotive systems.

Program agenda and schedule. Current U.S. research in advanced transportation technologies appears to be driven by specific interests rather than being the pursuit of any fully defined framework of long-term objectives. Public and political support for research and demonstration will be determined by an understanding of how advanced technologies will be integrated into the highway and transportation environment. Similarly, for industry to provide cooperative research funding, a clear definition of future commercial markets must be shown through a commitment on the part of government to provide and support the required infrastructure. This can be achieved by including implementation objectives in the program plan.

The success of certain overseas initiatives in the areas of IVHS results from the fact that they have established comprehensive agendas of research, demonstration, and standard-setting activities with a clearly defined time schedule. Such a framework is essential when the many separate activities are performed by a large number of independent organizations. Furthermore, using SHRP as a model indicates that establishing such an agenda with coordination between activities and defined milestones is important in encouraging the necessary program support. In particular, it allows those funding the effort to prioritize activities and to predict future commitments.

It is for these key reasons that substantial efforts have been devoted in this project to developing projects and activities for a national IVHS program and preparing parallel program timetables for research, demonstration, standard setting, and implementation.

Organizational structures. An effective national IVHS program will require a partnership of the public and private sectors. The structure adopted must encourage innovation and decentralization and must ensure private sector cooperation and subsequent competition. Of the structures that have been received, the structure of the DRIVE program could act as a good model for further development within the U.S. context. Additional work is urgently needed to develop this framework further in order to ensure that the most appropriate balance emerges between the various IVHS innovators and users.

Contracting approach. The outline national IVHS program prepared in this project contains a very broad range of projects and activities, many of which are directly interrelated or have strong implied linkages. Flexibility is therefore needed in the way that proposals to perform projects are prepared. This approach should allow organizations or consortia to select those activities that can best be grouped into single integrated projects, maximizing synergistic gains and exploiting the innovative ideas of the proposer. The traditional request for proposals (RFP) route used in the U.S. is probably too rigid to accommodate this approach.

Once again, the DRIVE program offers a good model for an alternative methodology. In DRIVE, a comprehensive workplan was prepared, containing a large number of outline research activities. This formed the basis of a call for proposals. Proposers selected and grouped activities from the workplan to form their overall project proposals. These proposals were then evaluated by experts in the relevant technical areas in terms of the contribution they would make to the overall goals and objectives of the program.

Funding. In Europe, funding levels committed to IVHS research and development total more than $1 billion over the next 3 to 7 years, when PROMETHEUS, DRIVE-1, subsequent DRIVE calls, and other Eureka transportation projects are combined. Implementation will be many times more costly. Japanese funding levels are uncertain. Current U.S. proposals for $100 million a year of federal funding with matched funding from other sources over 10 years are likely to be adequate for research and demonstration only, certainly not for implementation.

Cost estimates have not yet been developed for the projects and activities included in the outline national IVHS program developed in this research project. However, the importance of developing these estimates is recognized. The absence of a funding plan would be more likely to limit the development of a national program than any other factor. It is strongly recommended, therefore, that a significant effort be devoted to these financial estimates as an urgent priority.

10.6 SUMMARY

This chapter has described national and international efforts aimed at research, development and demonstration of advanced transportation technologies. An outline plan has been presented for a U.S. national IVHS program. This covers ATMS, ATIS, FMCS, and AVCS, as well as broad-based general issues.

In developing the IVHS program plan, a number of issues have been considered including the program objectives, structure, public and private sector roles, the program schedule, and funding issues. Through research in each of these areas, a blueprint has been set out for future work on advanced technologies that will ensure that their full potential is realized for alleviating urban transportation problems. It is recommended that action should be taken to implement such an IVHS program at an early date.

CHAPTER **11**

CONCLUSIONS

The overall objective of NCHRP Project 3-38(1) has been to assess the potential of advanced technologies for relieving urban traffic congestion. This chapter details overall conclusions from the research undertaken in the project. It also sets out recommendations for further work on advanced transportation technologies, within the framework of a national IVHS program.

1. Advanced transportation technologies show excellent potential for making significant impacts on urban congestion levels. The range of technologies reviewed in Chapters 2 through 5 that could help alleviate congestion is very wide. Some of these technologies have greater potential than others for addressing the congestion problem in the near term.

2. Many of the advanced technologies reviewed in this study offer other potential benefits, as well as increasing transportation system efficiency through congestion reduction. These include improvements in safety, reduction of environmental pollution, and improved driver comfort and convenience. The research team believes that these benefit areas should be considered alongside system efficiency improvements in future work on advanced transportation technologies.

3. There are important issues to be resolved in implementing advanced transportation technologies. These include financing sources for systems, jurisdictional issues, the roles of public and private sectors, and consumer/user issues, as described in Chapter 5. Alternative solutions are available in each of these areas; the most appropriate solution depends on the particular technology under consideration. The investigations in this study, particularly emphasize the importance of user reactions to new technologies. These reactions will need careful consideration in future development and implementation of advanced technology systems.

4. The three technologies selected for detailed investigation in this project each offers good short-term payoffs, with potential for significant impacts on congestion levels and traffic patterns. These are externally linked route guidance systems, the RDS for traffic message broadcasting, and adaptive traffic control systems.

Externally linked route guidance systems can potentially give significant benefits in two main areas of congestion reduction. First, they can directly benefit system users in terms of time, distance, and cost savings. These savings will result from improved navigation under all conditions, on the basis of the real-time information and guidance provided.

Second, electronic route guidance systems will also benefit nonusers, particularly where nonrecurrent congestion arises because of traffic incidents. Here, equipped vehicles can be diverted from a congested area along alternative, less congested routes, improving traffic flow for all vehicles. The investigations have shown that route guidance can provide maximum benefits in this situation when the diversion of equipped vehicles is just sufficient to prevent demand exceeding capacity. Such a system is able to balance demand on all facilities. Electronic route guidance systems are potentially able to achieve this balance through their real-time central traffic databases and optimal routing algorithms.

The RDS for traffic message broadcasting can also relieve spontaneous congestion caused by traffic incidents or unusual network conditions. Overall delay to all traffic can be significantly reduced by informing drivers of vehicles with RDS receivers that an incident has occurred, and by advising appropriate diversionary actions. RDS may therefore be particularly appropriate for diverting traffic from freeways or other major routes onto alternative parallel streets.

The analyses conducted in this study have shown that the benefits of using RDS to divert traffic in this way are sensitive to the demand and surplus capacity on alternative facilities, to the incident severity, and to the time lag between incident occurrence and information dissemination to drivers. Unlike electronic route guidance, RDS is only able to divert traffic at a strategic level and is less likely to balance flows on alternative facilities to achieve a global optimum. However, the system offers substantial net benefits and will probably achieve greater market penetration and spatial coverage than electronic route guidance in the short- and medium-terms because of its much lower equipment and infrastructure costs.

Adaptive traffic control based on real-time optimization could make a major contribution to relieving urban congestion through more efficient use of the existing highway system in urban areas. Real-time systems have been thoroughly tested and evaluated in other countries, and have been proved to give very significant benefits in comparison to their implementation costs. Adaptive traffic control systems provide additional benefits over fixed-time systems by responding to flow variations within a signal plan period, as well as to daily and seasonal fluctuations. Adaptive systems also adjust automatically to long-term changes in traffic conditions, avoiding the "aging" disbenefits which occur when fixed time signal plans are not updated regularly.

The analyses indicate that the significant benefits seen in other countries with adaptive systems will also be achieved in U.S. networks. Specific benefits of adaptive traffic control will be greatest where links are short, flows are high, and significant flow variations occur within a signal plan period. Of these factors, traffic flow volume tends to be dominant in determining overall benefit levels. As urban flow levels increase in the future, the benefits of adaptive techniques will become even more significant.

5. Each of the three technologies examined in detail has attractive features from an implementation issues perspective, some of which are summarized below. However, there are still important areas to be resolved before the systems are seen on U.S. streets. These concern technological development and adaptation, integration into the existing infrastructure, jurisdictional and funding arrangements, public/private sector roles, and issues of user acceptance.

With externally linked route guidance systems, an opportunity exists to build on the research, development, and demonstration efforts currently being undertaken worldwide. The state of the art is now sufficiently advanced that much of the basic research has been completed in recent years. U.S. expertise could capitalize on this basic research to make electronic route guidance systems in congested urban areas a realistic option within the next 5 years.

There is also significant potential for private sector involvement in developing, funding, and operating electronic route guidance systems as commercial ventures, which would minimize public sector investment and risk. The federal government would need to be involved, however, to establish standards and ensure compatibility between commercial systems.

Implementation of the RDS in urban areas would require very low central investment levels, with the majority of the cost being borne directly by the system users. Infrastructure requirements would be minimal, as RDS is able to use existing FM transmitters. These advantages would help the system overcome implementation barriers that might otherwise discourage public or private sector organizations from involvement in a new traffic information system.

As with electronic route guidance, there are significant opportunities for private sector involvement in RDS. Development of suitable radio receivers is likely to be market driven, with industry having the major involvement. Development and implementation of encoding and transmission equipment might be a joint private/public venture, while information gathering and analysis could be either a private or public sector function.

Government involvement would again be required in the initial stage to promote the concept and ensure that the necessary levels of standardization and compatibility are achieved. However, the basic system concept is already a worldwide standard, which should minimize any problems in this area. Interest in the RDS concept has already been shown in the U.S. and Canada, encouraging the belief that the system would be institutionally acceptable.

The implementation issues associated with introducing adaptive traffic control systems into U.S. urban areas are probably the least complex of the three technologies studied in detail. Frameworks for funding and operating fixed-time traffic signal systems already exist, and to a great extent many of these frameworks could be equally applicable to an adaptive system. More interjurisdictional cooperation may be required, however, where adaptive systems are implemented over the whole of an urban area.

6. In order that the full potential of advanced transportation technologies can be fully realized, a coordinated approach toward research, development, and demonstration is essential. This need has already been recognized in Europe and Japan, where major coordinated initiatives are currently in progress. It is also being increasingly supported within the U.S. transportation industry, with a number of initiatives recently started in various areas of advanced technology.

A most important recommendation is, therefore, that a national IVHS program should be implemented in the U.S. at an early date. The key objective of the program should be to make automobile travel safer, more efficient, more energy efficient, and more environmentally benign, through use of advanced technologies. The worldwide market opportunities for advanced technology systems provide a major commercial incentive for private sector involvement in such an IVHS program.

Within this study, an initial plan for the IVHS program has been developed, as described in Chapter 10. This covers a range of advanced technologies, under the following category headings: ATMS, ATIST, FMCS, and AVCS.

Three time horizons are considered in the program plan: short-term (up to 1995); medium-term (from 1995 through 2005); and long-term (from 2005 through 2020). Project and activity outlines for the short-term time horizon have undergone the greatest degree of development. Interrelationships between these projects and activities have been identified to ensure a logical program progression, and all activities occurring through the year 2000 have been placed on a detailed time line.

Based on the research, a major opportunity exists to make significant impacts on congestion problems currently being faced on the urban road network, using intelligent vehicle/highway technologies. A national IVHS program such as that developed in this project will enable that opportunity to be realized in full. Its main effect will be to assure America of a lead in world markets, and a domestic highway transportation system optimized to meet the challenges of life in the third millennium.

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LIST OF ACRONYMS

AA—U.K. Automobile Association
AASHTO—American Association of State Highway and Transportation Officials
ABS—Antilock Braking System
AFI—Hamburg Automatische Fahrplan Information
AHAR—Automatic Highway Advisory Radio
AHC—Automatic Headway Control
AHS—Automated Highway System
AIDS—Automated Information Directory System
AIT—Alliance Internationale de Tourisme
ALI—Autofahrer Leit und Informationssystem
AMTICS—Advanced Mobile Traffic Information and Communication System
API—Automatic Personal Identification
ARCS—Automatic Route Control System
ARI—Autofahrer Rundfunk Information
ARIAM—ARI aufgrund Aktueller Messdaten (ARI with Actual Measurement)
ASC—Automatic Steering Control
ATIS—Advanced Traveler Information Systems
ATMS—Advanced Traffic Management Systems
ATSAC—Automatic Traffic Signal and Control
AVC—Automatic Vehicle Classification
AVCS—Automatic Vehicle Control Systems

AVI—Automatic Vehicle Identification
AVL—Automatic Vehicle Location
AVM—Automatic Vehicle Monitoring
BESI—Bus Electronic Scanning Indicator
BISON—Betriebsfuhrungs und Informationssyteme fur der Offentlichen Nahverkehr—or Operational Control and Information Systems for the Public Transit Sector
CACS—Comprehensive Automobile Traffic Control System
Caltrans—California Department of Transportation
CBD—Central Business District
CCRTA—Cape Cod Regional Transit Authority
CCTV—Closed Circuit Television Cameras
CD-ROM—Compact Disk Read-Only Memory
CEC—Commission of the European Communities
CIC—Critical Intersection Control
CIS—Toronto Transit Commission's Communication and Information System
CRC—Castle Rock Consultants
DC—Direct Current
DR—Dead Reckoning
DRIVE—Dedicated Road Infrastructure for Vehicle Safety in Europe
EBU—European Broadcasting Union
ECU—Electronic Control Unit
ERGS—Electronic Route Guidance System
ERIC—European Road Information Center
ETC—Electronic Traction Control
ETS—Electronic Ticketing System
EVA—Electronic Traffic Pilot for Motorists
FCC—Federal Communications Commission
FETSIM—Fuel Efficient Traffic Signal Management
FHWA—Federal Highway Administration
FMCS—Fleet Management and Control Systems
GPS—Global Positioning System
GRID—Golden River Incident Detection
GWH—Great Western Highway
HAR—Highway Advisory Radio
HELP—Heavy Vehicle Electronic License Plate Program
HIDO—Highway Industry Development Organization
HOV—High Occupancy Vehicle
HP&R—Highway Planning and Research
IRTE—Integrated Road Transport Environment
IVHS—Intelligent Vehicle/Highway System
LCD—Liquid Crystal Displays
LED—Light Emitting Diode
LISB—Berlin Navigation and Information System
LVA—Linked Vehicle Actuated
MARIA—Mitsubishi Advanced Realtime Information Autosystem
MIS—Management Information System
MIT—Massachusetts Institute of Technology
MITI—Japanese Ministry of International Trade and Industry
MOC—Japanese Ministry of Construction
MOVA—Modernized Optimized Vehicle Actuation
MPT—Japanese Ministry of Posts and Telecommunications
NCHRP—National Cooperative Highway Research Program
NCTRP—National Cooperative Transit Research and Development Program
NHTSA—National Highway Traffic Safety Administration
NMCS-2—National Motorway Communications System
OBC—Onboard Computer
O-D—Origin-Destination
OSU—Ohio State University
OTA—Office of Technology Assessment
PACE—Plessey Adaptive Compass Equipment
PATH—Program on Advanced Technology for the Highway
PCU—Passenger Car Unit
PD—Performance Difference
PPD—Platoon Progression Diagram
PROMETHEUS—Program for European Traffic with Highest Efficiency and Unprecedented Safety
PWRI—Public Works Research Institute
RACS—Road-Automotive Communications System
RDS—Radio Data System
RDSS—Radio Determination Satellite Services
RD&T—Research, Development and Technology Transfer
RF—Radio Frequency
RFP—Request for Proposals
RTI—Road Transport Informatics
SAW—Surface Acoustic Wave
SCOOT—Split, Cycle and Offset Optimization Technique
SCOR—Standing Committee on Research
SDHPT—Texas State Department of Highways and Public Transportation
SEITU—Societé d'Etude pour l'Information sur les Transports Urbains
SFI—Support for Innovation
SHRP—Strategic Highway Research Program
SLG—Synchronous Longitudinal Guidance
SNCF—French National Railway
TAG—Transportation Alternatives Group
TexATT—Texas Advanced Transportation Technology
TFP—Technology for People
TIS—Travelers' Information Stations
TMC—Traffic Message Channel
TMS—Traffic Management System
TRAC—Washington State Transportation Center
TRANSYT—Traffic Network Study Tool
TRB—Transportation Research Board
TRRL—Transport and Road Research Laboratory
UCT—Universal Coordinated Time
UMTA—Urban Mass Transportation Administration
UMTRI—University of Michigan Transportation Research Institute
U.S. DOT—U.S. Department of Transportation
UTC—Urban Traffic Control
UTCS—Urban Traffic Control System
VDOT—Virginia Department of Transportation
VIPS—Vehicle Identification and Priority System
VMS—Vehicle Management Systems
VMT—Vehicle Miles Traveled
VSC—Variable Speed Control
VTS—Vehicle Tracking System
WIM—Weigh-in-Motion
WMATA—Washington Metropolitan Area Transit Authority
WSDOT—Washington State Department of Transportation
WSP—Washington State Patrol

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 private, 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. Frank Press 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, encourages 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. Stuart Bondurant is acting 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 purpose 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. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

TRANSPORTATION RESEARCH BOARD
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