ARIZONA DEPARTMENT OF TRANSPORTATION

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# THE ENTERPRISE PROGRAM

# EVALUATING NEW TECHNOLOGIES FOR ROADS PROGRAM INITIATIVES IN SAFETY AND EFFICIENCY

**Final Report**

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16. Abstract

This report defines the concept of a multi-state Intelligent Vehicle-Highway Systems (IVHS) coordination program known as the ENTERPRISE program. ENTERPRISE (Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency) is a proposal for a joint public-private sector program to research, develop and demonstrate selected IVHS technologies. This report identifies the needs, goals and objectives of ENTERPRISE and identifies why ENTERPRISE, as a consortium of interests, offers improved opportunities for IVHS research, development, testing and implementation. The report identifies likely project participants and summarizes the potential roles of both the public and the private sector. Through a worldwide review of the state-of-the-art IVHS initiatives and an inventory of proposed member initiatives, the report outlines specific projects which could be undertaken by the consortium. Finally, the report presents a proposed organizational structure of ENTERPRISE and identifies potential funding needs and resources.

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## LIST OF ACRONYMS

| | |
|---|---|
| AA | U.K. Automobile Association |
| ABS | Antilock Braking System |
| ADOT | Arizona Department of Transportation |
| AHAR | Automatic Highway Advisory Radio |
| AHC | Automatic Headway Control |
| AHS | Automated Highway System |
| AIT | Alliance Internationale de Tourisme |
| ALI | Autofahrer Leit und Informationssystem |
| AMTICS | Advanced Mobile Traffic Information and Communication System |
| ARCS | Automatic Route Control System |
| ARI | Autofahrer Rundfunk Information |
| ARIAM | ARI aufgrund Aktueller Messdaten (translated as ARI with Actual Measurement) |
| ASC | Automatic Steering Control |
| ATIS | Advanced Traveler Information Systems |
| ATMS | Advanced Traffic Management Systems |
| ATSAC | Automatic Traffic Signal and Control |
| ATT | Advanced Transport Telematics |
| AVC | Automatic Vehicle Classification |
| AVCCS | Advanced Vehicle Command and Control System |
| AVCS | Advanced Vehicle Control Systems |
| AVI | Automatic Vehicle Identification |
| AVL | Automatic Vehicle Location |
| AVM | Automatic Vehicle Monitoring |

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|---|---|
| CACS | Comprehensive Automobile Traffic Control System |
| Caltrans | California Department of Transportation |
| CCRTA | Cape Cod Regional Transit Authority |
| CCTV | Closed Circuit Television |
| CDOH | Colorado Department of Highways |
| CD-ROM | Compact Disk Read-Only Memory |
| CIS | Communication and Information System |
| CRC | Castle Rock Consultants |
| CTS | University of Minnesota's Center for Transportation Studies |
| DR | Dead Reckoning |
| DRIVE | Dedicated Road Infrastructure for Vehicle Safety in Europe |
| EBU | European Broadcasting Union |
| ENTERPRISE | Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency |
| ERGS | Electronic Route Guidance System |
| ERIC | European Road Information Center |
| ETC | Electronic Traction Control |
| EVA | Electronic Traffic Pilot for Motorists |
| FCC | Federal Communications Commission |
| FHWA | Federal Highway Administration |
| FMCS | Fleet Management and Control Systems |

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|---|---|
| GALACTIC | Global Liaison and Coordination in Traffic Information and Control |
| GPS | Navstar Global Positioning System |
| GRID | Golden River Incident Detection |
| HAR | Highway Advisory Radio |
| HDA | Highway Driver's Assistant |
| HELP | Heavy Vehicle Electronic License Plate Program |
| HIDO | Highway Industry Development Organization |
| HOV | High Occupancy Vehicle |
| IADOT | Iowa Department of Transportation |
| INFORM | Information for Motorists |
| IRTE | Integrated Road Transport Environment |
| ITS | University of California's Institute of Transportation Studies |
| IVSAWS | In-Vehicle Safety, Advisory and Warning System |
| IVHS | Intelligent Vehicle-Highway Systems |
| IVHS America | Intelligent Vehicle-Highway Society of America |
| MIDAS | Motorist Information and Driver Automation Systems |
| MIS | Management Information System |
| MITI | Japanese Ministry of International Trade and Industry |
| Mn/DOT | Minnesota Department of Transportation |
| MOC | Japanese Ministry of Construction |
| MOVA | Modernized Optimized Vehicle Actuation |
| MPT | Japanese Ministry of Posts and Telecommunications |

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|---|---|
| NCHRP | National Cooperative Highway Research Program |
| NCTRP | National Cooperative Transit Research Program |
| NMCS-2 | National Motorway Communications System |
| NODS | Near Obstacle Detection System |
| NYSDOT | New York State Department of Transportation |
| OC Transpo | Ottawa-Carleton Regional Transit Commission |
| PACE | Plessey Adaptive Compass Equipment |
| PATH | Program on Advanced Technology for the Highway |
| PPD | Platoon Progression Diagram |
| PROMETHEUS | Program for European Traffic with Highest Efficiency and Unprecedented Safety |
| PWRI | Public Works Research Institute |
| RACS | Road-Automobile Communication System |
| RDS | Radio Data System |
| RDSS | Radio Determination Satellite Services |
| RF | Radio Frequency |
| SAW | Surface Acoustic Wave |
| SCOOT | Split, Cycle and Offset Optimization Technique |
| SHRP | Strategic Highway Research Program |
| SLG | Synchronous Longitudinal Guidance |
| SSVS | Super Smart Vehicle System |

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|---|---|
| TBC | Time-Based Coordination |
| TDC | Transport Development Centre, Transport Canada |
| TIME | Traffic Information and Management Equipment |
| TIS | Travelers' Information Stations |
| TMC | Traffic Message Channel |
| TMS | Traffic Management System |
| TRANSCOM | Transportation Operations Coordinating Committee |
| TRANSYT | Traffic Network Study Tool |
| TRRL | Transport and Road Research Laboratory |
| TTC | Toronto Transit Commission |
| UTC | Urban Traffic Control |
| UTCS | Urban Traffic Control System |
| VICS | Vehicle Information Communication Systems |
| VSC | Variable Speed Control |
| VTIP | Visual Traffic Information Project |
| VTS | Vehicle Tracking System |
| WIM | Weigh-In-Motion |

# 1. OVERVIEW

## 1.1 Introduction

This report defines the concept of a multi-state Intelligent Vehicle-Highway Systems (IVHS) coordination program to be known as the ENTERPRISE program. ENTERPRISE (Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency) is a proposal for a joint public-private sector program to develop and demonstrate selected IVHS technologies. The program will involve government and industry participants from a number of federal and state or provincial agencies in the U.S. and Canada.

This concept definition report has been prepared by Castle Rock Consultants (CRC) under contract to the Arizona Department of Transportation (ADOT). It is the second in a series of reports investigating opportunities for the advancement of IVHS technologies. The report covers the establishment of a coordinated IVHS research and development program involving both interstate and international cooperation.

The preparation of this report has built significantly on work previously undertaken by CRC in earlier studies. This work led to the definition of the Arizona MIDAS (Motorist Information and Driver Automation Systems) program. MIDAS is a proposal for a state IVHS initiative, covering a three-phase effort over a ten-year period. Each of these phases is divided into a number of individual projects and activities, providing an overall coordinated approach toward the development of a state IVHS program.

Other federal, state and provincial agencies are also actively developing IVHS program proposals. An excellent example is the Minnesota GUIDESTAR program. Introduction of IVHS in Minnesota started several years ago when Minnesota Department of Transportation's (Mn/DOT) new Commissioner, Leonard Levine, declared three top priorities for Mn/DOT:

1. stable, adequate funding;
2. safety for travelers and Mn/DOT employees;
3. dealing with rapidly growing congestion in the Twin Cities of Minneapolis and St. Paul.

Congestion currently costs Twin Cities motorists $450 million per year, and congested freeway miles are projected to triple by the year 2000.

Within the first phase of MIDAS, the initial investigation focused upon the definition of a state IVHS initiative. The first element of the work involved preparation of an initial feasibility report. This reviewed a range of advanced technologies and systems that can be used to address the problems of highway congestion, safety and environmental impacts. The results of this review were used as the basis for the development of the technology research and development elements of the MIDAS program.

One of the major inputs from state representatives during this initial Phase #1A was that individual state IVHS developments should be set within a broader cooperative framework. It is for this reason that the collaborative initiative addressed by this report is now being defined. This broader program will provide a vehicle for practical coordination between interrelated programs addressing distinct areas of IVHS. Participating members will jointly plan, develop and demonstrate IVHS innovations in areas of mutual interest. Each organization will focus on an agreed area of excellence for in-depth systems research, demonstration and evaluation.

In order to ensure that maximum benefit is gained from a coordinated IVHS initiative, it is essential that full consideration is given to a number of important issues in the program development process. This has been the objective of Project #1B of the multi-state program, the results of which are reflected in this report. Project #1B has involved a concept definition study, building upon the work presented in the initial Project #1A feasibility report. The concept definition study has further examined the required IVHS research, development and demonstration activities, in the context of interstate and international collaboration and coordination. This provides a natural starting point for the detailed planning and implementation activities to be undertaken next.

The scope of this report includes potential program participants, their roles in the multi-state IVHS initiative, and program organizational issues. Early chapters review IVHS technologies and current IVHS initiatives. An outline of the proposed ENTERPRISE program structure comprises the key part of the work. Summaries are provided of potential state and private sector roles. The MIDAS program is then developed in more detail, as an example of a state IVHS initiative within the ENTERPRISE framework.

After this introduction, Section 1.2 of this chapter presents a problem statement, outlining the need for IVHS in the highway environment. This includes a brief definition of IVHS and an examination of its four major technology areas. Section 1.3 then goes on to define the key objectives of the IVHS research study addressed by this report. This covers the goals of the ENTERPRISE program and the rationale behind the definition of a multi-state IVHS initiative. The next section of the chapter outlines the approach adopted by the study team in carrying out the IVHS program definition study.

Following this initial overview, Chapter 2 of the report outlines the approaches taken by other major IVHS initiatives worldwide, and the lessons that can be learned. Chapters 3 through 6 then review the four accepted areas of IVHS technology. Each chapter sets out to identify current developments and highlight areas with major potential for IVHS breakthroughs.

Chapter 7 contains the key elements of this report, defining the multi-state program proposal from various aspects. It sets out the benefits of coordinating individual federal, state and provincial efforts under the umbrella of the ENTERPRISE initiative. The chapter identifies potential program participants and outlines their likely contributions within the broader cooperative framework.

Chapters 8 and 9 consider a typical state-level contribution within the ENTERPRISE program in greater detail. They set out the major reasons why a

participating agency should initiate an IVHS program, and describes typical state or provincial program elements or components. Definition of potential test sites and coordination with other advanced technology initiatives are also covered.

Organizational considerations for the ENTERPRISE program are presented in Chapter 10 of the report. This chapter includes definition of the bridging project known as GALACTIC, which will coordinate the various ENTERPRISE activities. Finally, Chapter 11 presents a short summary and the overall conclusions of this concept development study report.

## 1.2 Problem statement

Traffic congestion is rapidly becoming one of the most serious problems affecting the U.S. highway network. Urban travel in general is increasing at a rate of four 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 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 congestion and over a 400 percent increase in delay. Therefore, increased congestion and a continued loss of mobility are expected.

The projected growth in traffic is so great that traditional methods of road construction, demand management, and traffic control will not in themselves be satisfactory solutions. Only through an approach that captures the synergistic benefits of these traditional methods can we ensure traffic mobility in the future. 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.

What is meant by advanced technologies in the context of easing traffic congestion? Loosely, we can group them under:

* Intelligent vehicles, in which advanced technology units operate independently on individual vehicles; and

* Intelligent highways, involving the installation of advanced technologies within the highway infrastructure.

In combination, these two categories form the basis of the IVHS concept. IVHS also involves a significant degree of cooperation and integration of the on-vehicle units and the highway infrastructure.

A convenient way of grouping advanced technologies is by function. Four broad categories of advanced technology can be considered as follows:

* Advanced Traveler Information Systems (ATIS);

* Advanced Traffic Management Systems (ATMS);
* Advanced Vehicle Control Systems (AVCS); and
* Fleet Management and Control Systems (FMCS).

The following paragraphs briefly describe key features of the technologies included in the ATIS, ATMS, AVCS and FMCS areas which are expanded in later chapters of this report.

## Advanced Traveler Information Systems

ATIS technologies aim to provide motorists with in-vehicle information on congestion, traffic, weather, and highway conditions, and navigation, location or routing advice. ATIS will also provide pretrip information, allowing drivers to plan their journey before leaving the home or workplace.

Many technologies exist which can provide the traveler with this information. Some systems rely on a direct communications link to an external infrastructure, such as vehicle location systems based on satellites, while others utilize radio broadcast transmissions. An alternative class of system is entirely self-contained in the vehicle and uses techniques like dead reckoning to compute vehicle position.

Specific types of ATIS include pretrip electronic planning systems. With these, a traveler enters his origin and destination into a computer and a set of routing directions is produced. These directions can be based on minimum time, minimum distance or minimum cost routes. These systems also have strong potential for integration with transit information systems.

Traffic information broadcasting systems provide motorists with information on current highway conditions providing an opportunity to alter a route. Some systems, like the U.S. highway advisory radio, utilize conventional AM car radios but require the driver to retune to a specific frequency. Others use FM transmissions and self-tuning in-car decoders such as the West German ARI system and the Europe-wide Radio Data System.

In-vehicle navigation and location systems provide information through in-car displays. The most sophisticated systems, termed externally-linked route guidance, provide real-time information on traffic, road and weather conditions and provide appropriate route guidance to the motorists. These displays may show the highway network and the location of the traffic problems, allowing drivers to change routes and make more informed decisions, or may provide specific routing instructions.

## Advanced Traffic Management Systems

ATMS are assumed to differ from traditional traffic control systems in two major respects. First, they are responsive to actual traffic flows and second, they

operate in real-time. At present, control strategies react to congestion on the highway after it has occurred. An ATMS will incorporate algorithms that can predict when and where congestion will occur and will act to prevent it.

ATMS will include area-wide surveillance and detection systems. These provide information from the perspective of the overall highway network. ATMS will also integrate traffic control on the various facilities in an area. This implies collaborative management between the authorities responsible for managing both the freeways and the surface streets. Finally, ATMS will include rapid response incident management techniques, including incident detection, verification, and the implementation of appropriate response plans. Together this information is collected at a traffic control center, at which point truly optimal solutions to traffic problems can be developed for entire areas or regions.

A number of technologies already exist that will potentially provide the basis for future ATMS approaches. These include traffic signal control systems, ranging in complexity from fixed-time, isolated intersection control through to fully responsive control operating over an entire network. Much could be achieved through better use of these existing techniques, while there are also opportunities for the development of new signal control approaches with greater potential. In particular, adaptive traffic control technology could be integrated with real-time traffic monitoring, short-term forecasting and electronic route guidance. This would permit simultaneous optimization of signal coordination and vehicle route choice within the urban highway network.

## Advanced Vehicle Control Systems

Vehicle control is complex because of the many interactions which exist between the driver and the vehicle. The driver's key roles can be defined as:

* to observe the outside environment, including highway geometry, vehicles and obstructions;
* to operate the vehicle's control system;
* to feedback observations and compensate for changing situations; and
* to decide and select an appropriate trajectory ahead.

One way to improve drivers' ability to cope with increasingly demanding traffic conditions more efficiently and safely is using intelligent driver support systems and automatic control devices. Automatic vehicle control systems can help drivers to perform certain vehicle control functions, and may eventually relieve the driver of some or all of the control tasks. The use of such technologies is likely to result in greater safety, more consistent driver behavior and improved traffic flow characteristics.

Fundamental research into automatic vehicle control technologies has been taking place for several years. However, recent technological advances mean that the stage has now been reached where these investigations should move into a more advanced, coordinated research, development and demonstration phase, targeted on

system implementation within a defined timeframe. This reality has recently been recognized within a major study conducted for the National Cooperative Highway Research Program into the potential of advanced technologies to relieve urban congestion.

At the most basic levels, AVCS can provide the driver with useful information and warnings, for example when a vehicle is traveling with insufficient headway. The next stage is to assist the driver more directly, helping to avoid potentially dangerous situations. At this level, AVCS could be used to control travel speeds and maintain adequate vehicle headways. The third level would provide for system intervention during emergencies, illustrated by collision warning AVCS approaches. The final level would completely take over the driving task on automated highway sections. Though AVCS are least developed of the IVHS technologies, their potential for relieving urban traffic congestion and improving rural safety could be very high.

Fleet Management and Control Systems

The category of FMCS incorporates a range of technologies that are used to improve the efficiency, safety and convenience of vehicle fleet operations. Many FMCS technologies are also applicable to the other IVHS categories, particularly ATIS and ATMS, in the context of their use with individual vehicles. The FMCS category examines the application of these technologies to fleet operations, including trucks and other commercial vehicles, transit vehicles, and police and emergency service vehicles.

One approach that can be used to improve fleet operations is the application of computer software for design and planning activities. Software packages have been widely used in the transit industry, for example, providing increased convenience for service users and more efficient use of operators' resources. IVHS technologies can also provide an important input to fleet management activities, by collecting various data for historical analysis or input to operations software.

FMCS can additionally be used to provide more immediate feedback on fleet vehicles to a central control point. This can include real-time information on vehicle location, condition and schedule adherence. These data can permit fleet supervisors to initiate control strategies to ensure optimum fleet performance, convenience or security. A number of communication and location technologies have been developed that can support this real-time monitoring facility, in conjunction with on-vehicle sensors and processing equipment. Similar approaches can also be used to develop fleet dispatching systems for taxicabs, package delivery firms or emergency services.

## 1.3 Objectives

This section defines the primary objectives of this multi-state IVHS program definition study. The principal objective of this report is to delineate the potential and scope of a multi-state, coordinated initiative in the field of

IVHS. This has involved identification of potential participants and activities in the program, together with examination of organizational issues. To achieve the broad goals of the MIDAS and ENTERPRISE development efforts, the following specific objectives have been addressed through the IVHS research study:

1. Update existing literature reviews of IVHS technologies and the major national and international IVHS programs;

2. Consider the integration of existing or proposed advanced technology programs into broader IVHS initiatives for both individual program participants and for the multi-state consortium as a whole, in the context the of ENTERPRISE program;

3. Identify suitable locations for the operational testing of the most promising IVHS technologies in particular states, and consider potential test sites for the broader coordinated program participants;

4. Define proposed organizational structures for individual state IVHS programs and for the broader ENTERPRISE initiative, combining state and local government, private sector participation and interstate\international cooperation;

5. Identify initial outlines of potential projects to be undertaken by ENTERPRISE participants, as a basis for final definition of the program prior to detailed planning and implementation activities;

6. Define the reasons why specific states provide appropriate locations for developing and demonstrating IVHS technologies, and why these programs should be integrated within the broader ENTERPRISE initiative;

7. Detail a series of IVHS activities to pursue through a typical constituent state program. These cover research, operational testing and implementation activities from the full IVHS technology arena and progress from a short-term through a long-term timeframe;

8. Prepare a preliminary analysis of the benefits to be derived from the various projects proposed for inclusion in the ENTERPRISE program; and

9. Prepare outline proposals for funding representative elements of the IVHS program, describing the estimated resources for the various activities and potential sources for obtaining these funds.

This concept definition report represents Project 1B of the ENTERPRISE program. In accordance with Arizona's desires to fast-track the program definition process, the report makes maximum possible use of existing review material with only limited updating as required to reflect the rapid pace of IVHS developments. Acknowledgement is made of other CRC research sponsors, including the National Cooperative Highway Research Program (NCHRP) and the National Cooperative Transit Research Program (NCTRP), which provided substantial funding for the original compilation of much of the work presented in the review.

## 1.4 Research approach

This section outlines the approach taken by Castle Rock Consultants in investigating options for a multi-state IVHS initiative. The research approach builds on the objectives defined in the previous section and identifies a set of specific tasks that were performed to accomplish the overall goals.

### Literature review

This initial task brought together a review of literature covering the major IVHS technologies and programs on an international basis. In order to accomplish this major activity within the extremely tight timeframe of the project, the work relied extensively on previous state-of-the-art reviews performed by CRC. The efforts in this project were focused on reviewing the most recent IVHS advances.

### Identify ENTERPRISE participants

This task involved the identification of potential coparticipants for this cooperative IVHS effort. The study team contacted personnel in various proposed member organizations, identifying specific areas of interest in IVHS, available research and testing facilities and locations, and ongoing or planned advanced technology initiatives.

### Define a proposed ENTERPRISE organizational structure

In this task, the study team prepared a proposed organizational structure for the ENTERPRISE initiative. This involved consideration of the responsibilities of the various participating organizations, and the mechanism for coordination and liaison between program members. The organizational structure development included definition of the bridging project known as GALACTIC, which will achieve the required coordination of individual ENTERPRISE activities.

### Define why ENTERPRISE should be implemented

This task involved the preparation of a series of statements outlining why the ENTERPRISE program is an appropriate mechanism for IVHS research, development and operational evaluation. The task considered how a coordinated multiparticipant initiative offers improved opportunities over isolated efforts for rapid technological advancement.

### Outline ENTERPRISE projects and initiatives

In this task, the study team outlined a series of IVHS projects and activities for potential inclusion within the ENTERPRISE program. These were based on the specified needs and interests of the program members, with activities selected to take full advantage of the strengths and unique situations which exist among

the various participants. The task also involved consideration of the benefits that will result from each of the proposed ENTERPRISE projects.

Integration with other advanced technology programs

This task considered the integration of activities to be performed in the proposed IVHS program with other advanced technology initiatives. Potential program participants are already recognized leaders in the practical application of new and emerging technologies. Several have major projects already underway that demonstrate this expertise. This task aimed to identify the synergistic gains that can be accomplished by incorporating current efforts into the proposed program plan.

Identify operational testing locations

The study team identified a number of locations that can potentially be used to perform operational tests of IVHS technologies. Possible locations identified for IVHS operational tests include Crescent test sites; freeway management and traffic controls centers; and motor company high-speed proving grounds.

Define state-level organizational structure

The fourth task prepared a proposed organizational structure for a typical state-level IVHS program. The proposed structure was developed to reflect the management, technical direction and administrative needs of the future multi-strand IVHS initiative. Key participants who are expected to play vital roles in the proposed structure include state and local government representatives and the private sector.

Define why ENTERPRISE participants should implement an IVHS program

In this task, the research team prepared a series of clear and concise statements defining why participating agencies can provide appropriate locations for an integrated IVHS program. These statements serve to highlight the strengths, experience and expertise resident in the states which will be important in the development and demonstration of IVHS technologies. Statements were also developed which describe the benefits that participants can expect to derive from the ENTERPRISE program.

Develop typical state-level projects and activities

Based on the products of the earlier tasks, the study team developed a series of recommended IVHS projects and activities to be pursued through Arizona's MIDAS program, representing a typical state-level element of the ENTERPRISE initiative. These projects cover research, operational testing and implementation activities in the ATMS, ATIS and AVCS areas.

Identify the benefits of the proposed state-level projects

This activity builds directly on the work of the previous task. The study team defined the benefits of the projects included in the recommended IVHS program plan.

Prepare state-level funding proposal

This task developed an outline funding plan for the recommended Arizona MIDAS program. The funding plan provides estimates of resource levels required for specific projects and activities, as well as for overall program management.

Prepare final report

As the concluding activity of the Phase 1B effort, the study team has prepared this concept definition report on the work undertaken. This has further developed the initial feasibility report, expanding its conclusions and placing them within the overall context of the broader ENTERPRISE initiative.

## 1.5 Recommendations

In accordance with the conclusions and recommendations of the earlier feasibility report, this report recommends the establishment of a multi-state IVHS initiative for cooperative IVHS developments within a coordinated framework. The overall goal of the ENTERPRISE program will be the development and demonstration of selected IVHS technologies. This section provides a brief summary of the recommended steps required to accomplish this goal.

The key recommendation of this study is that participating state IVHS developments should be set within a cooperative program to be known as ENTERPRISE. ENTERPRISE will operate as an umbrella program, under which each participating member will address distinct projects and areas of IVHS, based on individual needs. Minnesota's GUIDESTAR and Arizona's MIDAS programs would represent specific elements of the ENTERPRISE program, while other members in the U.S. and Canada will implement comparable programs in their own areas of interest.

In order to accomplish the overall liaison and coordination functions envisioned within the ENTERPRISE initiative, a bridging project is proposed under the title of GALACTIC (Global Liaison and Coordination in Traffic Information and Control). As the name indicates, GALACTIC will address both North American and worldwide IVHS liaison activities related to the ENTERPRISE program.

These two aspects of the GALACTIC project can be summarized as follows:

* **Inter-Galactic**, addressing international cooperation and liaison between the ENTERPRISE program and other worldwide IVHS programs. These include DRIVE and PROMETHEUS in Europe, plus VICS and SSVS in Japan.

* **Intra-Galactic**, dealing with the needs of joint planning, development and demonstration for the constituent North American IVHS programs of the ENTERPRISE initiative.

These summary recommendations for a multi-state collaborative program are expanded in later sections of the report. Prior to this, relevant IVHS technologies of the ENTERPRISE initiative are described in technical review chapters.

# 2. IVHS INITIATIVES

## 2.1 Introduction

This chapter describes the major current programs and initiatives being undertaken throughout the world which have particular relevance to the objectives of this study. Following this introduction, the chapter is divided into three sections, covering the three geographic areas in which the majority of IVHS research has occurred. The first of these is the U.S., where IVHS activities have included both state-level programs and broader cooperative projects. The next section focuses upon European efforts within the multinational DRIVE and PROMETHEUS programs. Japanese IVHS initiatives are discussed in the final section of the chapter.

## 2.2 U.S. initiatives

It is generally acknowledged that the U.S. has some catching up to do in order to compete with the Europeans and Japanese in the area of IVHS. Both Europe and Japan had implemented large-scale coordinated IVHS programs before U.S. efforts were underway. However, substantial progress has been made in the U.S. in recent years toward redressing this imbalance. Several states have organized independent IVHS projects and activities, while a number of cooperative activities are also underway on a broader scale. Principal U.S. IVHS initiatives and organizations include the following:

* Mobility 2000;
* IVHS America;
* SMART Corridor;
* PATHFINDER;
* TRAVTEK;
* TRANSCOM;
* GUIDESTAR;
* PATH; and
* HELP.

**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 IVHS technologies. Mobility 2000 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.

The development of the Mobility 2000 effort has involved the formation of several technical committees. Four of these have investigated the broad technology areas outlined earlier in this report, ATIS, ATMS, FMCS and AVCS. A fifth technical committee has been responsible for evaluating operational benefits in each of these areas. Mobility 2000 has also considered IVHS program milestones, research and development needs, field test requirements and funding levels.

Mobility 2000 has now been adopted as the technical arm of the recently-formed **IVHS America** (Intelligent Vehicle-Highway Society of America). IVHS America was officially incorporated in the District of Columbia in August, 1990. The nonprofit, public/private scientific and educational corporation aims to advance a national program for safer, more economical, energy efficient and environmentally sound highways in the U.S. Membership of the group is open to companies, corporations, associations, government agencies and universities with an interest in IVHS. In addition to receiving technical support from Mobility 2000, IVHS America will benefit from the administrative support of the Highway Users Federation.

The **SMART Corridor** is a cooperative demonstration project currently being implemented by a number of agencies in the Los Angeles area. Participants in the study include the Federal Highway Administration, the California Department of Transportation, the California Highway Patrol, the Los Angeles County Transportation Commission, the Los Angeles Department of Transportation and the Los Angeles Police Department. The aim of the study is to integrate traffic sensors, computers and communications links on a 15-mile section of the Santa Monica Freeway and five adjacent arterials. The system will provide information on current traffic conditions that will be used to assist highway agencies in making control decisions. In addition, the system will provide up-to-date information to motorists through a variety of media.

The SMART Corridor project is funded at a level of approximately $50 million, and began in 1989 with a conceptual design study. Full implementation of the system is scheduled for 1992. One of the major focuses of the study will be the methods by which information can be communicated to and from motorists in the corridor. A number of alternative approaches will be evaluated, including variable message signs, highway advisory radio, cellular telephone systems, teletext and videotext.

Closely related to the SMART Corridor study is the **PATHFINDER** project. This is a cooperative field experiment involving Caltrans, the 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 is being performed within the SMART Corridor demonstration area.

The in-vehicle equipment selected for the Pathfinder is the Bosch TravelPilot version of the ETAK Navigator, described in Chapter 3 of this report. In addition to conventional map display facilities, the system includes a special two-way, time-multiplexed communications element. This is used to send vehicle speed and location data to a control center, and to return pertinent traffic data

to the in-vehicle unit. Areas of congestion are identified on the map display, allowing the driver to select an alternative route if necessary.

Testing of the Pathfinder system began in June 1990, using Caltrans employees to evaluate the ability of the system to avoid congested areas. In a second phase of testing, hired drivers will be used to establish time savings achieved through use of the system between various origins and destinations. A final test phase will examine the acceptability and perceived utility of the system for commercial drivers.

**TRAVTEK** is a cooperative project currently being undertaken in Orlando, Florida by the FHWA, General Motors, the American Automobile Association, Florida Department of Transportation and the City of Orlando. The study will demonstrate the use of prototype in-vehicle equipment for the provision of up-to-date traffic condition, routing and tourist information. TRAVTEK will cost approximately $8 million and will involve 75 GM rental cars and 25 vehicles used by high mileage local drivers.

The test vehicles will be equipped with navigation and driver information systems linked to information centers by radio data communications. The in-vehicle video monitor will be capable of displaying maps of the Orlando area, including areas of congestion and services, text information on traffic incidents or services, and route guidance instructions using simple graphical cues. A traffic management center will be responsible for combining and transmitting traffic information received from a variety of sources. A 12-month operational demonstration of the TRAVTEK system is scheduled to begin in 1992.

An organization that will potentially be undertaking a major IVHS initiative in the near future is **TRANSCOM** (the Transportation Operations Coordinating Committee). This is a consortium of transportation agencies in the New York/New Jersey metropolitan area. TRANSCOM is responsible for coordinating regional traffic management through increased interagency cooperation, review of procedures and programs, formulation of mutual assistance programs and coordination of planned construction and maintenance activities.

The TRANSCOM IVHS study will seek to investigate the use of automatic vehicle identification (AVI) technology for traffic monitoring and management. AVI equipment is already being used in the New York/New Jersey area for automated toll collection on facilities operated by the Port Authority of New York and New Jersey and the Triborough Bridge and Tunnel Authority. The TRANSCOM study will therefore aim to use the same AVI technology in an integrated system with subsequent cost sharing benefits.

The first stage of the TRANSCOM study will focus on the design of an area-wide traffic management system. This will examine issues such as the required density of AVI readers, the number of equipped vehicles, and communications and software needs. Following completion of the design stage, equipment will be purchased and installed in the New York/New Jersey area. TRANSCOM will then evaluate system performance from the perspectives of traffic surveillance facilities, incident detection and response capabilities, and clarity of data. TRANSCOM will also examine the cost sharing options for the system and the market for traffic data collected by the AVI technology.

Among individual state initiatives, **GUIDESTAR** is pe·haps the most important program currently being undertaken in the U.S. GUIDESTAR is a cooperative effort between the Minnesota Department of Transportation (Mn/DOT) and the University of Minnesota's Center for Transportation Studies (CTS), in partnership with other public and private organizations. The initiative has a high national profile and was the only IVHS program specifically referred to in the Secretary of Transportation's recent National Transportation Policy.

GUIDESTAR has been envisioned as a mechanism for coordinating current Mn/DOT and CTS advanced technology applications with a view toward future IVHS deployments. In the first year of the program, GUIDESTAR will review IVHS technologies and initiatives, resulting in the development of a six-year strategic plan for IVHS research and development. One aspect of GUIDESTAR will be a joint venture between Mn/DOT and CTS to test a video-based real-time traffic information system called Autoscope. This will use video cameras and processing equipment to measure traffic volumes, speeds and congestion levels. A $1.4 million evaluation of Autoscope is due to start in 1991 using 20 cameras installed on Interstate 394 in Minneapolis.

**PATH** (Program on Advanced Technology for the Highway) is the main element of the California Department of Transportation's new technology development program. The initiative has a proposed budget of $56 million over a six-year period, with sponsorship from Caltrans, the FHWA and the National Highway Traffic Safety Administration. PATH research is conducted primarily by the University of California's Institute of Transportation Studies (ITS) at Berkeley.

The main focus of PATH is vehicle and highway automation, with the ultimate goal of completely automated vehicle operations. A major element of the research is investigation of roadway electrification, continuing previous work undertaken in the Santa Barbara Electric Bus Program. PATH is also conducting research into longitudinal and lateral control of vehicles based on a number of alternative technical approaches. In addition, PATH is performing research on traffic management and driver information systems, including consideration of driver behavior and safety aspects.

The main U.S. initiative in the area of FMCS is **HELP** - the Heavy Vehicle Electronic License Plate program. HELP is a $20 million program funded and directed by a group of 14 states, the Port Authority of New York and New Jersey, various motor carrier organizations and the FHWA. The aim of the program is to research and develop an integrated heavy vehicle management system combining AVI, weigh-in-motion and automatic vehicle classification technologies with a networked data communications system, comprising roadside stations linked to regional and central computers. Arizona is the lead state of the HELP program, providing valuable opportunities for cooperation and integration with other IVHS initiatives in the state as described in Chapter 7 of this report.

## 2.3 European initiatives

In Europe, a number of large-scale IVHS programs have been implemented. These are generally multinational initiatives, in contrast to some of the individual

state activities being undertaken in the U.S. Most of the European programs are organized and coordinated under the control of the Commission of the European Communities, a group of 12 member countries working toward economic unification in 1992, or as part of EUREKA, an industrial research initiative involving 19 countries. Two programs that are of particular interest in the context of this study are PROMETHEUS and DRIVE.

**PROMETHEUS** (Program for European Traffic with Highest Efficiency and Unprecedented Safety) is a $700 million research program 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 which 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 in 1986 by the European automotive companies, to respond to increasing competition from Japan and North America in the field of information and communication technologies. In addition to strengthening European competitiveness through coordinated concepts, the program aims to produce a totally integrated highway transportation system throughout Europe. The time span for developments emerging from the program is expected to cover a period of more than twenty years.

The PROMETHEUS project combines both scientific basic research conducted by universities and research institutes, and applied research conducted by industry. This cooperation is being accomplished by 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 are being 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 and actuators 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 upon which they can individually optimize their driving patterns.

PRO-NET: The final aspect being performed by the industrial participants concerns the development of a communication network between vehicle computers. The implementation of such a network would allow vehicles

to be operated "electronic sight," enhancing the perceptive range of the driver beyond his own range of vision.

The remaining subprograms concern basic research. The four areas are outlined below:

PRO-ART: This subprogram is examining and developing the principles of systems which use artificial intelligence. Methodological investigations and studies of problem areas and experimental systems are included in this research.

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 are also being addressed in this subprogram.

PRO-COM: The field of communication is being considered in PRO-COM. Architecture and general protocols are being developed to optimize data communication between vehicles, road and environment.

PRO-GEN: The final subprogram of PROMETHEUS is aiming to develop scenarios in the area of traffic engineering, which adapt the road system to the technical developments.

**DRIVE** (Dedicated Road Infrastructure for Vehicle Safety in Europe) is a program coordinated by the Commission of the European Communities. DRIVE consists of approximately 60 projects in a $150 million research program linking information technology and transportation. Individual projects are being undertaken by international consortia consisting of private firms, government agencies and research institutions. DRIVE is focusing on infrastructure requirements, operational aspects and technologies of particular interest to public agencies responsible for transportation systems.

The general objectives of DRIVE are:

* to enable the timely adaptation of the highway infrastructure and services to take advantage of the opportunities opened up by technological advance;

* to exploit the opportunities for synergy between road and telecommunications infrastructure developments;

* to promote the consistent development of IVHS technologies so as to facilitate the development of an internal European market;

* to contribute to the international competitiveness of the equipment and service industries;

* to stimulate collaboration between government and industry in analyzing opportunities and requirements, basic research and development of

infrastructure technologies, and the development of specifications and initial system testing;

* to support international standardization in IVHS and for related equipment and services; and

* to contribute to the timely common adaptation of an appropriate regulatory framework for advances in IVHS.

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.

Sixty DRIVE projects began in January 1989. Many of these were completed at the end of 1990, though some projects involve a further year of work, running through 1991. Planning is now in progress for a further round of projects within a DRIVE-II program. This would take many of the systems from the preliminary research stages of DRIVE through to large-scale field trials. Funding for the DRIVE-II effort is currently proposed at a level of approximately $250 million.

The Advanced Transport Telematics (ATT) program, the official name for DRIVE-II, is almost fully defined. It is envisioned that the call for proposals will be approved by the European Commission in early 1991. Proposals will be due by the fall for work to start before the end of the year. The program will be completed by the end of 1995.

The ATT workplan identifies seven areas for pilot projects based mainly on the results of the initial DRIVE program. These are:

* demand management;

* traffic and travel information;

* integrated urban traffic management;

* integrated interurban traffic management;

* driver assistance and cooperative driving;

* truck fleet management; and

* public transit management.

Within the framework of these seven areas, the main emphasis will be on pilot projects. Other aspects of the new program, however, will also be devoted to systems engineering and evaluation, and technical development.

Two further European initiatives have already started in order to involve so-called infrastructure owner-suppliers. The first of these is POLIS, which is coordinating fifteen major European cities with a further eighteen involved as observers. The intention is that through POLIS, the appropriate city authorities

will coordinate their own IVHS activities and prepare proposals for EC funding. CORRIDOR, the sister initiative, will examine interurban areas suitable for use as IVHS operational test sites.

## 2.4 Japanese initiatives

Japanese researchers have been investigating a range of advanced transportation technologies since the 1960s. Early work examined traffic management systems, prior to a shift of emphasis toward development of driver information technologies. More recently, automated vehicle control projects have been undertaken in Japan. The main Japanese IVHS initiatives currently being carried out or proposed include RACS, AMTICS, VICS and SSVS.

**RACS** (Road-Automobile Communication System), described in more detail in Chapter 3 of this report, has involved the development of a short-range, high data rate microwave communications system. This will be used for a number of road-vehicle communication applications. These include beacon transmissions for the correction of positional errors in vehicle location systems; the provision of a communications link for an externally-linked route guidance system; and the ability to pass individual messages or data for display on in-vehicle units.

**AMTICS** (Advanced Mobile Traffic Information and Communication System), also described in Chapter 3 of the report, is an integrated traffic information and navigation system, being developed in Japan under the guidance of the National Police Agency. The system will display on screen in each vehicle traffic information gathered at Traffic Control and Surveillance Centers managed by the police in 74 cities. The major benefit of AMTICS will be its ability to display in real time, not only the vehicle's current position and route, but also information on traffic congestion, regulation, road work and parking.

Both RACS and AMTICS are now entering their final implementation stages. These systems are currently being coordinated within an initiative known as VICS (Vehicle Information Communication Systems). VICS is a joint effort between the Ministry of Construction, the National Police Agency, and the Ministry of Posts and Telecommunications.

One of the major IVHS programs currently being planned is the Japanese SSVS (Super Smart Vehicle System) initiative. This aims to promote the research and development of IVHS technologies, particularly those concerned with highway safety. The initiative is targeted toward technologies for implementation in the highway environment within the next 20 to 30 years. SSVS will address a number of factors, including the following:

* technical, social and economic issues concerned with the development and introduction of IVHS technologies;

* evaluations of the needs of IVHS in terms of safety, efficiency and convenience;

* analysis of the fundamental characteristics of in-vehicle units based on technological capabilities;

* investigation of man-machine interfaces and human factors issues; and

* policies concerning technology research, development and evaluation.

Current proposals for SSVS suggest that it will initially be a two-year research effort. During this period, the program will investigate future socioeconomic conditions and vehicle requirements, as well as planning research and development projects and related activities. After two years of preliminary study, the Japanese Ministry of International Trade and Industry will decide whether SSVS should be adopted as the country's major IVHS project.

Prospective participants in SSVS cover a range of Japanese academic institutions and industrial firms, including the majority of the large automobile manufacturers. The initiative will also involve the participation of the Japanese subsidiaries of two European car makers, Volvo and Mercedes-Benz.

## 2.5 Recommendations

Two major lessons can be learned from this brief review of IVHS initiatives elsewhere in America, in Japan and in the European Community. These two main factors which emerge can be summarized as follows:

1. Like electronics and automobile manufacture, IVHS is a single world market. It makes no sense at all to think in terms of unique systems for Phoenix, for Arizona, for the western states or for the U.S. Not even North America as a whole can constitute a trading block of sufficient weight to dominate the development of new IVHS technologies. Thus, effective, well coordinated and meaningful links to overseas efforts, leading to open, non-proprietary international standards, are an essential base for economically effective state and national IVHS programs.

2. The European Community's DRIVE and PROMETHEUS programs have set the pace in IVHS, ahead even of the Japanese who are now responding with innovative programs like SSVS. DRIVE and PROMETHEUS are characterized by their multi-center cooperative frameworks, set within genuine public-private sector joint research programs. Separate and inevitably partial state programs will not be as effective in meeting the challenge of IVHS. Thus, interstate and international cooperation and joint working is an essential requirement at a high level of the Arizona IVHS program, ensuring synergistic gains through technology transfer at all levels of the development process.

These two principles have been major factors in developing the program and organizational proposals of the remaining chapters. They are also recommended as a focus for continued work on Arizona's program and on broader, cooperative IVHS development efforts over the months ahead.

# 3. ADVANCED TRAVELER INFORMATION SYSTEMS

## 3.1 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 utilization of the highway network, and consequent benefit to traffic as a whole.

Research studies carried out in the U.S. and Europe [1, 2, 3, 4, 5] have shown that many drivers are currently inefficient in selecting and following a route, for a variety of reasons. This inefficiency leads to excess travel, contributing to unnecessary congestion of certain routes and consequent wastage 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 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. Re-planning 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 which have multiple stops or multiple purposes [2]. 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 exist for assisting drivers in one or more of these activities by providing improved information. The remainder of this chapter covers the main approaches and describes previous experience of their use.

## 3.2 Electronic route planning

Sources such as maps or memory can, at best, only supply 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 [6].

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 phone line, and see details of their optimum route displayed or printed out. Development of most electronic route planning systems has taken place within the last ten years. Some of the significant developments are described below.

In the U.S., an electronic route planning system has been developed by Navigation Technologies, Inc. (Figure 3.1). This selects destinations from a structured database, using a look-up table. The system has been used by rental car firms to provide customer directions.

In the U.K., a system known as AUTOROUTE is currently being marketed for route selection [7]. AUTOROUTE is a prejourney route planner for microcomputers based around standard U.K. road maps. A route optimization module enables the system to identify a user's optimum route between a specified origin and destination. Optimization is based upon time, distance and operating cost according to parameters specified by the user. An abnormal routing module capable of considering traffic data from several sources is also currently being developed.

Electronic route planning facilities are also receiving attention elsewhere 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 which are connected by phone to service suppliers. The database for ROUTE contains network information, together with current data on highway maintenance and construction activities, road conditions and weather.

Also in France, the ANTIOPE service provides up-to-date traffic information which can be used by motorists in planning routes. ANTIOPE is not an interactive system, but collects and displays 30-40 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 which 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] which provides traffic information to radio stations, TV and teletext services. This networked system operates around a database which is kept up-to-date with the latest details of variations in road conditions due to weather, highway maintenance or accidents.

DriverGuide ELECTRONIC DRIVING DIRECTIONS

--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 5.2 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.

DriverGuide ELECTRONIC DRIVING DIRECTIONS

Drive 1.5 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.

Figure 3.1 Electronic Route Planning

At a pan-European level, there is a developing system known as ATIS [illegible] 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 to the Geneva center by the police and motoring organizations in each of 12 European countries. Here it is processed and the resulting information transmitted back to each country, for dissemination via the motoring organizations.

### 3.3 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 drivers to adapt and replan routes as necessary. Systems can be used to warn drivers of various conditions including recurring congestion, short-term holdups caused by a traffic incident, or preplanned activities liable to cause congestion such as highway construction and maintenance.

In the U.S. and Japan, traffic information broadcasting is provided by highway advisory radio (HAR). HAR is a short-range broadcast service provided to the motoring public through standard AM car radios [13, 14]. 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, respectively. Transmissions on these frequencies can be received by most standard AM car radio receivers, and 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 3.2).

In 1980 the Federal Highway Administration (FHWA) initiated a program to develop automatic highway advisory radio (AHAR) [15]. AHAR avoids the need for roadside signing and manual tuning by using a subsidiary FM receiver. This automatically mutes the car radio and tunes to the correct frequency (45.80 MHz) on entering the coverage area of the AHAR transmitter. The radio is retuned to its normal state after the message has been repeated and received twice. The system prototype was developed to the stage where it was technically proven, though institutional barriers have so far prevented the transition from HAR to AHAR.

Other traffic information broadcasting systems include the West German system known as ARI (Autofahrer Rundfunk Information) [16, 17], developed by Blaupunkt. ARI is widely used in Germany and parts of Austria, Switzerland and Luxembourg.

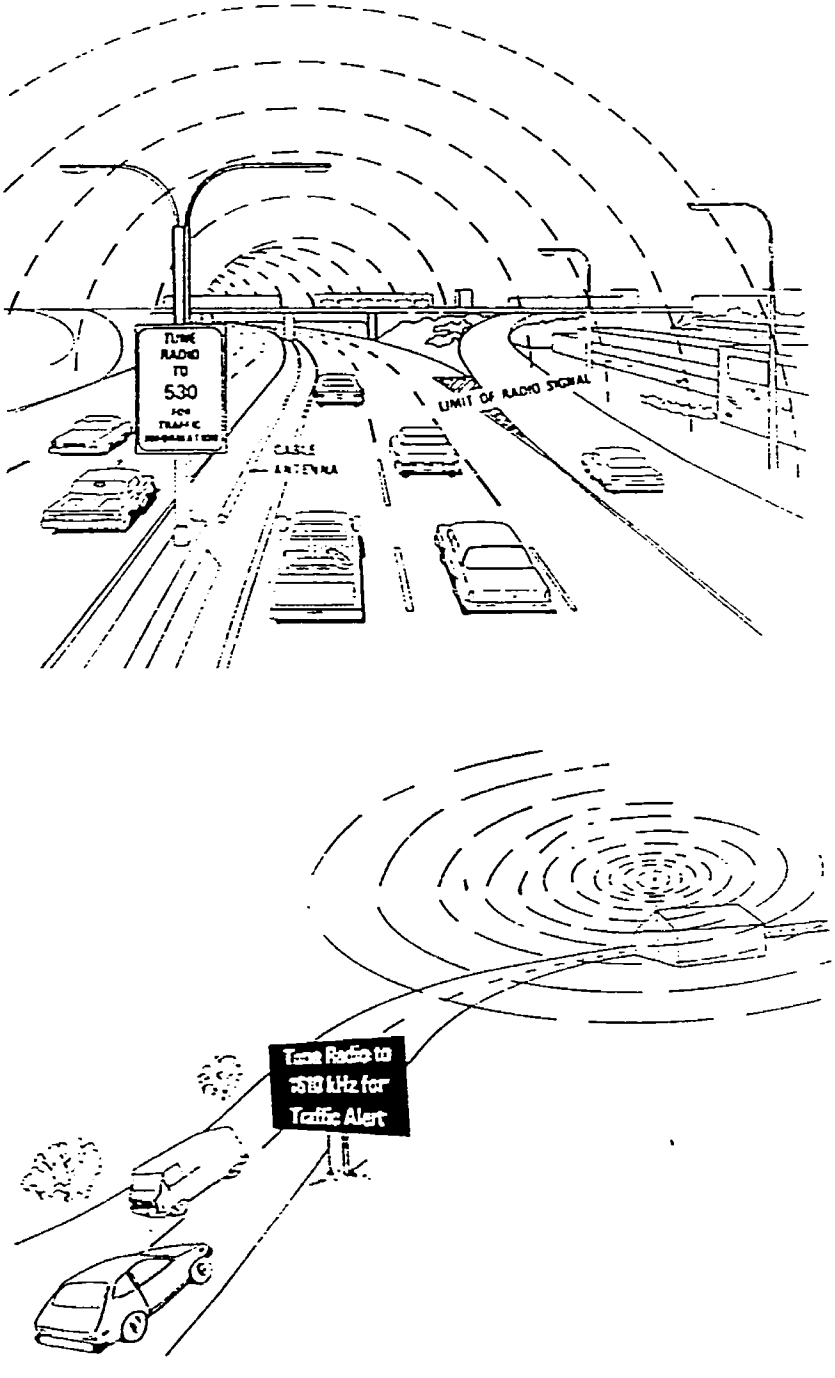



Figure 3.2 Highway advisory radio

(Source: Reference 13)

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 made up mostly of 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, disseminating that information 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 10-15 minutes earlier than a system relying on non-automated information collection.

A system which will eventually supersede ARI is the Radio Data System (RDS) of the European Broadcasting Union (EBU). This is a system which 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 Radio Data System 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 coordination with radio receiver manufacturers confirmed that RDS objectives had been achieved. 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 to investigate the possibilities of implementing RDS-TMC. These include Canada and Hong Kong. In the U.S., Chrysler has been carrying out trials of RDS traffic information in the Detroit metropolitan area.

Another traffic information broadcasting system of interest is EMERAUDE, developed in France [7]. This is based around the cellular radio-telephone system which will be installed over the entire French road network during the next ten years. The cellular system has been designed primarily for the transmission of personal voice communications, but has some spare capacity which will be used by EMERAUDE to transmit numeric data. This will include weather conditions, road passibility, traffic conditions and alternative route recommendations. Data will be collected by the police and road authorities, and will be updated on an hourly basis.

The onboard EMERAUDE equipment is a dedicated unit which receives, decodes and stores data. The driver can program the onboard unit according to the geographical areas in which traffic data are required. Data are passed on to the driver using a voice synthesizer, or can optionally be represented on an in-vehicle map display. The French telecommunications authority is currently in the process of implementing a trial of the EMERAUDE system in Paris.

While systems such as RDS-TMC and EMERAUDE are currently entering demonstration and field trial stages, however, a real-time in-vehicle traffic information system has already been made commercially available in London, U.K. [23]. The system, known as Trafficmaster, collects traffic information on major roads within a 35-mile radius of London using 115 sets of bridge-mounted infrared sensors. Detected congestion is broadcast to a portable in-vehicle unit using a VHF paging network. The screen on the receiver unit displays the motorway network with holdups pinpointed in red to allow the driver to make rerouting decisions. System portability allows the unit to be operated in the home or workplace to provide pretrip planning facilities.

The system manufacturer plans to extend Trafficmaster's area coverage to the British Midlands in 1991 and the complete U.K. motorway network by 1993. Receiver units can be purchased by users for approximately $860 with a $35 per month subscription charge. Message paging facilities can be provided for an additional $33 per month.

In the U.S., work is currently being undertaken by the Federal Highway Administration into the development of an in-vehicle safety, advisory and warning system (IVSAWS) [24]. This will provide an electronic extension of the driver's line of sight to warn of signs or hazards that are not clearly visible due to roadway curves, vegetation, poor visibility or other obstructions. The IVSAWS concept involves the use of radio transmitters mounted on regulatory and safety warning signs, on emergency or maintenance vehicles, or temporarily placed at roadway hazards. Upon activation, these would transmit short-range encoded messages to approaching motorists. Messages would be decoded by in-vehicle receivers and displayed to the driver, providing sufficient time for precautionary action to be taken.

## 3.4 Onboard navigation systems

Onboard navigation and location systems are a further 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 which provide 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 highway and some are currently commercially available to motorists. The systems can be divided into the following three categories:

* directional aids;
* location displays; and
* self-contained guidance systems.

**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 location relative to a known starting point. Several different technologies can be used to monitor both distance traveled and vehicle heading [25]. The odometer is the most common approach 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 generally consists of a microcomputer, a keypad and a display unit [9, 26]. 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. New headings and remaining distances are then displayed 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.

**Location displays** 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 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 [27] and Decca [28]. 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 U.S. (known as the mid-continent gap), as seen in Figure 3.3. Also, problems are encountered in receiving Loran-C transmissions in urban areas due to multi-path reflections and obscuration of the signals. Additionally, positioning accuracies are only of the order of 600 feet, which may be inadequate, particularly in urban areas.

Satellite trilateration techniques are currently based around the U.S. Navy TRANSIT system or the Navstar Global Positioning System (GPS). TRANSIT 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 [29, 30]. Ford's prototype TRIPMONITOR [31] system fitted in the "Concept 100" car in 1983 utilized TRANSIT, with a receiving antenna located in the trunk of the car.

TRANSIT, however, will shortly be superseded by Navstar GPS [32]. 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 Coordinated Universal Time to an unlimited number of suitably equipped users.

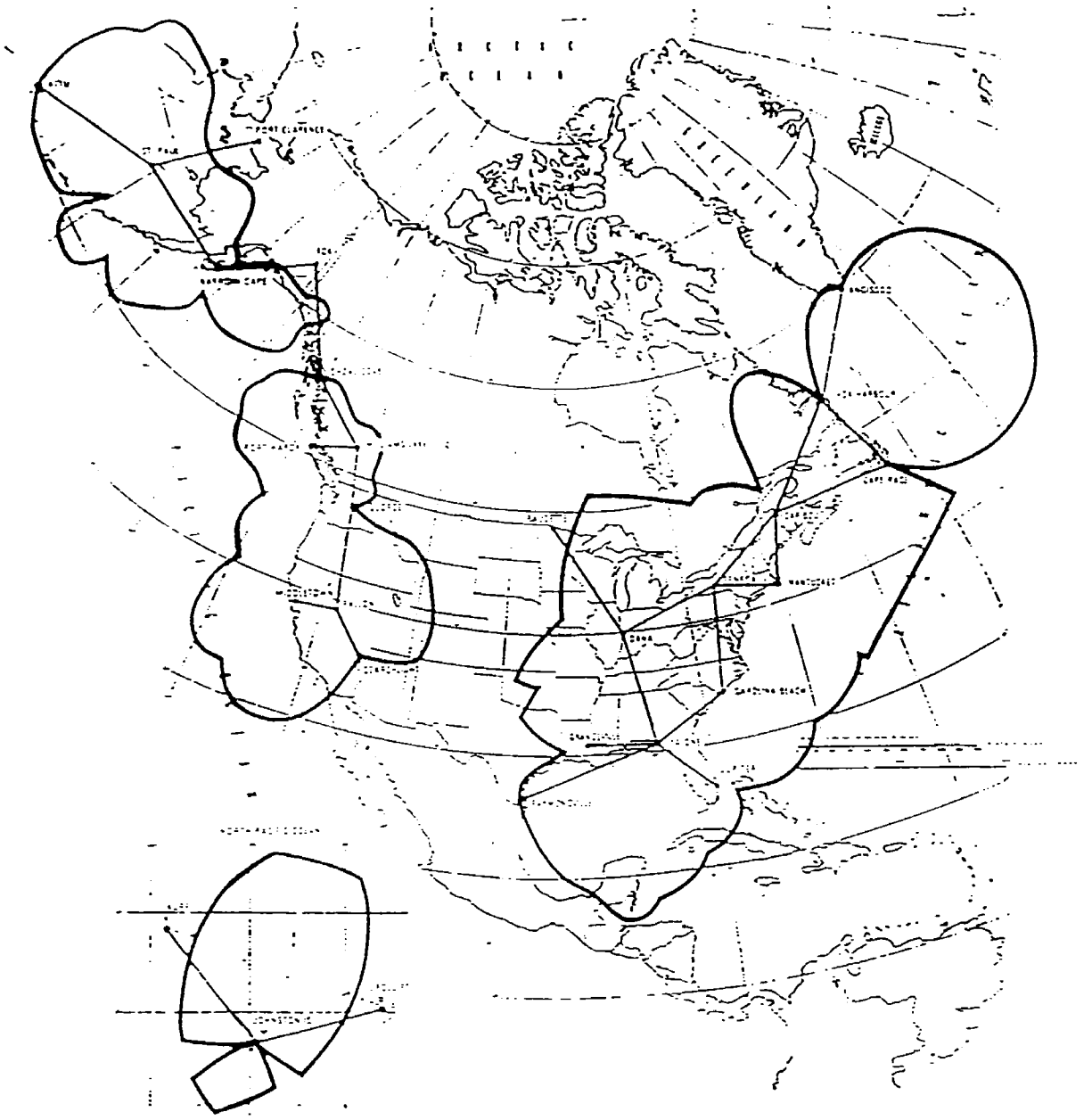


Figure 3.3 U.S. LORAN-C coverage

(Source: Reference 27)

However, GPS is not without [illegible] [33]. 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 Fair [34].

At present, however, the market place for location-display onboard navigation systems is dominated by systems which 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 [35]. 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, Car Pilot and Philips CARIN. The ETAK system [36, 37] is the only onboard navigation system which 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 odemetry for DR inputs, and uses compact disks or 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 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 so determine vehicle position at specific points where the pattern clearly changes, such as at a turn in the road.

In Europe, the ETAK system is currently being sold under license by Bosch-Blaupunkt, using the name Travelpilot. The system was launched in West Germany in May, 1990, and reportedly sold over 1,000 units within its first year. However, plans to introduce the system in France and the U.K. have been delayed after feedback from German users indicated insufficient network coverage. The German system contains only the autobahns, main routes and large towns. In contrast, the Travelpilot version available in the Netherlands has digitized maps for the entire Dutch highway network.

Competition for the Bosch Travelpilot will soon be provided in the form of the Dutch Car Pilot system. This is scheduled for official launch in the European market in January, 1991. Car Pilot will use wheel sensor-based DR and map matching techniques to establish vehicle location and desired destination. Road networks will be stored on CD-ROM, digitized from 1:10,000 maps and augmented by in-depth video data collection. CDs will need to be updated approximately every 6 months to reflect changes in the highway network.

The likely cost for the Car Pilot system is estimated at around $5,000. Optional enhancements will provide automatic vehicle location and route logging. This

latter facility will enable vehicle location to be recorded for every map-match. The data will then be stored on floppy disk for subsequent route reconstruction.

The Philips CARIN system [38, 39] currently exists as a prototype version. This system uses a compact disk 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.

**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 which 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 DR 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 alpha-numeric 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 [40] during the early 1970s. This used DR augmented with map-matching to track the vehicle location. Routing advice was provided by preprogrammed audio instructions which 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 define 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 [41]. 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 dictated the timing for displaying instructions.

Also in Germany, the EVA (Electronic Traffic Pilot for Motorists) system developed by Bosch-Blaupunkt [42] 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 were presented aurally via a speech synthesizer unit and also visually by a liquid crystal display unit.

In France, a prototype in-vehicle map display and routing system called DANA has been developed [7]. This uses road network data stored in an onboard computer to make recommendations on the shortest path to a desired destination. A visual display is used to provide turning instructions during a journey. DANA's location subsystem uses DR, with computer algorithms employed to minimize the deviation between the measured and the actual vehicle position.

Finally, Plessey has developed a self-contained route guidance system known as PACE (Plessey Adaptive Compass Equipment). PACE [43, 44, 45] 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.

### 3.5 Externally-linked route guidance systems

Externally-linked route guidance systems comprise all electronic route planning and route following aids which 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 depends 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. These are each described in the following paragraphs.

**Long range communications systems** are limited to receiving information on 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, due to the absence of an effective monitoring network in recording transient traffic conditions. Possible approaches in this first category are route guidance systems which utilize mobile cellular radio, systems which are linked with RDS, and systems using digital broadcasting such as AMTICS.

Cellular radio [46] 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 RDS 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 need 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 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 was made available in Tokyo and Osaka in 1990.

**Short-range communications systems**, which make up 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/or updates of road network and traffic conditions, which 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.

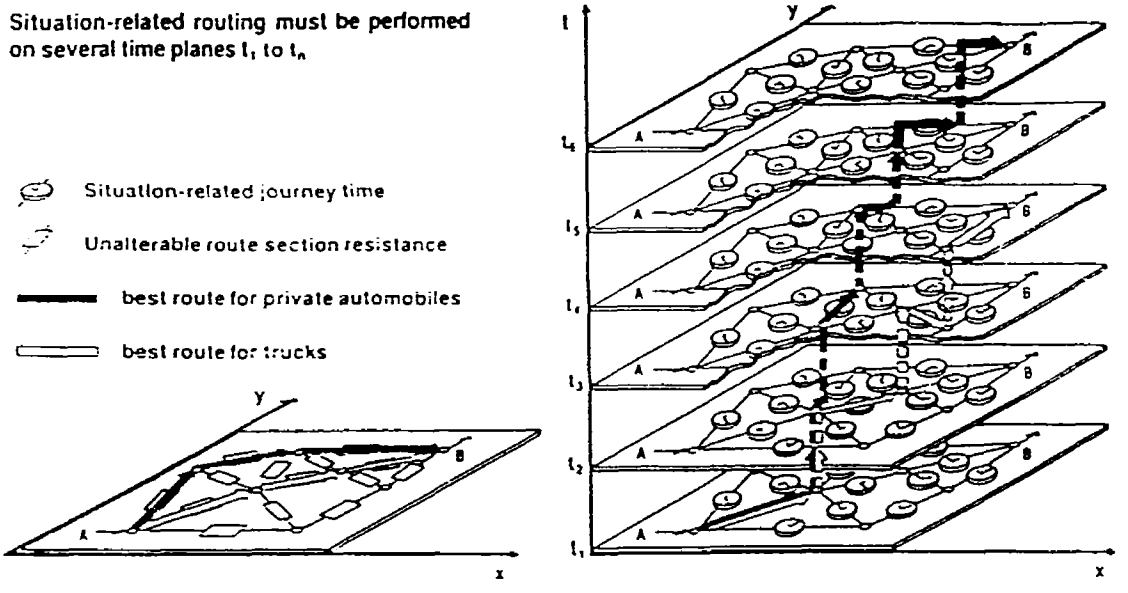
At the simplest level, a basic "beacon" system configuration with low data rate roadside-vehicle communication provides similar benefits to a self-contained onboard route guidance system. This configuration operates by equipping key points on the highway network with data transmission beacons, which continuously emit unique codes identifying particular locations. Techniques include use of inductive loop, radio frequency, microwave or infra-red 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 location sub-system 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 receiving 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 which 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 illustrated in Figure 3.4. 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. Optimum routing




Situation-unrelated guidance: a two-dimensional problem

Situation-related guidance: a three-dimensional problem

**Figure 3.4 Simulation-related guidance**

**(Source: Reference 61)**

advice is therefore provided at each decision point on the journey which 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 twenty years. Some of the earliest work was carried out in the U.S. in the late 1960s, with the investigation and development of a prototype Electronic Route Guidance System (ERGS) [47, 48]. The system concept was investigated by several organizations including General Motors [49] and Philco-Ford [50], under contract to the Office of Research and Development of the Bureau of Public Roads.

The ERGS concept was based around two-way communication 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, due to the high projected costs of the roadside infrastructure.

Japanese investigations into short-range externally-linked route guidance with two-way communications have been in progress since the early 1970s. The Comprehensive Automobile Traffic Control System (CACS) project [51, 52, 53], sponsored by the Japanese Ministry of International Trade and Industry (MITI), began in 1973 and ran for a six-year period.

The prototype CACS system demonstrated in Tokyo utilized 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 in the opposite direction. 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 [54] 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 [55] to test out the most recent technologies. The system tested utilized 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) [56]. HIDO is a consortium of vehicle and electronics manufacturers. A study of externally-linked route guidance involving PWRI and HIDO members started in August 1986 [57] entitled RACS.

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 and AUTO-SCOUT.

The ALI system (Autofahrer Leit und Informationssystem) [58, 59] was developed by Blaupunkt. Like ERGS and CACS, it utilized 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 five minutes 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 [60] was developed by Siemens and utilized infra-red 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 utilizing DR.

More recently, the ALI-SCOUT system [61] has been developed in a cooperative effort by Bosch/Blaupunkt and Siemens, using experience gained from ALI and AUTO-SCOUT. ALI-SCOUT (Figure 3.5) is an infra-red based system which utilizes a roadside infrastructure consisting of post-mounted infra-red 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. This is analyzed in a central computer, which updates map information giving relative impedances of alternative routes held by the roadside equipment.

A large field trial of the ALI-SCOUT system known as LISB began in Berlin in June, 1989. Infrared beacons were installed at 250 intersections and at 10 additional freeway locations. The field trials were designed to permit an evaluation of system performance, driver acceptance and user benefit, using a fleet of 700 specially equipped vehicles [62].

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 [63] in association with Plessey Controls. Demonstration systems [64] utilizing 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 [65, 66]. 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 3.6.

During the initial investigation of AUTOGUIDE [67], a choice was made between inductive loops or infra-red beacons for the roadside equipment to receive and transmit information. The main determining factors here were data transfer rate, cost and reliability. Post-mounted infra-red beacon systems are cheaper 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 infra-red approach, with a final commitment dependent on the results of field trials.

Work was subsequently carried out on the implementation of an AUTOGUIDE demonstration scheme in London [68]. The demonstration started in 1988 and utilized five beacons, sited along a corridor between Westminster and London's Heathrow Airport. In the demonstration beacons were not connected to a central computer, since the number of equipped vehicles and beacons was insufficient to collect detailed traffic data. Nevertheless, the demonstration was successful in verifying the infrared road-vehicle communications link and the format of the in-vehicle display unit.

The successful completion of the AUTOGUIDE demonstration led to the distribution by the U.K. government of a bid document for installation of an AUTOGUIDE pilot

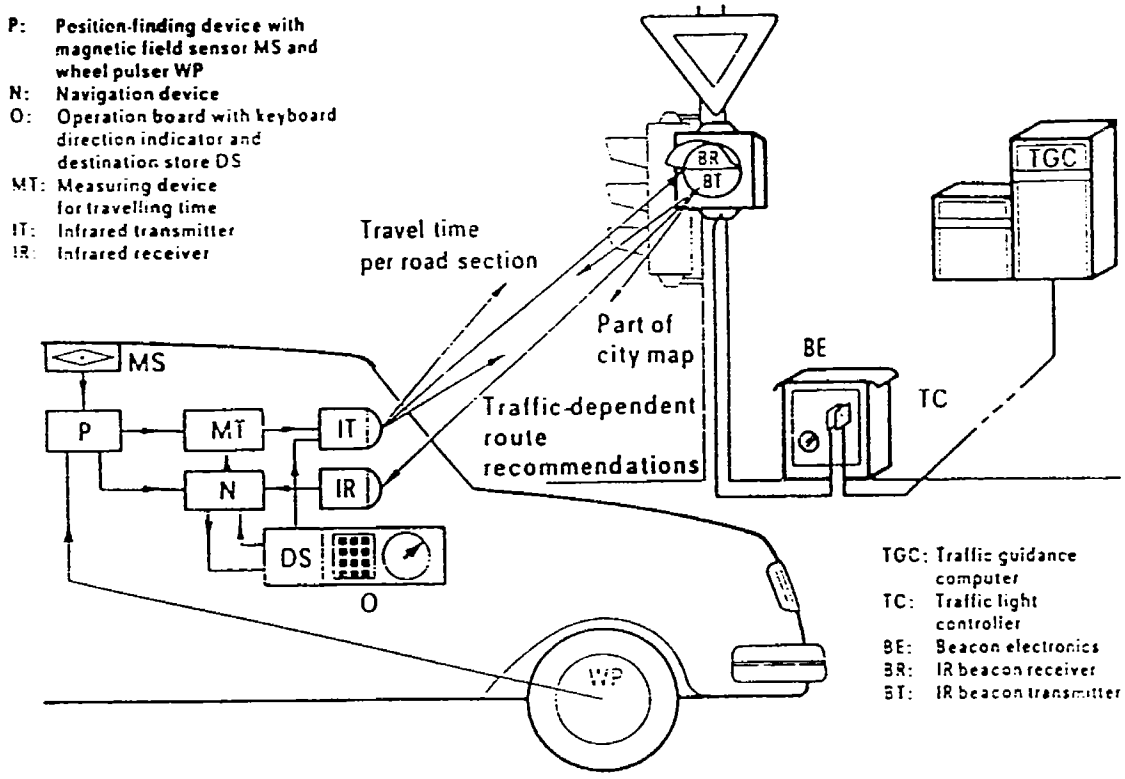



Figure 3.5 The ALI-SCOUT system

(Source: Reference 61)

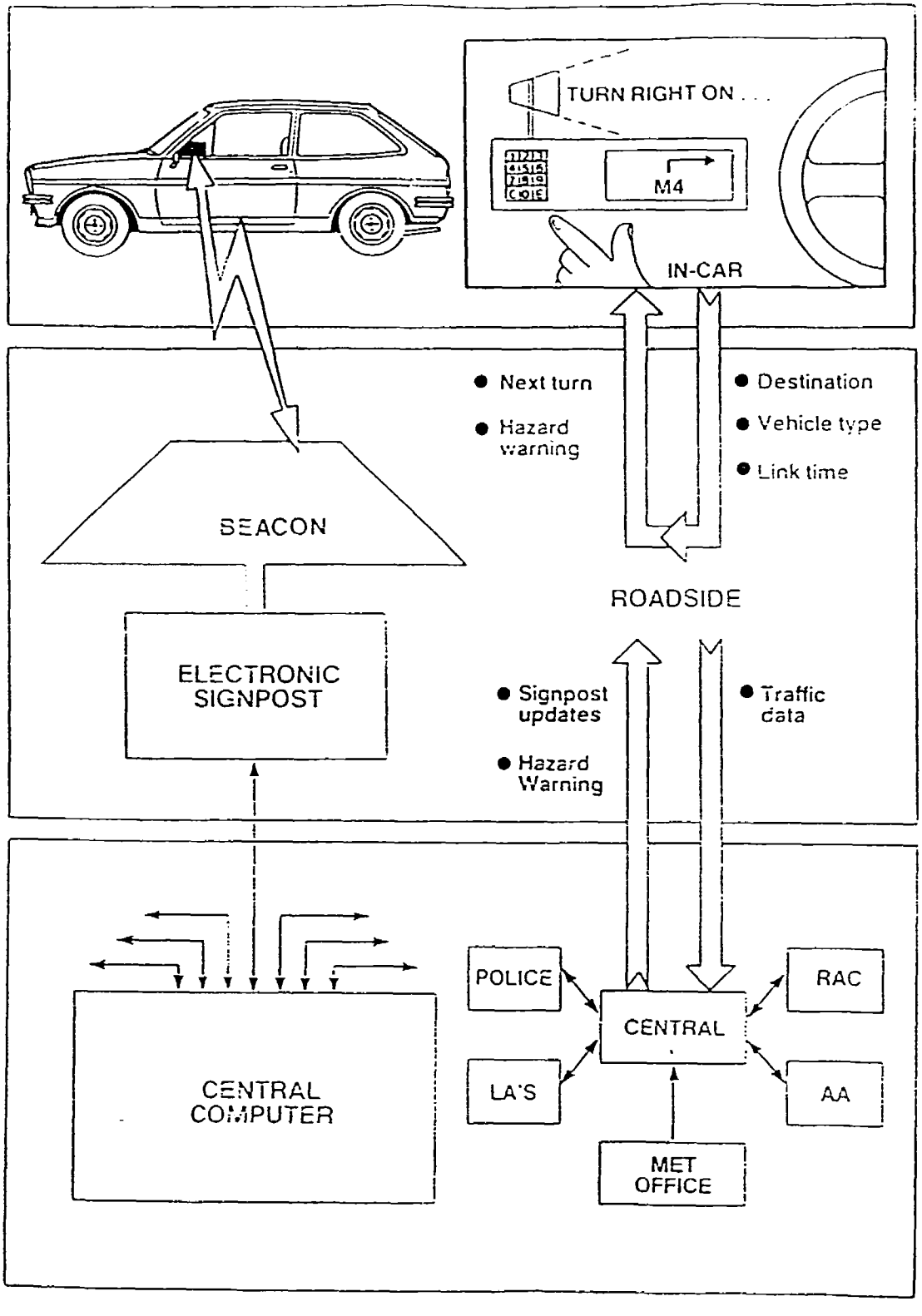



Figure 3.6 The AUTOGUIDE concept

(Source: Reference 67)

system. This would initially operate within the area encircled by the London beltway, before being extended to other parts of the country. GEC was selected by the U.K. government as the contractor for the AUTOGUIDE implementation. At the time of writing, however, negotiations between GEC and the U.K. government have yet to achieve agreement on the system licensing details. It is understood that one of the causes of the delay is local councils in the London area, which have expressed concern over the ways in which AUTOGUIDE will select and recommend routes in their areas of jurisdiction.

### 3.6 Automatic vehicle identification

AVI is the term used for techniques which uniquely identify vehicles as they pass specific points on the highway, without requiring any action by the driver or an observer. AVI systems [69] essentially comprise three functional elements: a vehicle-mounted transponder or tag; a roadside reader unit, with its associated antennas; and a computer system for the processing and storage of data. At the simplest level, information which identifies the vehicle is encoded onto the transponder. This 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 utilized 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 running in the field of AVI is the HELP program. The $19 million HELP program is funded and directed by a group of 14 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 [70, 71, 72].

AVI systems can be used to introduce 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 [73] is that road users should pay for their use of road space according to how much they are contributing to congestion. It therefore depends upon 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 are subsequently billed for their road usage.

AVI has been demonstrated for road pricing in Hong Kong on a trial basis, [74, 75] and has been shown to be technically feasible (Figure 3.7). 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 which contribute to the difficulties of implementing AVI systems for this particular application.

Finally, AVI systems may alleviate congestion where they are utilized for automated toll collection. AVI-based automatic toll collection facilities have been under consideration for several years, with experiments carried out by the Port Authority of New York and New Jersey, Caltrans [76] and the Golden Gate Bridge Authority. An operational system is currently being implemented on the Dulles Toll Road in Virginia [77]. 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 automatic vehicle identification 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 system can be divided into four main categories as described in the following paragraphs.

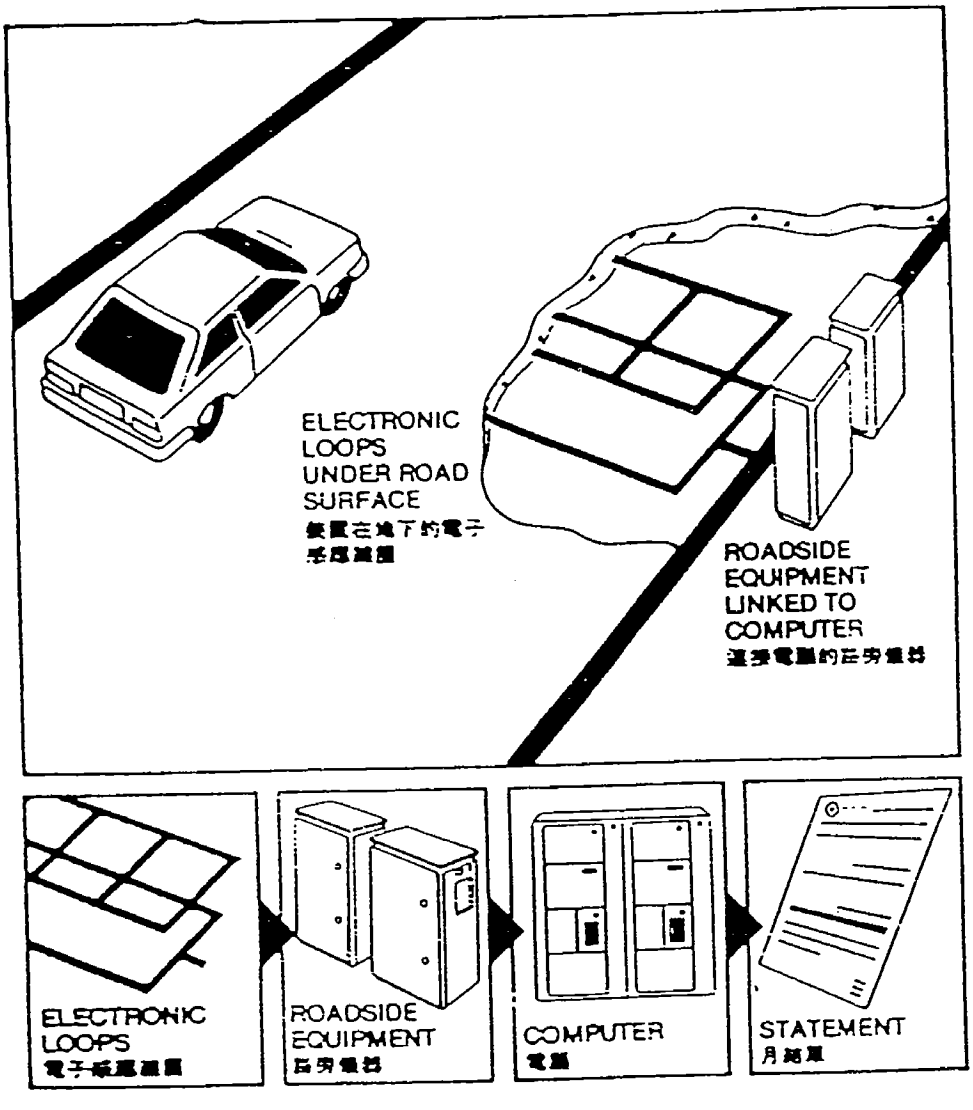



Figure 3.7 The Hong Kong electronic road pricing system

(Source: Reference 74)

Optical systems formed the basis of the earliest AVI technologies developed in the 1960s in the U.S. 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, though 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 many 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 and the fundamental nature of these problems is such that both optical and infra-red 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.

Radio frequency (RF) and microwave systems generally utilize roadside mounted or in-pavement antennas, transmitting or receiving on a wide range of frequencies in the kHz, MHz and GHz 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, as they operate at higher frequencies. However, a potentially serious problem associated with passive microwave systems concerns the power levels which 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 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 [78, 79]. A SAW tag consists of two elements, an antenna and lithium niobate SAW chip that serves as a multi-tapped 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.

## 3.7 Summary

In summary, a range of systems is being developed and demonstrated which can provide drivers with information on highway conditions and route availability. Traveler 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 externally-linked route guidance seeks to combine route choice with real-time response to congestion within a truly dynamic system.

# 4. . . .CED TRAFFIC MANAGEMENT SYSTEMS

## 4.1 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 management 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 U.S. and overseas [80, 81, 82].

Operational objectives of ATMS include making the best use of existing highway network capacity and cutting journey times, without creating adverse environmental effects [83]. By reducing congestion and delay, some systems have been utilized 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 ATIS technologies such as the route guidance techniques described in the previous chapter [84, 85].

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 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 ATMS. It includes fixed-time and traffic-responsive UTC strategies; incident detection techniques; freeway and corridor control systems; and future possibilities for interactive control, combining these techniques with those described in the previous chapter.

## 4.2 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 might be better utilized, and goes on to examine 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 utilized in most U.S. cities, while traffic responsive techniques are becoming more widespread in some other countries [86, 87].

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 utilization of existing approaches. Techniques already exist for the determination of optimal signal timings at isolated intersections and in fixed-time coordinated networks. The hierarchy of signal timing systems can be divided into the following categories, each of which is discussed in subsequent paragraphs:

* isolated intersection control;
* fixed-time coordination;
* partially-adaptive coordination;
* fully-adaptive coordination; and
* fourth generation systems.

**Isolated intersection control systems** may be operated fixed-time, semi-actuated 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 [88, 89, 90, 91, 92].

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 [93, 94].

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 feet and 330 feet from the stopline [95]. The LHOVA algorithm adopts a similar approach [96, 97].

**Fixed-time coordination** is another area where much could be achieved through the wider use of established techniques. In 1982 it was estimated that there were some 130,000 sets of traffic signals in the U.S. which formed some part of coordinated systems [98]. Cimento [99] described progress made during the 1960s

and 70s in bringing these systems under electronic computerized control (Figure 4.1).

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 [100] and PASSERII-84 [101].

For grid networks, one of the first, national initiatives to develop efficient fixed time coordinated traffic signal timings was the SIGOP program [102], produced in 1966 for the Bureau of Public Roads. The SIGOP optimization routine utilizes an algorithm which depends on two variables: ideal offset, calculated from speed, link length, and queue discharge time; and link weighting, 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 utilized 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 and a few references are quoted here [103, 104].

TRANSYT models traffic behavior using histograms to represent the arrival patterns of traffic. The histograms are called cyclic flow profiles [105] because they represent the average rate of traffic flow during one signal cycle (Figure 4.2). 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 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 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 [106]. TRANSYT was still in its developmental stages, and 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 apparent during the morning and evening peak periods.

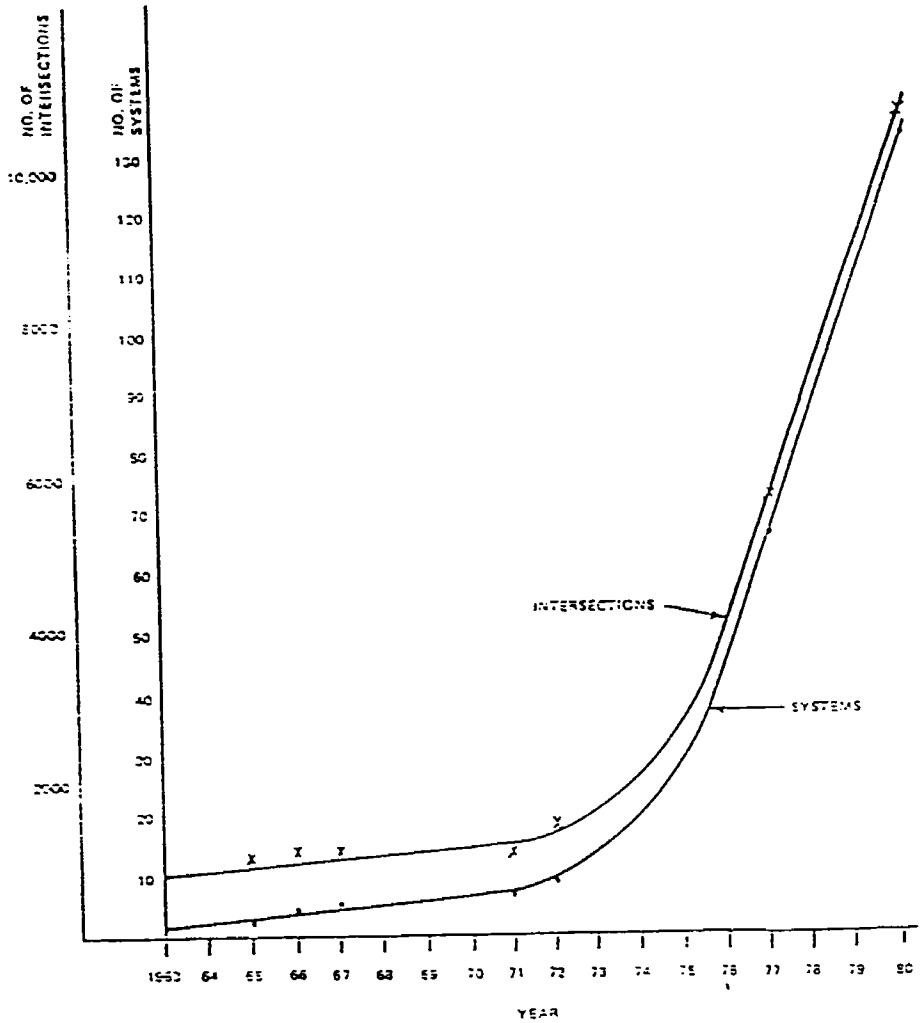



Figure 4.1 Number of computerized traffic control systems and controlled intersections in the U.S.
(Source: Reference 99)

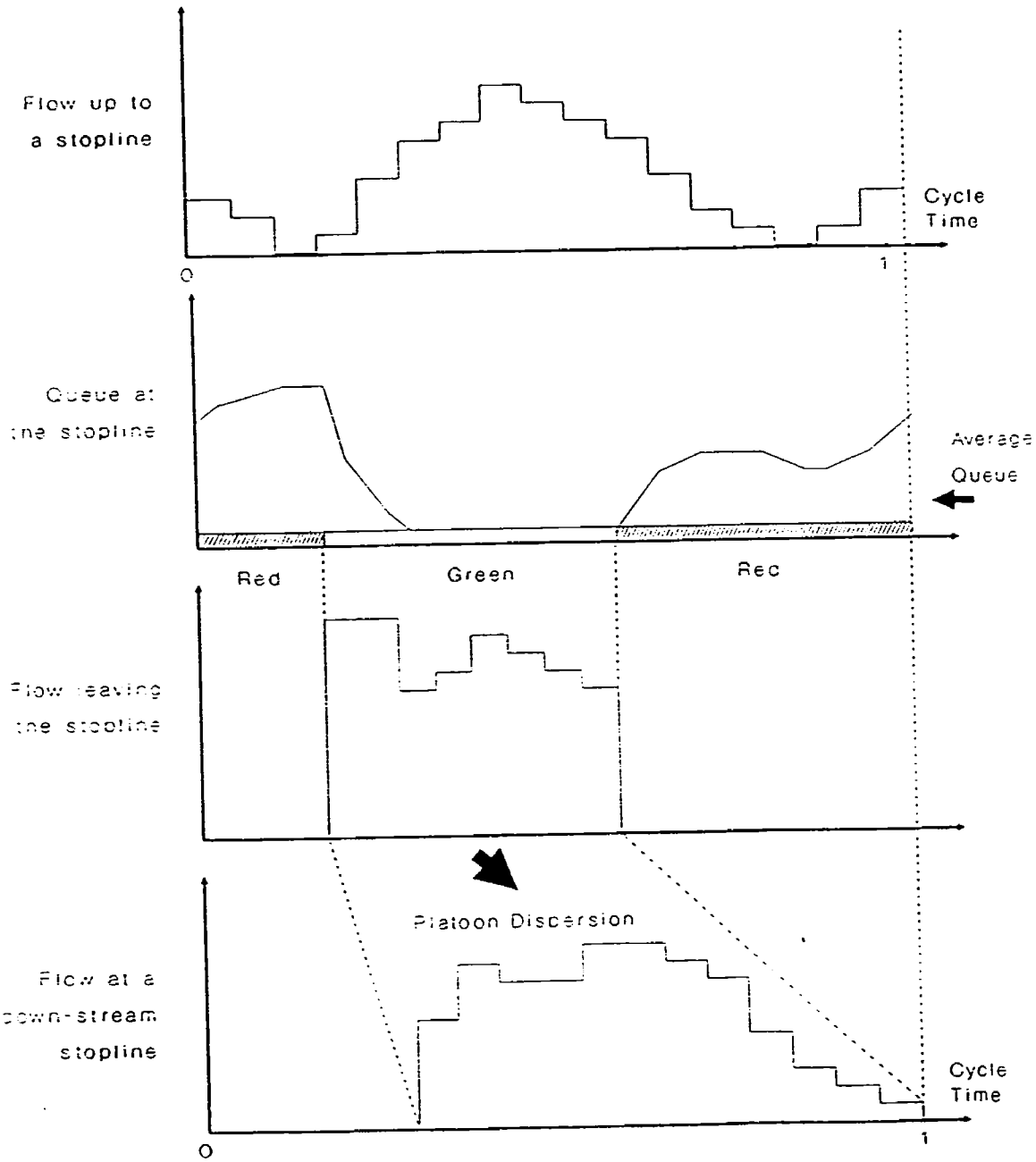



Figure 4.2 Cyclic flow profile in the TRANSYT model

(Source: Reference 104)

The current version of TRANSYT-7F was developed by the University of Florida Transportation Research Center, and evaluated in the NSTOP project [107, 108]. Since 1981, TRANSYT-7F has gone through five releases. Initially, a fuel consumption model was added to allow for optimization of energy usage. 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 now 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 [109, 110, 111, 112].

In Europe, also, enhancements to the TRANSYT program have continued, with two recent versions providing increases in capability. TRANSYT-8 included a fuel consumption model, explicit treatment of yield control, provision for modeling opposed turning movements, and inspection of a range of cycle lengths. More importantly, however, 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. These are:

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 five years. Actual rates of ageing may vary significantly about this mean and will tend to be more acute in grids than along arterials [113].

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 below.

**Partially-adaptive coordination approaches** monitor traffic conditions in a network using some form of detection, and react to the information received by implementing appropriate signal settings. In other 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 [114]. In more advanced systems, libraries of eight or ten alternative plans are normally prepared and switched in as required. Sometimes plan changes are carried out manually based on visual surveillance of traffic conditions using closed circuit television cameras (CCTV). However, 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 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 [106, 115].

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 UTC systems 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 [116]. In the ATSAC system, enhanced UTC equipment utilizes 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 unclear 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 [117]:

* **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 and so a new plan must operate for more than 10 minutes to achieve an overall benefit.

* **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.

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

* **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 [118]. SCATS combines several features of UTCS-1 and 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 sub-

systems 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 stop line 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 pre-calculated to suit the busier direction of travel. Progression is not guaranteed in the less busy direction at peak times [119]. During off-peak periods, SCATS selects the minimum of two or three precalculated cycle times giving good two-way time-distance progression [120].

**Fully-adaptive coordination approaches** represent a goal sought by researchers in several countries throughout the 1970s. In the U.S. work on UCTS-3 was designed to create a fully responsive, on-line traffic control system.

UTCS-3 [121] utilized two optimization algorithms: an approach with no fixed cycle times, for under-saturated conditions, and congested intersection control/queue management control for use along congestion paths. In the former approach, signal coordination was 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 aimed to maximize thoroughput 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 relative to the base case three-dial system. Overall, the third generation system produced about 10 percent more delay than the previous system utilized in Washington, D.C.

In Europe a coordinated, fully responsive traffic control strategy was developed by the U.K. TRRL. The system is called SCOOT, an acronym for Split, Cycle and Offset Optimization Technique. This system 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 4.3). 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 4.4.

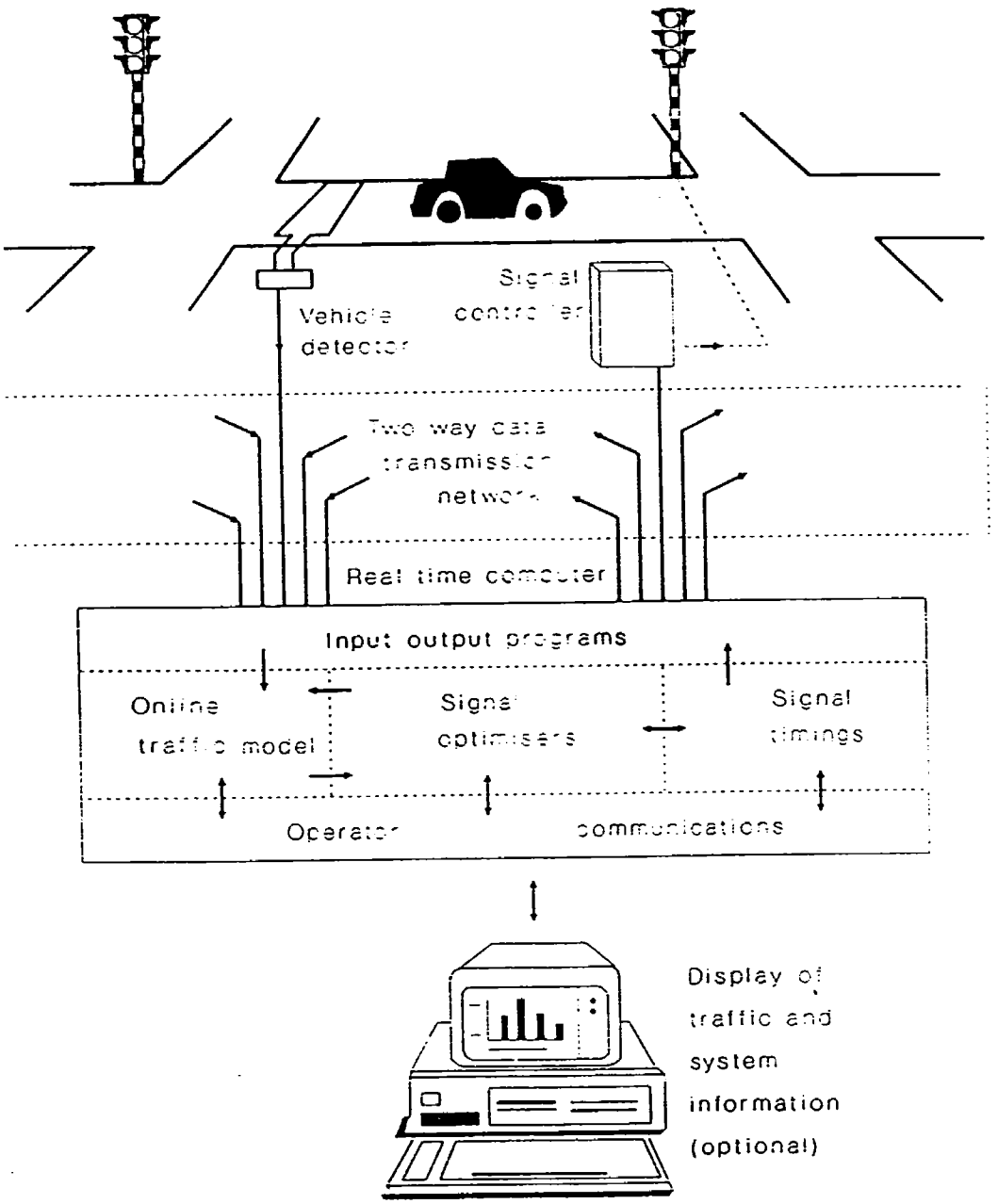



Figure 4.3 Flow of information in the SCOOT system

(Source: Reference 121)

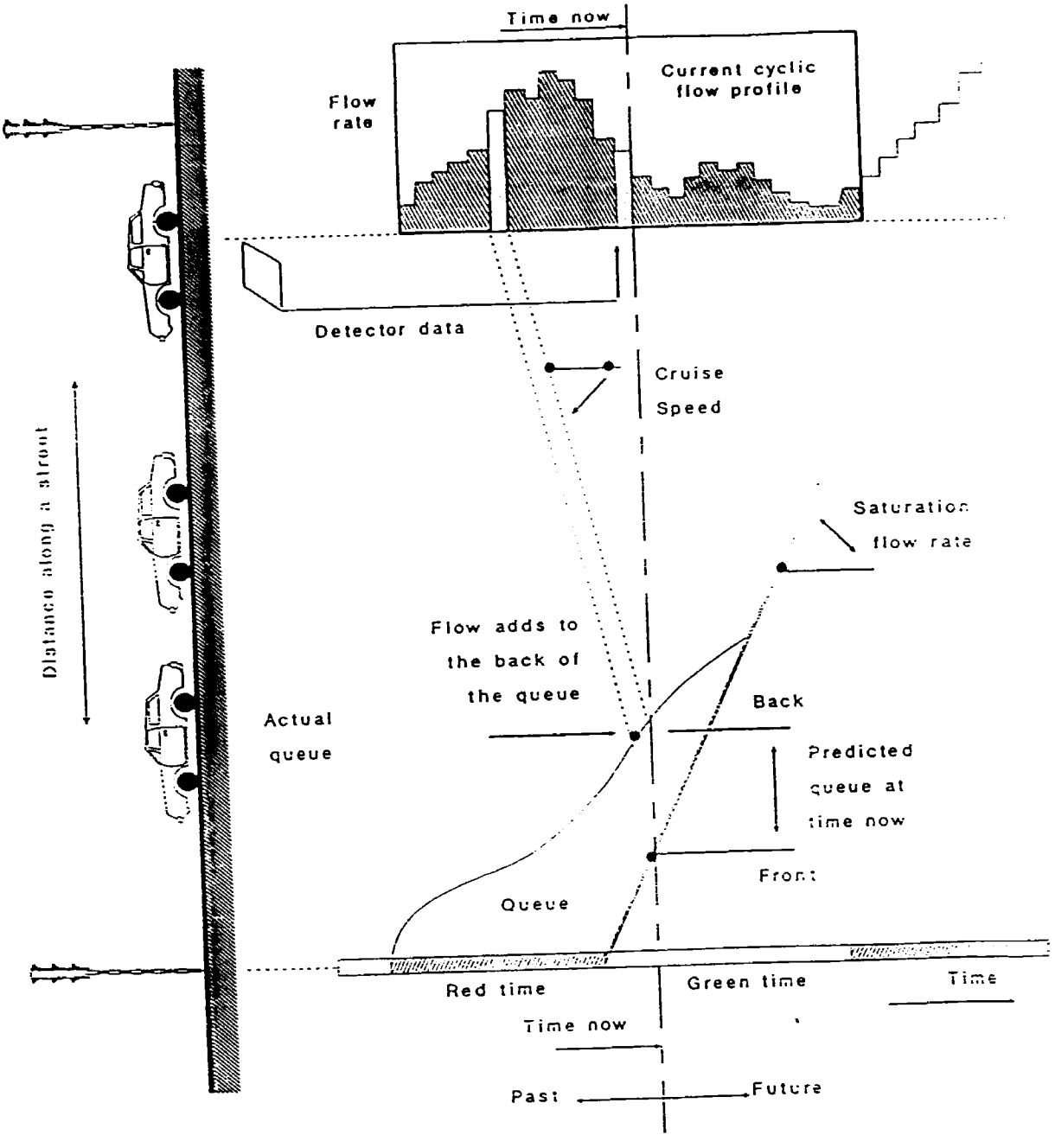



Figure 4.4 Principles of the SCOOT traffic model

(Source: Reference 121)

The first trials of fully adaptive control were carried out in 1975 [121], 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 was evaluated in Glasgow during Spring 1979. SCOOT was compared with up-to-date, carefully optimized fixed-time TRANSYT plans. Both in this evaluation, and in subsequent trials in other cities, 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 time control, as fixed time plans age and become less appropriate for current traffic flows [113]. Over the four to five 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 systems** represent the highest level of signal control complexity considered within this review. Systems such as SCOOT do not represent the end of the line in traffic control strategies, and are in a very real sense already 15-year old technology. Some of the limitations of SCOOT-type approaches which need to be addressed by future fourth generation systems include:

1) The current policy of minimizing transients and allowing only "creeping" plan changes is beneficial in maintaining coordination but mitigates against the objective of fast response when conditions change rapidly, for example due to an incident. A fourth generation system would decide when to kick in 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 disruption resulting 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 , for recently past traffic conditions, rather than the upcoming situation. The amount of lag differs in respect of 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 estimation, and perhaps later on feedback from externally-linked route guidance systems.

4) The loop detectors utilized 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 engineers who set it up, SCOOT's use of an on-line traffic model makes it into a black box you either love or hate. Recent development of SCOOT "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 4.1 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 CBDs where congestion is high and flow patterns are complex, varying from day-to-day. Fixed time control will work well where congestion is lower and flow patterns more consistent.

## 4.3 Incident detection systems

Another category of advanced technology systems included in this review is that of 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 which 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 incidents can generally be divided into recurrent and nonrecurrent problems. Recurrent problems occur routinely during peak periods when traffic demand exceeds capacity, even for relatively short time periods. Peak-period 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, oversize loads, etc. Environmental problems such as rain, ice, snow and fog also fall into this category [122, 123].

Automatic incident detection systems typically consist of a small computer or distributed microprocessor system, monitoring 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 U.S. 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 three 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

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

Table 4.1 Summary of the advantages and disadvantages of different types of UTC systems

closed subsystem every three miles. The actual field location of detectors usually depends upon 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 [124]. These are connected in turn to a surveillance center.

In Europe, different algorithms have been developed for incident detection. HIOCC, for example, 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 initiated 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 1600 feet, and preliminary investigations enabled improvements to be made in the system [125]. 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) [126] (Figure 4.5). Since these initial developments, the scheme has been extended to cover 50 miles of the congested M1 motorway [127] (Figure 4.6).

In West Germany, incident detection equipment has been used to alert motorists of the formation of queues at an autobahn bottleneck [7]. Inductive loop detectors are used to record traffic volume and vehicle speed data for analysis at a control center. If the traffic data reveal that a performance threshold has been passed, an automatic queue warning is given to approaching vehicles via variable message signs, and successively lower speed limits are set. This gradually reduces the speed of traffic nearing the queue, decreasing the danger of rear-end collisions.

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 of St. Louis, SFG in West Germany and ELIN Electronics in Austria [128, 129, 130].

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 4.7). 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 [132, 133, 134].

Another operational example of the use of incident detection to warn of adverse environmental conditions is in West Germany, where fog warning systems have been installed at several locations [7]. These are used on autobahns where fog occurs frequently and rapidly, often over localized areas. The equipment uses sensors to continuously measure the range of visibility. This information is relayed to a control center and compared with a threshold. Where poor visibility is detected, the roadside variable message signs and hazard warning lights are

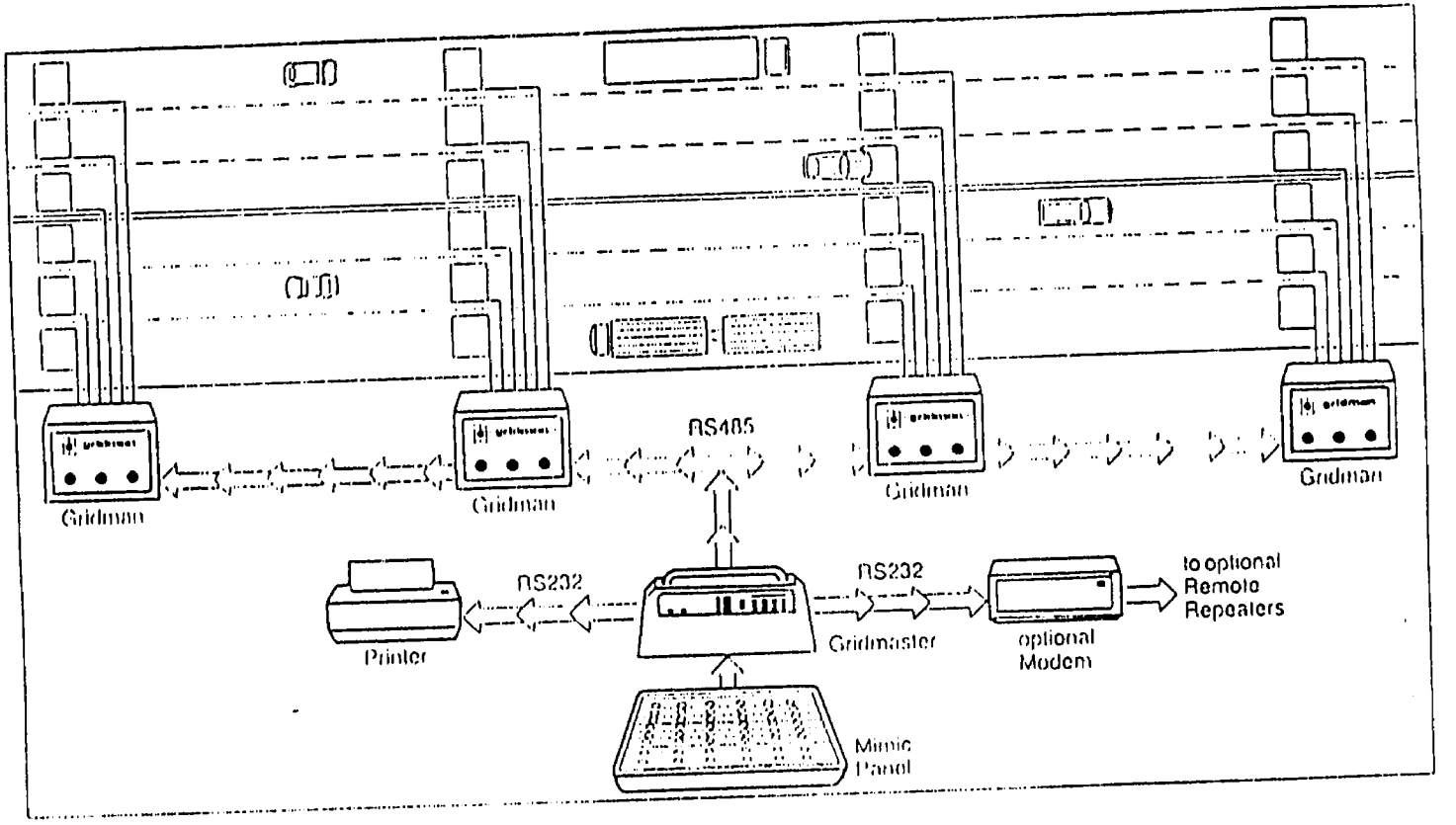



Figure 4.5 Grid incident detection system

(Source: Reference 126)

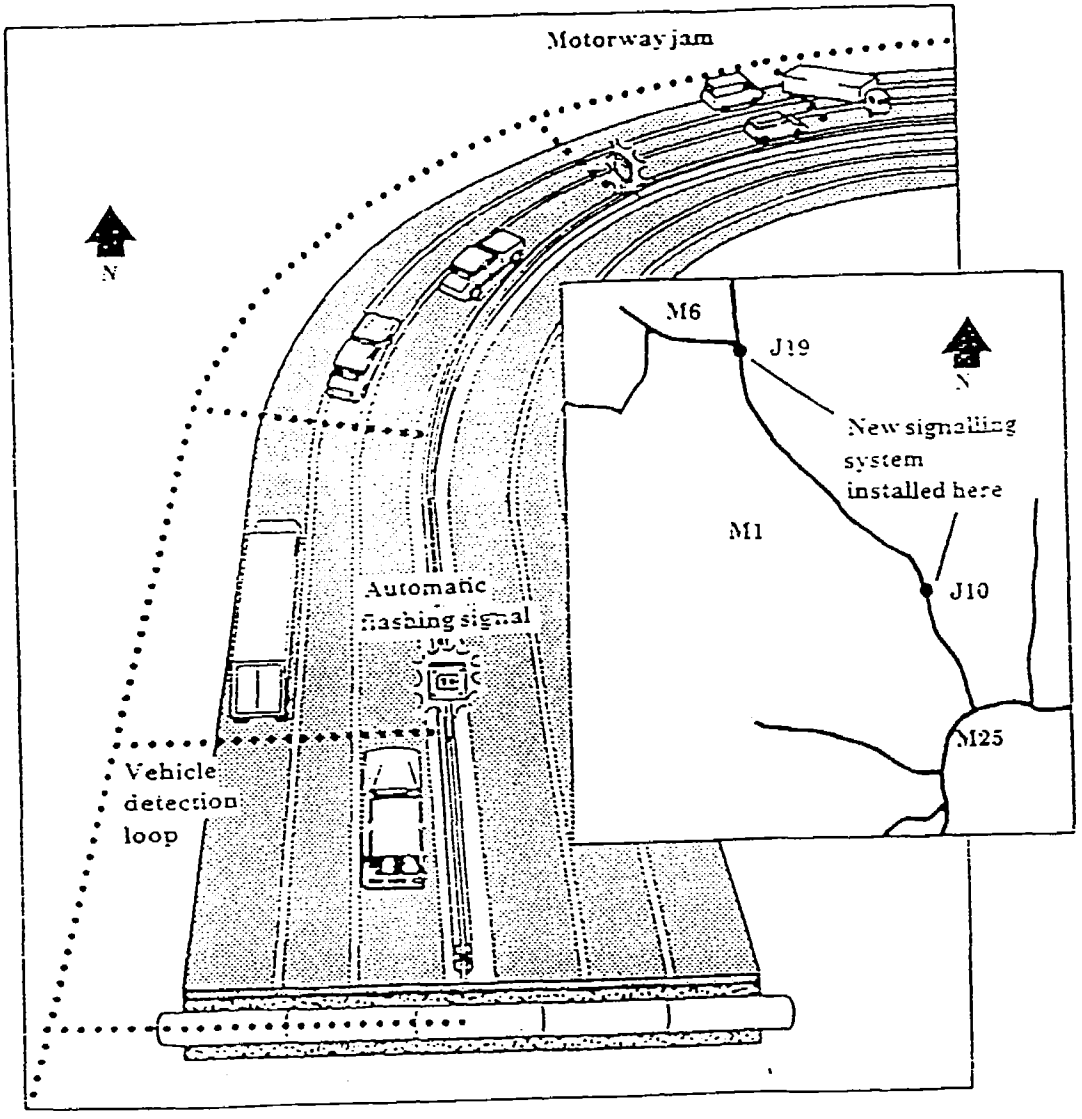



Figure 4.6 Incident detection system, M1 motorway

(Source: Reference 127)

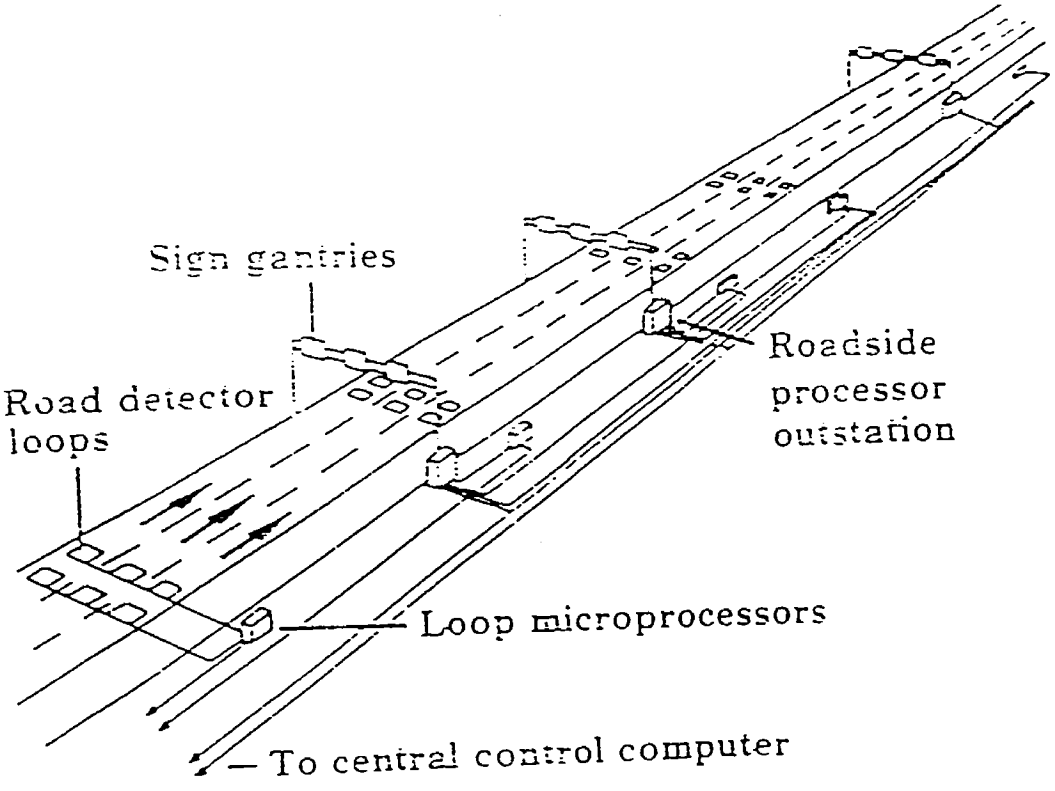



Figure 4.7 Rotterdam's motorway control and signalling system
(Source: Reference 131)

activated as a means of providing advance warning. Variable message signs are also used to display successively lower speed limits on the approach to the affected area.

## 4.4 Freeway and corridor control

Freeway management techniques fall into two main categories: capacity management and demand management [135]. Capacity management seeks to maximize throughput and improve the level of service, while demand management attempts to reduce the vehicle miles traveled or encourage off-peak travel. Examples of capacity management include ramp closures, ramp metering, variable speed control, lane control, express or reversible lanes, etc. 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 U.S. [136, 137], though they are routine in Japan [138, 139].

Ramp metering [140] is more widely utilized, 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 U.S., a single vehicle is commonly released per green, while in Europe, operation resembles conventional signals with longer green and red periods. Chicago was the first metropolitan area to practice ramp control in 1963 [141]. 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 1650 loop detectors.

Evaluations of ramp metering in Chicago found that the technique reduced peak period congestion by up to 60 percent and accidents by up to 18 percent [142]. Benefits will vary according to the level of congestion prevailing before the implementation of controls [143]. On Houston's Gulf Freeway, for example, travel times were reduced 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 [144, 145, 146, 147].

Ramp metering has also been experimentally implemented on the M4 motorway in Birmingham, U.K. A signal control algorithm responds to speed and flow data received from detectors located on the ramp and in the motorway lanes. Capacity downstream of the intersection is monitored continuously to allow metering rates to be adjusted in line with current conditions. The system is activated automatically in response to traffic conditions and remains in operation throughout the morning peak. Traffic on the ramp is given a green signal unless the combined ramp and motorway demand flow exceeds a critical limit, or traffic speeds at the intersection fall below a preset threshold.

Mainline control of speeds using variable message signs has been implemented in Britain, the Netherlands, Germany, Italy, Japan and the U.S. 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 U.S. commonly ignore advisory speed limits [148, 149, 150].

Lane reversal for tidal flow operation is implemented both on freeways and arterials in many countries. In the U.S., reversible 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 which are electronically switched at the appropriate times.

Traffic control centers are a vital requirement for integrating advanced technologies to improve conditions on urban freeways. Washington State Department of Transportation, for example, has had a freeway control center in operation for over 10 years. This is capable of monitoring flows, through a system of traffic detectors and data links. 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 is gathered by 550 traffic counters imbedded in the pavement of interstate lanes and entrance ramps. Current mainline traffic and incoming demand are balanced with the known capacity of the freeway using ramp metering. The VDOT system also includes variable message signing for communicating with drivers.

Typical European practice in control center and communications design, including closed circuit television, emergency telephone and radio systems, signalling, and maps has been set out in a U.K. Home Office publication [151]. 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 two miles. Traffic speeds and flows are continuously recorded and meteorological conditions monitored from roadside outstations [152].

Corridor control is a concept which 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 [145, 153, 154, 155].

## 4.5 Interactive signal coordination

Interactive signal coordination is a new concept which 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 interactive 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 interactive traffic control system has not yet been developed. However, a series of possible aims has been identified, including:

* Minimize vehicle delays;
* Minimize passenger delays;
* Minimize variability in transit times;
* Minimize user costs;
* Minimize negative environmental impacts;
* Minimize unnecessary travel; and
* 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, and classification systems.
* Inclusion of artificial intelligence and 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.

* Provisions for integration with automatic vehicle control.

## 4.6 Summary

Advanced traffic control systems are further developed than the information technologies reviewed in the previous chapter. 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. Incident detection systems may in future 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 3 with the traffic control systems of this chapter.