

Assessment of Advanced Technologies For Transit and Rideshare Applications

Final Report

NCTRP Project 60-1A

Prepared for

National Cooperative Transit Research and Development Program
Transportation Research Board
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CASTLE ROCK CONSULTANTS
Leesburg, Virginia



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PETER DAVIES, CHRIS HILL, NEIL EMMOTT, AND JEREMY SIVITER
Castle Rock Consultants
Leesburg Virginia

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ABSTRACT

This report presents the results of a study to examine advanced technologies and systems that can be applied to high occupancy vehicles, ridesharing and transit needs. Advanced technologies can be used to encourage the use of transit and rideshare facilities by improving their attractiveness and accessibility to travelers. In addition, they have the potential to increase the efficiency of transit and rideshare operations, reducing operational costs while offering higher levels of service to the public.

Technologies were reviewed in the areas of traveler information systems, traffic management systems, fleet management and control systems, and automatic vehicle control systems. Within these areas, developments in the U.S., Europe and Japan were considered and a number of individual technologies were identified.

Qualitative and quantitative assessments of the technologies in the broad technology areas were undertaken. Assessment frameworks were established to provide comparisons of system benefits and costs.

The study included a review of current moves toward a national intelligent vehicle-highway systems (IVHS) program. An outline of IVHS projects and activities directed at high occupancy vehicles, rideshare and transit vehicles has been prepared. These cover research, development, operational testing and standard setting activities for the technologies. Project descriptions are presented in limited detail, with emphasis placed more on the overall structure of the program than individual activities. Several of the near-term projects, with high-payoff potential, have been defined in more detail. The report concludes by recommending the direction of future work on transit and rideshare-related advanced technologies, within the framework of a national IVHS program.

LIST OF ACRONYMS

AFI	Hamburg Automatische Fahrplan Information
AGT	Automated Guideway Transit
AHC	Automatic Headway Control
AHS	Automated Highway System
AIDS	Automated Information Directory System
AMTICS	Advanced Mobile Traffic Information and Communication System
API	Automatic Personal Identification
ASC	Automatic Steering Control
ATIS	Advanced Traveler Information Systems
ATMS	Advanced Traffic Management Systems
AVC	Automatic Vehicle Classification
AVCS	Automatic Vehicle Control Systems
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
AVLC	Automatic Vehicle Location and Control
AVM	Automatic Vehicle Monitoring
BESI	Bus Electronic Scanning Indicator
BISON	Betriebsführungs und Informationssysteme für den Öffentlichen Nahverkehr- or Operational Control and Information Systems for the Public Transit Sector
Caltrans	California Department of Transportation
CBD	Central Business District
CCRTA	Cape Cod Regional Transit Authority
CCTV	Closed Circuit Television Cameras
CD-ROM	Compact Disk Read-Only Memory
CEC	Commission of the European Communities
CIS	Toronto Transit Commission's Communication and Information System
CRC	Castle Rock Consultants
DR	Dead Reckoning
DRIVE	Dedicated Road Infrastructure for Vehicle Safety in Europe
EUREKA	European Research Program: Industrial Cooperation Scheme in High Technologies
fax	Facsimile
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMCS	Fleet Management and Control Systems
GPS	Global Positioning System
GVW	Gross Vehicle Weight
GWH	Great Western Highway
HOV	High Occupancy Vehicle
ILP	Integer Linear Program
IRTE	Integrated Road Transport Environment
IVHS	Intelligent Vehicle-Highway System
IVHS America	Intelligent Vehicle-Highway System Society of America
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LRT	London Regional Transport
LRV	Light Rail Vehicles

LVA	Linked Vehicle Actuated
MARIA	Mitsubishi Advanced Realtime Information Autosystem
MIS	Management Information System
MOVA	Modernized Optimized Vehicle Actuation
mph	Miles Per Hour
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research Program
NTP	National Transportation Policy
NTSPS	National Transportation Strategic Planning Study
OBC	Onboard Computer
OCTranspo	Ottawa-Careleton Regional Transit Commission
PCU	Passenger Car Unit
PIN	Personal Identification Number
PROMETHEUS	Program for European Traffic with Highest Efficiency and Unprecedented Safety
RACS	Road-Automobile Communications System
RDSS	Radio Determination Satellite Services
RF	Radio Frequency
rpm	Revolutions Per Minute
SCC	Surveillance, Communications and Control
SCOOT	Split, Cycle and Offset Optimization Technique
SEITU	Societe' d'Etude pour l'Information sur les Transports Urbains
SLG	Synchronous Longitudinal Guidance
SNCF	French National Railway
ssvs	Super Smart Vehicle System
TFP	Technology for People
TIS	Transit Information System
TRANSYT	Traffic Network Study Tool
TRRL	Transport and Road Research Laboratory
TSM	Transitway Simulation Model
TTC	Toronto Transit Commission
TTI	Texas Transportation Institute
UMTA	Urban Mass Transportation Administration
U.S. DOT	U.S. Department of Transportation
UTC	Urban Traffic Control
VICS	Vehicle Information Communication Systems
VIPS	Vehicle Identification and Priority System
VMS	Vehicle Management Systems
VMT	Vehicle Miles Traveled
WMATA	Washington Metropolitan Area Transit Authority

1. INTRODUCTION

This report examines advanced technologies and systems that can be applied to high occupancy vehicles, ridesharing, and transit needs. It contains a review of previous and current examples of the implementation of advanced technologies for transit and rideshare schemes, as well as a discussion of options for future system applications. The report includes assessments of the advanced technology options from benefit and cost perspectives. Recommendations for transit and rideshare-related research, development, and operational testing projects within national transportation technology initiatives are also presented.

The research described in this report was carried out by Castle Rock Consultants (CRC) on behalf of the National Cooperative Transit Research and Development Program (NCTRP) and the Urban Mass Transportation Administration (UMTA). This work represents a continuation of the effort begun in Phase II of a companion study conducted under the National Cooperative Highway Research Program, NCHRP Project 3-38(1), entitled "Assessment of Advanced Technologies for Relieving Urban Traffic Congestion." NCHRP Project 3-38(1) was performed by CRC with support from Washington State Transportation Center. The project produced a widely based review and assessment of advanced technology developments in the field of highway transportation. Details of that research are documented in the project final report (to be published as NCHRP Report 340).

It is worth noting here that the NCHRP Project 3-38(1) review and evaluation of advanced technologies encompassed a range of systems that can be applied to reduce congestion. However, the direction of the research meant that the review was focused primarily on general highway traffic, and even though many of the technologies and systems could be applied to specific categories of vehicles, a detailed examination was not carried out within the scope of NCHRP Project 3-38(1).

One particular sector of highway traffic that has significant potential to reduce congestion is transit and rideshare vehicles. These have the capability to carry an increased number of travelers in fewer vehicles, thereby improving people-moving efficiency. As a follow-up effort to NCHRP Project 3-38(1), the objective of this study was to investigate the application of new and emerging systems to transit and rideshare schemes. The research has built upon that performed in the previous project by reviewing a similar broad range of technologies.

A review of some recent statistics indicates that 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 4 percent per year, but construction of new facilities is expected to accommodate less than one-fourth of this demand. The 37 largest U.S. metropolitan areas are annually experiencing a total of 1.2 billion vehicles-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 problem is further highlighted by the following recent reports: (1) In September 1988, it was reported that the average speed for commuters across the Woodrow Wilson Bridge near Washington, D.C., was 23 miles per hour (mph), down from 47 mph in 1981. (2) A report published by the Texas Transportation Institute placed the cost of congestion in 19 U.S. cities in 1986 at over \$24 billion, based on delays, wasted fuel, and higher insurance premiums. (3) In September 1989, the Southern California Association of Governments forecast that average peak-hour speeds on Los Angeles freeways will soon be reduced to as low as 17 mph.

Against this backdrop of serious existing and growing congestion, traffic operation techniques and systems are needed that can substantially increase capacity and improve traffic flow efficiency. Application of advanced technologies in the area of transit and rideshare promises to make a substantial contribution toward these goals. The greater use of these facilities would enable the total number of vehicles using the

nation's highways to be reduced, potentially resulting in a subsequent reduction in congestion.

In order to fully evaluate potential transit and rideshare applications, it is first useful to consider what is meant by advanced technologies in the context of highway transportation. Loosely, they can be grouped under: (1) intelligent vehicles, in which advanced technology systems operate independently on individual vehicles; and (2) intelligent highways, involving the installation of advanced technologies within the highway infrastructure. In combination, these two categories form the basis of the Intelligent Vehicle-Highway Systems (IVHS) concept. IVHS also involves a significant degree of cooperation and integration of the on-vehicle units and the highway infrastructure.

The ready availability of low-cost and reliable microelectronics components opens up vast new areas of potential for information and control systems in traffic and automotive engineering. When intelligence is linked by a whole range of new communications networks, the scope for changing the way we operate highways is immense. This is the essence of IVHS.

A more convenient way of grouping advanced technologies is by function, rather than location of intelligence. Three broad categories of advanced technology can be considered, as follows: (1) Advanced Traveler Information Systems (ATIS); (2) Advanced Traffic Management Systems (ATMS); and (3) Advanced Vehicle Control Systems (AVCS).

ATIS technologies are designed to provide travelers with information on highway conditions and travel options. They include in-vehicle devices for the provision of real-time data, as well as remote information systems. The general philosophy of ATIS, in the overall context of IVHS, is to provide travelers with appropriate data to ensure optimum decision-making. This will lead to more efficient use of the highway network, and consequent benefits to traffic as a whole.

The goal of ATMS technologies is to achieve the best use of existing highway network capacity without creating adverse environmental effects. Developments in the field of ATMS include urban traffic control (UTC) strategies, incident detection techniques, and freeway and corridor control systems. Because the benefits can be great, the use of these techniques is already widespread in the U.S. and overseas.

AVCS technologies can help drivers perform certain vehicle control functions, and may eventually relieve the driver of some or all of the control tasks. The use of AVCS is likely to result in safer, more consistent driver behavior and improved traffic flow characteristics. The ultimate goal of AVCS is the automated highway system (AHS), where all elements of control would be removed from the driver.

In each of these three categories, advanced technologies have potential to reduce congestion, improve safety, increase convenience, and reduce vehicle emissions. In addition, a number of IVHS technologies have the potential to significantly enhance commercial fleet productivity. Consideration of this aspect has therefore led recent IVHS initiatives in the U.S. to create a fourth category for investigation, Fleet Management and Control Systems (FMCS). FMCS involves a number of technologies from the three groups outlined above, applied specifically to the needs of fleet operations.

The importance of IVHS as a major component of the future U.S. highway network is illustrated by the content of the recently published National Transportation Policy (NTP). While congestion is noted as a major area of concern, the NTP states that there will be a shift in federal focus away from building transportation facilities. Instead, emphasis will be placed on adapting and modernizing to meet demand. IVHS is identified as an area of significant potential, with the NTP calling for the immediate pursuit of the most promising near-term IVHS technologies. Continued research into longer term options such as the AHS is also advocated.

IVHS will be important in the context of general highway traffic. However, it may be even more

critical in the area of transit operations. This stems from the NTP's comments on the subjects of transportation funding and operation. Although transit is seen as essential for reducing metropolitan congestion and serving the disadvantaged, the NTP states that transit funding from general taxpayer revenues must be reduced. Federal government outlay from this source is currently in excess of \$2 billion per year. The withdrawal of federal transit subsidies may be overcome by improved efficiency and increased reliance on user fees.

Further pertinent data can be found in the National Transportation Strategic Planning Study (NTSPS). This document was mandated by Congress as a long-range, multimodal study to the year 2015 of transportation facilities and services. The NTSPS was also used as a major basis for the development of the NTP.

In the NTSPS, figures are presented outlining trends in transportation demand in recent years. These reveal that the use of mass transit for work trips has declined from 12.5 percent in 1960 to just over 5 percent in 1985. For nonwork travel, meanwhile, the automobile is reported as being almost the exclusive mode of transportation.

The declining popularity of mass transit provides just one indication of the pressing need for IVHS technologies to improve services and increase usage. The importance of this is supported by discussion of investment in public transit in the NTSPS. Operating costs have reportedly increased faster than both passenger fare payments and inflation over the last twenty years. On a national basis, passenger fares now provide less than 36 percent of mass transit operating costs. The remainder is made up of operating subsidies.

Just as IVHS would appear to be vital for the future success of the transit industry, an equally strong case can be made for the application of advanced technologies to rideshare operations. The NTP seeks to encourage the use of rideshare facilities such as high occupancy vehicle (HOV) lanes, correctly identifying these as having the potential to reduce congestion caused by high volumes of private, low-occupancy vehicles. In addition, the NTP outlines the need for research into innovative management and finance options for HOV alternatives and toll combinations.

In order to justify the continued operation of rideshare and HOV schemes, however, it is essential that these facilities are sufficiently used by the traveling public. A potential problem is revealed in the statistics of the NTSPS. Based upon the comparison of figures from the 1980 census and the 1985 American Housing survey, the NTSPS shows that travel by automobile increased only slightly during these 5 years. Over the same period, however, the proportion of work travelers driving alone increased from 66 percent to 75 percent, while the proportion ridesharing decreased from 20 percent to 14 percent. Again, IVHS offers an approach that can potentially reverse this downward trend in ridesharing.

Overall, therefore, IVHS technologies are required that can make transit and rideshare options efficient and attractive to the traveling public. This will enable these travel options to hold their own in the competitive field of transportation. The following goals can be set in support of this objective:

- Information on transit and rideshare facilities should be thorough, up-to-date and easily accessible for prospective users.

- Travel by transit or rideshare options should be convenient, comfortable and tailored to the needs of service users.

Transit and rideshare facilities should avoid disincentives caused by complex reservation and payment methods.

- The higher efficiency of transit and rideshare vehicles should be acknowledged by the

introduction of preferential traffic control measures to reduce delays in congested areas.

- Transit and rideshare vehicles should be provided with priority or reserved facilities, where appropriate.
- The illegal use of reserved facilities by unauthorized vehicles should be subject to effective monitoring and enforcement activities.
- Planning activities for fleet operations should be enhanced and supported by the provision of a range of data categories.
- Fleet operations should be optimized by the application of real-time monitoring and control techniques.

The review of advanced technologies applicable to transit and rideshare operations has been international in scope, covering major initiatives in the U.S., Europe, Japan, and other developed countries. European developments are particularly emphasized, in view of the continent's extensive use and development of transit services. Detailed information on the technologies has been obtained from sources including literature and product searches and consultations with research agencies, system users and industry.

This report is divided into eight chapters. Following this introduction, the next four chapters each cover one broad area of advanced technology. Within each of these broad areas, a number of individual technologies and systems have been identified, which are discussed in the subsections of the relevant chapters.

In examining the application of advanced technologies to transit and rideshare schemes, a matrix approach has been adopted within each of the four technology review chapters. This has been used to indicate the functions and services to which various technologies can be applied. The matrices also provide an indication as to when the technologies are likely to be suitable for implementation for each of the functions or services. This considers four categories of technology, as follows: (1) technologies that have already been widely applied for the corresponding function or service; (2) technologies that have the potential for immediate application, though have not yet been implemented; (3) technologies that show potential for implementation in the near term, say within a period of 5 years; and (4) technologies that will possibly be developed for longer term future applications.

The first broad technology area, reviewed in Chapter 2, is ATIS. These systems can be used to provide travelers with the information required to complete a successful transit or rideshare journey. The closely related systems that provide ticketing and trip reservation functions are also discussed. Overall, the chapter divides ATIS technologies into the following four categories: pretrip planning information; trip reservation and payment; in-terminal information; and in-vehicle information.

Chapter 3 focuses on the application of ATMS to transit and rideshare operations. When applied to general highway traffic, ATMS technologies aim to make the best use of existing network capacity, reducing journey times for all vehicle types. For transit and rideshare schemes, however, the intention is to bias the highway environment to give priority to these preferred vehicles. Chapter 3 examines the application of ATMS technologies in each of the following areas: signalized intersections; specialized highway environments; and enforcement.

The application of FMCS to transit and rideshare operations is investigated in Chapter 4. This incorporates a range of technologies that are used to improve the efficiency, safety and convenience of vehicle fleet operations. As discussed earlier, FMCS generally encompasses technologies from the other IVHS classifications, applied specifically to fleet operations. Chapter 4 is therefore divided into individual technologies, rather than into technology categories or areas utilized in Chapters 2 and 3. The following

systems are reviewed in Chapter 4: transit operations software; electronic ticketing; onboard computers and smart cards; automatic vehicle identification; automatic vehicle location; automatic vehicle monitoring; and paratransit dispatching systems.

The final broad technology area is AVCS, which is covered in Chapter 5. This examines how AVCS approaches can be employed to automate certain control functions in the transit and rideshare environment. The chapter is divided into three principal application areas, as follows: automated guideway transit systems; bus fleet applications; and rideshare applications.

Following the technology review chapters, Chapter 6 investigates the costs and benefits of systems from each of the broad technology areas. To accomplish this, an assessment framework approach has been adopted to evaluate the technologies. Quantitative cost and benefit figures have also been included where feasible. The evaluation of technologies has been based on a review of existing literature and ongoing research, as well as knowledge of the costs and benefits of similar systems or system components.

Chapter 7 describes the development of a proposed national IVHS program geared toward transit and rideshare operation. This was prepared as an extension to the outline IVHS program for general highway traffic developed in the original NCHRP 3-38(1) study. A broad range of research, development, and demonstration projects is included in the program outline, together with a time schedule up to the year 2000. It is envisioned that this program will form an important element of the strategic planning of the broader IVHS program, ensuring the specific requirements of transit and rideshare users are fully considered in this important work.

Finally, Chapter 8 of the report presents the conclusions of the study. It summarizes the need for IVHS technologies in transit and rideshare, and outlines areas where particular benefits can be expected. Chapter 8 concludes with an outline of some current programs in the U.S., Europe, and Japan which have particular relevance to the objectives of this study. In reviewing advanced technology applications, the objective has been to investigate systems that can potentially be integrated into existing IVHS programs. This will ensure that transit and rideshare developments are compatible with broader transportation initiatives. Current IVHS programs include the following: Mobility 2000, IVHS America; PROMETHEUS; DRIVE; VICS (Vehicle Information Communications Systems); and SSVS (Super Smart Vehicle System).

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 chapter, 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 Intelligent Vehicle-Highway Society of America (IVHS America). IVHS America was officially incorporated in Washington, D.C., 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 in 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.

PROMETHEUS is a \$700 million European 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 that will make vehicles safer and more economical, with less impact on the environment, and that 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 more than 20 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 was originally subdivided into seven program areas. Three were 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 subprogram area was to develop systems which will assist or support the driver in performing the driving tasks. Using onboard computers, these systems 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 concerned 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 performed by the industrial participants concerned the development of a communication network between vehicle computers. The implementation of such a network would allow vehicles to be operated with "electronic sight," enhancing the perceptive range of the driver beyond his own range of vision.

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

- PRO-ART: This subprogram was examining and developing the principles of systems which use artificial intelligence. Methodological investigations and studies of problem areas and experimental systems were included in this research.
- PRO-CHIP: The aim of this area was primarily the development of microelectronics required for artificial intelligence systems, of a size and reliability for incorporating within vehicles. Other microelectronics required by PROMETHEUS were also addressed in this subprogram.
- PRO-COM: The field of communication was 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 was aiming to develop scenarios in the area of traffic engineering, which adapt the road system to the technical developments.

More recently, PROMETHEUS has been restructured into: thematic projects, common European demonstrations, and functions.

Thematic projects provide the technical competence for specific subjects, such as sensing systems or man-machine interfaces. These projects involve cooperation with other companies and research institutes. Basic research, electronics and supply companies work together in these working groups.

Common European demonstrations provide platforms to monitor results and to compare different approaches in terms of performance, benefits and costs. Demonstrator vehicles employing PROMETHEUS-based technology will be used to show the feasibility and effectiveness of the PROMETHEUS ideas and findings. This includes developing and testing models for traffic scenarios to estimate and assess the utility of selected measures.

To structure the research tasks, functions have been derived from the PROMETHEUS objectives, and grouped under headings such as "Improved Driver Information," "Active Driver Support," "Cooperative Driving," and "Traffic and Fleet Management." The realization of such a function group requires the acquisition of traffic-related information concerning operating environment, vehicle and driver status, and real-time processing of these data. Presented to the driver, the results will improve his status of information about his actual situation.

DRIVE is a program coordinated by the Commission of the European Communities (CEC). 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: (1) to enable the timely adaptation of the highway infrastructure and services to take advantage of the opportunities opened up by technological advances; (2) to exploit the opportunities for synergy between road and telecommunications infrastructure developments; (3) to promote the consistent development of IVHS technologies so as to facilitate the development of an internal European market; (4) to contribute to the international competitiveness of the equipment and service industries; (5) to stimulate 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; (6) to support international standardization in IVHS and for related equipment and services; and (7) 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 with additional projects starting later that year. Many of these were completed at the end of 1990, though some projects will continue through 1991.

In Japan, two of the most important recent IVHS programs are RACS and AMTICS. RACS (Road-Automobile Communication System) 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) 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 a 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 stages, and are undergoing coordination work under the name 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 initiatives currently being planned is the Japanese SSVS 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. ADVANCED TRAVELER INFORMATION SYSTEMS

2.1 Introduction

This chapter describes systems designed to provide travelers with the information required to complete a successful transit or rideshare journey. The closely related systems that provide ticketing and trip reservation functions are also discussed. Traveler information systems can assist the traveler in choosing between appropriate services, modes, and travel times. By efficiently supplying this information, the service provided can be made more accessible, and hence attractive to both the regular and occasional traveler. The benefits provided can positively impact the operation of the service and should lead to improvements for highway traffic as a whole.

Traveler information systems have the potential to improve customer or user services while providing reductions in operating costs. Many systems discussed in this chapter have been tested or implemented with cost reduction as their primary goal. The discussions presented here address this aspect while focusing on the use of such technologies to encourage increased participation in transit and rideshare facilities. The discussions are illustrated by reviews of current and previously evaluated systems. These are combined with descriptions of systems currently under trial and those that presently exist only as concepts. Using this information, the systems and related facilities that provide the greatest all-around potential benefits can be targeted for further work and implementation.

Traveler information systems have been divided into four categories for the purposes of this chapter: pretrip planning information; trip reservation and payment; in-terminal information; and in-vehicle information.

A technology matrix has been prepared for each category in the format described in Chapter 1. They show the different facilities that can be offered as part of a system, along with the technologies that have potential for realizing them. The matrices also give an indication of implementation status of each technology to allow approximate implementation timescales to be associated with each option.

Pretrip planning information is primarily provided to the traveler in their home or work environment. Conventionally, preprinted timetables or the traveler's own knowledge would be used to plan the journey. This will usually restrict the number of alternative modes and services considered for the journey and will not take into account recent rescheduling and real-time timetable fluctuations. More up-to-date information can often be obtained via telephone, but again this will generally be limited to details about an individual service.

Trip reservation and payment facilities typically vary with the type of journey being undertaken. Collector-distributor or around-town journeys will often be paid for on the vehicle or by the prepurchase of multi-use tickets. Line haul trips, however, are often booked further in advance with tickets purchased sometime prior to departure. Conventional reservation methods have utilized computer technologies for many years, however, there are still significant opportunities for integrating these systems into more complex facilities and for providing more varied and accessible interfaces to the facilities. Reservation and payment facilities can be provided at transit terminals or from any remote point.

In-terminal information systems provide many of the same facilities as those described above. In addition, information on terminal layout and up-to-date, real-time schedule and status information is now expected by all patrons. Fixed timetables and chalkboards have gradually been replaced over the years with a wide array of electronic and electromechanical display devices with increasing levels of integration and automated control. An additional area of particular importance within the terminal is the consideration of disadvantaged sectors of society. In terms of information systems, this primarily concerns those people with

hearing or sight impairments, or language problems. Advanced technologies have an important role to play in providing solutions for these sectors of the population.

In-vehicle information systems can range from route guidance for rideshare users to business communication systems on line haul buses. Information describing the next stop for a transit vehicle is often provided by fixed maps or by the vehicle driver. Additional information that would help to reduce passenger anxiety and stress, creating a more comfortable journey, could include timeliness information and information regarding the status of connecting services. It is again important to ensure the on-board systems are part of an integrated overall system to ensure maximum gains in all areas.

The various technologies and system concepts introduced in this chapter should not be considered stand-alone solutions. Effective implementation of the majority of these systems relies on integration with a range of other advanced technology solutions. To provide the majority of the advanced information and service systems described here, comprehensive data collection and dissemination facilities must be available. Many of the systems rely on the application of state-of-the-art communication and computing technology to provide real-time status information and integrated trip planning and reservation systems.

Real-time information is often difficult to collect and disseminate by conventional manual methods. Automated real-time information may be best provided by some form of automatic vehicle location (AVL) system. AVL has numerous applications in FMCS, as described in detail in later chapters. To effect a successful and cost-effective implementation it is important to consider advanced traveler information and service systems as part of an integrated high-technology transit solution.

Having accepted this as the case, it is possible to step back and identify a selection of advanced traveler information systems that can be implemented individually. These may form the basis of a phased implementation and could eventually form part of an integrated system. Examples of these systems, which will be discussed in detail in this chapter, include: computerized fixed schedule and fare information; reservations database; route guidance for rideshare; next-stop announcement; cashcard payment systems; and in-terminal guidance systems.

2.2 Pretrip **planning information**

This section covers the application of advanced technologies to meet the information requirements of travelers or prospective travelers prior to embarking on specific journeys. The application of advanced technologies in this area has the potential to provide significant advantages to the transit authority and traveler alike. Table 2.1 presents a summary of these systems.

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

The airline industry has generally led the development in areas relating to computerized information access and reservations. Some of the approaches used in the airline industry could be applicable to other transportation sectors such as transit. This review, however, concentrates on transit bus and rail applications of direct potential relevance to addressing urban congestion issues.

The use of a computerized database to improve the speed and accuracy of information retrieval was successfully demonstrated through the Washington Metropolitan Area Transit Authority (WMATA)

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

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

Table 2.1 Pre-trip planning

Automated Information Directory System (AIDS) [1]. After an agent answers the call, a terminal is used to obtain detailed individual schedule and route information which is then relayed to the customer.

The Hamburg Automatische Fahrplan Information (AFI) is another example of a fully automated system [2] using voice synthesis and the telephone as its means of communication. The AFI system uses codes input through the caller's telephone to define the trip origin and destination and to select items from menus. Detailed optimum route information is generated, together with fare information, and presented to the caller via a speech synthesizer. A Teletrip system recently installed for the Long Island Railroad in New York similarly provides automatic answering and fare schedule information selected by the telephone tone dial keys.

A real-time automated telephone transit schedule system was demonstrated in Salt Lake City, UT [3]. The real-time information on schedule variations was entered manually by the bus dispatchers. The Telerider system [2], successfully implemented in a number of U.S. and Canadian cities, also offers automated real-time schedule information to the transit user. Each bus stop in the system has an individual telephone number associated with it. Travelers calling the number are told the time of arrival of the next one or two buses by a digitized speech system.

The GoTime system [4, 5] implemented in Halifax, Nova Scotia, also provides similar real-time bus enquiry facilities. GoTime is a complete computer-based monitoring, information and communications system using telephone enquiries, bus stop speakers and video displays to provide patrons with specific up-to-date schedules. Schedule information is automatically adjusted using AVL systems. A project was also carried out in Erie, PA in the early 1980s [6], combining computer technology and voice response units to provide information on the arrival time of the next bus at any stop within the system.

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

Videotex systems capable of providing these facilities are now becoming more widespread and accessible in the U.S. Perhaps one of the best known is the Prodigy system produced as a joint venture between IBM and Sears [7]. Prodigy provides the software and hardware to give a user-friendly link between a home computer and a central facility via the telephone line. Prodigy offers a wide variety of different services to its customers, including home shopping, electronic encyclopedias and travel information. These systems offer huge potential for transit and paratransit operations in supplying detailed route and schedule information tailored to the customers' needs. The system also permits implementation of complex carpooling facilities. Using Videotex, travelers could easily identify and reserve suitable matches via a remote database and route planning facility.

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

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

There are many advantages in using a central agency to provide transit and rideshare information. First, potential patrons need to remember only one contact point for a variety of different trips. By making the agency responsible for integrated multimodal information, the traveler would require only this single contact for all journeys. This may greatly increase the chance of a traveler switching from the private automobile to transit. Additionally, the information provided must be accurate, comprehensive and reliable in order to generate the correct level of public support. The scheme would also allow large amounts of accurate origin-destination data to be collected to allow transit agencies to quickly target areas that require particular attention.

A system such as that outlined above would provide particular attractions to the occasional user. Most commuters generally know which service best suits their needs, and are likely to be familiar with schedules and alternatives. Conversely, the occasional or nonregular user will make greatest use of such a service. This may be essential if a high-volume switch to transit is sought for this group.

Many systems providing remote general transit information have been implemented throughout the world. Typically, these systems are installed at activity centers such as shopping malls, and use keypads or touch screens with video displays and occasionally printing facilities. Examples of these systems are the system implemented by Technology for People (TFP) for the Central Ohio Transit Authority [S] and the self-service computer terminals installed in some suburban shopping centers. The computer terminals offer bus route, schedule and fare information along with useful telephone numbers in response to selection from a list of choices including restaurants, stores, theaters and services. The Central Ohio Transit Authority system, no longer operational, used full motion picture video with text and voice and was activated through a touch sensitive screen. The system also included a built-in printer to allow the user to take away helpful information.

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

Stand-alone route planning facilities can be provided relatively inexpensively using a PC or similar microcomputer. A system implemented by the CTCRO in Hull, Quebec [9] has been designed with this application in mind. An initial implementation of this system acts as the information retrieval and route planning tool for a telephone bus enquiry service. The system calculates best route and schedule information from carefully-validated origin and destination data. Geographical positions, based on street names or landmarks, are used by the system to select the most suitable bus stops. Graphical maps are also available to allow the operator to give the enquirer detailed directions to and from the stops. The structure of the system is intended to be flexible to allow application to a large transit network. Additional applications include the installation of touch screen terminals at activity centers and the use of in-home Videotex terminals for system access.

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

In a simple application of this technology, communication with the database computer would be achieved via the tone keypad associated with the fax machine, and prompts and questions would be output audibly or via the fax printer. A more innovative use of this technology would combine the database computer with automatic character recognition or other form of "fax reading" equipment. To use this, the traveler would

complete an information or itinerary request form, by hand. This would be faxed to the central computer system where the form contents would be interpreted and the information generated for transmission to users.

The final technology considered in this review applicable to pretrip planning is teletext-based information systems. Teletext services are provided by invisibly encoding pages of alphanumeric data onto conventional TV station carriers, which are then read by a special decoder built into the television receiver. Most Western European countries include information on real-time transit schedules and delays within their normal teletext services. Commuters using the service consult a teletext TV set before leaving home, and can adjust their travel plans in the event of unusual service delays or disruptions. Teletext services are becoming more widely available in the U.S. A system providing a dedicated traffic update television channel is in operation in Los Angeles [10]. Late-model TV sets or those with suitable adapters are able to receive up-to-the-minute information on any particular commuter route. In Ann Arbor, real-time bus operating information is available on cable TV.

2.3 Trip reservation and payment

The application of advanced technologies to the reservation and payment aspects of transit range from the widely-used dial-up booking facilities to conceptual post-trip billing requiring no action from the traveler. Many of the technologies identified in the previous section, for trip planning and itinerary generation, are also capable of providing facilities for reservation and payment using conventional credit card procedures. The interactive systems suitable for remote booking can also be used to generate tickets if hard copies can be produced. These systems are summarized in Table 2.2.

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

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

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

Currently, multimodal or multiservice travel requires the purchase of individual tickets for each leg of the journey. Widely acceptable payment methods such as credit cards can often ease the payment procedure, but are really only applicable to higher cost journeys. The current credit card infrastructure does not lend itself to low-cost, short journeys where rapid payment methods are important [11]. The method of automatically reading and verifying a credit card would greatly reduce the flow of passengers on a pay-as-you-enter service. This problem has been addressed in the West German state of Lower Saxony by the development of a magnetic stripe card system [12]. The card has the holder's bank account number encoded

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

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

Table 2.2 Trip reservation and payment

on the magnetic stripe, which is recorded by an on-bus reader unit. The fares accumulated over the month are automatically debited from the customer's bank account with the maximum due amount not exceeding the cost of a monthly bus pass.

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

One scenario for the application of smart card technology is the replacement of current multi-journey card punch or magnetic stripe-based pretrip purchase schemes. It has been demonstrated that bus passengers suffer their greatest inconvenience at the fare paying stage of their journey [11]. Improvements in speed of entry and processing of passengers will be of additional benefit to the transit operator, providing time, and hence cost, savings.

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

A system successfully utilizing smart card technology has been implemented by Milton Keynes City Bus in the U.K. [13]. The cards carry the account balance, which is debited with a discounted fare each time the patron uses the bus. The account balance may be credited with multiples of £5 on the bus or in the company's travel shop. An increase in demand has been reported due to the ease of on-bus account crediting and the discounted fares.

Contactless ID cards could also be used to implement post-use payment for transit systems. The fare charged would be based on information stored on the passenger's card, but the charge would be recorded in an on-vehicle unit rather than on the card itself. Data would be collected centrally, either in real-time by a radio-type link, or at the end of journeys or shifts by a physical connection. The central computer performing data collection functions would periodically generate statements for mailing to system users outlining the amount of travel expended and the required payment due.

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

The final technology application to be considered in this section is automatic personal identification (API). This could consist of a microwave or RF tag carried by the traveler, similar to the already proven automatic vehicle identification (AVI) technology. The tag would be read as the traveler entered and exited the transit vehicle, thus allowing their fare to be calculated and bills generated or an associated in-credit account debited by the relevant amount. Several vendors have undertaken the development of such systems [14], using tags as small as one inch that can be carried in the holder's pocket or purse.

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

2.4 In-terminal information

The information and services required by passengers in the terminal consist largely of those required for pretrip planning. In addition, travelers require information describing the layout of the terminal and the identification of the particular service to be used. It is also important to provide accurate real-time schedule data within the terminal. Terminals are frequently used as meeting points, where it is particularly important to provide reliable service arrival information. Transit terminals present particular additional difficulties for people with impaired hearing or sight. Advanced technologies can provide methods of addressing these problems and enhancing the accessibility of transit or rideshare for all sectors of the public. In-terminal information systems are summarized in Table 2.3.

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

The provision of on-time or schedule information at high-volume bus stops is being addressed by a variety of systems, in addition to the bus stop dial-up facilities described in Section 2.2 of this chapter. The Ottawa-Carleton Regional Transit Commission (OCTranspo) has approved the first phase of a project with these goals [15]. The project uses an automatic vehicle location and control (AVLC) system, with one objective being the improvement of the quality of passenger information. In addition to informing patrons of schedule status, the system will provide bus arrival details at multiple stops and bus terminals. A similar facility will be available using the Japanese RACS system [16]. Bus stops could be equipped with suitable communications and display devices to show present location and expected arrival time of an approaching bus.

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

A system of this type has been implemented in the Oslo Bus Terminal in Norway using technology based on the Omega Electronics and Philips PREMID system [17]. The technologies include 19 departure display boards and 33 video monitors at various points in the terminal. The buses are automatically identified on entry to the terminal by their programmable windshield tag and given directions, displayed on monitors by a central computer, to an empty parking bay. The system automatically combines real-time arrival and departure information with stored timetables to update the departure information boards and video monitors.

A similar system using the Dowty Videobus system has been installed at the Heworth interchange station on the Tyne and Wear Metro network [18]. The system uses automatic vehicle monitoring equipment and video displays. The system displays the following information on six display units: an alphabetical list of destinations possible, in a series of services and appropriate bus numbers; real-time information for the departure of the next four vehicles, with ultimate and intermediate destinations; special messages and

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

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

Table 2.3 In-terminal information

announcements with advertising displays; and an extended route profile of the next vehicle to depart. Passenger surveys of the Heworth interchange system indicated that the information helped to plan journeys, allowed selection of alternative routes and reduced perceived waiting times.

Systems have been operating on urban metro systems for many years, providing real-time information on dot-matrix displays located on the platforms. Systems have been provided by vendors including Thorn EMI Electronics, GEC General Signal and Westinghouse Signals, that can identify the current status of the network and display information on the destination and arrival times of the next few trains at that platform. Studies have been carried out in the U.K. for the Science and Engineering Research Council [19] exploring the benefits provided by such systems to London Underground users. Of the users surveyed, 95 percent stated that they found the information useful, with 17 percent indicating a positive psychological benefit. The system resulted in perceived time savings giving rise to a 16 percent return on London Regional Transport's (LRT) initial investments.

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

As discussed earlier in this section, many of the pretrip planning services will share common technology with the facilities described in Section 2.2. However, one system worthy of mention here is the Situ equipment manufactured by Societe' d'Etude pour l' Information sur les Transports Urbains (SEITU). This system provides a high-functionality self-help passenger enquiry service. The user may enter an address, location, public monument or name of an activity, such as opera. Situ will produce a printout detailing the best way to get there and the approximate journey time. Travelers may also choose their preferred transport mode, including "least walking." Transport authorities in Paris, Caen, Nantes, Valenciennes, and Nimes have adopted Situ.

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

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

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

By linking the rideshare parking lot system to a telephone line, rides could be assigned in advance. The traveler would use a touch-tone telephone, home computer and modem or videotex to inform the system of their departure place and time and desired final destination. The system would then generate an expected arrival time and use the information during allocation of rides. Enhanced facilities could be provided by linking in large area route guidance and/or an expert system. In the enhanced scenario, the traveler would be given an optimum route to the rideshare parking lot. This would be calculated by the system and be based on: measured traveling times so far that day, past history of traveling time from previous days, and any available external traffic condition or congestion information.

The same route guidance system could be used to plan journeys from the rideshare parking lot. It would be used to generate the most appropriate route using the data described above combined with a list of traveler drop-off points.

The potential for improving the attractiveness of ridesharing using a dynamic system is evident from this review. A system such as this would be capable of minimizing delays to participants and overcoming the necessity for keeping to fixed time schedules. Using the enhancements described above combined with advanced in-vehicle systems described below, a complete integrated system could be provided that would guide ridesharers from their doorstep to their final destination.

2.5 In-vehicle information systems

This section discusses the types of information required within the transit or rideshare vehicle, as well as methods of presenting it to travelers. The discussion focuses mainly on information systems that address particular needs associated with this mode of travel. However, many of the ATIS that are applicable to the private automobile can be used to benefit transit or rideshare operations. These in-vehicle information systems can be divided into two main areas: traffic information broadcasting systems and on-board navigation and guidance systems [20]. Table 2.4 presents a summary of these systems.

Traffic information broadcasting systems utilize various technologies to provide travelers with details of the current condition of the road network. Many of the systems currently available use radio broadcasts as the information carrier. The traffic information may be carried in voice format or silently encoded in digital format onto regular radio programs. A variety of in-vehicle information displays are available, ranging from conventional radio output to digitized speech facilities.

On-board navigation systems are available at a number of levels of complexity. The systems provide the traveler with information on their current location and how it relates to their desired destination. In its simplest form, an on-board system will provide the traveler with information regarding the distance and direction to their destination. Location displays show current vehicle position often in the form of a point on a map display. A further enhancement is the addition of routing advice alongside vehicle location information. This can be provided in the form of a self-contained route guidance system or by an externally-linked route guidance system.

A self-contained system uses internal maps with preassigned weightings for different roads. This means that the system cannot take account of recent changes to the road layout or real-time traffic incidents when calculating the best route. Externally-linked systems can constantly reidentify the optimum route by taking into account the current status of the road network. This method is more costly, requiring a comprehensive communications infrastructure to be in place. This often takes the form of roadside beacons as in Autoguide [20] or cellular radio network in the case of the AMTICS system described earlier.

The approaches described above are most relevant to ridesharing applications where drivers have the ability to alter their routes. A route guidance system would allow carpool drivers to locate riders in unfamiliar locations. Externally linked systems would also allow incidents to be avoided. Therefore, car or van pools

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

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

Table 2.4 In-vehicle information

show promise as an ideal test bed for these technologies. By linking the route guidance and rideshare participant selection system, full automation could be achieved, making single trip sharing more accessible.

Bus services which do not operate on a fixed route such as paratransit or dial-a-ride may also benefit from the application of these technologies. The route guidance systems will be particularly useful for dial-a-ride services operating very varied routes, often with little driver knowledge of the area.

Often, the first item of information required by a traveler entering a transit vehicle is where to sit. In the case of a passenger who has not booked a seat, directions are required to a suitable empty seat. On small transit vehicles, the use of information technology in this area will obviously provide little benefit. On larger vehicles, a seating plan display could be provided to show which seats are empty and where reserved seats are located. A system developed by Focon Electronic Systems for the Danish State Railway's IC3 [21] uses a dot matrix display at the train's boarding point to display the destination, departure and arrival times, and the seating plan. Further dot matrix displays are located in railcars, which give more detailed seat reservation data.

Once the passenger is seated correctly, information on the timeliness of the service, the current location and distance and time to destination will be of most interest. Any of the conventional display technologies discussed in earlier sections could provide these data. For example, a dot matrix display is used to provide in-bus information in Panasonic's Bus Operation Improvement System. The display gives details of the next stop, current time, and time until next stop, and is also used to provide topical information such as news, weather and advertisements. Synthesized speech has also been used for stop announcements in a system, developed at Sweden's Lund Institute of Technology, which is being implemented on a number of buses belonging to a local transportation authority.

Video displays have been chosen by Mitsubishi Corporation for their MARIA (Mitsubishi Advanced Realtime Information Autosystem) system, one of the applications of the Japanese AMTICS. AMTICS consists of a communications system, based on a cellular network, with a variety of in-car route guidance, trip planning and information systems. In addition to supplying location and stop information to passengers, the MARIA system can identify tourist sights and other places of interest using information stored on compact disc read-only memory (CD-ROM). This system is also capable of providing more detailed incident information or reasons for delay to passengers, to help reduce some of the frustrations associated with unexplained or unquantified holdups.

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

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

3. ADVANCED TRAFFIC MANAGEMENT SYSTEMS

3.1 Introduction

The overall goal of traffic management can be defined as the optimal coordination of road space and road time. This is intended to lead to freer traffic flows, shorter journey times, fuel savings and generally reduced congestion. Traffic management projects can be implemented for individual intersections or ramps to provide localized improvements. Integrated wider-area schemes can also secure more major traffic benefits at relatively modest cost.

Developments in the field of ATMS cover fixed-time and traffic responsive UTC strategies; incident detection techniques; and freeway and corridor control systems. Technologies required to support these traffic management activities include traffic signals and variable message signs, used to control road time and space segregation, regulate speed, and provide advisory messages.

To accommodate the wide variety of highway situations and traffic demands, a range of signal equipment and control techniques has been developed. These can operate around either fixed-time or traffic-responsive control strategies. U.S. jurisdictions typically used fixed-time techniques, though traffic responsive systems are becoming more widespread overseas. In addition, signal control strategies may be operated at individual intersections, or over entire networks.

ATMS technologies can also serve to influence the pattern of highway travel in pursuit of certain policy objectives. These can include, for example, environmental protection, increased safety, or pedestrian assistance. In addition, congestion can be redistributed among areas of the highway network more suited to the accommodation of traffic queues. Traffic control centers can provide warnings or advisory messages to drivers through variable message signs or in-vehicle units. Drivers can then be directed away from incidents, reducing congestion and preventing secondary accidents.

When applied to general highway traffic, therefore, traffic management aims to make the best use of existing network capacity. This reduces average journey times for all vehicle types, without creating adverse environmental effects. In applying ATMS to transit and rideshare schemes, however, the goals are essentially different from those when the same technologies are used in other traffic control applications. In this specific application, the intention is to somehow bias the highway environment to give priority to selected vehicle types.

The use of ATM.5 technologies for transit vehicles and other HOVs can therefore have two principal effects which may encourage the wider use of these travel options. First, the implementation of priority measures in a traffic management system can reduce the variability of transit and HOV travel times, and will assist travelers in avoiding areas of congestion. This serves to enhance travel by these means, where similar benefits are not available to private or low-occupancy vehicles.

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

This chapter considers recent and ongoing developments in the application of ATMS technologies to transit and rideshare schemes. Following this introduction, the investigation of ATMS is divided into three

areas, reflecting different applications of the technologies within the transit and rideshare environment. The first is the implementation of priority measures at signalized intersections. This covers both isolated intersections and integrated intersection signal timing plans. In addition, techniques for the selective identification of vehicles for signal preemption are examined.

The second application area for ATMS technologies is specialized highway environments. These are areas in which transit or rideshare vehicles are given preferential treatment or reserved facilities. Examples of this include HOV-reserved lanes and ramp bypass lanes. The use of advanced technologies within these specialized highway environments is investigated.

The final application examined is enforcement. A significant problem with many current priority schemes for transit and rideshare operations is violation by other vehicles. Enforcement systems that can be used to prevent violations are therefore investigated. These include systems for continuous monitoring of a facility, as well as systems capable of operating remotely and unmanned for unique violation detection.

Within each of these areas, the study team has considered possible future developments, as well as previous and ongoing work. This has involved identifying potential applications of advanced technologies that have not been implemented to date. The study team has used its knowledge of the capabilities of state-of-the-art transportation systems in identifying these applications, as well as the likely results of future research and development efforts.

To demonstrate the applicability of advanced technologies in each of the three key ATMS areas, a framework approach has again been adopted. For each area, the framework identifies the functions and services provided by ATMS, as well as the technologies used to support these applications. The framework also considers the likely implementation timeframe for each of the technologies under consideration.

3.2 Signalized intersections

Conventional traffic signals installed at highway intersections allow the movement of vehicles to be optimized through time and space segregation and speed control. A range of signal equipment and control techniques has evolved to accommodate the wide variety of highway and traffic situations. This section examines how current traffic control systems can be operated in favor of transit and rideshare vehicles.

In their present application, traffic signal control systems are generally used to optimize the movement of all vehicles through an intersection or over a network. This includes, but does not specifically favor, transit and rideshare schemes. It will, therefore, be useful to examine the fundamental operating characteristics of traffic control technologies. This will assist in identifying potential applications of the systems in favor of transit and rideshare vehicles.

The lowest level of complexity in the hierarchy of traffic signal systems is isolated intersection control. The simplest methods involve manual calculation of signal timings, in proportion to projected traffic demands at an intersection. More complex methods calculate timing plans using computer optimization programs. An example of this is SOAPS4, which was developed for the Federal Highway Administration (FHWA) and calculates optimum cycle times and green splits for isolated intersections [22, 23].

At an increased level of complexity, signal timing can be calculated over an entire network, rather than for an isolated intersection. This enables signal timings to be coordinated, improving system efficiency. The concept of coordination is to control the durations and offsets of green periods at adjacent traffic signals. Coordinated signal timing plans were first produced manually using time and distance diagrams. These methods have now been superseded by computer programs such as MAXBAND [24], PASSERII-84 [25] and SIGOP [26].

One of the most extensively used and documented coordinated signal timing plans is TRANSYT (Traffic Network Study Tool), developed by the U.K. Transport and Road Research Laboratory (TRRL) [27, 28]. TRANSYT models traffic behavior, carries out an optimization process, and calculates the best signal timing settings for the network. Signal timings are conventionally based upon the movement of passenger car units through the system. Unless otherwise specified, TRANSYT seeks to achieve a solution that will minimize a performance index such as the weighted sum of vehicle stops and delays over the entire network.

A further increase in signal timing complexity introduces the concept of adaptive coordinated signal systems. These use traffic data collected from the highway as the basis for real-time changes to coordinated signal timing plans. An example of this is the SCOOT (Split, Cycle and Offset Optimization Technique) system, which was also developed in the U.K. by TRRL [29]. SCOOT uses inductive loops located upstream of each intersection to gather traffic data. This information is used by SCOOT to recalculate traffic model predictions and gradually implement recommended changes to current signal settings.

Overall, therefore, there are several alternatives for traffic optimization using signal timing approaches. The same methods, in combination with other advanced technologies, can also be used to preferentially operate traffic signals in favor of transit and rideshare vehicles. This can be achieved for individual intersections, or for a coordinated network. In addition, systems can be operated with either fixed-time or traffic-responsive signal timing plans. The applicability of ATMS technologies at signalized intersections is summarized in matrix form in Table 3.1, and is discussed further in the following paragraphs.

For isolated intersections, traffic signal timing programs could be used to optimize signal settings to achieve minimum person delays, rather than minimum vehicle delays [30]. This would bias signal timings in favor of traffic streams containing transit vehicles. Given an appropriate knowledge of HOV routes and vehicle occupancy data, it should also be possible to use a similar approach for rideshare vehicles.

More effective traffic signal priority can be obtained using selective detection techniques. These involve the identification of individual vehicles or vehicle types on the approach to an intersection, and the adjustment of traffic signal timings in their favor. With transit vehicles, identification can generally be achieved using automatic vehicle classification (AVC) techniques, making use of inductive loops or piezoelectric axle sensors. This is because transit vehicles often have distinctive “signatures,” measured by inductive loops, and well-defined axle configurations for piezoelectric classification. Transit vehicles can therefore be classified by in-pavement equipment without the need for an on-vehicle identification system. This does not apply to rideshare vehicles, however, since these will be mostly the same as general highway traffic.

One isolated intersection control program that already includes an element of vehicle actuation is the MOVA (Modernized Optimized Vehicle Actuation) system [31]. MOVA uses inductive loops to identify vehicles approaching the signal. The option of stopping the approaching vehicles is then compared with the disbenefit of holding already-stopped vehicles for a few more seconds. Systems such as MOVA that are based around vehicle detection could potentially be reconfigured to provide preferential treatment for transit vehicles.

An alternative to AVC for signal preemption involves the use of AVI technology. This enables vehicles to be uniquely identified through a communications link between an onboard transponder and a roadside reader unit. Several alternative AVI approaches have been developed, including optical, infrared and radio frequency systems. The AVI transponder contains a vehicle identification number which is decoded each time the vehicle passes a reader location. AVI can therefore be used to detect transit vehicles for signal preemption, as illustrated in Figure 3.1.

Significant work has already been undertaken on the use of AVI for signal preemption, particularly in Europe. By 1976, for example, research on AVI conducted at the U.K. TRRL had led to the development

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

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

Table 3.1 Signalized intersections

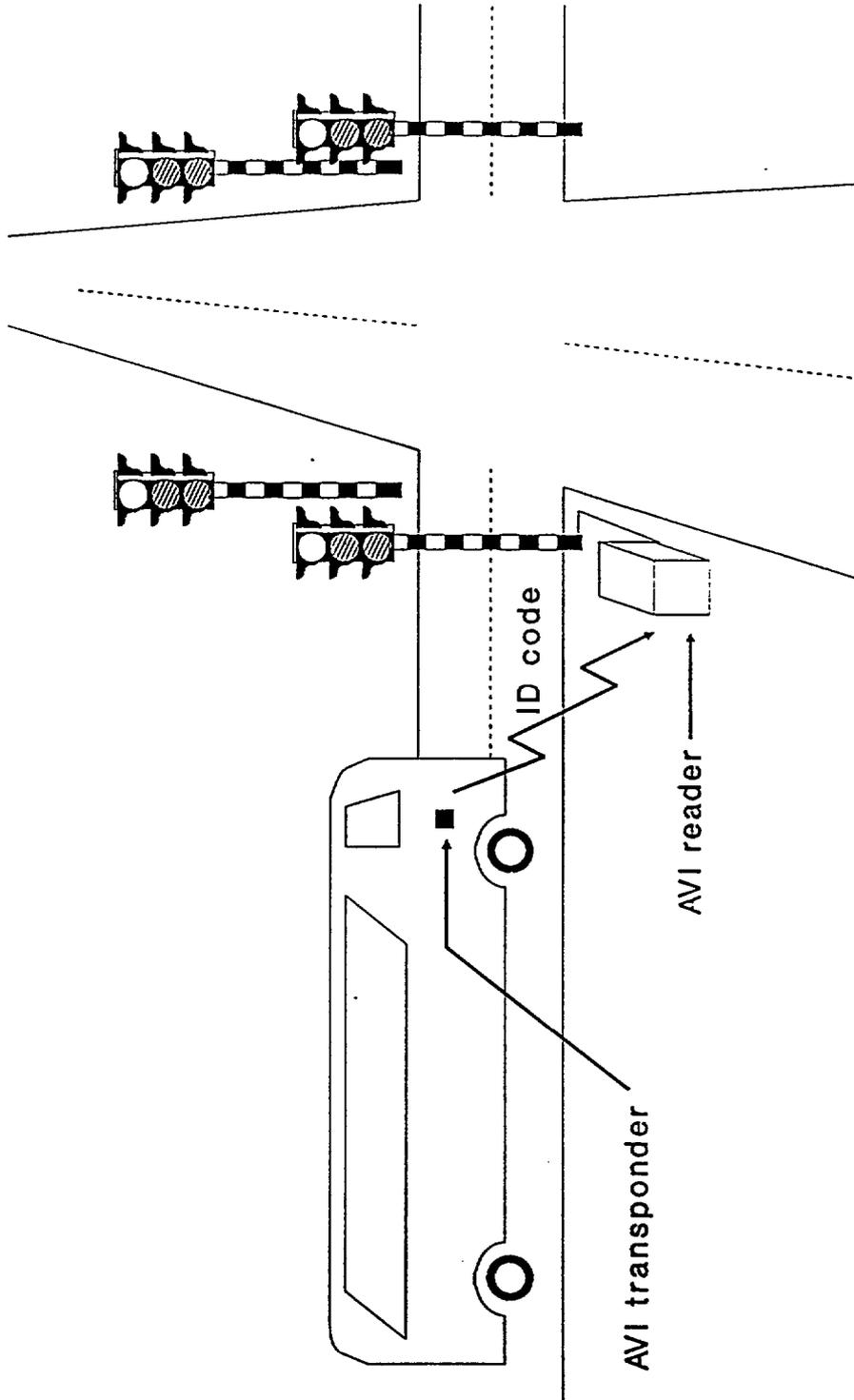


Figure 3.1 AVI for signal preemption

of a selective vehicle detection system for bus and emergency vehicle priority at signalized intersections [32]. This was initially installed on 110 buses in Swansea, U.K. Selective detection then enabled them to initiate a priority call on the approach to twelve intersections and eight signal-controlled pedestrian crossings in the city center. A similar system developed by Mullard for the U.K. Department of Transport was called EVADE and was first used for the identification of emergency vehicles in Northampton [33].

Elsewhere in Europe, one of the earliest applications of AVI for public transit took place in Delft, Holland in 1971 [34]. Buses between the Hague and Delft were given local priority at signalized intersections using a simple form of inductive AVI known as VIPS (Vehicle Identification and Priority System). This was reportedly successful in reducing travel times and delays. Similar systems have since been implemented in a number of other Dutch locations. These include the city of Almere, the Leiden-Katwijk bus line, and 28 intersections in S' Hertogenbosch and on the road between Rotterdam and its satellite cities, Krimpen and Capelle [35, 36]. Traffic signal preemption in the Netherlands has also been accompanied by the activation of an acoustic signal to warn pedestrians and cyclists.

During the 1970s, the Philips Vetag AVI system was implemented in Holland for automatic tram control. In 1977, a trial installation of the system was implemented by Amsterdam Municipal Transportation Authority for automatic switching on one line of Amsterdam's tram system [37]. Following this trial, the Hague commissioned an automatic interlocking system covering the city's tram network [38].

AVI technology has also been used to provide priority and identification functions for a light rail transit system in Tuen Mun, Hong Kong [39]. This is used to control the flow of up to 100 light rail vehicles (LRVs) per hour entering an intersection. The equipment automatically identifies each LRV approaching the intersection and establishes the intended direction of movement. This information enables the traffic signal controller to provide the correct clearances and a signal to proceed. The automated system is also used to activate the points controller, serving the next vehicle within two seconds of the lead LRV clearing the points.

Transit-preferential signal priority schemes have also been tested at a number of locations in the United States. These have included experimental systems installed in Kent, OH, Louisville, KY and Washington, D.C. in the mid-1970s [40]. In addition, a project carried out in Philadelphia in the early 1980s provided signal preemption for trolley buses in the city.

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

Another technology that could be used for selective vehicle detection is license plate scanners. These are capable of automatically reading the characters on vehicle license plates. In the United States, the 3M Company has developed a commercial automatic license plate reader, based upon earlier research and development by the Perceptics Corporation [42]. The system is used to extract the characters from reflective license plates, which are imaged by a video camera and illuminated by an infrared strobe lamp. A shuttered image of the camera's field of view is captured and analyzed to determine if a license plate exists in the image.

Tests on the 3M license plate reader were carried out on the Dulles Toll Road in Virginia in January, 1989. The system performed well, although some shortcomings were identified. These included the inability to identify excessively dirty, partially obscured or damaged plates. In addition, since the character recognition software was optimized for Virginia, the system was less successful in reading plates from other states. Read

accuracy for Virginia plates was around 65 percent, although 3M has reported accuracy improvements due to system modifications since the time of these tests [43].

The use of license plate scanners for traffic signal preemption would involve the comparison of license plates read by the system with a database of preferred vehicle records. Detection of a license plate included in the database would serve to preferentially trigger the traffic signal. A possible advantage of using license plate scanners over conventional AVI is that no additional on-vehicle equipment is required, potentially leading to significant cost savings in this area. However, this must be weighed against the current high cost of license plate readers, which are typically four or five times the price of a conventional AVI reader.

The principal limitation in the current generation of license plate reading technology is read accuracy. Although research and development efforts have led to improved accuracy in recent years, it is unlikely that the technology will ever provide the performance levels available from AVI. This need not prevent the use of the technology for priority signal control, however, since it is not essential that every vehicle be identified. The French Elsydel company has recently claimed accuracy levels of 95 percent for its infrared license plate scanner [44]. This should be sufficient to beneficially operate a signal priority scheme for transit vehicles.

Techniques are also available for the preferential treatment of transit vehicles over a network, rather than simply at isolated intersections. In the U.K, for example, TRRL has examined the use of TRANSYT for bus priority in Glasgow [45]. This experiment involved the modification of signal timing plans in the city to optimize the movement of people, rather than the more conventional passenger car units (PCUs). For the purposes of calculating signal timings, the average occupancy of a bus was assumed to be 28 passengers, with 1.4 occupants assumed for other traffic. This represented a significant shift in weighting toward buses, which would normally count as only two PCUs.

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

Two other experiments implemented in the U.K. for bus priority at traffic signals were BADGE and PUMMEL. BADGE provided only a limited variation from a fixed-time plan to give priority to individual buses. The principal constraint in this system was that BADGE would not implement timing variations that would oversaturate an approach on any cycle. Tests on the BADGE system showed reductions in bus delays of 15 percent, 10 percent and 13 percent during the morning peak, off-peak and evening peak, respectively. Anticipated increases in delay to other traffic due to the implementation of bus priority were found to be too small to measure.

PUMMEL allowed greater variation from a fixed-time plan, using TRANSYT to estimate resulting delays to nonbus traffic. PUMMEL was found to be less effective than BADGE at reducing bus delays, with savings of 11 percent, 2 percent and 7 percent in the morning peak, off peak and evening peak, respectively. Delays to other traffic were again too small to measure.

In North America, an alternative approach has been evaluated for accommodating transit vehicles in fixed-time signal plans. This was carried out by The Transport Group of the University of Waterloo's Department of Civil Engineering [46]. The research was intended to improve TRANSYT's consideration of the effects of bus or streetcar stops on other vehicles near signalized intersections.

The first version of TRANSYT containing a facility for the modeling of buses traveling in mixed traffic was developed in 1975. This allowed buses to travel at their own speeds and stop for passengers. Buses were

assumed to travel independently of other traffic between intersections, despite using the same lanes. The major concern noted in the University of Waterloo's research was TRANSYT's failure to take account of buses holding up traffic while loading or unloading passengers at an intersection. Instead, TRANSYT assumes that all buses stop between intersections and therefore do not reduce capacity. This will reduce the validity of TRANSYT predictions and optimizations, particularly where the transit vehicles have significant dwell times near intersections.

To address this issue, an alternative type of network formulation was adopted. This used dummy nodes and dummy links with appropriate link costs to model the effects of transit stops on intersection performance. Although this approach required one dummy node and four to six dummy links for each transit stop that held up traffic, the experiment reportedly improved TRANSYT's realism for such operation significantly. Calculation of fixed-time signal timing plans in this manner could therefore improve intersection control efficiency for both transit and nontransit vehicles.

As discussed in the introductory section of this chapter, the implementation of transit priority schemes may increase delays for other traffic, in some cases. This has been considered by the U.K. Department of Transport in developing recommendations for the introduction of bus priority measures [47]. Ideally, a scheme would produce no reduction in network capacity. Delays would simply be redistributed between priority vehicles and nonpriority vehicles. The higher occupancy levels of priority vehicles would then produce an overall reduction in person delay.

In reality, however, some loss of capacity is likely to occur as a result of transit priority schemes. U.K. Department of Transport guidelines state that for a good scheme, capacity loss should be no more than one or two percent. Total vehicle journey times might then be expected to increase by three to ten percent. Poor schemes would produce much greater disruption and would need to be modified or withdrawn.

At a more advanced level, it should also be possible to achieve transit-preferential responsive network control. This would involve the use of the fully adaptive signal timing techniques described earlier. The recalculation of traffic model predictions would be based on the movement of transit vehicles, possibly including an assumed average occupancy such as that used in the Glasgow TRANSYT experiment. Detection of transit vehicles could be achieved using classification systems, such as inductive loops, or could use AVI technology.

One system that could potentially be used to implement transit response network control is SCOOT. SCOOT already makes use of conventional in-pavement inductive loops to provide traffic data for real-time signal timing variations. These inductive loops could also be used to identify transit vehicles, which could be accommodated in the revised signal timing plan. Some software modifications would probably be required to support this, however.

For a fully adaptive traffic control system to accommodate other HOVs, some form of unique vehicle identification would be required. This is because HOVs would not differ from other general traffic vehicles for AVC purposes. HOVs could therefore be identified using AVI transponders distributed to registered ridesharers. Alternatively, automatic license plate scanners could potentially be used to read license plates and identify registered HOVs in a computer database.

The integration of a unique vehicle identification facility with adaptive traffic control would represent an initial step toward the concept of interactive traffic control. This is being examined within current TVHS initiatives throughout the world due to its significant traffic benefit potential. Interactive traffic control would use real-time origin-destination data collected from on-vehicle units to modify signal timing plans in response to actual traffic demands. Transit and rideshare vehicles could therefore provide a sizeable fleet for initial implementation of interactive traffic control technology, prior to installation of the system in other categories of highway traffic.

Other potential future ATMS developments in the area of traffic signal control include the research and application of alternative systems for vehicle detection and signal actuation. Infrared beacons or digital radio communications, for example, could be used to provide the unique vehicle identification function required for priority signal control. These systems could have advantages over AVI and license plate scanners in providing increased scope for the integration of ATMS with ATIS technologies.

Another technology that could be applied to the future ATMS environment is video image processing. At a relatively low level of complexity, this technology could be used to identify transit vehicles for signal activation. Video image processing techniques are similar to the methods used by license plate readers for character recognition. Computer software is used to analyze a captured image and establish its principal characteristics. An example of this is the DACimage system developed in France by Elsydel [44]. This uses a line camera to periodically scan across the lane and rebuild the full side-view outline of the vehicle. Classification is then based on the features of the vehicle, such as its number of axles and height at precise locations.

In the longer term, it may become possible for video image processing systems to estimate or calculate the number of occupants in a vehicle. Infrared heat-sensing technology is potentially applicable in this area. Systems that could establish vehicle occupancy levels could then be used to implement HOV-preferential signal control schemes without requiring any on-vehicle equipment or a database of registered participants. The system could also support adaptive or interactive traffic control based upon the movement of people, rather than vehicles. However, the current state of video image processing technology leads the study team to believe that the ability to accurately establish vehicle occupancy is unlikely to be achieved for several years to come.

3.3 Specialized highway environments

Outside of traffic signal control, there are a number of other specialized highway environments where advanced technologies could be used to give some form of priority or preferential treatment to transit vehicles and other HOVs. These include the following situations: reserved highway lanes, ramp controls, toll highways, and parking areas.

The use of advanced technologies in implementing and operating priority schemes in specialized highway environments can have two alternative goals. First, systems can be used for access control, preventing the use of the priority facility by unauthorized vehicles. Second, advanced technologies can be applied to the detection of unauthorized vehicles that are illegally using the facility. This will support enforcement activities and will subsequently deter potential violators. Access control is discussed here; enforcement is considered in the next section of this chapter.

In general, the use of advanced technologies for access control will be applicable to schemes where a physical barrier prevents use of the priority facility by unauthorized vehicles. The requirement will then be to identify the preferred vehicle types as they approach the barrier, and to permit their passage through the controlled zone. The principal role of advanced technologies will therefore be to provide this identification facility for barrier activation. A second application of the technologies will be to optimize the movement of vehicles within the reserved facility.

The applicability of ATMS technologies to specialized highway environments is summarized in matrix form in Table 3.2. As before, this presents the functions and services for which the various systems can be used, and estimates of their likely implementation timeframes. The use of advanced technologies in operating specialized highway environments is discussed in the following paragraphs.

One of the most significant ways in which priority can be given to transit vehicles or other HOVs is through the use of reserved highway lanes. These can be of substantial benefit, particularly where the general highway lanes are severely congested. The principal operational concept is that only those vehicles carrying

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

KEY:

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

Table 3.2 Specialized highway environments

above a specified number of passengers are permitted to use the facility. Therefore, although the number of vehicles may be much lower than in other lanes, the combination of higher speeds and vehicle occupancy levels leads to an increase in the lane's people-moving capacity.

In the U.S., a variety of schemes have been implemented involving the reservation of certain highway lanes for preferred vehicle types. These have included separated and nonseparated concurrent flow lanes, as well as contra-flow reserved freeway lanes [48]. Some highways, such as Interstate Highway I-66 in Northern Virginia, are reserved exclusively for buses and other HOVs during peak periods.

As discussed earlier, the use of ATMS technologies to restrict access to HOV lanes will be applicable to schemes involving a physical barrier between the reserved facility and the other highway lanes. An example of this was the Shirley Highway Express-Bus-on-Freeway demonstration project of the early 1970s [49]. This used an 11-mile, two-lane reversible busway in the median of an existing freeway in the Virginia suburbs of Washington, D.C., to increase efficiency of transit operations.

In implementing an access control system, the objective would be to identify preferred vehicles, and to permit their entry into the controlled area. The technical approach required to achieve this will be dependent on the preferred vehicle types permitted to take part in the scheme. As described in the previous section, identification techniques will differ for buses and other HOVs.

For buses, nonselective identification could be achieved using some form of AVC device. Inductive loop or piezoelectric axle sensor systems could currently be used for this purpose. In the longer term, video image processing could potentially be applied to vehicle classification, as described previously.

Buses or other public transit vehicles could also be identified during the approach to a reserved lane using selective detection techniques. As with signal preemption systems, AVI is probably the technology most applicable in this area. However, license plate scanners could also be used to detect vehicles for barrier activation, given suitable advances in reading accuracy.

For car or vanpool-reserved HOV lanes, selective detection techniques will necessarily be required, for reasons discussed previously. AVI technology could potentially be used to regulate access to HOV facilities for these vehicles. Drivers who wished to participate in the scheme would be required to obtain an AVI transponder for installation on the vehicle. Interrogation of the transponder at the entry point would then permit access to the HOV lane. Some form of smart card system could again be used to verify the number of passengers in the vehicle.

Another technology that could potentially be used for vehicle detection at the entry point of a separated HOV lane is license plate scanners. License plates of registered carpool or vanpool vehicles would be stored in a computer database, allowing access to the facility when an authorized vehicle was detected. In this case, however, it would not be possible to incorporate the passenger-counting element available using a combination of AVI and smart cards. Instead, it would be the responsibility of the driver to ensure that the vehicle contained the required number of occupants. Drivers could still choose to enter the facility with an inadequate occupancy level, but would be open to manual identification as a violator.

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

In the future, it may be possible to use video image processing equipment for access control at HOV facilities. This would be similar to the application of the technology for signal preemption described previously. The use of video image processing would remove the need for on-vehicle equipment, and would also eliminate the requirement for a database of registered participants. Conceptually, any vehicle containing the required number of occupants would be analyzed by the processing equipment and granted access to the facility. However, it is again emphasized that this is a long-term solution, requiring significant advancement over the current state-of-the-art in video image processing technology.

Another area in which advanced technologies could be used for access control is in bypass lanes at metered ramps. Bypass lanes for HOVs have been introduced in several U.S. locations, particularly in California, and have been shown to be effective, safe, relatively inexpensive and publicly acceptable [48]. In addition, the Blue Streak Bus Rapid Transit project, carried out in Seattle, Washington in the early 1970s, demonstrated an express bus service with exclusive use of a reversible ramp in the central business district (CBD) [50].

However, many ramp bypass schemes have experienced problems with violations of reserved ramps by low occupancy vehicles. A solution to this could again be the installation of barriers within the reserved bypass lanes. These would be activated only upon detection of an authorized vehicle. Several alternative technology approaches could be used to identify vehicles for barrier activation, as discussed previously.

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

As well as restricting access to reserved facilities, advanced technologies can also be used to monitor and optimize traffic flow on HOV lanes. In the U.S., for example, the Texas Transportation Institute (TTI) has evaluated the use of surveillance, communications, and control (SCC) equipment for the operation of limited access HOV facilities [51]. Surveillance is required to monitor the facility, to detect and evaluate problems, and to establish an appropriate solution. A number of factors can be monitored using surveillance equipment, including vehicle volumes, speeds and classifications, and detection of incidents.

One technology that can be used to monitor HOV lanes is electronic surveillance. This uses inductive loop detectors installed at critical locations in the roadway to provide traffic data for real-time analysis. Incidents can then be detected as a result of the reduced traffic flow upstream of the occurrence. The same equipment can also be used to detect vehicles traveling in the wrong direction along a reversible facility, or to establish metering rates for traffic-responsive ramp metering systems.

The communications element of an SCC system is required to provide information to travelers using the HOV facility. Variable message signs, for example, can communicate operating rules and general information, as well as provide advisory and warning messages. In addition, lane control signals can indicate the correct direction of flow or warn of incidents or lane closure ahead.

The final element of an SCC system is the control function. There is some overlap with the communications element here, since variable message signs and lane control signals can be used to impose traffic control, as well as to provide information to facility users. Additional control can be provided by the use of ramp control signals and intersection signals. These reduce conflicts at intersections and regulate the flow of traffic onto the reserved section.

Operation of the SCC is typically coordinated from a control center. This combines the automatic data processing, display and control technologies with manual surveillance and control systems. Computer equipment is used to automatically initiate control and communications actions in response to traffic conditions sensed by the external surveillance devices. Operators can monitor and override the actions of the controlling computer, based upon traffic information printouts, dynamic map displays and video displays.

It should also be possible to integrate SCC technologies with conventional UTC systems [52]. This would be particularly desirable where HOV schemes include reversible lanes to increase traffic capacity in the peak direction. To develop an optimal signal timing plan, the UTC control algorithm will require accurate information from the reversible lanes. Sensible interpretation of data from sensors in the reversible lanes also creates a need for knowledge of the lane's status. Integration of the UTC and SCC systems will enable the times of operation to be adjusted if unusual conditions exist.

Another application that would be supported by an integrated system is dynamic alteration of HOV restrictions. If detector data reveal that traffic volumes have declined sooner than usual, the HOV restriction could be lifted early. Similarly, higher than average traffic flows could result in extension of the HOV restricted period. The ability to manipulate HOV restrictions in this manner could be advantageous during emergency situations. An example of this is the I-66 system in Northern Virginia, which is normally an exclusive HOV freeway during peak hours. During major incidents, however, the facility is opened up to other vehicles, with the information conveyed to drivers via variable message signs.

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

The use of AVI for toll collection has been implemented in a number of locations throughout the world in recent years. In the U.S., this has included several experimental installations, as well as a smaller number of fully operational systems. Interest in AVI continues to grow among toll authorities, indicating that substantial benefits could be achieved if HOV-preferential treatment can be built into the new generation of toll collection equipment.

Despite the recent growth in automatic collection, however, the study team knows of few examples where the AVI system has also been used to provide priority for HOVs. One illustration is the Port Authority of New York and New Jersey, which operates an AVI system at the Lincoln Tunnel for buses only. The system was installed in two lanes to expedite the movement of buses into Manhattan on weekday mornings. One lane is reserved exclusively for buses, while the other is combined with a conventional toll lane to provide a backup in the event of AVI system failure.

Another example of HOV-preferential automatic toll collection will potentially be the Virginia Department of Transportation's Fastoll system. The Fastoll system will be installed on the Dulles Toll Road, which runs into the I-66 peak-hour HOV freeway. Regular users of the toll road will have AVI transponders fitted to the underside of their vehicles, allowing them to pass through special express lanes without stopping.

Although the Fastoll system has not yet been installed, the Commonwealth of Virginia Transportation Board has passed a resolution designating the left lanes of the Dulles Toll Road as exclusive HOV lanes. During peak hours, these will be reserved for buses, emergency vehicles and other vehicles containing three

or more occupants. When the Fastoll system becomes operational, the two inside lanes in each direction will be reserved for AVI users, with the median lane being HOV during peak periods. If an HOV vehicle is not equipped with an AVI transponder, it will need to go through one of the other lanes as usual. This will encourage HOV users to participate in the AVI system, and could therefore result in the installation of transponders on a larger number of HOVs. A number of other priority measures discussed in this chapter could then be supported by the AVI technology, once a sufficient fleet of equipped HOVs has been established.

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

One technology that has been used to provide priority access to parking lots for transit vehicles is AVI. An example of this is the system installed in the long-term parking areas at Washington National Airport. This enables the Airport's shuttle buses to enter the parking lots via an exclusive lane, activating a barrier using a small on-vehicle transponder. Buses can therefore avoid the delay associated with entering the lots through the general traffic lanes.

In the U.K, a system has been developed which makes use of license plate scanners for parking lot entry control and fee charging [53]. License plate numbers of vehicles entering the lot are read by a scanner and transmitted to a central computer. If license plates are obscured or broken, an attendant is alerted and the license plate number is input manually. When vehicles exit the parking lot, the license plate number is again read, and the appropriate fee displayed to the driver. Such a system could equally be applied to HOVs using a local database of registered vehicles' license numbers.

3.4 Enforcement

A significant problem with many current priority schemes for transit and rideshare operations is violation by other vehicles. This is operationally undesirable, in that the illegal use of the facilities by low occupancy vehicles reduces their utility to legitimate users. In addition, persistent and unpenalized violations cause frustration among HOV users. This may ultimately lead to the public perception that a priority scheme has failed, despite any operational benefits which may have been achieved. An HOV scheme in Miami, for example, was reduced in scope due to a high violation rate in combination with underutilization of the facility and a lack of police commitment to the project [48].

As described in the previous section, one method of overcoming the problem of violations is physically restricting access to the facility. This requires some form of barrier that can be activated upon detection of an authorized vehicle. Using automatic identification or detection techniques, this barrier activation could generally be achieved without the need for any manual involvement. Inevitably, however, some time penalty will result from the installation of traffic barriers, as vehicles will be forced to reduce speed or stop as they approach the authorization area. In addition, some vehicles may be compliant with the HOV restriction, but may not possess the necessary activating equipment. A manual monitoring system such as CCTV will therefore be required to permit access for these vehicles.

A further problem with the use of barriers for access control is their limited range of application. Specifically, barriers could not practically be applied to unseparated, concurrent flow HOV lanes. These constitute a significant proportion of HOV facilities in the U.S., and are particularly vulnerable to violations by unauthorized vehicles.

An alternative solution to access control would therefore apply advanced technologies for compliance monitoring and violation enforcement on restricted facilities. In general, enforcement systems used in transit

and rideshare schemes would operate remotely and unmanned. Some technology configurations would be capable of automatically identifying violators, while others would require manual assessment of the records produced. The application of ATMS technologies for enforcement is summarized in Table 3.3, and is discussed further in the following paragraphs.

One existing technology that can be used to monitor and enforce compliance with HOV restrictions is video or CCTV equipment. Cameras would be placed on poles adjacent to the HOV lanes at regular intervals. These would transmit signals to a control center for display on monitors. The direction and focal length of the cameras would be adjustable using a console in the control center.

The detection of violators using CCTV equipment would need to be undertaken manually. This could be carried out in real-time by operators in the control center. Operators could identify unauthorized vehicles in the lane, as well as other violations such as speeding, violation of minimum headways or other unsafe driving activities. This information would then be relayed to the appropriate field crews, who would be responsible for enforcing the detected violation.

Alternatively, HOV lane violations could be detected through assessment of taped footage recorded from CCTV equipment. In this case, it would not be possible to enforce violations as they occur. However, using suitable equipment, it should be possible to obtain an image of violators' license plates as the basis for enforcement action. If suitable legislation was enacted, this information could be used to mail citations to identified violators. Even without such legislation, the operating authority could maintain a database of violations on the reserved facility. This could be used to identify frequent violators and establish violation patterns. Manual enforcement activities could then be planned on a more consistent basis making use of these data.

The ability to identify violators on a reserved facility will be a function of the monitoring equipment and the vehicle type restriction. Where only buses or other large transit vehicles are permitted, it will be relatively simple to identify violators using CCTV. For HOV schemes that permit carpooling or vanpooling, however, violation detection will be a more difficult task. In this case it will be necessary to establish the number of occupants within a vehicle in order to detect violations.

A survey of HOV compliance monitoring methods published in 1989 reveals that, although video or CCTV equipment has been installed on a number of HOV facilities in the U.S., it has generally not been used for enforcement purposes to date [54]. The California Department of Transportation (Caltrans) uses video cameras to monitor traffic and to provide images of license plates for origin-destination studies, but not to determine vehicle occupancy. Recently, however, Caltrans has been testing a system incorporating three high resolution cameras and sophisticated VCR playback equipment [55]. The three cameras are positioned at different locations and angles to obtain a detailed view of a vehicle's interior. Manual assessment is subsequently used to determine the occupancy level.

Work has also been carried out in Texas on the use of CCTV equipment for HOV violation detection in Texas [56]. This system uses a television camera to monitor the HOV lane, and a computer located in a vehicle near the facility. The CCTV images are displayed to an operator in the vehicle, who produces a still photograph on detection of a potential violator. Confirmed violators are then issued citations through the mail.

The use of CCTV equipment to detect violators will inevitably be affected by weather and lighting conditions, as well as the type of vehicle. However, it seems reasonable to expect that CCTV equipment could be used to accurately determine vehicle occupancy at least under the range of conditions in which human observers can operate. In addition, CCTV equipment can be used for a number of other tasks on the HOV facility in addition to violation detection. These include verification and evaluation of incidents detected by

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

KEY: ● Currently applied
 ▲ Potential current application
 ▽ Possible future application
 ■ Near-term potential application (within 6yrs)

Table 3.3 Enforcement systems

in-pavement sensors; confirmation of the operation of signs, signals, barriers and other equipment items; and the provision of information on traffic, pavement or environmental conditions to assist in decision making.

Work has also been reported on the investigation of stills camera equipment for HOV violation monitoring [54]. A prototype system consisting of a 16 mm camera, a flash unit and an optical vehicle sensor was developed by the Naval Surface Weapons Center in 1977. Tests on the Shirley Highway I-95 HOV facility in Virginia indicated that the number of vehicle occupants could usually be determined, though in some cases light from the flash unit was absorbed by the car windows. The study also revealed that the presence of the camera had no adverse effects on passing traffic, and that the equipment was capable of recording the entire peak period without failure.

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

The disadvantage of the use of either conventional or electronic stills cameras in this way is the lack of selectivity in recording violators. Unless a manual operator is used to monitor traffic and activate the camera on detection of a violator, all vehicles must be photographed. This creates a need for substantial data analysis, in order to differentiate between compliant vehicles and violators.

A more complex level of enforcement would therefore involve selective vehicle detection and recording of violations. For some applications, this could be achieved using AVC techniques. Violations of bus reserved lanes, for example, could be detected using piezoelectric axle sensors based upon recorded wheelbases, or through vehicle "signatures" monitored by inductive loops.

In the Netherlands, some of the schemes described earlier for the provision of traffic signal priority have included an element of bus lane violation detection. In Almere, for example, the buses travel in reserved lanes and are equipped with Vetag AVI transponders to initiate a priority call on the approach to signalized intersections. Other vehicles using the lane are detected by inductive loops in the pavement, which also act as antennas for the Vetag equipment. The presence of a violator is reported to the control center, from where the police can be informed to clear the route [35].

In the U.K, a prototype system for the enforcement of truck prohibited zones has also been demonstrated that could potentially be reconfigured to identify bus reserved lane violators [57]. The system uses in-pavement piezoelectric vehicles and a processing unit to measure vehicles' wheelbase configurations as they approach a restricted area. This information is then compared with a database which relates axle spacings and the number of axles with the most likely legal gross vehicle weight (GVW). The processor is connected via a cable link to a 35 mm camera system, enabling photographs of suspected violators to be triggered. The photographs display the license plate of the violator, and also record the time and date of the offense. Subsequent investigation with the appropriate licensing authority can then reveal if the vehicle's GVW is above the limit for the restricted area.

The nature of this system means that it would be relatively easy to adapt for the detection of violators in a bus reserved lane. This is because buses usually have consistent wheelbase dimensions that could be stored in the processor unit's database. The detection of any vehicle with an unusual wheelbase would then serve to activate the camera system to record the event, as illustrated in Figure 3.2.

When implementing transit preferential signal control schemes, such as those described earlier in this chapter, it may also be desirable to incorporate red light enforcement to deter potential violators. An example of this is the Nottingham Zones and Collars experiment implemented in the U.K. in the 1970s. This sought

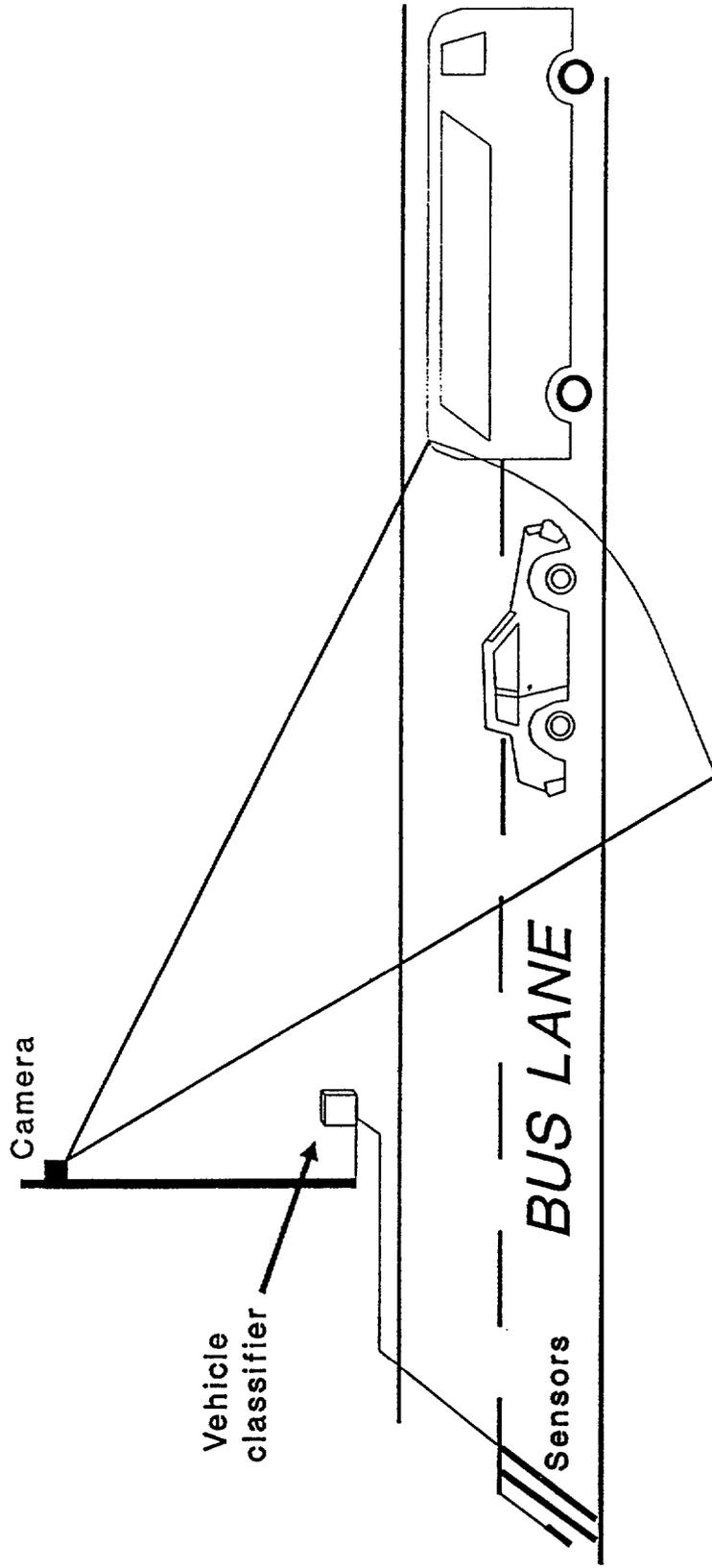


Figure 3.2 Bus lane violation enforcement

to encourage the wider use of buses by giving priority at traffic signals while imposing artificial delays on private vehicles. New traffic signals were installed at various approaches into the city to delay private vehicles, while buses were provided with reserved lanes and were permitted to ignore the red light delay signals. Without a suitable deterrent, however, motorists were not prepared to wait for long periods at red signals and incur the intended time penalties. The Zones and Collars experiment was eventually abandoned, due in part to the high violation rates, and public opposition to the scheme.

Since that time, a number of red light camera systems have been developed that could potentially have assisted the Zones and Collars concept. These detect and photograph vehicles that illegally cross an intersection during a red light. Cameras can be connected to flash units, in order to allow enforcement photographs to be taken at night.

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

A technology that could potentially provide both violation detection and recording facilities is video image processing. Video cameras would be used to provide images of vehicles on a reserved facility. These would be analyzed by a computer, providing an estimate of the occupancy level. Suspected violators could then be displayed to an operator for manual verification. As with previously described applications of video image processing, however, significant technological advances will be required before a system such as this can be implemented.

A final enforcement option is that of telephone hotlines for the public to report restricted facility violators. These were initially introduced for HOV monitoring in the State of Washington in 1984, in a scheme known as the HERO program. This allows Seattle-area motorists to report the license plates of HOV violators by telephone, with violation data stored in a HERO program database. Reduced violation rates in Washington have subsequently led to adoption of the technique in other parts of the country. Recent research into the HERO program has called for greater encouragement of the use of car phones for reporting violations, possibly through a call-collect payment facility [55]. In addition, the installation of an interactive telephone answering service during nonwork hours has been advocated. This would be capable of prompting callers through a series of questions to obtain complete information on violators.

4. FLEET MANAGEMENT AND CONTROL SYSTEMS

4.1 Introduction

The category of fleet management and control systems (FMCS) incorporates a range of technologies that are used to improve the efficiency, safety, and convenience of vehicle fleet operations. Some of these technologies have already been described in this report in the context of their application to individual vehicles. This chapter focuses on their application to fleet vehicles, and in particular to transit and rideshare vehicles. Other technologies that may potentially be integrated with FMCS are also discussed.

The chapter is divided into a number of sections, covering a range of FMCS functions and services. The first section covers computer software for transit operations design and planning. Software packages can be used to optimize transit services, providing increased convenience for users of the facility and more efficient use of resources for the operating authority. The section also discusses specialized computer programs that have been used to simulate and evaluate priority schemes for transit, such as those described in Chapter 3.

The next section examines the use of electronic ticketing systems in FMCS applications. These can be used to collect detailed information on in-vehicle transactions as passengers enter the vehicle and pay their fare. These data can be input to transit operations software packages to identify any changes required to optimize the service. Electronic ticketing machines can additionally provide useful information for marketing activities by transit agencies.

Section 4.4 focuses on an examination of the use of onboard computers and smart cards in the transit industry. Onboard computers have been used extensively in vehicle fleet operations, demonstrating a range of capabilities and cost. Smart cards, which are essentially miniaturized computers, have yet to be widely implemented in transit, but have the potential for several highly beneficial applications. The section describes possible uses of smart card systems, and discusses some of the implementations of the technology to date.

Section 4.5 examines the use of AVI in FMCS applications. Previous chapters of this report have already discussed the application of AVI to support traveler information services and vehicle priority schemes. This section investigates the use of AVI to provide vehicle location data for fleet management services. Examples of where this facility has been introduced are reviewed.

In Section 4.6, discussion is focused on the application of AVL systems to transit operations. This section describes the principal alternate technical approaches within this area. These include land-based systems using roadside beacons, dead reckoning or trilateration, and satellite-based systems. Examples of the implementation of AVL around the world are also reviewed.

Section 4.7 examines automatic vehicle monitoring (AVM) technologies and systems. These integrate vehicle identification and location data with other vehicle-specific information, to provide a more detailed fleet monitoring facility. AVM systems can contain a number of component technologies for data collection, as described in the section. These are illustrated by reference to previous implementations of AVM in the transit industry.

The final section of the chapter reviews dispatching systems for demand responsive or paratransit operations. This section is included to acknowledge the fact that paratransit has different needs than those of more conventional transit schemes. The section covers dispatching systems for demand responsive bus services, as well as systems designed specifically for taxicab fleets.

Within the FMCS category of advanced technologies, several systems can be used to support a range of functions and services. The applicability of various technologies to FMCS is summarized in matrix form in Table 4.1. As in previous chapters, this presents the current and potential areas of application for the systems, as well as the likely timeframes for system implementation. Further details on the use of advanced technologies for FMCS applications are presented in the following sections.

4.2 Transit operations software

The optimization of transit services to ensure a combination of maximum efficiency for the operator and convenience for the passengers requires careful consideration of several operational factors. In recent years, this has led to the development and widespread application of computer software packages for transit operations design and planning [58]. Principal applications of these packages include network and operations planning, vehicle and crew scheduling, marketing, and management and administration.

Network and operations planning software is used to assist transit managers to develop new or revised networks and to evaluate the effects of proposed actions. Some packages develop optimum routes and vehicle frequencies, based on passenger travel data gathered by the transit operator. An alternative to this approach involves the use of software packages to assess networks developed manually. These generally assign passengers to routes of prespecified trial networks, based on the level of service of each route.

Some previous researchers have expressed reservations over the validity of the latter approach when precise service times are not included in the analysis [58]. Though passengers may be influenced by a number of factors in selecting a transit vehicle, most will simply board the first vehicle that will take them to the correct destination. If two alternative routes have the same destination with the same level of service, an assignment model would distribute passengers equally between them. However, if vehicles on one route are scheduled to arrive at the boarding point just before vehicles on the other route, the division of passengers will be unequal. Future development of network planning software should therefore aim to include this facility, to improve the realism of network evaluations. In addition, software should take account of alterations in passenger behavior which may result from the increased availability of real-time service information at boarding points.

Scheduling packages are used by transit operators to determine the optimum times for vehicles to run on defined networks. These packages use passenger travel data, and typically operate in one of two ways. In North America, schedule calculations usually aim to achieve an equal number of passengers in every vehicle. This results in a set of vehicle departure times with intervals that change gradually as demand varies. In other countries, vehicles operate with fixed schedules, though additional vehicles may be used during peak periods.

Vehicle scheduling programs can be either route-based or network-based. Route-based scheduling is relatively simple, with packages requiring only basic data to produce timetables and other documentation. Network-based scheduling is more complex, but can yield greater benefits, particularly if some routes have irregular schedules, or if the peak flow is directional or varies between routes.

Another application of transit scheduling software packages is run cutting. This involves consideration of factors such as crew sizes, changeover points, relief opportunities and working rules. Early approaches used heuristic resource scheduling techniques, though these can be difficult to apply where strictly defined operating conditions exist. This constraint led to the development of interactive approaches, where the user has a greater degree of input to the duty allocation process. Integer linear program (ILP) systems have also been developed recently. These are used to automatically compile large schedules, avoiding the need for time-consuming interaction with a manual operative.

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

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

Table 4.1 Fleet management and control systems

Marketing aspects of transit operations software can include a number of desirable features. Software can be used to support an on-line interactive route inquiry service to assist in optimum passenger route selection. Material can also be produced for display at boarding points, outlining vehicle routes and times and recommending routes to alternative locations. In addition, software can be used to develop a format for travel directories to be distributed in the local community.

A final important element of transit operations software is management and administration facilities. These can assist transit operating authorities in the production of a wide range of documents, including correspondence, contracts, manuals, technical specifications and reports. Accounting activities can also be substantially supported using computer software packages.

One example of a software package developed for the activities described above is BUSMAN [58, 59]. BUSMAN is an on-line interactive mini computer system which supports a wide range of computer programs for use by public transit operators. The architecture of the BUSMAN suite is presented in Figure 4.1. This illustrates the system's key components, including: ROUTEPLAN, used for the development of new or revised routes based upon known travel demands; TASC, designed for the scheduling of regular service vehicles based on user defined routes, which may be obtained from ROUTEPLAN, and required levels of service; VAMPIRES, a network-based program designed for the scheduling of complete networks, which enables the user to define a target number of vehicles, and can be used either individually or integrated with TASC; COMPACS, used for scheduling crews in coordination with TASC vehicle schedules; and IMPACS, which provides input to, and receives output from COMPACS, and is used to produce an estimate of the number of duties required for a given schedule.

BUSMAN is by no means the only software currently in use for transit operations planning. Perhaps one of the most widely used packages for network planning is the Volvo Interactive Planning System. This is used to evaluate the performance of alternative networks input by an operator. Networks are represented in terms of vehicle routes, frequencies and running times, with various corresponding performance indicators produced by the system. These include vehicle loadings, passenger totals, revenue information and levels of service. Passenger trips are assigned to the network by VIPS according to the relative attractiveness of the alternative routes. VIPS can also construct a trial network for evaluation, if required. The system has been used throughout Scandinavia, as well as in the U.K. and Singapore.

In North America, software packages used in transit operations have included RUCUS, SAGE and HASTUS. RUCUS was developed to satisfy both route-based and network-based vehicle and driver scheduling needs. The program treats vehicle scheduling as a problem of network flow, and uses heuristics for run cutting. RUCUS has been widely applied in the U.S., and was updated by the introduction of the interactive RUCUS II in the mid-1980s.

The SAGE computer software package combines scheduling facilities with more general management functions, including timekeeping and payroll control. The SAGE suite contains programs such as MINI-SCHEDULER, which was developed to enable vehicle schedules to be built up interactively. MINI-SCHEDULER is one of only a small number of programs currently used to develop timetables that vary according to demand.

Probably the most widely used ILP system is HASTUS, developed at the University of Montreal. HASTUS forms idealized duties, which are assumed to be approximations of the actual duties that will be created. These are matched and evaluated against the actual transit work, partitioned into stretches using heuristics. HASTUS can also be used to estimate the cost of a transit service, as well as to assess the number of duties of various types.

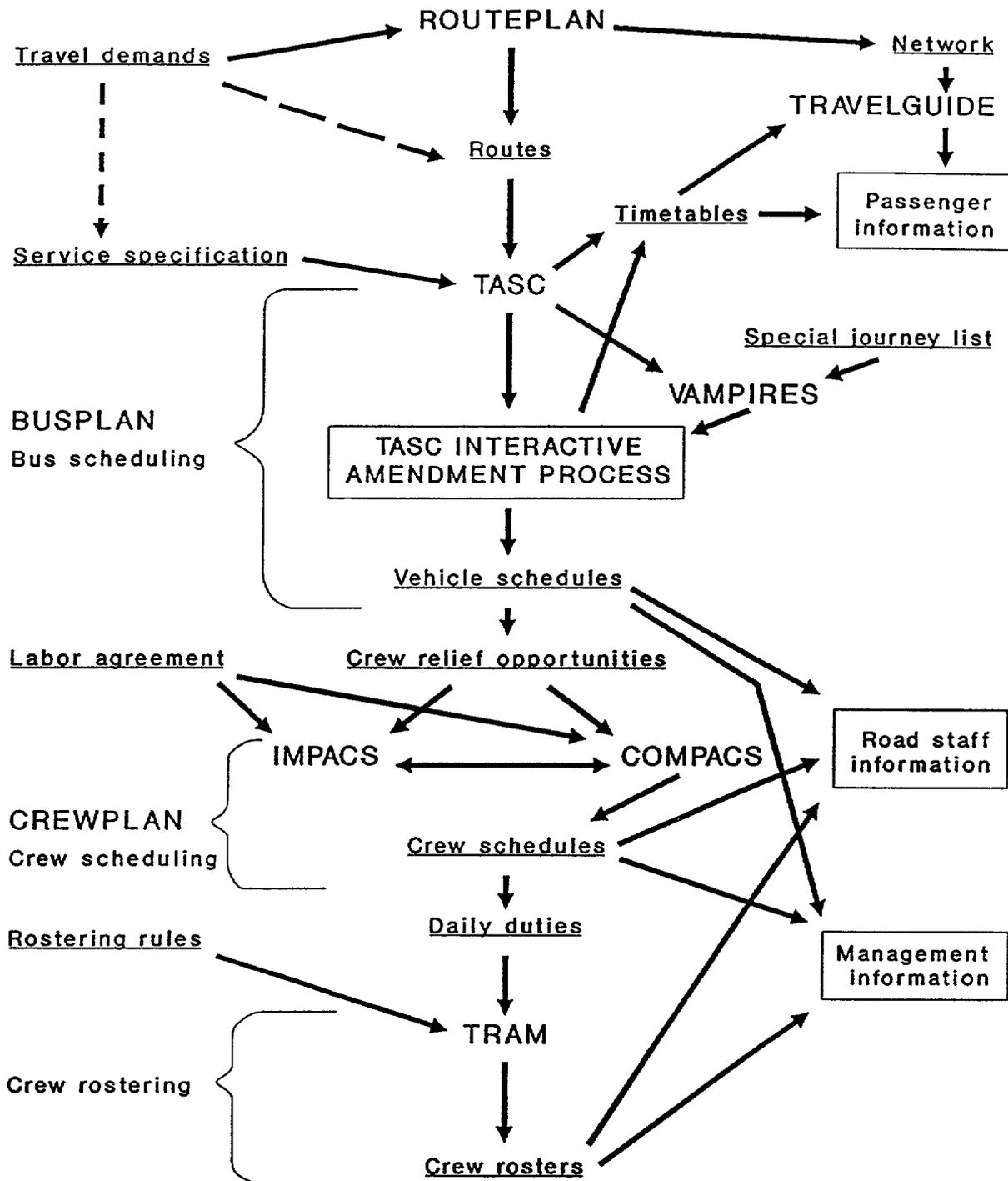


Figure 4.1 The BUSMAN suite
(Source: reference #58)

The West German Ministry of Research and Technology has also funded research and development of transit operations software in an effort known as the BISON (Betriebsführungs und Informationssysteme für den Öffentlichen Nahverkehr - or Operational Control and Information Systems for the Public Transit Sector) project [60]. Applications of the BISON software include route planning and scheduling, duty rostering, performance analysis, production and spare part control, and administration.

Other applications of computer software to transit operations have focused on the simulation and evaluation of priority measures or other proposed transit-related schemes. In the U.K, for example, research has been carried out into the simulation of convoying transit vehicles [61]. This has been seen to offer improved conditions for transit operations and passengers in central urban areas. The concept involves the movement of platoons of several transit vehicles in succession, each having its own area for passengers to board and alight on a subway-like loading platform. To date, convoying has been applied primarily in South America, though successful applications of the concept have also been demonstrated in the U.S.

To examine the potential for introduction of convoying systems into European cities, a computer simulation process was carried out using central London as a case study. This utilized the Transitway Simulation Model (TSM) developed in Canada by the Regional Municipality of Ottawa-Carleton. A variety of control scenarios were evaluated using the TSM, including the effects of altering bus supply, convoy size, headway groupings, and bus stop location.

Elsewhere in Europe, computer software has been used to simulate bus priority measures at signalized intersections [62]. This research used a simulation package called MISSION to investigate the effects of the use of bus guidance and control measures on traffic flow in urban areas. Such a package could have useful application in determining the benefits of a number of alternative transit priority schemes.

4.3 Electronic ticketing

Another technology that may be applied to fleet operations is electronic ticketing for transit vehicles. The benefit of this technology lies in its ability to capture detailed information on in-vehicle transactions, as passengers enter the vehicle and pay their fare [14]. Conventional mechanical ticket machines collect only a limited amount of data, such as a revenue summary and passenger count. Depending upon the complexity of an electronic ticketing system (ETS), data that may potentially be collected include the following: revenue information disaggregated by route, by ticket type or by passenger type; passenger information by ticket class, by route or by time of day; passenger boarding and alighting information by stage; and partial origin-destination data.

Data collected using ETS technology can be used for a variety of management information applications (Figure 4.2). Marketing of transit services can be improved, through the analysis of travel patterns of particular passenger groups. The use of various ticket types by time of day on different routes will also support marketing activities. Continuous monitoring of demand can be undertaken, as a basis for considering changes in a transit network. Following implementation of modifications to a transit service, ETS technology will also provide data to evaluate the accuracy of any predicted effects.

Another useful application of ETS data for private transit operators is the negotiation of compensation payments for concessionary fares. In this application, ETS would maintain a record of all journeys made using tokens or concessionary permits. This record would provide the transit operator with the information required to establish the corresponding financial compensation due from the subsidizing government agency.

ETS technology also exhibits a number of additional advantages over conventional ticketing systems. Revenue accountability, security and reliability are all improved, while operating speed is increased and equipment operation is simplified. Further, the cost of equipping a fleet of vehicles is moving in favor of the

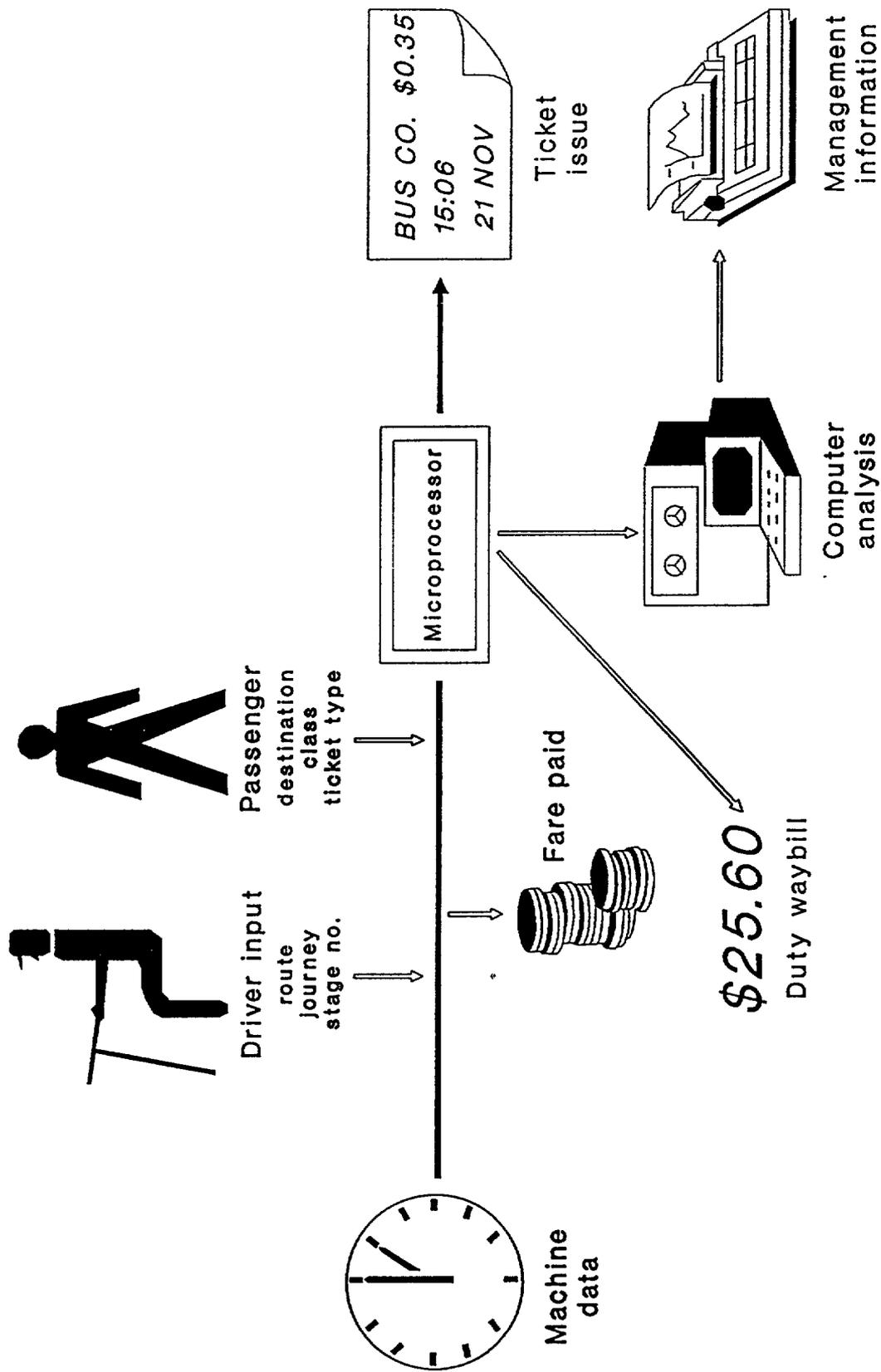


Figure 4.2 The ETS concept
(Source: reference #14)

ETS approach. This is because only one ETS unit is required per vehicle, rather than one per driver in older systems.

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

One of the principal limitations in the use of ETS technology for data collection is in its ability to deal with noncash paying passengers. These can include holders of prepurchased travel cards or concessionary permits for free travel. The inclusion of these travelers within the collected data requires some form of action by the vehicle driver. On low-density routes, the driver will potentially have time to enter the required information on passenger time, stage boarded and intended alighting point, without causing excessive disruption. On busier routes, however, it will often only be possible for the driver to maintain a boarding count in support of the compensatory payments application described earlier. This inevitably reduces the utility of the data for planning and management purposes. The next section of this chapter considers the use of smart card technology to provide a solution to this problem.

A further limitation associated with ETS technology is the lack of software appropriate for the analysis of data collected by the equipment. This is addressed to an extent by the transit operations software packages discussed in the previous section of this chapter, though these use only a proportion of the data provided by ETS. As a result, many operators equipped with ETS use software packages that produce only basic statistical reports. This poor use of data represents a lost opportunity, and could potentially be addressed by the development of software by the ETS manufacturers, for sale with their in-vehicle hardware.

4.4 Onboard computers and smart cards

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

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

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

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

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

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

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

Computer-based VMSs represent the highest level of current technology. A wide range of Vh4Ss is currently available, varying in levels of sophistication and cost. Typical vehicle parameters monitored by the systems include engine revolutions per minute, speed, total trip miles, ignition on/off, water temperature and oil pressure. Information is fed continuously from the sensors to the computer, as illustrated in Figure 4.3. Some systems make provision for manually entering additional information such as fuel purchases or other expenses.

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

An interesting example of the use of OBC technology in transit vehicles has recently been evaluated in Reading, U.K. [64]. This system, called Optimizer, operates in a similar way to the “black box” recording devices used on airplanes. Optimizer is wired into various circuits on the vehicle, providing data on speed, stops, starts and position. In addition, by monitoring whether the doors are open or closed, the system can establish whether the vehicle is at a boarding point or simply stationary in traffic. Boarding and alighting data are also collected by Optimizer.

The Reading experiment began in January 1989 and ran for over a year. At the end of the evaluation period, the collected data were used to develop a vehicle schedule based on actually measured traffic conditions and demands. Data were also used to identify the nature, location and extent of delays, which were highlighted for further study by the highway authorities. As a result, it was possible for the transit operator to calculate the potential benefits of priority measures at the delay areas, both in minutes per journey and in overall operating costs.

Another potential use of OBCs would involve their integration with the signal preemption measures described in Chapter 3. In this application, the onboard computer would contain a record of the vehicle’s schedule, including its correct arrival time at each intersection and boarding point. As the vehicle approached a signalized intersection, the OBC would compare the actual time with the intended arrival time. The signal would then need to be activated in favor of the transit vehicle only when the onboard computer detected a significant deviation from the required schedule.

Smart card technology has already been discussed earlier in this report, for use in traveler information systems, particularly in the area of trip reservation and payment. However, since smart cards are essentially miniaturized computers, they can also potentially perform many of the same functions as OBCs but in a much more portable form. The technology has only recently been applied to transit operations, and offers a number of potential benefits that have yet to be fully realized. Some possible uses are described in the following paragraphs.

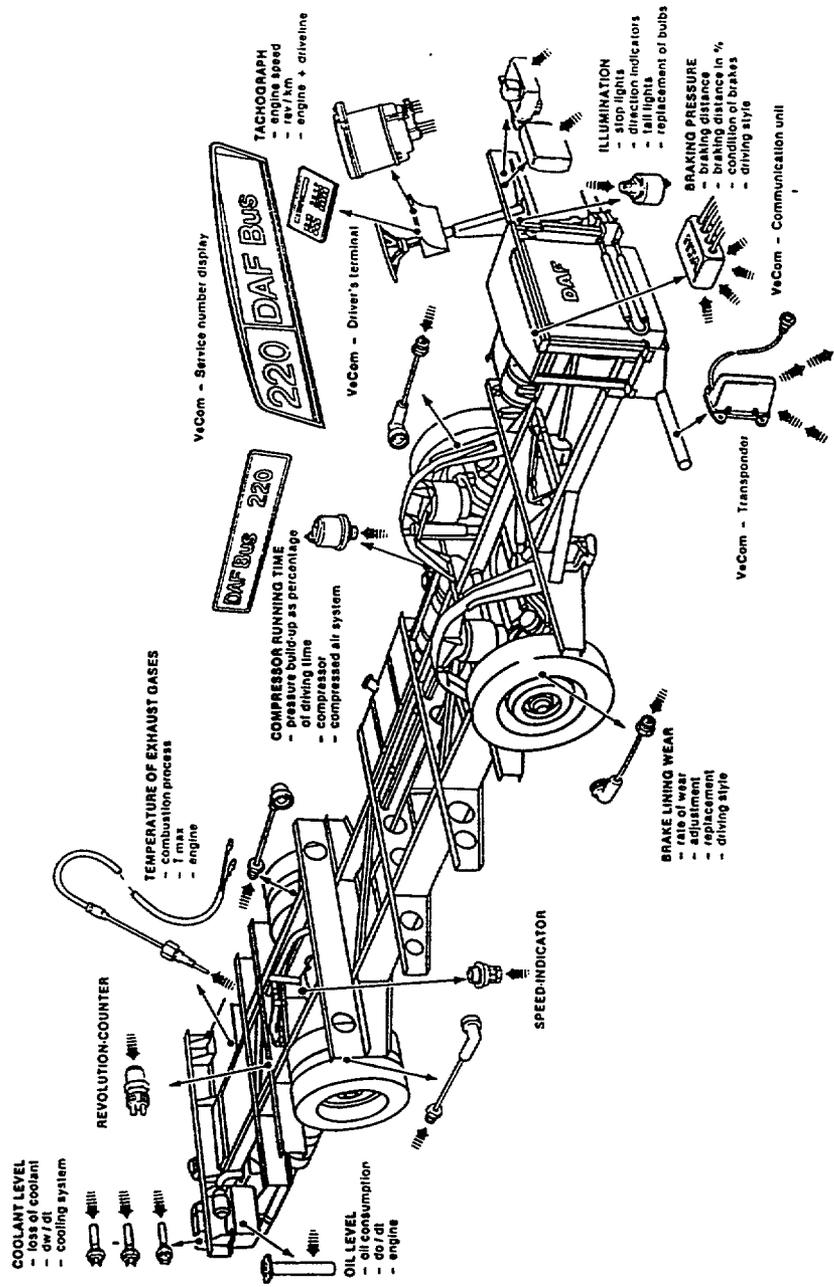


Figure 4.3 Sensors for vehicle condition monitoring (Source: reference #63)

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

Other statistical data could also be carried on the card, providing information about the user such as age, sex and frequency of travel. An important factor in public transportation marketing is price discrimination, through which different market sectors are identified and charges set reflecting different elasticities of demand. Airlines use this approach in their complex pricing structures aimed at maximizing business revenue while permitting leisure travel at much lower fares. Data collected using smart card technology could open up similar potential for transit price discrimination by time of day, age or route.

An alternative approach to the storage of statistical data on the smart card would simply be to include a unique passenger identification number. This would be recorded by an onboard computer each time a passenger used the service. Age, sex and other details corresponding to the smart card holder would be stored in a central computer database maintained by the transit operating authority. The downloading of passenger identification data on a regular basis would enable the appropriate user files in the database to be accessed. This information would facilitate the production of service usage reports disaggregated by route, section and passenger type.

The use of smart cards to collect travel data in this manner could have some cost advantages for the transit operator. More specifically, the storage of a simple identification number would be less complex, and therefore less expensive, than the storage of a detailed passenger profile on the card. Card reading and data storage equipment on the transit vehicles would also be correspondingly less complex. However, the transit operator would be required to maintain a more powerful central computer system, which could offset these cost savings to an extent.

A simple passenger identification card system has recently been developed for experimental installation in the cities of Lueneburg and Oldenburg in Germany [12]. As described in Chapter 2, the system is to be used initially for automatic fare collection, with bank accounts debited once a month according to usage. However, it would also be possible to use the system for the data collection role described above, given the establishment of a passenger information computer database by the transit operator.

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

Another potential fleet management application of smart cards in the area of fare payment is their use on more than one mode of transport or transit service. As well as providing added convenience to the user, this could offer a significant breakthrough in its ability to collect travel data. The system would enable operators to develop usage reports broken down by transit mode, as well as by age, sex, route or section.

In Hong Kong, a smart card system has recently been introduced that can be used by travelers on more than one transit service [65]. Compatible card readers have been installed on 130 buses belonging to the Kowloon Motor Bus and City Bus companies. Fares are automatically deducted from a balance stored on the

card. The fares were negotiated between the two transit companies, and vary according to the route and time of day.

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

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

4.5 Automatic vehicle identification

AVI technology has already been discussed in some detail in this report, both in the context of providing information services for private vehicles, and in implementing priority schemes for transit and rideshare vehicles. This section discusses a further application of AVI to transit vehicles: vehicle location monitoring for fleet management purposes.

The use of AVI for fleet monitoring involves the installation of transponders on transit vehicles in the fleet, and the siting of reader equipment at selected monitoring locations. This configuration can be used as a management tool to display the route number, location and identity of vehicles at a central control point. Monitoring of services in relation to a planned timetable can then be undertaken, allowing early remedial action to be initiated where problems are identified [66].

In Europe, the implementation of AVI for fleet monitoring purposes has often been combined with signal preemption measures and, to a lesser extent, with passenger information services. The Philips VETAG system, for example, has been used for these purposes in the town of Almere in the Netherlands [35]. As well as providing for traffic signal priority, the system displays operational data on a supervision screen in the control center. This enables an operator to establish the positions of individual buses, trace failure reports, initiate test programs for individual components, set intersection controllers to local operation and modify programs. When the control center is unmanned, information can be passed on via a data line to the operator's house, if required. Data collected and stored by the central computer can also be used for economic and statistical analyses, and for maintaining logbooks and failure records.

In another FMCS application of VETAG in the Netherlands, the system has been installed on the recently constructed high-speed light rail system connecting the city of Utrecht with its satellite communities [67]. All rail cars are fitted with transponders, which are used to provide vehicle identification, route and present location data. This information is used for automatic points switching and to ensure that only one car is present on a section of track. The AVI data also allow cars to be routed to empty platforms at the terminals.

The VETAG system has also been implemented for FMCS applications in several other locations in Europe [67]. In France, the equipment has been used to support transit operations in the cities of Lyon and Grenoble. The system in Grenoble is used to provide data on the status of buses and streetcars, as well as offering priority at intersections and automatic point switching. Vehicle status data are displayed on a monitor at the control center and provide the position of the vehicles in the network. Different colors are used on the

display to indicate whether vehicles are arriving, departing or stationary. In Lyon, meanwhile, the VETAG system is used to identify vehicles automatically as they enter the main bus terminal. Vehicles can then be automatically directed to the appropriate platform, ensuring optimum use of platform space and maximum convenience for passengers and crews.

In Brussels, Belgium, VETAG has been used to identify cars on the city's underground metro network. Car identification data are sent to a central computer, which maintains control of the 15-mile metro system. A similar system has been installed on London's Underground metro network for control of railyards. The control system is used to register incoming and outgoing vehicles, setting routes automatically through alteration of switches and junctions. Vehicle identities are displayed on a monitor for review by the train supervisors.

An additional feature of the VETAG AVI system relevant in the context of FMCS is its Registration and Communication Module. This allows the system to automatically log the times and dates of vehicles passing a particular inductive loop antenna. The equipment could therefore be used to collect detailed data for reporting purposes and input to transit operations software.

More recently, in the U.S., AVI has been implemented at airport locations for the purpose of monitoring and controlling landside traffic, particularly taxicabs and transit vehicles. Examples of this include the international airports in San Francisco, Minneapolis/St. Paul and Los Angeles.

The system installed at San Francisco Airport is based around the radio frequency AVI system manufactured by General Railway Signal [68]. Participation in the system currently extends to 1,400 vehicles equipped with tags. Readers and antennas are installed at three locations in the airport. The system also includes modems, computers and portable readers.

Transponders are mounted on the roof of participating vehicles, with antennas mounted overhead. The system is used to identify each vehicle, record the time and date, store, file and sort trips, and automatically bill the vehicle owner on a per-trip basis.

In Minnesota, the Metropolitan Airports Commission has evaluated four AVI systems with a view to automating taxicab dispatch operations [69]. Tests were conducted in 1988, with transponders mounted on airport shuttle buses. This was believed to be a more reliable method of testing than tracking randomly-selected cabs. However, the Commission has yet to make a decision on the full-scale implementation of AVI at the airport.

In California, AVI equipment manufactured by Amtech Corporation has been installed at Los Angeles International Airport [70]. One of the principal applications here is to identify and monitor vehicles circulating within the airport landside network. These are then charged a fee according to the dwell time they spend within the airport. Transponders are installed on 5,000 vehicles participating in the scheme, which covers 40 lanes at the airport.

The system installed in Los Angeles was initially used to monitor the flow of door-to-door shuttles. Seven hundred of these vehicles currently operate at the airport, representing approximately \$150 million worth of business every year. The system produces a tape at the end of each month, providing a summary of the number of passenger pickups per vehicle. The tape is then used to input data to a mainframe computer, which carries out automatic billing based on the number of circuits made of the passenger pickup level.

The Los Angeles system has subsequently been extended to cover courtesy vehicles supporting off-airport car rental companies, as well as limousines, charter buses and taxicabs. The system is used to monitor the levels of activity of these vehicles types operating at the airport. In addition, the system enables the airport

to verify funds collected from taxi drivers by the dispatchers. Payment processes are not automated by the AVI system, however.

Most recently, the Metropolitan Washington Airports Authority has commissioned an evaluation of the use of AVI technology at Washington National Airport [71]. This would involve automating airport fee collection from the taxi drivers. Other potential applications of the proposed system would offer increased options for the identification of unauthorized taxicabs at the airport, as well as an automated taxicab dispatching facility.

4.6 Automatic vehicle location

Perhaps the most widely used category of technologies and systems that has been applied to transit operations is AVL. AVL systems are different in emphasis from AVI systems, although both technologies can perform the function of identifying a vehicle. With AVL, the primary focus is on locating the vehicle at a specific time, rather than identifying the vehicle at a specific location [72, 73]. AVL is therefore concerned mainly with monitoring through temporal sampling, while AVI is aimed at monitoring through spatial sampling.

AVL systems typically comprise in-vehicle units which are used to compute vehicle location, and a central monitoring facility to which location data are transmitted. One possible AVL system configuration is illustrated in Figure 4.4, though it is emphasized that there are several alternative technical options. AVL can generally be divided into ground-based approaches, where all elements of the system are located on the earth, and satellite-based approaches.

Ground-based AVL systems can use one or more of three techniques to fix a vehicle's location [74]. These are: proximity beacons, dead reckoning, and trilateration.

Proximity beacon techniques, which are also known as signpost techniques, involve the installation of transmitting beacons at key points on the highway network. These continuously emit unique codes identifying their particular position. These transmissions are decoded by a receiver in the vehicle, enabling it to determine its own location within the network.

Within the proximity beacon AVL technique, systems can be further divided into those operating "sharp" or "broad" beacon transmissions [75]. "Sharp" systems operate using a very localized signal for transmission of the beacon's identity, rather like an inverse AVI system. "Broad" systems, on the other hand, transmit a longer-range signal centered on the beacon. An area can therefore theoretically be covered with overlapping reception areas, with the nearest beacon deduced from the relative signal strengths received.

The main advantage of proximity beacon approaches to AVL is that the receivers are relatively simple and inexpensive. However, where a high degree of coverage of vehicle movements is required, either beacons need to be sited in a relatively dense network, or some other position-fixing capability is required to locate the vehicle between beacons.

Dead reckoning AVL techniques use measurements made by distance and heading sensors on a vehicle to continuously compute location relative to a known starting location. The most common basis for distance measurement is the odometer, with electronic odometers often used in AVL systems. These monitor sensor signals from a calibrated rotating shaft or wheel to calculate distance traveled. Differential odometers include sensors on both wheels of an axle, and can be used to compute changes in direction from the differential movement of the opposite wheels.

Heading sensors for dead reckoning include the magnetic compass and the gyrocompass. The magnetic compass is widely used in AVL systems, despite reported accuracy problems due to variations in the

earth's magnetic field around large metal objects [76]. Current dead reckoning AVL systems normally use flux-gate compasses with algorithms to compensate for the permanent and induced magnetism of the vehicle.

Although dead reckoning systems are relatively low cost by comparison with some alternative AVL approaches, even the most precise dead reckoning systems accumulate error with distance traveled. Periodic reinitialization is therefore required, which can be achieved using roadside proximity beacons. An alternative approach to reinitialization uses map matching techniques, in which computer algorithms are used to match the vehicle's actual path with that of the feasible path on the map.

Trilateration location-fixing techniques involve the detection of radio frequency transmissions from three or more fixed points. Ranges or differences in range to the fixed points are then calculated, allowing the position of the vehicle to be established. Because of the need for a number of relatively long-range transmitters, ground-based systems using trilateration tend to use existing standard navigation networks such as Loran-C, Decca Navigator or the Omega system as their basis. Some difficulties can arise due to signal interference in cities with high-rise buildings or with difficult topography.

Satellite-based AVL systems essentially work on the trilateration principle used in some ground-based approaches. However, the long-range transmissions which allow the vehicle position to be established originate from satellites in orbit around the earth, rather than from ground-based transmitters. Most satellite trilateration systems are currently based around the U.S. Navy's Transit System [77], though this is being superseded by the Navstar Global Positioning System (GPS) [78]. GPS is a space-based radio positioning system being implemented by the U.S. Department of Defense; it is scheduled to become fully operational in the early 1990s.

The vehicle position information calculated by the onboard receiver is generally monitored at a central control facility in AVL systems. Some means of automatically transmitting the data to the control facility is therefore required. Options for communicating this information include two-way mobile radio systems, onboard cellular telephones linked to modems, or land mobile satellite communications services. These communications options are each applicable to systems which use any of the ground-based or satellite-based location fixing techniques.

There is also significant potential for AVL through use of the new Radio Determination Satellite Services (RDSS), recently licensed by the Federal Communications Commission (FCC) [79]. RDSS will provide commercially-operated satellite-based location services, together with the capability to send and receive short data messages. A major difference between RDSS and other AVL systems is that the location determination takes place not on the vehicle, but at a stationary central location processor.

For transit operators, the principal application of AVL technology is the provision of vehicle location data to a central control, allowing fleet managers to make more efficient use of their vehicles. The earliest recorded experience with AVL systems was the development and use of the experimental Bus Electronic Scanning Indicator (BESI) system by London Transport in 1959 [80]. Following this, significant interest developed in the U.S. in the late 1960s in the concept of using AVL systems for public transit applications. This led to a major cooperative effort by the Chicago Transit Authority, the U.S. Department of Housing, and Motorola, to develop a wide-area AVL system called Monitor for the Chicago bus fleet [81].

In the U.S., the main AVL activities in the 1970s were promoted by the newly-formed UMTA of the U.S. Department of Transportation (U.S. DOT). Starting in 1971, field tests were undertaken in Philadelphia on four AVL systems, with the goal of providing 500-foot location accuracy for 95 percent of the time. Although results for three of the four systems tested failed to meet this criteria [82], a further AVL testing program was initiated in Philadelphia in 1975. Four systems were again tested in this program; one system was subsequently selected and implemented in a demonstration project in Los Angeles in 1980 [83].

Toward the end of the decade UMTA conducted a study into the benefits and costs of AVL systems [84]. This identified a range of potential benefits and cited practical evaluations of the extent of those benefits. U.S. DOT also sponsored a study into alternative AVL techniques [85]. This concluded that any of the ground-based location techniques could provide sufficient positional accuracy for a range of applications, although in hostile environments or for high accuracy applications a combination of techniques might be required.

Outside the U.S., a number of AVL initiatives also took place during the 1970s. In Europe, Canada and the Far East these included several demonstration and pilot projects, ranging in size from coverage of 12 vehicles to 900 vehicles.

During the 1980s, ground-based AVL systems continued to gain acceptance for small- to medium-scale applications in vehicle tracking for public transit fleets and other vehicles, both in the U.S. and Europe. One example is an AVL system that was installed by the Salem Police Department in Oregon to monitor the locations of all its marked patrol cars [86]. Other similar small-scale systems have been implemented for vehicle location monitoring in Seattle, San Diego, Los Angeles, Washington, D.C., Chicago and Detroit [87].

Among European experience of ground-based AVL during the 1980s was the London Transport BUSCO system. BUSCO was implemented in 1983 as a pilot system covering 52 vehicles, with possible future extension to a scheme covering the complete vehicle fleet [55]. The system uses road loops and odometer readings to calculate vehicle location, allowing the buses on each route to be constantly monitored in detail.

In a more recent AVL implementation in London, a microwave-based system is being used to track midibuses along two downtown routes [89]. The system works in conjunction with conventional radio communications between bus drivers and the operating base. A network of ten microwave beacons along the routes is used to identify vehicles and provide unique location data to London Transport's main control center. The information is then relayed to a pair of local microcomputers at the operating base for the midibus service. Although only ten beacons are used in the network, the system is reportedly adequate for the role of providing an overview of vehicle movements along the two routes.

A AVL approach similar to that adopted in London is currently being implemented in Ottawa, Canada [15]. The system, being introduced by the Ottawa-Carleton Regional Transit Commission (OCTranspo), includes vehicle identification devices, on-street detectors that will read and transmit information about passing buses, and a computer to store and distribute the information. This equipment is being installed as the first stage of a three-phase project by OCTranspo. Ongoing system extensions and enhancements within the second and third phases are scheduled to continue until 1996. The equipment will provide service performance data to controllers for real-time analysis to assist OCTranspo in meeting its goal of 95 percent on-time service at all bus stops.

Although the approaches adopted in London and Ottawa are adequate for the task of providing a broad indication of vehicle movements, an inevitable drawback is that location data cannot be accurately established while vehicles are between beacons. As discussed previously, some AVL systems therefore utilize more frequent radio communications between the vehicle and the control center to overcome this problem. In these systems, location data are usually established on the vehicle, using either radio navigation or dead reckoning techniques.

Where dead reckoning is used to calculate vehicle location, the information is often supported by data transmitted from roadside beacons. These data serve to correct errors that may accumulate during location calculations. An example of this type of system has been developed in West Germany and installed in the cities of Hannover and Wiesbaden [90]. Onboard equipment is used to calculate vehicle location and other data, which are transmitted to the control center every 15 seconds. Infrared beacons installed at regular intervals along the bus route are used to calibrate the data stored on the vehicle. The system is used to

compare the planned schedule with the actual state of the vehicle fleet, enabling timetable deviations and potential connection problems to be identified and resolved at an early stage.

While dead reckoning or beacon-based AVL systems have been relatively widely applied to transit in **recent** years, there have been far fewer implementations of trilateration-based technologies. A principal reason for this is the high cost of radio systems compared with beacon proximity or dead reckoning systems. In addition, accuracy problems have been reported with some radio transmission systems, particularly in built-up urban areas [91].

One recent example of a radio navigation technology that has been applied to transit operations in the U.K. is the Datatrak system [92]. This uses low frequency transmitters spaced at intervals of just under 100 miles as the basis for trilateration location-fixing calculations. Though initially developed to support security vehicles and precision positioning for offshore oil exploration projects, the system has subsequently been extended to cover a range of additional applications. This has led to the use of the system by a number of U.K. transit operators. The low transmission frequency and relatively small distances between transmitters enable the system to avoid accuracy problems experienced by some other radio approaches in urban areas.

Overall, therefore, AVL has been widely and successfully applied to the provision of vehicle fleet data to a central control point for real-time analysis. However, AVL technology can also be used to support several further activities, making it an increasingly attractive proposition for transit operators. One such application is the provision of off-line statistics for management and planning activities. This could include data for input to transit operations software. Finally, AVL can also support a range of traveler information services described in Chapter 2 of this report.

4.7 Automatic vehicle monitoring

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

As well as schedule adherence and vehicle location, other information that can potentially be gathered using AVM includes passenger counts, fare information, vehicle condition data and emergency status messages. A typical AVM system configuration is illustrated in Figure 4.5.

Passenger counting technologies have been incorporated into a number of fleet management systems in North America and Europe. An example was General Motors' transit information system (TIS), demonstrated on Cincinnati's Queen City Metro transit system [93]. This produced data on passenger boardings and alightings, as well as travel times, per bus trip or bus route segment. Vehicle locations were established using electronic beacons and bus odometer readings. The TIS was developed as an off-line system, however, and was used for trip scheduling and route planning rather than real-time vehicle monitoring.

Elsewhere, passenger counting systems have demonstrated real-time communication of count data to a control center. In Ontario, Canada, passenger counting is achieved through the interruption of an infrared beam as travelers enter and leave the bus [94]. Count data are transmitted to a control center via roadside beacons, along with other information such as dwell time and location. The system has been designed as a planning tool, aiming to provide realistic schedules and fewer service irregularities.

The system uses 27 electronic beacons to gather data from vehicles for transmission to the control center. 72 buses have been equipped with the passenger counting equipment, allowing at least one equipped

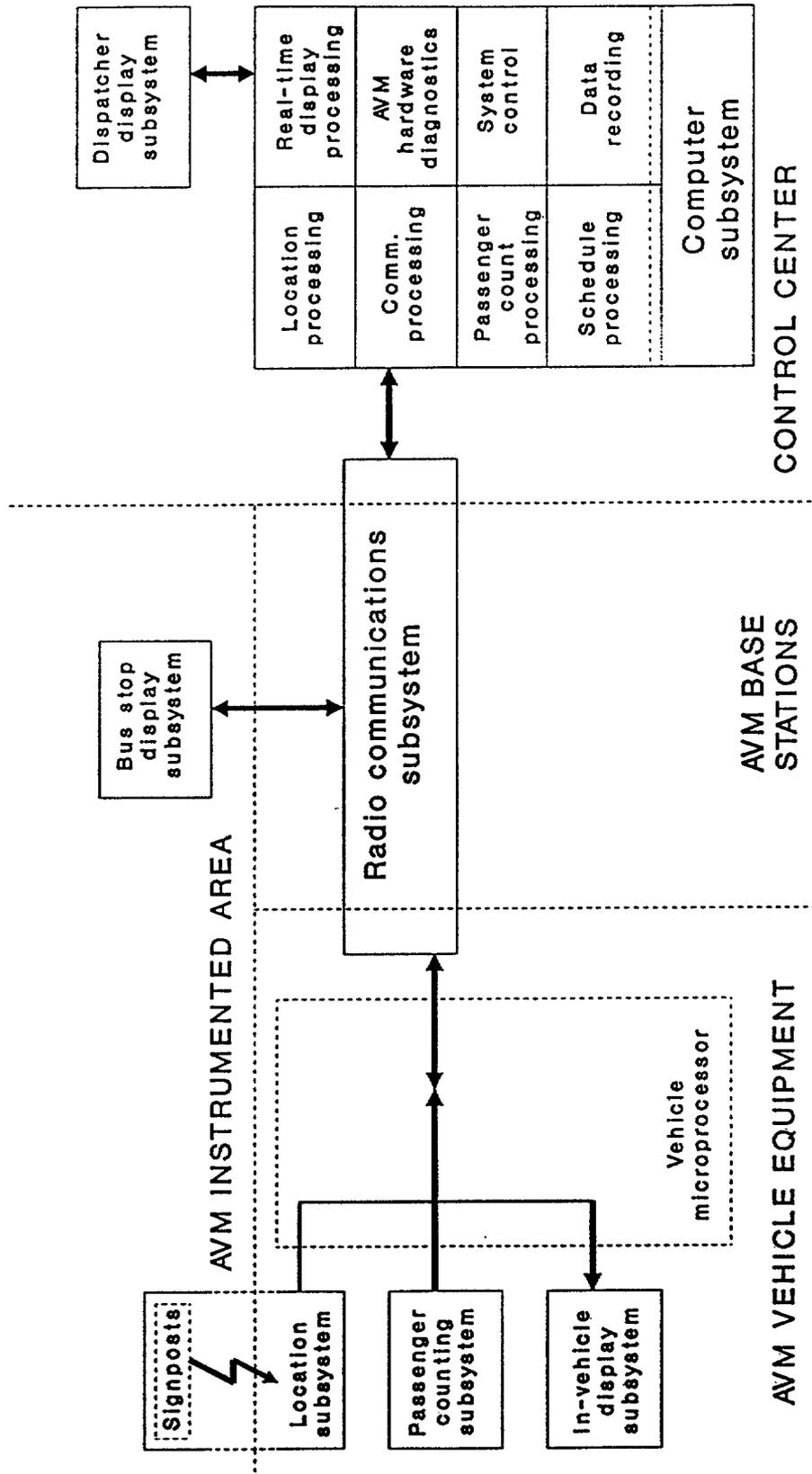


Figure 4.5 Typical AVM system configuration (Source: reference #93)

vehicle to be placed on every route in the network. Where specific problems are under investigation, more detailed data are obtained using several equipped buses on the route every day.

A similar automatic passenger counter has also recently been developed at Virginia Polytechnic Institute [95]. This system uses an infrared light sensor at the vehicle's doors to monitor movement of passengers. An internal clock is used to record the times of events, while an odometer sensor provides data on distance traveled between stops and total distance moved.

An alternative to infrared technology for passenger counting involves the use of treadles at each door of the vehicle. This has been demonstrated in Turin, Italy, with data transmitted via a radio data channel to the control center [96]. The system also includes a facility for automatically estimating the load on the bus using air spring pressure sensors. For each stop on each route, passenger boarding and load data are collected. Load data are transmitted in real-time to the control center. The sequence of passenger boarding and loading is transmitted to the control center when the vehicle reaches its terminus.

Fare information can be collected by electronic ticketing machines, as described earlier in this chapter. This would enable the transit operator to maintain an overview of the funds collected in each vehicle in the fleet. Electronic ticketing could also offer an alternative method of passenger counting to the infrared beam or treadle technologies discussed above.

At a further level of sophistication, smart cards distributed to passengers could be used to supply a variety of data to support AVM systems. The integration of smart cards with a communications link to a control center could potentially provide a powerful tool for monitoring the status of fleet vehicles. As well as providing information on vehicle location and schedule adherence, the smart card element would permit operators to monitor vehicle occupancy levels, and to review individual driver or passenger details if required.

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

AVM systems can also include a facility for the transmission of emergency messages to a control center. An example of this has been incorporated in the Toronto Transit Commission's communication and information system (CIS) [97]. The Toronto CIS enables bus drivers to contact the control center by pushing a button labeled "yellow emergency" when an automobile accident or similar situation is witnessed. Control center personnel are alerted by a buzzer, and can direct emergency services to the location of the accident, which is automatically transmitted from the alerting vehicle. The CIS also has a silent alarm that can be activated when the driver is in danger. This automatically opens a voice channel, overriding other communications elements of the system.

A review of progress in AVM was carried out by UMTA in the early 1980s [98]. This review reported on UMTA's program to evaluate the application of AVM in transit operations. A number of AVM systems were discussed, including the Bus Electronic Scanning Indicator (BESI), developed in London in 1959, through to more recent projects such as the Radio-Data-Locator system implemented in Queens Village, New York. This latter system uses digital radio communications to report on the status of 230 Queens Village buses every 90 seconds. As well as providing schedule adherence and location data, the vehicles have been fitted with mechanical sensors to check on items such as engine overheating, oil pressure or fare box tampering.

AVM has continued to develop since the UMTA study findings were published in 1981. This has been due in part to technological advances in AVI and AVL systems, which provide the communications network for many AVM systems. In Japan, for example, the development of RACS has been seen as a powerful tool

to support **AVM** systems [16]. RACS provides high-speed, two-way digital radio communications between an in-vehicle unit and a roadside beacon. Similar systems are currently being developed in the U.S. and Europe that could find useful application in fleet management operations.

One of the most prominent recent examples of AVM implemented in U.S. is a system developed for **VIA** Metropolitan Transit in San Antonio, Texas [99]. The system tracks the location of transit vehicles, automatically warns dispatchers of delays, and provides two-way voice and data communications between dispatchers and drivers. In addition, it has the capability to monitor vehicle operating characteristics such as oil pressure and coolant temperatures, as well as operational information such as passenger counts. The system was put into full use in San Antonio in early 1989, following more than a year of successful testing in the city.

VIA's system uses a network of roadside beacons to transmit location data to on-vehicle receivers. Between beacons, a calibrated odometer is used to continuously track location. Beacon transmissions can be read as vehicles pass at speeds up to 65 miles per hour. Location data transmitted from vehicles to the control center are reportedly accurate to within 100 feet.

In addition to transmitting location data and other vehicle-specific information, the VIA system provides three methods of communication between dispatchers and drivers. For commonly-used messages, standard coded radio transmissions are sent by pushing a button on the driver's keypad or dispatcher's keyboard. When more detailed communication is required, a voice radio link is provided. Dispatchers can talk with any and all bus drivers. The drivers can call the dispatcher using either a "request to talk" or a "priority request to talk" message. Each bus is also equipped with a silent alarm for emergency use.

Outside of the U.S., one of the major examples of AVM is the Toronto CIS, discussed earlier in the context of its emergency alarm features. The CIS permits continuous automated monitoring of all surface vehicles operated by the Toronto Transit Commission (TTC), comprising buses, streetcars and trolley coaches. Like the system in San Antonio, the CIS uses a combination of roadside beacons and odometer readings to track vehicle location. All data, including vehicle location and information on mechanical problems input by the driver, are stored in an onboard microprocessor unit. The data are transmitted to the control center every 10 seconds via one of 10 intermediate radio sites in the network. TTC plans to integrate some 2,000 surface vehicles into the CIS by the end of 1991 [100].

In Europe, the two-way communications capability of the VECOM AVI system developed by Philips has been used to implement a modular vehicle monitoring and management system known as TRANSMATION [101]. TRANSMATION differs from some other AVM systems, in that data processing and decision making are carried out on the vehicle, rather than at a control center. This is intended to increase processing and cost efficiency, and to reduce the need for communication on scarce radio channels.

The system's onboard unit consists of a terminal with push buttons to input the route and run number, the driver's identity, direction control codes and other required data. The terminal is interfaced with a microprocessor unit, which also connects to a two-way transponder installed on the underside of the vehicle. In addition, the microprocessor can be connected to passenger counters in the vehicle entry and exit points, and to an odometer for distance measurement. An example printout of data collected by the TRANSMATION system is presented in Figure 4.6.

4.8 Paratransit dispatching systems

Demand-responsive transit, or paratransit schemes have somewhat different needs than those of more conventional transit operations. This has led to the development of advanced technology systems specifically for paratransit operations.

In the U.S., for example, the Cape Cod Regional Transit Authority (CCRTA) has implemented a computerized management information system (MIS) for its b-Bus program [102]. When the MIS was first introduced in 1980, the b-Bus program was a 25-vehicle regional advance-reservation, demand-responsive service. Annual ridership exceeded 150,000, with a significant proportion of elderly and handicapped passengers.

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

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

Another system developed for paratransit is the West German Ruf-Bus system [7]. Ruf-Bus enables travel requests to be entered by passengers into computer terminals at bus stops. Data entered into the computer include the number of passengers in the party, so that a standard-sized bus, a mini-bus or a micro-bus can be dispatched in response to the request. The city of Friedrichshaven in West Germany has reportedly reduced annual transit operating costs by 20 percent following implementation of the Ruf-Bus system, and has also increased ridership, particularly in suburban areas.

In addition to the demand responsive service, the Ruf-Bus system can be used to control buses that call at stops with a predetermined frequency [103]. A further element of flexibility allows the system to deviate the route of fixed- schedule services when telephone requests are received from auxiliary demand stops. In periods of low usage, Ruf-Bus works in conjunction with a central dispatch computer to provide a purely demand-responsive service.

Some high-technology dispatching systems have also been developed specifically for application to taxicab fleets [104]. These combine computers, microprocessors and digital radio communications to improve taxicab management and dispatching activities. Such systems can increase the efficiency and speed of service for conventional purposes, as well as provide particular benefits for the transport disadvantaged.

The major elements of an advanced taxicab dispatching system are a microprocessor-based unit located in each vehicle, a central computer system and a communications system. Communications are provided digitally via telephone or radio links, relieving drivers and dispatchers of the inefficient task of voice communication. Strategically-positioned relay stations can be used to boost communications, if required.

In the operation of a typical advanced taxicab dispatching system, the customer would telephone the control center to request a vehicle. Appropriate data would immediately be entered into the central computer by an operator. The computer would then poll all available or soon-to-be available taxis, transmitting the pickup request to the closest vehicle. The microprocessor on the vehicle would respond automatically with a digital data message, enabling the dispatcher to confirm the customer's order and to provide an estimated time of arrival. As little as 15 seconds could be sufficient for this process to be completed.

In addition to providing this automated dispatching function, the system could be used to calculate demand, and to plan fleet requirements and allocate vehicles over an area. The system would also support

several other valuable services, including ridesharing requests, standing account management and route planning for package delivery.

Principal examples of the implementation of advanced taxicab dispatching systems to date have been primarily in Europe. One of the most advanced systems is known as Taxi-SO, which has been in commercial operation in Sweden since 1982. Similar systems are also operational in London, Zurich and Oslo. Although the technology has yet to be widely deployed in North America, the U.S. has developed technically similar systems for police departments, public utilities, fire departments and delivery firms. These systems are often highly advanced, and appear to have significant potential for improving the operation of taxicab fleets.

5. AUTOMATIC VEHICLE CONTROL SYSTEMS

5.1 Introduction

Automatic vehicle control systems (AVCS) can help vehicle drivers control certain vehicle functions, and may eventually relieve drivers of some or all of the vehicle control tasks. In the transit and rideshare environment, AVCS has the capability to improve traffic flow characteristics, provide a more reliable and convenient service, and contribute to greater safety.

AVCS functions can be very complex as they attempt to replicate the large number of interactions between the driver, vehicle and environment. The key roles undertaken by the transit drivers can be summarized as follows: (1) to observe the outside environment, including highway geometry, vehicles and obstructions; (2) to operate the vehicle's control system; (3) to feed back observations and compensate for changing situations; (4) to make decisions and select an appropriate trajectory ahead; and (5) to monitor the needs of the vehicle's passengers and take appropriate action where necessary.

On a journey, a driver is constantly required to assess vehicular lateral position, speed, and distance to vehicles ahead, and judge gaps for merging and passing. Additionally, the driver must anticipate the actions of other road users and make decisions on opportunities for getting through lane changes, merges, and intersections by achieving smooth braking and acceleration. Within the transit vehicle, there must be the ability for the passengers to exert some control over the vehicle. This can be implemented through the driver or by locating devices such as emergency brake controls or signals throughout the transit vehicle.

In the most basic form, AVCS will provide the driver with useful information and warnings. This information differs from that provided by the traveler information systems described in Chapter 2, in that it will be derived mainly from various onboard sensors. However, some overlap exist with the route guidance systems described in Chapter 2. Route guidance information would be analyzed by the onboard information system and combined with the current status of the vehicle. The directional information provided to the driver would then be supplemented with advice on correct speed and timing for smooth and safe maneuvering of the vehicle.

The next stage of implementation of AVCS is to provide assistance to the driver in controlling the vehicle. This can be achieved by allowing the control system to intervene and manage the vehicle under critical circumstances. In the transit applications these types of maneuvers may include merging into a stream of traffic, emergency braking due to an internal or external incident, and alignment of the vehicle at a terminal, platform or bus stop.

The highest level of AVCS is for the system to completely take over the driving tasks. This may be implemented as a permanent control system such as in a driverless personal rapid transit (PRT) system or as a manually-selectable option which could be used for a dual-mode bus.

The combination of high passenger-carrying capability and large centrally-operated fleets associated with transit operations makes them ideal candidates for the implementation of AVCS. Indeed, it is in the transit area where the greatest advances in vehicular control have been made. Today, there are numerous successful driverless automated guideway transit and people-mover facilities in operation. Dual-mode vehicles that have the capability of driving on normal roads and being automatically guided along specially tracked or mark lanes have also been used around the world.

Rideshare vehicles also offer an as yet unexploited opportunity for implementing AVCS. The desirability of separating these vehicles from the regular automobile allows them to be targeted as users of

specialized lane designs currently being considered to implement automatic vehicle control. However, careful consideration of the method of implementation will be necessary to ensure no disincentive to existing rideshare participants.

This chapter discusses the application of IVHS automatic vehicle control technologies in three categories: (1) automated guideway transit (AGT), including people movers, personal rapid transit and light rail transit; (2) dual-mode and conventional buses; and (3) rideshare applications.

Potential or existing applications of IVHS technology are reviewed under each of the above categories. For AGT, the discussions primarily focus on concepts and systems that are applicable to the other categories of vehicles or those that have been adapted from systems applied in other areas of IVHS.

The review of technologies applicable to buses covers a selection of systems ranging from driver warning to electronic guidance. Buses have many specific needs that are not directly applicable to the other types of vehicles. Particularly, the maneuvering of vehicles within busy bus terminals is unique to this form of transportation. Dual-mode vehicles also have individual requirements; a large amount of previous work has been carried out in this area. Much of this previous work has been concerned with mechanical guidance systems and providing alternative methods for powering the vehicle. These areas are briefly revisited to indicate areas where leading edge technology advances have the potential to provide significant benefits.

Automatic vehicle control technologies currently under development for the private automobile will be equally applicable to the rideshare vehicle. The final section of this chapter will provide a brief overview of these types of systems. This will be supplemented by a discussion of the implementation issues related to use of specialized lanes which are particularly suited to shared vehicles.

5.2 Automated guideway transit

AGT is a class of urban transit operating under automatic longitudinal and lateral control on exclusive guideways. This will often be a mono or twin rail arrangement, both to guide the vehicles and provide point contact for longitudinal acceleration. Many technology advances have been applied to create the networks of these vehicles implemented around the world. A significant proportion of these advances have been in the area of vehicle propulsion, and are not directly related to information technology systems, which form the basis of this review.

A particular innovation in this area that has seen much publicity is the use of the linear induction motor. The first system in the U.S. in daily usage that uses this technology was installed at the Walt Disney World Resort in Orlando, Florida, in 1975 [105]. The system, known as the WEDway People Mover, was subsequently installed at Houston Airport, where it has been operational since 1981. At Houston Airport, four 3-car trains operate on a 2-mile loop. The small number of vehicles that can be accommodated, and the low speeds of only 14 mph in these systems, imply that the control strategies and on-vehicle sensing systems may have little application in the more demanding IVHS arena.

Several innovative proposals have been received by the Regional Transportation Authority in Chicago for the system design phase of a Personal Rapid Transit System project [106]. A system proposed by the Personal Rapid Transit Corporation uses small-vehicle designs holding up to five passengers with a common destination. Mitchell Transit Systems, Inc. also proposes to implement a small nonstop vehicle. However, in this system the vehicle will hold only two people, allowing the vehicle to be very narrow and light.

Information technology has an important part to play in the control of AGT systems. A hierarchical vehicle management concept [107] could consist of two primary levels: a network controller and a vehicular controller. The two levels would be linked through some form of communication system. The network controller would use basic information on each vehicle and network status to issue commands to the vehicles.

The vehicle controller would base its maneuvers on the instructions received from the network controller.

Advances in microprocessor-based technology over the last two decades make it possible to implement “smart” vehicles. These smart vehicles require minimal instructions from the network controller and are able to operate autonomously in case of failure of the network management system or the communications system.

Two principal techniques are generally recognized for the longitudinal control of vehicles on AGT networks. These are known as point-following or synchronous longitudinal guidance (SLG) and vehicle-following. A point-following system regulates the position of each vehicle relative to a conceptual moving point. In a vehicle-following system, the position and state of each vehicle is governed by the state of neighboring vehicles. Both types of technique are applicable to the implementation of an automated highway system carrying any form of suitably-equipped vehicles. The restrictions and applications of the techniques to road vehicles are discussed in Sections 5.3 and 5.4.

Technology advances can provide increasingly powerful and reliable systems in which to implement the control strategies described above. Each vehicle, however small, would have at least one microprocessor unit which would accept signals from a variety of sensor processing units. In an advanced control application, the microprocessor systems may be responsible for:

Controlling the drive unit. AGTs may be driven internally or externally. Power will usually be derived from some part of the guideway, either by electrical contact or some form of induction. As well as controlling acceleration, the processor may use the motor driver to control deceleration by using regenerative braking techniques. Recent advances in linear electronic power devices and hybrid devices containing digital and linear power elements can allow implementation of a wide range of microprocessor power control strategies. This can help lighten the vehicles and provide improvements in the quality of the ride.

Monitoring emergency sensors. Emergency sensors may include obstacle detection, power failure, fire and smoke detectors, and passenger-activated alarms.

- Activating emergency braking or collision avoidance systems.
- Passenger information which can be derived in real-time from control system parameters that describe the vehicle.
- Monitoring lateral and longitudinal measurement sensors. Longitudinal sensing will be used to determine the position of the vehicle on its path and the position of neighboring vehicles. This may be carried out using dead reckoning with reference markers and communication with neighboring vehicles, or may use radar-type proximity detectors. Lateral sensing requirements will often be limited due to the construction of the exclusive guideway. However, there are many alternatives to the conventional mechanical guidance arms and longitudinal cables. For example, discrete points could be marked using small RF tags which would be capable of giving detailed location information and directional information to the next marker.
- Complex control algorithms taking into account vehicles dynamics under relevant loading conditions; condition of guideway; limits of acceleration that affect ride quality; and desired course.

Communication with network control system and other vehicles. This will permit the vehicle to pursue the desired course in an optimum manner. Change of direction, merging, etc., will be accomplished using these communication links. The maneuver may be calculated either onboard the vehicle or as part of the network controller tasks, depending on the control technique used.

- Routing strategies, These may be calculated within the vehicles from information generated by the network controller, other vehicles and the passengers. Vehicles may pass chosen routes back to the network controller for verification and to ensure interchanges and merges are prebooked and handled with minimum interruption to free flow.

5.3 Bus applications

Buses have long been a target for application of AVCS. This is due to the unique requirements and operational parameters associated with this form of public transit. The punctuality and predictability desired of bus services indicate a need to separate bus routes from the general flow of traffic, particularly in congested downtown areas. This requirement, combined with restricted availability of downtown land and a need to reduce noise and air pollution, points toward some form of automatically-guided or electrically-powered vehicle.

The same bus network will often also be used outside the central downtown area where it is uneconomical to install means of providing electrical power to the vehicle. It is also inconvenient and undesirable to require travelers to change services when they enter or leave these areas. These requirements have resulted in the concept of the dual-mode bus [108].

The dual-mode bus will run using automatic guidance where specially-designed guideways are constructed. In areas where this is not available, the vehicle may be controlled in the normal way. This facility is often combined with different drive technologies in order to implement the features described above. Buses have been demonstrated [108] that combine electric motor and diesel propulsion in the same vehicle. Such dual-powered buses have been put into service in downtown Seattle [109]. The use of overhead-powered electric drive has enabled much of the downtown service to be routed through specially built tunnels. This has allowed some journey times to be reduced from as much as 30 minutes down to only 8 minutes. Other vehicles may use battery storage to power the electric motor outside of the guideway/power supply area. The ideal dual-mode bus design uses a modular approach that allows the techniques discussed here to be mixed in any combination without major modification of the basic vehicle.

The dual-mode bus concept provides a number of advantages to both the operating authority and the traveler, including: punctual services due to minimal random holdups; narrow lanes and narrow tunnels in downtown areas, making efficient use of available land space; faster operation through no competition for road space; ability to use high-level platforms for bus entry due to accurate automatic alignment at bus stops, allowing better facilities and easier entry for the travelers; greater safety through reduced driver involvement in the decision making process; flexibility and user convenience arising from the ability to operate the vehicles within and outside downtown areas.

Recent technology advances in the areas of electric motors, high-power batteries and high-power linear electronic control devices are making such vehicles a more attractive proposition. Many automobile manufacturers have produced prototype automobiles that would be acceptable even to the discerning private motorist. The area of transit is more attractive for the electrically powered vehicle due to its less stringent requirements for acceleration and top speed.

Lateral guidance systems or automatic steering control (ASC) for buses have been provided by mechanical linkage. Guiding wheels are usually connected to the front axles of the vehicle and act directly on the steering mechanism. Mechanical guidance systems can suffer reliability problems due to the protuberance of guidance wheels from the side of buses and the limited ground clearance. Tests of a MAN guided bus, under consideration for potential application in the Seattle area revealed the possibility of problems associated with damaging the guide arms when pulling up to bus stops. The same buses achieved a guidance arm failure rate of 1 in 30,000 miles in Essen, West Germany. The guided bus system is also in operation in Adelaide, Australia.

Alternatives have been provided using electronically regulated guidance. With this method, a cable is laid in the center of the roadway. Sensors on the front vehicle interface with a microcomputer to provide measurements of deviation from the ideal path. Microcomputer-controlled hydraulic activators are connected to the steering mechanism to adjust the course of the vehicle as necessary. When activated, the guidance system provides total lateral control.

Mechanically guided buses were successfully demonstrated in Essen, West Germany in the early 1980s [110]. The trial system used a dual power option providing diesel-powered operation outside the central area and pollution-free electric operation in certain areas with overhead power cables. Representative surveys on the initial test route indicated that both passengers and drivers were extremely satisfied with the operational quality of the system.

Both techniques described above are applicable to the automatic lateral control of the vehicle. Longitudinal, or speed and headway, control remains the responsibility of the driver. An alternative approach that can combine lateral and partial longitudinal control can be implemented using discrete markers in the lane. The markers would be read by onboard sensors as the vehicle traveled down the lane, providing lateral and longitudinal position information.

Markers may be implemented in a variety of ways, each with its own advantages and disadvantages and current development status. A selection of these marking methods can be briefly summarized as follows:

- Reflective paint is easy and inexpensive to apply to the road surface. Sensor technology is available to extract positional information but has not been reliably demonstrated or proven for this application. Optical systems such as this are also prone to significant interference from precipitation and dirt and to attrition of the markings.

- Metallic or magnetic markers are relatively easy to install into slots or holes in the road surface. Current sensor technology is capable of determining the required information from such markers, but is susceptible to interference from other metallic objects embedded in the road surface.

- Microwave-activated, silicon chip-based marker tags would be able to provide relatively large amounts of information at each point. This would allow a large amount of redundancy to be built into the system, improving the highly important safety aspects. The markers or tags would require a more complex installation, with each tag being individually programmed prior to being carefully positioned in the roadway. Although this concept is feasible with current state-of-the-art technology, significant research and development work would be required before a system could be implemented.

A further method of providing combined guidance facilities is to use video cameras and video image processing technology. Several research projects into such systems are currently underway such as that being undertaken by Texas A&M University [111]. This system uses stereo cameras to provide detailed three-dimensional information. Systems of this type also provide additional facilities essential to providing a complete AVCS, including obstacle detection and vehicle following. Obstacle detection is important for ensuring unusual events are reorganized and collision avoidance measures can be activated at the appropriate times. Vehicle-following facilities allow automatic control of headway between vehicles. This is important when increasing capacity or service by closely spacing or platooning vehicles. Radar-based systems that can implement these applications are also under development.

The final area applicable to providing a high level of bus automation is inter-bus communication. In an ideal fully-cooperative bus lane or as part of an AHS, vehicles will communicate to provide optimum merging and priority maneuvers. Such systems could be radio-based and would allow vehicle position, immediate maneuvers and priorities to be passed between neighboring vehicles. Although these systems could

theoretically provide vehicle-following capabilities, a backup obstacle detector such as radar or video is essential if the safety of the passengers is to be assured.

The systems described above are particularly applicable to bus applications. The nature of bus transit operations make them the ideal candidate for implementation of such technologies. This fact is corroborated by the amount of effort that has been expended internationally in researching, developing and implementing basic guidance systems in bus transit vehicles. Factors which make this the ideal environment include: large vehicle fleets; requirement for dedicated lanes, using minimum space; close collaboration between transit and highway authorities; good public perception of automated transit; high frequency usage of some routes; and regular professional maintenance and safety checks.

Large vehicle fleets operated by a single organization will allow the cost of the AVCS to be minimized. It is also possible to implement the system on a large number of vehicles simultaneously. This is essential if an efficient automated system is to be implemented. Communication between vehicles and to the control center is also desirable in implementing other applications, such as those described in the sections covering ATIS and FMCS. Further advantages lie in the similarity between individual vehicles and hence the similarity between the control characteristics. This will allow the control systems to be identical rather than having to fine-tune each system for different vehicles.

As previously described, the utilization of AVC allows narrower lanes to be used because of the greater predictability of vehicle path. This may allow dedicated bus lanes to be implemented in areas where there are tight restrictions on available road space. The large vehicle fleets also ensure that the dedicated lanes receive high early usage. This is essential if maximum benefits are to be gained and a good return on investment is to be immediately visible.

The close collaboration between highway and transit authorities will help to ensure that an integrated and compatible system is implemented. The authorities can work together in the sound knowledge that the system will be fully utilized when complete. Creating a suitable AVC infrastructure for the private motorist has risks and complexities associated with ensuring that a large take-up rate is achieved.

The general public has already demonstrated an acceptance of automation in the transit environment. Millions of journeys are made every day on driverless automated trains or AGTs. The application of automation to the road transit vehicle should be simply an extension of this acceptance. Conversely, the private motorist may require significant persuasion before being willing to pass control of his car to an automated system.

Bus routes are usually well defined and, especially in downtown or central business areas, handle a high volume of vehicles. The routes of the vehicles will vary little and will have significant common elements between different services. This type of travel lends itself well to platooning of vehicles, a method of effectively increasing roadway capacity. It is essential that automatic vehicle guidance equipment is inspected regularly since so much reliance is placed on safe operation. The maintenance and safety inspection of buses is strictly controlled, again making them good candidates for implementation.

Obstacle warning and maneuvering guidance is a final area where bus operations can benefit from the application of vehicle control-based technology. These systems fall into the lowest level of AVC, providing the drivers with assistance in their task. A basic system, using video cameras and monitors external to the vehicles, is provided as part of a safety system installed at the Oslo bus terminal [112].

There are a number of commercially-available systems providing this type of information. These provide control data to the driver in a variety of forms, ranging from video displays of blind spots, to measured distance to the nearest object. The Electronic Backing system supplied by Fleet Specialties [113] provides a combination of warnings of front or rear obstacle with a linear distance-to-object measurement. More

comprehensive information is provided by the “Eagle Eye” manufactured by Chase Manufacturing, Inc. The Eagle Eye provides both reversing and passing visual and auditory warnings if an unsafe condition is detected.

5.4 Rideshare applications

The previous section focused primarily on the application of AVCS to buses. Many of the technologies discussed are equally applicable to the ridesharer’s automobile. However, many of the advantages highlighted at the end of Section 5.3 do not apply in the rideshare environment. The greatest hurdle to be overcome may be that of negative public perception.

Use of full AVCS for buses and AGTs will help to increase public awareness and confidence in this technology. A phased implementation of the various AVCS techniques will help provide an awareness to the general motorist. An additional disadvantage unique to ridesharers is that, often, the same vehicle will **not** be used every day. Car owners often take turns in providing their car and driving. The result of this may be that several travelers would have to invest in the AVC equipment if the full benefits are to be derived.

Even considering the additional issues to be addressed, rideshare or cat-pooling participants could make a suitable target for early-implementation AVCS technology. The participants have already demonstrated a commitment to improving their daily commute and may therefore be more accepting of technological assistance. Ridesharers also often have the use of dedicated travel lanes. The operation of such lanes, and so the attractiveness of ridesharing, could be enhanced by requiring that HOV lane users have some level of AVCS.

6. TECHNOLOGY ASSESSMENT

6.1 Introduction

This chapter presents an evaluation of selected advanced technologies that can be applied to transit and rideshare operations. Following this introductory section, the results of this initial assessment are presented for each of the major technology areas described in this report.

The operation of transit and rideshare facilities can be identified as having a number of benefits for the transportation system and for society as a whole. First, transit and rideshare options take a proportion of motorists off the road and put them as passengers in higher-occupancy vehicles. This decreases the total number of vehicles on the highway network, thereby decreasing congestion, fuel consumption, air and noise pollution and accidents.

The motorist benefits of high-occupancy travel have recently been estimated by comparing existing traffic conditions in six urban areas of Texas with alternative scenarios in which transit does not exist [114]. This analysis assumed that all transit users would switch to private vehicle travel, with associated costs then resulting from reduced speeds, increased delays, vehicle operating costs and accidents. On this basis, the annual benefits of transit on the six urban areas were found to be approximately \$348 million, rising to \$484 million in 1992. Half of this benefit could be attributed to lower motorist operating costs, with 40 percent related to time savings and 10 percent due to accident savings. Contributions to the total benefit of \$348 million per year ranged from \$168 million in Houston to just over \$4 million in the smaller Austin area.

A second major benefit area of transit systems is in supporting the economy of a community or state. Expenditures on transit are used to provide jobs, wages and increased sales, the effects of which can circulate throughout the economy. The importance of these expenditures has been estimated using an input-output model, in conjunction with the traffic impacts analysis outlined above [114]. This found that the income impacts of transit expenditures for 18 systems in Texas amounted to over \$243 million in 1986. It was also estimated that the transit services provided an additional 2,907 jobs.

The third area in which transit provides substantial benefits is in supporting the mobility of the disadvantaged. Public transportation offers one of the major travel options for citizens who do not have access to an automobile, or for whom personal transportation is not physically or economically feasible. In particular, public transit plays a vital role in serving the needs of the elderly or disabled, often on a demand-responsive basis.

Clearly, then, transit facilities and rideshare schemes are desirable elements of a transportation system from operational, economic and social viewpoints. The application of advanced technologies to these travel options should aim to extend these important benefit areas. The overall philosophy in applying advanced technologies to transit and rideshare schemes can therefore be seen as:

1. To improve facilities, in order to better serve existing transit and rideshare users.
2. Through service improvements, to draw more travelers toward the transit and rideshare options, thereby further reducing the number of private vehicles on the network.
3. To make operation of transit and rideshare services more efficient for the managing agencies.

These are the major objectives underlying the use of advanced technologies within the transit and rideshare environment. However, each individual technology or system will have its own different areas of benefit, contributing to these overall goals. A number of benefit areas have been investigated in this study, as outlined in the following paragraphs.

The first area of benefit considered by the study team is time savings. These can be attributed to reduced passenger waiting time at a boarding location, or reduced traveling time in a transit or rideshare vehicle. People generally have a strong tendency to dislike excess time involved in travel, suggesting that this could be an important factor in improving the image of these transport modes.

Another benefit area is fuel savings. These will occur primarily as a result of improving service efficiencies, for example by reducing the number of vehicles required or the amount of delay experienced on a route. Reduced fuel consumption will also lead to environmental improvements in terms of air quality. Other potential environmental benefits include less noise pollution and land requirements.

Traffic safety has been an important consideration in most of the major IVHS initiatives to date. This will be equally applicable in the area of transit and rideshare schemes. Since users of these facilities have effectively placed their trust in another driver's control, safety is perhaps of even greater significance for transit and rideshare operations than for general highway traffic. In addition, since transit and rideshare vehicles contain more passengers than private automobiles, the consequences of an accident can potentially be more severe. Safety is therefore an important benefit area in the context of this study.

Another area in which advanced technologies can benefit transit and rideshare schemes is in improving levels of traveler comfort and convenience. While passengers' physical comfort is inevitably one important consideration, advanced technologies can be used to improve travelers' confidence in a service. This could be achieved, for example, by providing passengers with pretrip or journey information, removing the element of uncertainty that many travelers find disconcerting. In a related area, advanced technologies can be used to enhance the safety and security of transit or rideshare operations, protecting both the driver and the passengers.

Efficiency and productivity is a further benefit area for the application of advanced technologies to transit and rideshare schemes. This essentially relates to improving the operation of a service for a managing agency. Potential efficiency and productivity gains include reducing the number of staff required to operate a service, reducing the number of vehicles needed to satisfy demand, or increasing the productivity of a service using existing resources.

Transit and rideshare operations can also be improved in the areas of reliability and dependability. For the traveler, one of the most desirable features of a transit service is reliable schedule adherence. Where data on a service are obtained, it is important that these are up-to-date, accurate and consistent with alternative sources. In addition, advanced technologies can assist in providing reliable and consistent data sources for management and planning activities.

The final benefit area considered by the study is incentives for use of transit or rideshare facilities. Some approaches may provide indirect incentives, attempting to increase usage by improving overall levels of service and therefore attractiveness. Other techniques may offer more direct incentives, such as the dedication of reserved facilities for transit and rideshare vehicles. In addition, advanced technologies can offer disincentives for violation of reserved facilities by unauthorized users.

In evaluating the advanced technologies reviewed in previous chapters of this report, an assessment framework approach has been adopted. For each of the four broad technology areas, an assessment framework has been developed outlining the principal benefits of the various systems and approaches. These have been assessed qualitatively by the study team, and are presented in the benefit areas outlined above.

The technology assessment has also included an investigation of the costs of various systems within the broad technology areas. Costs encompass not only the purchase and installation price for new equipment, but also costs of training, commissioning and ongoing operation and maintenance. A further item that has been considered under the overall heading of cost is any disbenefits to general traffic that may be caused by the introduction of transit- or rideshare-preferential measures.

Where costs have been presented for advanced technologies, the principal source has been existing literature, in accordance with literature used for the technology reviews of the previous chapters. Where appropriate, the study team has also used its knowledge of similar systems or system components to develop technology cost estimates.

6.2 Advanced traveler information systems

As described in Chapter 2, there is a range of advanced technologies and systems that can be placed within the overall category of ATIS. For the purposes of the technology review, these were divided into four areas of application, covering pretrip planning information services, trip reservation and payment systems, in-terminal information systems and in-vehicle information systems.

In carrying out the ATIS technology review, it was noted that some systems and technologies were applicable to more than one of these four areas. For example, systems for the provision of pretrip planning information can also be used to support trip reservation and payment activities, in some cases. The technology assessment has therefore focused on the overall benefits of individual systems or approaches, rather than examining benefits in the four application areas. The principal ATIS technologies selected for evaluation in this section are as follows: automated telephone information systems; computer information retrieval; teletext data displays; smart card or interactive credit card systems; automatic personal identification; information display and announcement systems; interactive video and audio terminals; dynamic rideshare routing; and in-vehicle communications facilities.

The overall benefits of these technologies and systems are summarized in an assessment framework, shown in Table 6.1. Further discussion is presented in the following paragraphs.

The main applications of automated telephone information systems are in providing travelers with **service** and schedule data, and in permitting advance trip reservation and payment. From the travelers' point of view, the principal benefits of these facilities will be increased availability and accuracy of data, resulting in greater confidence in the service. The availability of up-to-date information on estimated vehicle arrival times should also help to reduce unnecessary waiting time at boarding areas. This feature will also help serve to lessen travelers' vulnerability to crime while they are waiting for transit vehicles.

There will also be benefits in implementing automated telephone information systems from the transit operator's perspective. First, by improving information services through the introduction of a new system, the operator will hope to increase ridership. This will be translated into additional revenue in fare payments. A second area of benefit for the transit agency concerns the employment of information operators. Depending upon the level of complexity adopted in an automated telephone system, an operator could seek to achieve staff savings, an increase in productivity of existing staff, or reduced training requirements.

The costs of an automated telephone information system will also be dependent on the complexity and functions of the technology selected. One example, the WMATA/AIDS, was implemented at a system cost of just under \$1 million [1]. This system uses an agent to answer a telephone call, obtain information from a terminal and relay it to the customer. A system involving a higher degree of automation than this would potentially cost more to introduce, but could lead to significant staff savings in the longer term.

Benefit Areas									
Technology	Time Savings	Fuel Savings	Environmental Considerations	Traffic Safety	Comfort & Convenience	Safety & Security	Efficiency & Productivity	Reliability & Consistency	Incentives
Automated telephone information	Reduced waiting/booking time	None	None	None	Increase confidence; data easily available	Less waiting time and cash handling	Reduce staff; improve work rate	Provide reliable real-time data	Increase service awareness
Computer data retrieval	Reduced waiting/booking time	None	None	None	Increase confidence; complex planning facilities available	Less waiting time and cash handling	Reduce staff; improve work rate	Provide reliable real-time data	Interactive data retrieval
Teletext	Reduced waiting time	None	None	None	Convenience of television display	Less waiting time	Match travelers to transit operations	Provide reliable real-time data	Easy to obtain service data
Smart cards	Reduce payment and boarding time	Small benefit from boarding time savings	Small benefit from boarding time savings	None	Convenient form of payment	Passenger profiles; reduce cash handling	Improve financial reconciliation	Reliable data for transit operators	Fare reductions and convenient payment
API	Minimum payment time	Some benefit	Some benefit	None	No manual payment action required	Passenger profiles; reduce cash handling	Improve financial reconciliation	Reliable data for transit operators	Fare reductions
Display/announcement systems	Some benefit	None	None	None	Reduced anxiety	None	Supports more efficient operation	Provides reliable data	Increased traveler awareness
Interactive video/audio terminal	Some benefit	None	None	None	Reduced anxiety; hard copy trip plans	None	Reduced staffing requirements	Reliable data source	Interactive data service

Table 6.1 ATIS assessment framework

Benefit Areas									
	Time Savings	Fuel Savings	Environmental Considerations	Traffic Safety	Comfort & Convenience	Safety & Security	Efficiency & Productivity	Reliability & Consistency	Incentives
Technology	Eliminate excess time and VMT	Savings through reduced travel	Reduced noise and air pollution	Reduced exposure to risk	Avoids congestion; aids route following	Rideshare participant profiles	Efficient use of rideshare facilities	Detailed route and operational data	Rideshare encouragement
Dynamic rideshare routing system									
In-vehicle communications systems	Allows work during journey	None	None	None	Convenient facility for travelers	Emergency application	Source of revenue for operator	None	Improved appeal

Table 6.1 ATIS assessment framework (continued)

While automated telephone information systems would offer one method of improving information services and trip reservation and payment facilities, an alternative approach would make use of computer terminals. In this case, the customer would access the transit agency's database via a personal computer. This would be supported by a communications link such as a fax machine or modem. The benefits of this approach would be similar to those of the telephone system discussed above. Using a computer, the customer would also be able to obtain a detailed record of the requested travel information or booking confirmation. However, the adoption of this approach would require users to have access to an appropriate computer, which would inevitably limit the system's appeal to those with the suitable equipment.

A further benefit associated with the use of either of the approaches described above will lie in the area of payment for transit usage. By allowing travelers to pay in advance, for example using credit cards, waiting lines and hence delays at transit terminals will be reduced. In addition, the increased use of credit cards for payment will reduce cash handling requirements, improving security and accounting procedures.

Another technology that can be used to provide transit schedule and service information to travelers is teletext. Again, this would enable travelers to review the current status of transit services and select the appropriate travel option. Increased ridership and reduced waiting times could therefore be expected to result from the introduction of this technology. Since teletext would not provide a communications link to a transit agency's database, it would be unable to provide personalized travel data available from other systems. However, teletext would have one important advantage in that users would simply need to switch on their television to obtain data, rather than contacting the transit operator.

Teletext has already been available for several years in Europe, where it is used to broadcast a variety of data. These include news, weather, and financial information, in addition to transit and other travel data. Teletext-compatible televisions typically cost around \$100 more than conventional units, and represent a sizeable share of the market. However, the cost of implementing a teletext service in the U.S. would be high, requiring the purchase of data coding and transmission equipment. This would appear to make the introduction of exclusive teletext services by transit agencies unlikely. A more promising approach would therefore be for transit agencies to obtain transmission time on teletext services operated by others. In California, for example, Caltrans has introduced an experimental teletext channel to broadcast highway condition data to motorists [10]. With suitable cooperation between Caltrans and the transit operators, this system could also be used to broadcast transit information to California commuters.

Another technology investigated in the category of ATIS was smart cards. Smart card systems can be used to automate reservation and payment procedures, and to support in-terminal information systems, as described in Chapter 2. Interactive credit card reading systems can also be employed for similar purposes, effectively representing a very low level of smart card complexity.

The principal benefit of smart cards for the traveler will be in reducing the delay and complexity involved in entering a transit vehicle and paying the fare. Cash handling will be reduced, and the convenience of travel by transit will be improved. In addition, the use of smart cards offers the potential for flexible fare schemes and travel discounts, which may help to increase ridership. From the transit operator's perspective, smart card payments will assist in financial reconciliation activities, and will reduce the risk of farebox theft from transit vehicles. Smart cards will also have a number of benefits in the area of fleet management, as discussed later in this chapter.

The cost of implementing a smart card scheme will vary according to the complexity and features of the equipment chosen. Simple card readers, such as those that only obtain a passenger identification number, could be expected to cost around \$2,000 per unit. Corresponding cards would then be of very low cost, effectively representing the same technology employed in credit cards. Prices would increase as the amount of data required on the card was expanded, and the processing capacity of the card enhanced. However, one of the major cost elements would come not from the smart card hardware, but from the software development

needed to support the system. In the German system being implemented in Lower Saxony described in Chapter 2, this work is being carried out by a private contractor at a cost of approximately \$330,000 [12].

API technology can provide many of the functions of smart cards, while further increasing convenience for the user. This is because travelers will no longer need to swipe their card through a reader unit in order for the card data to be reviewed. Passengers will therefore be able to enter the transit vehicle at an increased rate, and will not be required to perform any action in paying their fare. The increased boarding rate will also assist the transit operator in adhering to schedules, since lengthy boarding delays will be avoided.

The cost of API will be higher than that of smart cards, reflecting the need for a short-range communications link between the tag and the reader. However, a simple identification system could still be of relatively low cost, with tags priced at around \$5 each and readers costing \$5,000. Again, one of the major cost elements would be software development for the operating system.

A proven technology area that can provide substantial benefits for travelers is information display and announcement systems. As described in Chapter 2, there are several alternative approaches in this area, including flap displays, matrix displays, television monitors and audio systems. Each technology has its merits, and should be chosen carefully to match the cost and the application.

Possibly the major benefit of these systems is in providing arrival or departure time details at boarding areas or terminals. This information has been shown to reduce travelers' perceived waiting times [18], increasing the attractiveness of travel by transit. Information display and announcement systems can also provide data to assist travelers in planning journeys and selecting routes. This could ultimately also benefit the transit operator, since better-informed travelers will permit more efficient operation of the transit service.

At an increased level of complexity, interactive video or audio terminals can be used to supply travel data at terminals or boarding areas. These would provide similar categories of data to the information systems described above, though tailored to the needs of the requesting travelers. Users will therefore be able to obtain specific route information and departure and arrival times, rather than having to review a display system or listen for an announcement. Terminals will also be capable of supplying hard copies of trip details, providing travelers with a continued source of reference during their journey.

For the transit operator, interactive information terminals offer the potential for staff reductions, based on the reduced need for manual information centers. However, this must be weighed against the higher cost of interactive approaches over the conventional information systems discussed previously. As with many other technologies, the cost of interactive information terminals varies greatly according to complexity and characteristics. However, the technology is affordable for major transit agencies requiring a large number of terminals, since additional terminals are available at minimal extra cost following initial implementation.

A longer term goal that was investigated in Chapter 2 of this report is dynamic rideshare routing. This would assist users to identify fellow rideshare travelers and to book rideshare journeys in advance, and would also provide ridesharers with optimum routes to their destination. Features such as these could substantially enhance ridesharing as a travel option, drawing significant numbers of users from private automobiles.

One of the major technology elements of the dynamic rideshare concept is externally-linked route guidance. This would be used to direct travelers to the rideshare parking lot, as well as to plan journeys from the lot to a list of traveler drop-off points.

Inevitably, the implementation of an externally-linked route guidance system in a sizeable urban area will represent a major financial commitment. In NCHRP 3-38(1), the study team calculated that the cost of equipping the Seattle urban area with a route guidance infrastructure would amount to approximately \$10 million. In order for an externally-linked route guidance system to operate successfully, however, a significant

number of vehicles must also be equipped with the appropriate equipment. This enables the system to collect travel time data and establish traffic conditions in different routes.

Some previous discussions of externally-linked route guidance have therefore asked the question: "Who will provide the initial market?" One possible answer to this would be to supply the initial onboard equipment to transit and rideshare vehicles. In addition to supporting the increased mobility of these vehicles, this solution would also provide a suitable fleet for the traffic analysis component of the route guidance system.

The final technology considered in the area of ATIS is in-vehicle communications systems, such as pay telephones. While having no operational benefit, these could greatly increase the appeal of travel by transit vehicles. This would be particularly true for business travelers, who would be able to continue their work during journeys. In-vehicle communications devices could also be used to report emergencies or incidents occurring in the vehicle or witnessed by the driver or a passenger. An extra source of revenue for the transit operator would additionally be created by the introduction of the in-vehicle facilities.

6.3 Advanced traffic management systems

The second area of advanced technology reviewed in this study was ATMS. As indicated in Chapter 3, ATMS approaches generally involve combining more than one technology to support a traffic management philosophy. In the context of this study, the traffic management philosophy is to provide some form of priority or preferential treatment. Chapter 3 identified three principal areas in which this can be achieved: signalized intersections, specialized highway environments, and identification and enforcement of vehicles abusing transit or rideshare-reserved facilities.

Within these three areas of application, a range of ATMS strategies has been investigated. Many of these can operate around the same technical approaches toward vehicle detection and identification, required in several transit and rideshare priority schemes. The second major element involved in ATMS is the control function, initiating traffic management strategies on the basis of the vehicle detection and identification data. The technology assessment outlined in this section of the report has focused upon combinations of advanced technologies supporting the following ATMS approaches: traffic signal optimization; traffic signal preemption; responsive network control; access control for reserved facilities; surveillance, communications and control for reserved facilities; priority at toll plazas and parking lots; automatic violation detection on reserved facilities; red light enforcement; and telephone enforcement. The major advantages of these ATMS approaches are summarized in the assessment framework of Table 6.2. Benefits of each approach are discussed further in the following paragraphs.

The first application of advanced technologies considered in the area of ATMS was the optimization of traffic signals in favor of transit or rideshare vehicles. This would involve resetting signal timing plans to achieve minimum person delay, rather than minimum vehicle delay. The technique would be particularly applicable for transit vehicles with well-defined routes and schedules. However, the approach could also potentially be used in favor of rideshare vehicles, given a suitable knowledge of HOV routes and occupancy data.

The optimization of traffic signals for transit or rideshare flow could be undertaken both for isolated intersections and over integrated networks. In either case, signal timing programs that could be used to calculate the revised timing patterns already exist. As described in Chapter 3, this would simply require the optimization process to be based on passenger flow levels, rather than vehicle flow levels.

Retiming of traffic signals would therefore be a relatively low-cost traffic management option, requiring little or no new equipment. The major cost elements would be the data collection effort to obtain the necessary details for input to the optimization software, and the labor associated with operating the software

Benefit Areas									
Technology	Time Savings	Fuel Savings	Environmental Considerations	Traffic Safety	Comfort & Convenience	Safety & Security	Efficiency & Productivity	Reliability & Consistency	Incentives
Optimized traffic signals	Overall reduction in journey times	Uncertain	Uncertain	Uncertain	Less delayed vehicles	None	Improved service efficiency	Reduced variability of transit times	Level of service improvement
Traffic signal preemption	Significant benefit for delayed vehicles	Uncertain	Uncertain	Uncertain	Less early and late arrivals	None	Improved service efficiency	Reduced variability of transit times	Less chance of delay
Responsive network control	Substantial benefit	Uncertain	Uncertain	Uncertain	Optimized transit services for maximum convenience	None	Increase vehicle productivity	Provides reliable travel data for operator	Substantial service improvements
Reserved facility access control	None	None	None	Some benefit	None	Prevents unauthorized use	Reduced enforcement required	None	Demonstrates commitment
SCC system	Control traffic for optimum flow	Some savings	Reduced noise and air pollution	Identifies hazardous situations	Improves conditions on facility	CCTV monitoring	Improved monitoring efficiency	Reliable data fed-back to travelers	Improved traffic flow
Reserved toll/parking lanes	Major benefit	Uncertain	Uncertain	Uncertain	Gains in reduced waiting time	None	Efficient use of access points	None	Reserved lanes and cost incentives
Violation detection	None	None	None	Some benefit	None	Deters unauthorized use	Reduced police enforcement	Reliable data on usage and occupancy	Disincentive to violators

Table 6.2 ATMS assessment framework

Benefit Areas										
	Time Savings	Fuel Savings	Environmental Considerations	Traffic Safety	Comfort & Convenience	Safety & Security	Efficiency & Productivity	Reliability & Consistency	Incentives	
Red light enforcement	Prevents accident-induced congestion	None	None	Major benefit	None	Deters red light violators	None	None	Demonstrates commitment	
Telephone enforcement	None	None	None	None	None	Deters violators	Reduced police enforcement	None	Feeling of involvement	

Table 6.2 ATMS assessment framework (continued)

and implementing the changes. For transit vehicles, however, information routinely collected by the transit operator will provide much of the data needed for the optimization process. In addition, conventional traffic signal timing plans should in any case be revised regularly to accommodate recent changes in traffic demand. Retiming in favor of transit vehicles will therefore not represent a substantial cost for the highway authority.

The main benefit of optimizing traffic signals in favor of transit or rideshare vehicles will be in improving the throughput capacity of an intersection, in terms of the total number of travelers. This will principally be achieved by reducing the delays imposed on HOVs at signalized intersections. In the U.K., for example, an experiment implemented in Glasgow realized increases in bus speeds of 9 percent, 8 percent and 7 percent during the morning peak, off-peak and evening peak, respectively [45]. The overall reduction in time spent delayed by signals was 16 percent. These benefits were achieved by simply retiming the city's traffic signals using the TRANSYT program, increasing the weighting of buses by a factor of ten to take account of their increased occupancy levels.

While reduced delay and increased speeds will be the major advantages, they will also lead to several further benefits. First, transit vehicles will be able to adhere more strictly to their schedules. In addition to assisting operation by the transit agency, this will greatly improve services for the travelers. Passengers will also benefit from the perceived reduction in waiting time and delay at traffic signals. Overall, these improvements could help to make services more attractive to the traveler, thereby leading to increased ridership and farebox revenue.

Some vehicle operating cost reductions could also potentially be achieved by optimizing traffic signals for HOVs. By experiencing reduced stops and delays, wear and failure of various vehicle components will be reduced. Fuel savings can also be anticipated in the preferred vehicle types, subsequently leading to reductions in air pollution.

An inevitable consequence of retiming traffic signals in favor of transit or rideshare vehicles is that vehicles traveling along other routes may experience increased delays. In the Glasgow experiment discussed earlier, cars traveling off bus routes faced a 15 percent increase in journey time. This was offset substantially by reduced delays to vehicles traveling along bus routes. It could also be argued that increased delays to private vehicles are justified on the basis of overall efficiency increases in people-moving capacity. However, the vehicle emissions and fuel consumption impacts of this should be considered carefully before embarking on a signal retiming process.

A second way in which transit or rideshare vehicles can be offered priority at signalized intersections is through signal preemption measures. These would identify preferred vehicles on the approach to an intersection, activating the signal in order to reduce their delay. The technique has been widely applied to transit operations, using AVI technology for vehicle detection. Conceptually, a similar approach could be introduced for rideshare vehicles, though at greater cost and complexity.

Like signal optimization, the main benefit of traffic signal preemption will be in reducing stops and delays for transit vehicles. However, signal preemption techniques will provide a greater degree of control than optimization. This is because the traffic signal will need to be activated in favor of the transit vehicle only if it is found to be running behind schedule. As a result, schedule adherence in terms of both early and late arrival can be improved. Again, this will make services more attractive for travelers, and will also reduce vehicle operating costs.

In the Netherlands, where AVI has been widely applied for traffic signal preemption, the approach has been found to greatly reduce variations in transit journey times [36]. In some areas, service improvements have been sufficient to permit the transit operator to reduce the number of vehicles operating, representing substantial cost savings. Significant increases in ridership have also been reported as a result of the introduction of signal preemption measures in the Netherlands.

The integration of the two approaches described above--signal optimization and preemption--leads to the concept of responsive network control. This would detect transit vehicles traveling within the network and make real-time adjustments to traffic signal timing plans. Though this could be achieved at various levels of cost and complexity, signal timing programs already exist that could be used for this application without extensive alteration.

One example of responsive network control is the SCOOT system, described in Chapter 3. SCOOT uses inductive loop sensors to provide traffic data for real-time traffic signal variations. Theoretically, the inductive loops could also be used to detect transit vehicles, enabling SCOOT to take account of their higher occupancy levels in calculating timing plans. This could potentially provide significant reductions in transit vehicle stops and delays, improving services and operating costs.

Another area considered within the overall category of ATMS was specialized highway environments, including reserved highway lanes and ramp bypasses. One potential application of advanced technologies here is to introduce access control schemes, ensuring that only authorized vehicles obtain the intended benefit. This would be achieved using a physical barrier, which would be activated by some form of detection system such as AVI or AVC.

In general, the implementation of access control schemes will have little impact in reducing delays, increasing speeds or saving fuel. In some cases, the introduction of a barrier may require vehicles to reduce speed as they approach the access control point, causing a slight disbenefit in this area. However, the major benefit of access control systems will be in preventing the use of reserved facilities by unauthorized vehicles. This will ensure that the facilities are used efficiently, in the intended manner. It will also be possible to reduce manual enforcement activities, potentially providing substantial cost savings.

A further justification for the introduction of access control systems will be in demonstrating commitment to transit or rideshare operations. Where reserved facilities are subject to frequent violations, this may lead to the public perception that a priority scheme has failed. Among some travelers, there may also be an element of the "if they can get away with it, I can get away with it" philosophy. By installing access control equipment, authorities will prevent unauthorized use and encourage legitimate vehicles.

As with other ATMS approaches, the cost of introducing access control will vary according to the complexity of the system. For transit vehicles, a low-cost solution would involve barrier activation by AVC equipment. This might be priced at around \$10,000 per access control point, with no on-vehicle equipment required. A more reliable approach would involve AVI technology, and might then cost \$20,000 per entry point. This solution would also require on-vehicle transponders, typically priced at around \$40 per unit. While the cost to equip a transit fleet could be acceptable, the investment required to extend a scheme to rideshare vehicles would be more substantial. Costs of transponders could be passed on to ridesharers, though this may act as a disincentive to potential participants.

A traffic management approach that would involve the combination of several advanced technologies is the surveillance, communications and control (SCC) system, described in Chapter 3. This would be used to monitor and optimize traffic flow on transit and rideshare reserved facilities. By improved monitoring and incident detection, congestion would be cleared more quickly and hazardous situations avoided. As a result, delays, fuel emissions and air pollution will be reduced. While this is operationally desirable, it will also make travel on the reserved facilities more attractive, acting as an incentive to potential users. The increased efficiency of monitoring activities may also enable highway authorities to reduce staff in control centers.

SCC systems can involve a number of alternative traffic management approaches, and can therefore be implemented at a range of costs. For illustrative purposes, however, an evaluation of SCC system in Texas calculated an average SCC hardware cost of \$265,000 per mile [51]. This included terminals, access ramps, variable message signs, CCTV cameras, incident detection and lane and traffic control signals. The study noted

that this represented less than 5 percent of the cost of constructing a typical at-grade transitway with elevated interchanges.

Another area in which transit or rideshare vehicles can be treated preferentially is through providing priority access or reserved lanes at toll plazas or parking lots. This could be supported by AVI or some other form of vehicle identification equipment. The approach would enable preferred vehicles to pass through reserved lanes, avoiding the waiting lines experienced by private automobile travelers. This will reduce stops and delays, making the use of transit or rideshare options more attractive for the traveler. Fuel consumption and air polluting emissions will also be reduced among these preferred vehicle types. However, this must be weighted against increased fuel consumption among private automobiles.

A further way in which transit and rideshare vehicles could benefit from the use of advanced technologies at toll plazas or parking lots is in fee payment. Using AVI or a similar approach, these vehicles could be charged a lower fee than that applied to private automobiles. This would provide an additional incentive for travelers to use these modes of transportation.

As discussed previously, the operation of some reserved facilities may be improved by the introduction of access control measures. However, these will not be applicable to all reserved facilities. In particular, many HOV-reserved lanes are unseparated from the general highway lanes. For these facilities, violation detection equipment can be used to detect unauthorized vehicles. Chapter 3 described a number of alternative technical approaches toward identification and enforcement of violators on reserved facilities.

Like access control measures, enforcement systems will probably have little impact in improving traffic flow on reserved facilities. Rather, enforcement systems will provide a disincentive to potential violators, encouraging efficient use of the facility. Enforcement can also help to eliminate the public perception of failure of a priority scheme caused by high violation rates. In addition, police enforcement activities can be reduced, with subsequent cost savings.

One technology that can potentially be used for enforcement of reserved facilities is CCTV. This has been estimated to cost around \$22,000 per camera link, inclusive of camera controls and control center equipment [51]. One of the advantages of CCTV is that it can be used for purposes other than enforcement, such as integration into an SCC system. CCTV monitoring will also provide reliable usage and occupancy data upon which to evaluate the success of a priority scheme.

An enforcement technology that could be used to support transit or rideshare-preferential signal priority measures is red light cameras. These would be applicable for inclusion in schemes that impose a delay on general highway traffic. Red light cameras will prevent motorists from violating the traffic signal, ensuring that the priority measure operates effectively. Studies carried out in the U.K. indicated reductions of 64 percent and 57 percent in violation rates at two demonstration sites [115]. Traffic safety will also be improved through the introduction of red light equipment. For a large equipment order, costs could be less than \$10,000 per site. This investment could be quickly recouped as a result of reduced accident rates.

The final enforcement technology considered within the ATMS review was telephone hotlines. These enable users of the reserved facility to report violators via the telephone. By establishing a telephone hotline system, the highway authority provides a demonstration of its commitment to the priority scheme. More important, perhaps, the approach enables travelers to feel that they can do something to prevent abuse of the facility. Telephone hotlines have also demonstrated a successful ability to deter a substantial proportion of would-be violators. For example, initial evaluations of Washington's HERO hotline indicated that it had reduced violation rates on the region's HOV facilities by 33 percent [54].

6.4 Fleet management and control systems

The third area of advanced technologies that can be applied to transit and rideshare operations is FMCS. Fleet management and control systems were reviewed in Chapter 4 of this report, and represent a range of systems from the other technology areas, applied specifically to the needs of fleet operations. The initial beneficiary of FMCS technologies will therefore be the transit or rideshare operating agency. However, by improving services through FMCS approaches, the benefits will also be passed on to the system users.

The review of FMCS presented in Chapter 4 identifies seven technology approaches toward improving fleet operations. These are (1) transit operations software, (2) ETS, (3) OBCs and smart cards, (4) AVI, (5) AVL, (6) AVM, and (7) paratransit dispatching systems. The potential benefits of each of these approaches are evaluated in the following paragraphs of this section. A summary of benefits is also presented in Table 6.3 in assessment framework form.

The first technology identified in the area of FMCS was computer software for transit operations planning. Software can be used to develop routes, networks and schedules, to assist in marketing services, and to support management and planning activities. Substantial cost savings can be achieved by the transit operator, while services can also be optimized to suit the users' demand.

Overall, transit operations software will have benefits in several of the areas identified in the introductory section of this chapter. Through computer analysis, services will be established with the maximum time efficiency. This will prevent transit agencies from unnecessarily operating excess vehicles. An example of this is provided by the initial application of the VAMPIRES program, described in Chapter 4. This enabled a schedule involving 41 buses to be progressively reduced to 31 vehicles [58].

The reduction of number of vehicles in this manner will lead to several follow-on benefits for the transit operator. Excess vehicle miles traveled (VMT) will be eliminated, resulting in substantial fuel savings and improvements in air and noise pollution. Reduced VMT will also lessen the risk of accidents involving transit vehicles,

From the passengers' point of view, transit operations software should lead to improved services and therefore increased ridership. Since travel demand will be an important input in planning transit operations, the resulting services should cater efficiently to passengers' needs. In addition, the optimization of services will permit operators to charge lower fares, providing a further incentive for use of transit vehicles.

While transit operations software can offer substantial benefits at relatively low cost, it requires accurate travel data in order to evaluate service options. One technology that can collect travel data, while simultaneously performing the fare collection function, is ETS. From a fleet management context, the main benefits of ETS are in providing data that lead to service optimization, through its use in transit operations software. ETS can therefore have an important role in realizing time and fuel savings, in reducing air and noise pollution, and in improving services for travelers.

ETS will also improve fleet operations management in the area of financial control. More specifically, the technology will provide data outlining when and where fares have been collected, to permit accurate financial reconciliation. ETS will also allow fares to be collected more rapidly, increasing convenience for the passengers and improving overall schedule adherence.

Another area of technology that can be used to collect data for transit operators is OBCs and smart cards. Either of these approaches can be used as an alternative to ETS devices discussed above. OBC's and smart cards can also collect a range of additional data beyond fare payment information, as described in Chapter 4. This increases the scope for their application in fleet management activities.

Benefit Areas									
Technology	Time Savings	Fuel Savings	Environmental Considerations	Traffic Safety	Comfort & Convenience	Safety & Security	Efficiency & Productivity	Reliability & Consistency	Incentives
Transit operations software	Optimize services for time efficiency	Minimum VMT saves fuel	Minimum noise and air pollution	Minimum exposure to traffic risk	Services matched with demand	None	Route/schedule optimization	None	Develops attractive services; marketing
ETS	Reduced boarding time	None	None	None	Increased speed for traveler	None	Improved financial control	Reliable data collection	Improves services via operations software
OSG/smart cards	see ATIS	Data permits vehicle performance optimization	Reduced air pollution	Reduced component failure	see ATIS	see ATIS	Data support maximum productivity	Detailed data collection	see ATIS
AVI	Permits time saving intervention	Some benefit	Some benefit	Uncertain	Reduced delays for travelers	Location monitoring	Supports fleet efficiency	Provides schedule adherence data	Improved services
AVL	Major benefit through continuous control	Some benefit	Some benefit	Uncertain	Reduced delays	Location monitoring and emergency messages	Increased vehicle and staff productivity	Provides schedule adherence data	Improved service reliability
AVN	Major benefit	Some benefit	Some benefit	Uncertain	Reduced delays	Emergency message and vehicle status	Substantial vehicle and staff productivity benefits	Substantial data collection	Major service improvements
Paratransit dispatching systems	Minimum VMT	Eliminate unnecessary fuel consumption	Reduced noise and air pollution	Some benefit	Customer specified service	Some benefit	Improved fleet and staff efficiency	Reliable vehicle dispatching	Responsive to travelers needs

Table 6.3 FMCS assessment framework

One potential application of OBCs is in collecting data on vehicle condition and performance. These data can be used to determine the effectiveness of maintenance programs, to assess manpower and equipment needs, and to evaluate long-term fleet performance. As a result, the transit operator can initiate changes identified as being cost-effective using the OBC-derived data.

OBC systems vary greatly in technical complexity, ranging from simple tachographs to full computer-based management systems. The cost for a relatively basic OBC capable of recording time, vehicle and engine speed, mileage, and engine and water temperature would typically be around \$1,000. Even these limited data could potentially be of substantial use to transit operators in improving the performance and efficiency of their vehicle fleets.

Smart cards are essentially miniaturized computers, and can potentially perform many of the same functions as OBCs. They will therefore be capable of collecting data for input to transit operations software, as well as for assessment of vehicle and service performance. In addition, smart cards will support a range of ATIS applications, as described earlier in this chapter. This dual role will be an important factor for transit operators to consider in implementing advanced technologies for fleet management and traveler information applications.

While ETS, OBCs and smart cards can all collect valuable data for input to transit operations software or service analysis activities, a further area of FMCS technologies introduces an element of real-time monitoring. One technology that can be used for this purpose is AVI, described in Chapter 4. The installation of AVI reader equipment at selected monitoring sites enables the transit operator to periodically ascertain the route number, location and identification of vehicles.

The principal benefit of this system is in enabling transit operators to monitor services in relation to a planned timetable. Where problems are identified, the operator will be in a position to initiate immediate remedial action. The use of AVI for fleet monitoring will therefore prevent unnecessary delays, subsequently saving fuel and reducing vehicle emissions. Rapid response to delays will also serve to improve the reliability and convenience of transit services for travelers.

In addition to this real-time monitoring function, the implementation of AVI will permit the calculation of detailed travel data for input to transit operations software packages. Furthermore, AVI can also be used to support real-time traveler information systems, and to implement signal priority measures. Overall, therefore, AVI has the potential for a range of highly beneficial applications in an integrated systems approach. The technology may be particularly attractive to smaller transit agencies, since it would be possible to build up a system over a period of time without requiring a substantial initial investment. For example, an operator could start by implementing limited signal priority measures, going on to develop a more detailed vehicle monitoring facility, ultimately leading to the introduction of real-time traveler information services.

A technology that could be used as an alternative to AVI for fleet monitoring applications is AVL. Unlike AVI, which provides only periodic data, AVL will enable the transit operator to review vehicle location and status information on a continuous or semicontinuous basis. Incidents and problems will therefore be identified more rapidly, providing increased scope for remedial action at an early stage. Therefore, although the benefits of AVL, will fall into the same categories as those of AVI, in the context of fleet management they can be expected to be of greater magnitude. The increased availability of data will allow more complete operational control, as well as permit more frequent updates of traveler information systems.

The advantages of AVL, over AVI will not be without cost penalty, however. While the price of implementing AVI will typically be measured in hundreds of thousands of dollars, the cost of an AVL-based system will more likely be measured in millions of dollars. An example of this was provided by the London BUSCO AVL pilot project. This covered only 52 buses, but was implemented at a cost of over \$3 million

[116]. Despite this substantial investment, London Transport calculated that a reduction of just 34 seconds in the average excess waiting time of 2 1/2 minutes would create enough additional revenue to pay for the installation and operation of BUSCO. This calculation was based on the assumption that a perceived improvement in service regularity would be translated into increased ridership and therefore increased farebox revenue.

A further problem associated with AVL, is the initial investment required for system implementation. While AVI can be introduced in a modular fashion, AVL will immediately require a central control room with computers and other monitoring equipment. AVL, will therefore be costly initially, as well as being more expensive than AVI in the longer term. It would therefore appear that AVI offers a more promising fleet monitoring approach for smaller transit agencies with limited operating budgets.

Despite its high cost, however, the potential benefits of AVL should not be underestimated by the larger transit operators. As demonstrated by the London BUSCO system, high benefits can accumulate from apparently unspectacular operational benefits. In addition, some valuable features will be provided by AVL that will generally be unavailable using AVI. For example, most AVL, systems will contain a two-way radio communications link between the vehicles and the control center. This will enable the driver to report emergency situations such as accidents or hijacks. While this benefit is difficult to quantify, the value associated with human life implies that substantial benefits could result from the ability to rapidly dispatch emergency services on the basis of AVL data.

Another technology area for the provision of real-time vehicle data to a central control point is AVM. AVM systems collect and transmit a range of data, including occupancy levels and the condition of various vehicle components, in addition to location and identification details. The communications link can be provided by AVI technology, though will more commonly be an AVL-based radio communications system.

Just as AVL represents an increase in complexity over AVI, so AVM demonstrates a further technology increase. AVM will promote increased schedule adherence through a process of continuous monitoring and control. In addition, AVM has the potential to collect a vast array of data through the integration of OBCs, ticket machines and passenger counters with the communications subsystem. Personnel relations can also be improved by reducing driver workload and increasing safety.

For passengers, AVM can improve services by bringing about improvements in punctuality and travel time. Travelers will also benefit from the provision of AVM-derived data displayed in vehicles or at boarding areas.

Again, however, the price of AVM will probably put it out of reach for many smaller transit operators. In Canada, for example, the Toronto Transit Commission (TTC) is planning to install its Communication and Information System (CIS) on 2,000 surface vehicles by 1992, at a total cost of over \$30 million [117]. Annual operating costs are estimated at approximately \$2 million. Combining operating costs with installation costs leads to an all-inclusive annual cost of \$5 million.

Despite this substantial investment in the CIS, however, even larger benefits are anticipated by TTC. These include annual cost savings due to improved vehicle and manpower utilization of between \$5 million and \$7 million; ridership increases amounting to between \$1.5 million and \$3 million; and more efficient use of supervisory staff contributing approximately \$1.2 million. TTC has also targeted several nonquantifiable benefits, including increased schedule adherence, reduced complaints, improved work environments and community-oriented emergency reporting facilities.

The final technology considered within the area of FMCS is paratransit dispatching systems. The principal benefit of these systems lies in their ability to dispatch vehicles accurately and efficiently in response to demand. This will enable VMT to be minimized, thereby reducing operating costs, fuel consumption and

exposure to risk of accidents. In addition, travelers' confidence will be high for a system that dispatches vehicles quickly following a service request.

Automated paratransit dispatching systems will also provide benefits for the service operator. The system will provide data to support management activities such as reporting, billing and accounting. Systems also offer potential for staff reductions and cost savings through increased automation. An example of this is provided by the CCRTA's dispatching system, which led to a reduction in the information management cost from \$0.43 per trip to \$0.30 per trip [102].

One area of paratransit dispatching technology that has been relatively widely used, particularly in Europe, is taxicab dispatching systems. A review of this area, carried out by UMTA in 1985, identified 13 principal implementations of the technology, covering between 62 and 1,725 vehicles [104]. The study also found an average system cost of \$1.8 million, based on a fleet size of 580 taxicabs.

6.5 Automatic vehicle control systems

AVCS is the final category considered within this scope, in the context of their application to transit and rideshare vehicles. AVCS technologies are used to help vehicle drivers to control certain vehicle functions. Eventually, AVCS may replace the role of the driver in some or all of the vehicle control tasks. Overall, AVCS technologies have the capability to improve traffic flow, provide more reliable and convenient transit and rideshare services, and contribute to greater safety.

Many of the technologies and systems considered within the category of AVCS are generally longer-term options than those in the other broad IVHS categories. This is because AVCS must successfully replicate the large number of interactions between the driver, vehicle and environment in order to ensure safe and consistent travel. Substantial research and development work will therefore be required to achieve the required levels of performance.

As described in Chapter 5, transit and rideshare vehicles will potentially be a suitable target for early AVCS implementations. Transit vehicles, in particular, have unique requirements and operational characteristics that are well suited to automation. Despite this, the long-term nature of many AVCS concepts makes it inappropriate to attach cost estimates to the alternative technology approaches. Instead, our review has focused upon a general qualitative discussion of the benefits of AVCS.

Based upon the review of AVCS technologies presented in Chapter 5, the study team has selected a number of advanced technologies for further investigation in this section. These are automated guideway transit (AGT), dual-mode buses, automatic steering control (ASC), automatic headway control (AHC), obstacle warning and maneuvering guidance, and the automated highway system (AHS). The potential benefits of each of these approaches are evaluated in the following paragraphs of this section. A summary of benefits is also presented in Table 6.4 in assessment framework form.

AGT is a class of urban transit operating under automatic longitudinal and lateral control on exclusive guideways. As such, AGT systems experience no interaction with general highway traffic, and therefore do not truly fall into the overall definition of IVHS. However, AGT has a number of benefits over alternative modes of transport that are discussed here.

One inevitable consequence of the exclusivity of AGT guideways is the elimination of accident risks associated with highway travel. Though AGT will still experience accidents caused by mechanical failure or operating error, these will be substantially less likely than accidents among conventional transit vehicles.

Another result of AGT's avoidance of highway traffic will be its immunity to congestion. In congested areas, AGT therefore has the potential to provide substantial time savings when compared with conventional

Benefit Areas									
Technology	Time Savings	Fuel Savings	Environmental Considerations	Traffic Safety	Comfort & Convenience	Safety & Security	Efficiency & Productivity	Reliability & Consistency	Incentives
AGT	Substantial benefit in congested areas	High fuel efficiency	Low noise and air pollution	Separate from highway traffic	Avoids congestion and delays	None	None	Reliable schedule adherence	Independent system
Dual-mode buses	Savings on reserved sections	Savings on reserved sections	Less noise and air pollution	Some benefits	Avoids serious disruptions	None	Increased vehicle productivity	Improved schedule adherence	Service Improvements
Automatic steering	Uncertain	Uncertain	Reduced land take	Major benefits	Uncertain	None	Permits narrow lanes	None	Uncertain
Longitudinal control	Optimum headway for time savings	Improved fuel efficiency	Reduced noise and air pollution	Major benefits	Reduced stops and delays	None	Increased vehicle productivity	Improved schedule adherence	Improved services
Obstacle warning/maneuvering guidance	Uncertain	None	None	Major benefits	Uncertain	None	Reduces vehicle maintenance and downtime	Uncertain	Improved safety
AHS	Substantial savings	Substantial savings	Major benefits in air and noise pollution	Reduction in accidents	Reduced delays and congestion avoidance	None	Reduced vehicle and staff needs	Automated schedule adherence	High level of service

Table 6.4 AVCS assessment framework

transit vehicles. This will also lead to increased efficiency of energy usage in AGT vehicles. In addition, since AGT typically operates using an electrical power source, both noise and air pollution will be substantially reduced.

Many of these benefits will also be achieved in dual-mode buses, particularly along route sections operating on electric power. In Seattle, for example, dual-mode buses can pass through specially-constructed tunnels, using overhead electric cables to gain power. This has reportedly reduced some journey times from as much as 30 minutes to as little as eight minutes [109].

Increased energy efficiency and reduced air and noise pollution can again be anticipated on dual-mode services' electrically-powered reserved sections.

One of the advantages of dual-mode buses over AGT is their ability to continue a journey where the electrified section ends. In many areas, the option of AGT may be unattractive due to high construction costs or existing facilities making construction impractical. In these instances, AGT travelers would need to transfer to an alternative transit service, providing an inconvenient break in their journeys. With dual-mode buses, however, the vehicle will simply switch to conventional power where the electrified power source ends, providing a single-vehicle journey for users of the service.

A further benefit associated with both AGT and electrified route sections for dual-mode buses lies in their ability to constrain vehicles to narrow lanes. As a result of this feature, landtake requirements for new facilities will be reduced. This will have beneficial implications from both environmental and cost perspectives.

The use of narrow lanes in automated transit is usually associated with automated steering, such as that found in AGT or dual-mode vehicles. However, this does not mean that all ASC techniques are associated with electrically-powered vehicles. Indeed, the technology review presented in Chapter 5 presents a number of alternative lateral control approaches that could be applied to conventionally-powered transit vehicles. These include reflective paint, metallic or magnetic markers, and microwave-activated silicon chip-based marker tags.

As discussed previously, one of the main potential benefits of ASC lies in its potential to introduce narrow lanes. This could allow an increase in capacity to be obtained without the need for new construction. In the case of existing bus-reserved lanes, the introduction of ASC would enable widths to be more tightly restricted, reducing the impacts of the reserved facility on the general highway. Additional areas of potential benefit include reduction of accidents and increased passenger and driver comfort and convenience.

Another AVCS technology that could potentially be applied to transit vehicles is longitudinal control or AHC. This could operate around the marker system used as the basis for lateral vehicle control. Alternative approaches toward longitudinal control include radar systems and video image processing approaches.

Longitudinal control would provide benefits to transit vehicles through optimizing speeds and controlling headways. One potential application of longitudinal control systems would therefore be in supporting the bus platooning approach, commonly used in South America. The use of automatic longitudinal control in transit vehicles could result in reduced accidents, improved fuel efficiency and reduced congestion through increased highway capacity. Improved passenger comfort and convenience could also accrue from the system's ability to avoid unnecessary stops and starts.

Obstacle warning and maneuvering guidance is a further area where bus operations can benefit from the application of AVCS technology. These provide transit drivers with advice and warnings in hazardous situations. The principal benefit of these systems will therefore be in assisting both drivers and other travelers to avoid accidents involving transit vehicles. This will also reduce the cost of maintaining and repairing

damaged vehicles. Accidents will reduce the number of vehicles operating in a fleet. Obstacle warning and maneuvering guidance can therefore be expected to offer some benefit in fleet operations, through ensuring that an adequate number of vehicles remain in service.

The ultimate level of AVCS technology considered for application to transit and rideshare operations is the AHS. Many previous research efforts into this subject have advocated the implementation of AHS sections in a phased approach. As discussed in Chapter 5, reserved transit and rideshare facilities could offer a suitable target for the initial stages of AHS implementation.

The realization of full highway automation could have far-reaching consequences in the areas of congestion, safety, time savings, fuel consumption, vehicle emissions, comfort and convenience and operating cost savings. The initial implementation of AI-IS facilities for transit vehicles could therefore act as a substantial incentive for travel by this mode. Buses have long been a target for the introduction of AVCS technologies, as demonstrated by the advent of dual-mode buses. Travelers may therefore be more willing to accept automated travel if it is initially introduced in transit vehicles, before being extended to other areas. The attractiveness of ridesharing lanes could also be enhanced by conversion to AHS control. The gradual acceptance of the AHS concept in the transit and rideshare environments would then lead to its more widespread application, introducing the full benefits of automated traveling to the entire highway system.

7. FUTURE DIRECTION

7.1 Introduction

This chapter describes the definition of a series of proposed intelligent vehicle highway systems (M-IS) activities directed toward high occupancy vehicles, rideshare and transit vehicles. These cover research, development and operational testing of advanced technologies at two levels of detail. Following this introduction, the next section discusses the approach adopted by the study team in preparing a national program for HOV and transit-related IVHS activities. This includes a broad range of projects over the full spectrum of IVHS technologies. Project descriptions are presented in limited detail, with emphasis placed more on the overall structure of the program than on individual activities. It is envisioned that this program will form an important element of the strategic planning of the broader IVHS program, ensuring the specific requirements of rideshare and transit users are fully considered.

With a program of this size and importance, it is essential that it is effectively managed and coordinated. Common tools and assessment criteria also need to be developed to provide consistent evaluation procedures. Implementation aspects relating to legislative and regulatory frameworks, standardization, safety, financial and user acceptance all need to be considered. These core program activities, relating to all of the four main technology areas, are addressed within the outline program.

The subsequent sections of the program deal with each of the individual areas of advanced technology applicable to transit and rideshare schemes. These are advanced traveler information systems (ATIS), advanced traffic management systems (ATMS), fleet management and control systems (FMCS), and automatic vehicle control systems (AVCS). Each section is subdivided into research projects, demonstration projects, standard-setting projects and implementation projects, as appropriate. These are further divided into short-term and medium-term according to the perceived current level of technological development. The outline national program plan is included as Appendix A to this report.

The objective of this development process has been to build on the outline program plan prepared with NCHRP project 3-38(l). This original plan was focused on the application of IVHS technologies to the general automobile user. The goals of the plan developed within this research study are essentially as follows: to demonstrate that many of the technologies, systems and applications defined for general automobile users are equally applicable to transit and rideshare operations; to ensure that transit and rideshare operations are given equal consideration as proposals are developed for IVHS research and operational testing activities; to ensure that appropriate flexibility is built into IVHS activities which may initially be focused on general automobile users to subsequently accommodate transit and rideshare needs; and to highlight the unique needs, opportunities and benefits afforded by the application of IVHS specifically to transit and rideshare.

Following discussion of the national program development process, Section 7.3 covers the more detailed definition of selected transit and rideshare-related IVHS activities. This work has led to the production of eight project descriptions for technologies that are seen to have near-term, high-payoff benefit potential. Section 7.3 outlines why these activities have been selected for more detailed definition, providing an overview of the likely results of each study. Corresponding project descriptions are included in Appendix B to this report.

7.2 National program development

This section describes initial work undertaken toward defining a national IVHS program for transit and rideshare applications in the United States. This effort has involved identifying and outlining projects or activities to be undertaken within such a program. These cover research, operational testing, standard-setting,

implementation and on-going support, with most emphasis given in this project to the first three. A preliminary timeframe for the program is also included.

The project and activity descriptions have been divided into five categories. A general category has been included to cover areas such as IVHS program management and coordination, policy formulation and broad-based institutional issues. The remaining categories reflect the four main IVHS technology areas as follows: (1) ATIS, (2) ATMS, (3) FMCS, and (4) AVCS.

The program has been divided into three broad time horizons: short-, medium- and long-term. Short-term is considered to be the period up to 1995, medium-term is the period 1995 to 2005, and long-term is beyond the year 2005, through to 2020. Project and activity outlines for the short-term time horizon have undergone the greatest amount of development.

For the general, ATIS, ATMS, and FMCS categories, no project descriptions have been prepared beyond the medium-term. Specific widespread implementation programs for systems and technologies in these categories can be developed at a later stage. However, recognizing the longer timescale associated with the development and demonstration of certain automated vehicle control systems, some outlining of a recommended long-term AVCS program has been undertaken.

The initial step in developing an outline IVHS program has been to identify specific individual projects, tasks and activities that need to be considered. The approach followed involved examining each of the program areas in turn and defining the work needed to fully develop those advanced technologies and systems which show the greatest potential for a significant impact in terms of improving transportation system efficiency and safety through application for transit and rideshare users.

It was recognized that the many technologies and systems are each at different current levels of development. In some cases, basic or applied research is required on techniques and approaches which show particular promise. In others, systems are sufficiently developed to permit full operational tests to take place in the near-term. Certain systems would also benefit from near-term standardization and so standard setting activities have been identified. Finally, some advanced technology systems have passed through these early stages, so that widespread deployment and implementation are now needed to realize the benefits of the technologies. Therefore, each project activity identified has been categorized into the appropriate development category within its broad technological area.

Additionally, for a program of this magnitude, a number of general activities are also required. These include activities such as defining policy objectives, overall program management and coordination, project review and evaluation guidelines, and liaison with standardization bodies. Other issues are also addressed in the general activities, including anti-trust concerns, impacts on society, behavioral responses, and the need for legislative changes to allow the implementation of certain technologies.

Finally, in developing an outline national program, two other areas have been addressed. The first of these has involved identification of the interrelationships between projects or activities. Work has been undertaken to ensure there is a logical progression for each system or technological development from research through demonstration, standard-setting and implementation. Additionally, the development of certain systems or approaches will rely on the completion of technological developments in other areas. The relationships of projects within and between individual technology areas have also been considered.

7.3 Detailed project definition

The national IVHS program for transit and rideshare activities, described in the previous section and presented in Appendix A, contains a broad range of research, development and operational testing projects. In developing the program, the study team has placed significant emphasis on ensuring full coverage of

applicable IVHS technologies. Equally important is the proposed structure for the program, which sets out a logical sequence of projects and activities in a coordinated approach. For strategic planning purposes, the overall concepts and structure of the program will be of greater importance than details on specific projects or activities. Individual activities have therefore been outlined in limited detail, within the framework of the national program.

Inevitably, however, some time will be required for the U.S. to fully establish a coordinated IVHS program. During this period, it is important that the impetus of IVHS is maintained through a series of near-term research, development and operational evaluation activities. In consultation with UMTA personnel, therefore, the study team has identified and outlined eight projects for the transit and rideshare sectors. These cover the following technology areas: transit service information systems; transit pretrip planning services; transit communication and location systems; real-time vehicle condition monitoring; passenger identification and automated payment systems; advanced transit operations software; rideshare management and matching; and HOV occupancy verification.

Project definitions corresponding to each of these technology areas are presented in Appendix B. These are more detailed than the project descriptions included in the national program, reflecting the near-term, high-payoff benefit potential of the activities. The remainder of this section provides further discussion on the selection of the projects. This includes potential technology benefits, as well as the recommended approach and likely results for each of the studies outlined.

Transit service information systems

The first project outlined within Appendix B to this report focuses on transit service information systems. This covers technologies that can be used in the public environment to provide information on transit routes, schedules, arrival and departure times and other required data. Systems to be investigated in the study include display systems, interactive devices, voice synthesis and data printout technologies.

The project has been selected for detailed definition due to the highly promising nature of transit service information systems. Used in a variety of public environments, transit service information systems can greatly increase the availability and accuracy of data. This has been shown to be of significant value for travelers, particularly in reducing perceived waiting times, assisting passengers in selecting the appropriate service or route, and generally improving confidence levels in transit services.

Potential consequences of these improvements will include increased ridership and therefore revenue growth for the transit operator. By reducing waiting times and increasing efficiency of service usage by passengers, it may be possible for transit agencies to optimize services and hence achieve operating savings. In addition, transit service information technologies will provide scope for further cost savings through reduced traveler assistance staffing requirements.

Transit service information systems also have the potential to provide valuable assistance to disadvantaged passengers. Transit services represent a principal transport option for visually- and hearing-impaired travelers, and it is important that the information needs of these passengers are adequately addressed. Automatic information systems can also be designed to assist non-English speaking travelers through multi-lingual data terminals.

A further benefit of transit service information systems is in providing an outlet for data collected by other advanced technologies. In particular, as communication and location systems find widespread use in transit services, the data volumes generated may be too large for dissemination by conventional approaches. Use of automated information services will therefore ensure that data are put to best use in the most efficient manner possible.

The approach outlined for the transit service information systems study involves a process of technology review, selection, implementation and evaluation. Several important findings can therefore be anticipated to result from the study. From the review stage, for example, an understanding of the data needs of travelers at various locations will be gained. This will include definition of the specific needs of disadvantaged travelers. By examining alternative technologies and approaches, it will then be possible to identify the most appropriate system for each application.

Through the implementation, and operational evaluation elements of the study, the in-service performance of the selected technologies will be assessed. This will include considerations of the technologies' ability to satisfy travelers' data needs, and the utility of the systems to disadvantaged travelers. Installation, operating and maintenance cost information will also result from the study. Overall, the study will be used to develop conclusions on the cost-efficiency of transit service information systems and their potential for wider use on a full-time basis.

Transit pretrip planning services

This study will involve investigation of systems that provide pretrip planning information to the potential transit user. These will primarily be used in the home or at the office, using a range of technologies to access an information database by the transit operator. The study will therefore complement the previously defined project, which will investigate transit information systems for use at public locations.

Some of the approaches to be investigated in the study also introduce the potential to automate trip reservation and payment functions, as well as simply providing service details. Alternative approaches toward pretrip planning include television and radio, telephone enquiry systems, computer enquiry and videotext.

As with the previous study, this project has been selected for detailed definition due to its potential to achieve worthwhile benefits in the near-term. Many of these benefits will be the same as those identified for transit information systems. In particular, pretrip planning services will improve the simplicity of transit usage by providing passengers with more accurate, readily available data. These data will be available at the home or office, enabling travelers to review options and make decisions in a very convenient manner. Since information will be provided before the traveler sets out on a journey, it will also be possible to adjust travel plans in accordance with unusual service delays and disruptions.

The ultimate benefit for the transit operator resulting from these passenger benefits will be increased revenue through ridership growth. This can be expected to occur as travelers gain confidence in transit services through use of the pretrip planning data. The transit operator will also potentially benefit from staff savings, made possible by the replacement of manual enquiry services with automated alternatives. In addition, the use of pretrip planning services for trip reservation and payment will provide further scope for staff savings, as well as reduced passenger waiting time at ticketing locations.

An initial element of the pretrip planning services will be a review of user needs and applicable technologies. This will provide a clear understanding of the data requirements of travelers, covering both data format and content. It will then be possible to establish the technologies and systems that best serve this user needs, including the specific requirements of disadvantaged travelers. This will include identification of cost-saving opportunities based upon the use of existing in-home or office technologies.

The performance and utility of the pretrip planning services will be assessed in an operational evaluation. This will provide the opportunity to draw conclusions on the cost-efficiency of the technologies and their potential for wider use on a full-time basis.

Transit communication and location systems

The third study defined in Appendix B of this report covers the investigation and development of transit communication and location systems. A range of communication and location systems have previously been implemented in the transit industry for a variety of purposes. These include traffic signal preemption, fleet monitoring and control, and data collection for real-time and historical analysis. This study will aim to develop and evaluate an integrated communication and location system capable of supporting several desired applications.

A principal reason for selecting the study for detailed definition is that it will assist transit operators to select communication and location systems for their fleets. A number of alternative approaches currently exist, with different costs, applications and benefits. Furthermore, several newly-developed systems have yet to be applied on transit vehicles but could potentially bring about significant gains. The study will therefore aim to review the full range of options, resulting in the identification of a communication and location system representing the optimum combination of cost and functionality.

A further reason for selecting the study is that, like previously recommended projects, it shows good potential to achieve near-term high-payoff benefits. Used for traffic signal preemption or fleet status monitoring, communication and location systems can improve schedule adherence and the incidence of on-time arrivals. Travel and waiting times for passengers will therefore be reduced, resulting in increased confidence in the transit service among travelers. This can be expected to lead to increased ridership and greater farebox revenue for the transit operator.

Other benefits of communication and location systems for the transit operator will include improved vehicle and manpower utilization, and improved use of supervisory staff. In addition, facilities for emergency reporting and driver-to-supervisor communications will be provided. Communication and location approaches will also provide a convenient source of data, both for management review and for input to transit information and pretrip planning systems.

The study approach outlined within the project description of Appendix B includes a review of existing technology approaches and applications for transit vehicle communication and location. This will provide comparative data on the performance and utility of the various alternative approaches. As a result, an overall design will be produced that represents the most efficient combination of technologies in an integrated system. Operational evaluation of the system will provide valuable performance data, including information on technical performance, ridership increases, and operational improvements. Conclusions will then be drawn on the overall cost-efficiency of the system and its potential for more widespread future use.

Real-time vehicle condition monitoring

This project will investigate transit vehicle condition monitoring approaches, building on the previous study of communication and location systems. The project will involve the installation of systems to measure a variety of parameters on transit vehicles. These will be integrated with the previously installed location and communication system to provide for real-time data transmission to a control center. The principal technologies to be investigated in the study are passenger counting systems and vehicle component monitoring systems.

There have been relatively few instances to date where vehicle condition monitoring systems have been integrated with communication and location systems, as proposed in this study. The project has therefore been selected to enable the benefits of the concept to be fully evaluated through actual system use by a transit operator. This will cover both real-time data review at a control center, and historical analysis in conjunction with time and location data.

Real-time monitoring of vehicle occupancy data derived from passenger counting systems will enable a number of control strategies to be evaluated. This will include adjustment of signal preemption measures in accordance with occupancy levels. It will also be possible for fleet supervisors to add vehicles or remove vehicles from service as demand fluctuates. These real-time control options offer potential improvements in fleet efficiency with subsequent cost savings for the transit operator.

Operational efficiency may also be improved through historical analysis of occupancy data. By examining passenger loading levels by route, by section and by time of day it will be possible for operators to implement schedule alterations in accordance with demand. Unnecessary services can be removed to reduce operating costs. In addition, optimization of transit services in response to measured travel demands will also potentially improve convenience for travelers.

Real-time review of data received from vehicle component monitoring technologies will serve to identify hazards and faults at an early stage. Operators can then take remedial action at an early stage, avoiding unnecessary service disruption. Historical data on vehicle components will support maintenance scheduling and parts control activities, improving efficiency and providing cost savings for the operator.

The study definition included in Appendix B involves a process of technology review, selection, implementation and evaluation. The project will therefore identify the most suitable technical options for passenger counting and component monitoring, in accordance with identified data needs. An operational evaluation will then establish the performance of the selected approaches, and the utility of their resultant data. This information will be used to draw conclusions on the cost-effectiveness of the concept and its suitability for wider use in the transit industry.

Passenger identification and automated payment systems

This project will investigate and develop approaches for transit passenger identification and automated fare payment. The study will initially involve comparative evaluation of smart cards and automatic personal identification (API) devices. The utility and efficiency of the preferred approach will then be assessed through an operational evaluation.

The study has been included within the detailed project descriptions of Appendix B due to the high benefit potential of passenger identification and automated payment, coupled with limited operating experience to date. While both smart cards and API have been technically proven, their applications within the transit industry have yet to be fully evaluated. The study will also provide the opportunity to investigate several further factors associated with use of passenger identification equipment, including data security and privacy concerns.

One of the principal benefits of automated fare collection based on unique passenger identification will be in reducing the time required for payment at boarding points. Previous studies have indicated that the process of payment represents one of the major causes of delay in transit vehicles. By automating fare payment, therefore, delays will be reduced and schedule adherence will be improved. This should increase the attractiveness and convenience of transit, leading to growth in ridership with subsequent economic benefits for the transit operator.

In addition to the time savings associated with automated fare collection, both passengers and transit operators should benefit from reduced cash handling requirements. Passengers will no longer need to find the correct fare on entering the vehicle, since it will be automatically deducted from a user account. Transit operators will experience improved security and auditability as a result of the introduction of automated fare collection. Further benefits will include the ability to accommodate concessionary fares, passenger counting and origin-destination data collection, and applications in trip reservation, payment and information systems at travel terminals.

An initial element of the study will involve a comparative evaluation of smart cards and API devices, and a review of potential applications. This will identify the most suitable technical option for passenger identification and automated payment, and the most worthwhile uses of the system. The study will also reveal the desirable features with regard to data storage, communication capabilities and other system characteristics.

The use of the selected passenger identification and automated payment approach will be assessed through an operational evaluation. This will provide data on system costs, performance and user acceptance. Benefits of the system in areas such as time savings, operational improvements and data applications will also be investigated. Conclusions will then be drawn on the overall efficiency of the system and its suitability for wider use in the transit industry.

Advanced transit operations software

This study will involve the development of computer software for use by transit operators. The software will support a range of activities, including route and network planning, vehicle and crew scheduling, maintenance planning, management and administration. In developing the software, particular emphasis will be placed on the use of operating data collected by advanced technologies in the transit environment.

The project has been selected for detailed definition primarily to address the limitations of current transit operations software in accommodating new data categories. While there are a number of commercially available software packages, these were generally developed before the advent of IVHS within the transit industry. Valuable data collected by automatic vehicle identification, automatic vehicle location, onboard computers and other systems are therefore not used to their full potential.

The use of transit operations software also offers scope for significant service improvements at relatively low cost. Once the major task of software development has been completed, packages can be applied repeatedly to a range of transit services with little additional cost. The study will therefore aim to provide an inexpensive means of optimizing transit services, making full use of a range of available data sources.

One of the main benefits of transit operations software is in identifying the most efficient options for networks, routes and schedules. This enables the transit operator to optimize services, providing cost savings through reduced vehicle and staffing requirements. Transit operations software also ensures that services are developed in accordance with measured travel demands, maximizing convenience for passengers. This should help to increase ridership and thus raise farebox revenue.

Software packages can also assist transit operators to achieve cost savings in other areas. Automated reporting facilities will reduce the burden imposed by manual paperwork responsibilities. Software will also assist transit operators in maintenance scheduling and parts control activities, ensuring minimum vehicle downtime and optimum use of manpower.

An initial task of the study will involve a review of current transit operations software packages, in conjunction with an assessment of the needs of transit operators. This will help to identify the inadequacies that must be addressed in the software development process. The study will also lead to an understanding of how IVHS technologies can provide useful input data, and the ways in which these data should be used by the software.

The software developed in the study will be evaluated through application to a selected transit fleet. Assessment will focus on operational improvements achieved through the use of the software, together with the benefits of the various IVHS data sources. Conclusions will then be drawn on the suitability of the software for more widespread use by transit operators.

Rideshare management and matching system

This study will aim to investigate and develop a rideshare management and matching system based around a number of IVHS technologies. The system will be used to help travelers in selecting ridesharers with similar destinations and travel times. Initially the system will be used at the home or office, accessing a central database via a computer and telephone link. However, the system will also be designed to permit future upgrades introducing dynamic operation at out-of-town parking lots.

The rideshare management and matching study has been selected for detailed definition because it has the potential to make a major impact on ridesharing operations. The study has been identified as a high-priority objective by UMTA, in recognition of this fact. The scope of the project will therefore take the rideshare management and matching concept from the initial review and development stages through to system implementation and operational evaluation.

A main objective of the system will be to improve the attractiveness of ridesharing as a travel option. This will involve providing travelers with the opportunity to reserve journeys in advance from the home or office location. Uncertainty associated with finding compatible travelers will therefore be eliminated. The system will also aim to increase user confidence by incorporating a range of security features. The overall objective of the system will be to increase the incidence of ridesharing as a result of these improvements in service convenience and user confidence. A reduction in congestion should then be achieved as the proportion of ridesharers grows.

The study definition includes an initial review of the needs of rideshare travelers. This will lead to an understanding of the way in which the system should operate, and the data that must be considered in matching travelers. A technology review will then identify the most applicable technologies for the rideshare management and matching system. This will lead to the development of a preferred system design representing the optimum combination of functionality and cost.

The study will also involve an operational evaluation of the rideshare management and matching system. This will provide valuable data on system costs, performance and user acceptance. In particular, the evaluation will provide the opportunity to examine the system's potential to increase ridesharing participation. Conclusions will then be drawn on the effectiveness of the approach and its potential for wider implementation.

HOV occupancy verification

This final project will involve the investigation and development of a system for verification of HOV occupancy levels. The system will then be implemented and its use in a number of applications will be evaluated. Possible uses of the system include reserved HOV toll lanes or reduced toll charges, HOV parking lots, ramp metering bypass lanes and reserved HOV highways.

Overall, therefore, the HOV occupancy verification system has several potential applications that could significantly enhance ridesharing as a travel option. While the individual technologies envisioned as components of the system have all been individually proven, however, the overall system has yet to be produced. This task will be the principal goal of the study, taking the HOV occupancy verification system from the concept stage through development, implementation and evaluation.

The principal function of the HOV occupancy verification system will be to detect compliant HOVs as they approach reserved or priority facilities. The system will then be able to initiate the necessary priority measure, such as activation of a barrier for access control. Suitably equipped vehicles will then benefit by avoiding waiting lines and time delays associated with non-HOV travel. System users will be provided with a distinct feeling of priority, while non-HOVs will be denied use of reserved facilities. This latter application

will be important in preventing HOV violations, since repeated misuse of reserved facilities can lead to a public perception of failure.

The HOV occupancy verification system will provide scope for a number of priority measures that could not otherwise be implemented. Overall, the system will help to improve the attractiveness and convenience of HOV travel, subsequently increasing participation and reducing congestion.

The initial stage of the study will involve a review of technologies for possible inclusion within an integrated system design. This will identify the most appropriate approaches for elements such as vehicle detection, occupancy verification and violation enforcement. It will also lead to development of an integrated system design for operational evaluation. This will provide information on costs, benefits and user acceptance. Overall conclusions on the efficiency of the system and its suitability for wider use will then be drawn.

7.4 Summary

In this chapter, the approach adopted toward development of a U.S. national IVHS program in the area of transit and rideshare applications has been discussed. This covers ATIS, ATMS, FMCS and AVCS, as well as broad-based general issues.

In developing the IVHS program plan, a number of issues have been considered. These include the program objectives, structure, public and private sector roles, the program schedule, and funding issues. Through the research in each of these areas, we have set out a blueprint for future work on advanced technologies that will ensure that their full potential is realized for providing the benefits to transit and rideshare users. Our recommendation is that action should be taken to implement such an IVHS program at an early date.

The chapter has also described the more detailed definition of selected transit and rideshare-related IVHS projects. These are felt to have near-term, high-payoff benefit potential, and are therefore recommended for immediate consideration. This will ensure that the impetus of IVHS is maintained during the time period required for establishing a coordinated national program.

8. CONCLUSIONS

The overall objective of this study has been to assess the potential for the application of advanced technologies to transit and rideshare operations. This final chapter details the overall conclusions and findings of the research undertaken in the project. It also sets out recommendations for future work on transit and rideshare-related advanced technologies, within the framework of a national IVHS program.

The work described in this report has been carried out as a complementary study to NCHRP Project 3-38(l). Entitled “Assessment of Advanced Technologies for Relieving Urban Traffic Congestion,” NCHRP 3-38(l) produced a wide-ranging review and evaluation of IVHS developments in the field of general highway transportation. The research described in this report has built upon that performed in NCHRP 3-38(l), by reviewing the application of a similar broad range of technologies specifically to the needs of transit and rideshare schemes.

The application of advanced technologies to transit and rideshare can be seen as having a number of objectives. These vehicle types have the capability to carry an increased number of travelers in fewer vehicles, thereby improving a highway’s people-moving capacity. Transit also provides a vital service in supporting the mobility of the disabled or other disadvantaged groups. It therefore seems particularly appropriate to investigate and develop systems that can enhance transit and rideshare schemes, in order to take full advantage of these benefits. It also seems appropriate to further acknowledge the high efficiency of transit and rideshare vehicles by introducing priority measures and reserved facilities based around advanced technologies. These will enable the preferred vehicle types to avoid delays and areas of congestion caused by general highway traffic.

A principal goal in applying advanced technologies to transit and rideshare vehicles will therefore be to achieve operational improvements and enhancements. In itself this also has the potential to help reduce congestion among general highway traffic, in two ways. First, transit and rideshare vehicles, like all other vehicles, add to the overall levels of congestion on the U.S. highway network. The optimization of services using advanced technologies will ensure that transit and rideshare’s contribution to congestion is minimized. Second, improvements in transit and rideshare operations brought about by the implementation of advanced technologies will greatly increase the attractiveness of travel by these options. This will encourage travelers to use these facilities instead of private automobiles, resulting in an overall decrease in the number of vehicles on the network.

While the application of advanced technologies to transit and rideshare schemes makes sense from an operational point of view, it may also be important simply to ensure the continued widespread operation of these transport modes. This conclusion has been drawn from a review of the recently published NTP, and the associated NTSPS report.

IVHS offers one approach toward increasing transit efficiency and usage, providing economically viable operation while improving levels of service. Similarly, IVHS offers a solution that can make ridesharing more attractive to the traveling public, increasing overall usage levels.

In reviewing the application of advanced technologies to transit and rideshare operations, four broad categories of IVHS have been considered. These are as follows ATIS, ATMS, AVCS, and FMCS.

ATIS technologies are designed to provide travelers with information on highway conditions and travel options. They include in-vehicle devices for the provision of data on-the-fly, as well as external information systems. The general philosophy of ATIS, in the overall context of IVHS, is to ensure that drivers make

optimal decisions on route choice, journey time, etc., by providing them with pertinent and timely travel data. This should lead to more efficient use of the highway network as a whole.

In carrying out a review of advanced technologies within the scope of this study, the study team has identified several areas in which ATIS technologies can be applied to transit and rideshare operations. These have been divided into four areas, as follows: (1) pretrip planning information, (2) trip reservation and payment, (3) in-terminal information, and (4) in-vehicle information.

The application of advanced technologies in the area of pretrip planning has potential to provide significant advantages to the transit authority and traveler alike. One development in this area is the automation of telephone inquiry services, supported by computerized information access, touch tone selection or automatic voice recognition systems. Videotex systems have also been evaluated, demonstrating significant potential for transit and paratransit operations in supplying detailed route and schedule information. In addition, systems installed at activity centers such as shopping malls can provide travelers with data, using keypads, touch screens, video displays and printing facilities.

The application of advanced technologies to the reservation and payment aspects of transit range from the widely used dial-up booking facilities to conceptual post-trip billing requiring no action by the traveler. Many of the technologies reviewed in this area can also be used to support reservation and payment activities, enabling operators to increase the cost-efficiency of equipment implementation. While many of these systems could operate around credit card payment, smart cards appear to have particular potential to improve fare collection. Other technologies investigated in this section have included passenger verification using fingerprint imaging and API systems.

Many of the pretrip information and advance reservation and payment facilities reviewed by the study team are also applicable at transit terminals. Terminals are frequently used as meeting points, where it is particularly important to provide accurate schedule data. Transit terminals also present particular difficulties to those with impaired hearing or sight. Among the technologies investigated in the report are real-time information systems using video, matrix or flap displays, as well as interactive systems. Conceptually, advanced technologies could also be used to provide ridesharing information at a parking lot or collection point. Such a system could greatly improve the attractiveness of ridesharing by offering functions such as automatic matching of travelers, advance journey booking and the provision of travel data.

The final category of ATIS technologies considered in the review is in-vehicle information systems. In this area, externally-linked route guidance systems would allow carpool drivers to locate riders in unfamiliar locations, and to avoid areas of congestion. For transit vehicles, in-vehicle systems can be used to disseminate information on the timeliness of the service, the current location and the distance and time to destination. Another potentially useful application of in-vehicle systems would be in supplying real-time information on connecting services.

ATMS technologies aim to achieve the best use of existing highway network capacity without creating adverse environmental effects. Developments in the field of ATMS include UTC strategies, incident detection techniques and freeway and corridor control systems. Because the benefits of traffic management can be substantial, the use of existing ATMS technologies is already widespread in the U.S. and overseas.

In the context of applying ATMS technologies to transit and rideshare operations, three principal areas have been identified in the study. These are: (1) signalized intersections, (2) specialized highway environments, and (3) enforcement.

Priority or preferential measures for transit and rideshare vehicles can be implemented at signalized intersections in a number of ways. At a relatively low level of complexity, traffic signal timing programs can

be used to optimize signal settings to achieve minimum person delays, rather than minimum vehicle delays. This approach can be used for isolated intersections, or over a coordinated network. In addition, traffic signals can be activated in favor of preferred vehicle types detected on the approach to an intersection. This has already been successfully applied at a number of European locations, though has yet to see widespread implementation in the U.S.. Conceptually, it would also be possible to develop an interactive traffic control system, capable of adapting signal settings in response to real-time movements of transit or rideshare vehicles.

Outside of traffic signal control, there are several other specialized highway environments where advanced technologies could be used to give priority to transit and rideshare vehicles. In conjunction with access control systems, vehicle classification and identification devices could be used to restrict entry to reserved highway lanes. Reserved lanes can also be provided at highway toll plazas, supported by the growing number of installations of automatic toll collection equipment. In addition, HOVs could be provided with priority access to parking lots, or charged lower fees for use of a parking facility.

The third category of IVHS considered in the report is ATMS technologies. These can be used to detect and identify violators on transit- or rideshare-reserved facilities. Enforcement is an important element of ATMS, since consistent and unpenalized violations may lead to the public belief that a priority scheme has failed. Applicable technologies for enforcement include CCTV and conventional camera systems, as well as license plate scanners and video image processing.

AVCS technologies can help drivers perform certain vehicle control functions, and may eventually relieve the driver of some or all of the control tasks. The use of AVCS is likely to result in safer, more convenient driver behavior and improved traffic flow characteristics. The ultimate goal of AVCS is the AI-IS, in which all elements of control would be removed from the driver.

In reviewing advanced technologies, the study team has examined ways in which AVCS approaches can be employed to automate certain control functions in the transit and rideshare environment. The review has been divided into three principal application areas: AGT systems, bus applications, and rideshare applications.

AGT is a class of urban transit operating under automatic longitudinal and lateral control on exclusive guideways. Information technology has an important role to play in the control of AGT systems, particularly in the area of “smart” AGT vehicles. These require minimal instructions from the network controller and can operate autonomously in the event of failure of the communications or management system. Other applications of IVHS technologies in AGT include vehicle status monitoring, emergency braking and collision avoidance, and passenger information systems.

Buses have long been a target area for AVCS because of their unique requirements and operational parameters. The desire for punctuality and predictability in buses, combined with restricted availability of downtown land and a need to reduce noise and air pollution, point toward the use of automatically-guided and electrically-powered vehicles. When the same vehicles also run outside the central downtown area, the use of dual-mode buses can remove the need to provide electrical power where this is uneconomical. Buses could also provide an ideal candidate for the initial implementation of several other AVCS technologies, including inter-vehicle communication, obstacle detection and avoidance, and AHC for vehicle platooning.

Rideshare or carpool participants could also provide a suitable target for initial implementations of AVCS technologies. These travelers have already demonstrated a commitment to improving their daily commute, and may therefore be more accepting of technological assistance. Ridesharers often have the use of dedicated HOV lanes, which could potentially be used as one of the first areas of installation for preliminary AVCS technologies.

FMCS technologies encompass a range of systems from the three other IVHS categories outlined above. The FMCS category involves the application of advanced technologies specifically to suit the needs of fleet operations. FMCS technologies can therefore be used to improve the safety, increase the efficiency and raise the productivity of vehicle fleets.

In the context of this study, a number of IVHS technologies have been identified that can be applied to improve fleet operations. The following systems have been reviewed within this study: transit operations software; ETS; OBCs and smart cards; AVI; AVM; and paratransit dispatching software.

Transit operations software packages can be used to support a number of activities of fleet operators. Software can be used to develop or assess vehicle routes and schedules based on predicted passenger demand, enabling unnecessary services to be avoided. Management activities such as accounting and marketing can also be enhanced by the use of computer software. In addition, the impacts and benefits of proposed priority measures for transit can be evaluated using computer simulation models.

The principal application of ETS is in providing data on service usage levels and passenger information. As travelers enter the vehicle and pay their fare, ETS can collect details on the payment stage, fee paid and corresponding passenger type. These data can provide valuable input to transit operations software for fleet optimization, management or marketing. In addition, ETS can provide a basic source of data for the transit operator to negotiate subsidiary levels corresponding to concessionary fare payments.

OBCs could also be used to collect a variety of data on transit vehicles. These include fare details as well as information collected from condition monitoring sensors installed on the vehicle. OBC data can therefore be used to support transit operations software, as well as assisting in vehicle maintenance and service activities. Smart cards are essentially miniaturized, removable microprocessors, and can perform many of the same functions as OBCs. In addition, smart cards can be distributed to passengers to automate payment, and can be associated with an individual driver or vehicle for more detailed data collection and management applications.

The principal application of AVI, in the context of fleet management, is in providing vehicle location data to a central control point. AVI can be used to detect vehicles at strategic locations on the highway network. This information can then be relayed to a control center, enabling an operator to assess schedule adherence. Potential problems such as bunching of vehicles can also be identified.

Another technology that can be used to assess fleet location and schedule adherence is AVL. AVL operates differently from AVI, in that information is provided to the supervisor on a continuous or semicontinuous basis, rather than at strategic highway locations. A number of component technologies are included within AVL, including radio communications, dead reckoning and location beacon transmissions.

AVI or AVL can also provide the communications element for more complex fleet supervision in AVM systems. In AVM, a range of data is collected on the vehicle and transmitted to a control center, rather than simply vehicle location. Data items of interest include the number of passengers, the performance of the driver, the vehicle and its individual components, and emergency messages. In addition to providing a real-time monitoring facility, AVM can be used to collect data for off-line evaluation.

The final technology considered in the area of FMCS is paratransit dispatching systems. This category has been included in the study to acknowledge that demand-responsive systems have different needs than those of conventional transit. Among the systems investigated in the review are computerized dispatching systems capable of optimizing the use of demand-responsive transit vehicles. Systems designed specifically to support taxicab operations have also been reviewed in the study.

Following the review of systems within the four IVHS areas, the study team has carried out an evaluation of the costs and benefits of applying the advanced technologies to transit and rideshare approaches. An assessment framework approach has been used for this, outlining the principal areas of benefit and describing the major advantages of the alternative approaches. Quantitative costs and benefits have been outlined where appropriate.

The study has also covered the development of a proposed national IVHS program geared toward transit and rideshare operations. This has built upon the outline IVHS program for general highway traffic prepared in the original NCHRP 3-38(l) study. A broad range of research, development and demonstration projects has been defined. More detailed work scopes have been developed for a number of short-term projects.

The need for a coordinated approach toward IVHS research, development and demonstration has already been recognized in Europe and Japan. In these areas, several major coordinated programs are currently in progress. A similar approach is also being increasingly supported in the U.S. transportation industry, where a number of initiatives are gaining momentum. It is important that transit- and rideshare-related projects are integrated into these broader IVHS efforts. This will ensure that the specific needs of transit and rideshare operations are fully considered in these important programs. In addition, an integrated approach will lead to the development of technologies for transit and rideshare vehicles that are consistent and compatible with those produced for other highway vehicles. This feature will be critical for the success of the IVHS concept, which ultimately centers around cooperation and intercommunication of all vehicles on the highway network.

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APPENDIX A

OUTLINE NATIONAL IVHS PROGRAM FOR TRANSIT AND RJDESHARE APPLICATIONS

Appendix A of NCTRP Project 60-1A final report is not published herewith. It is contained in Appendix A of the agency-prepared report, entitled "Outlining a National IVHS Program," May 1991. A limited number of copies of that report are available on loan or purchase at a cost of \$10.00 from the NCTRP, Transportation Research Board, Business Office, 2101 Constitution Avenue, NW, Washington, DC 20418.

APPENDIX B

DETAILED PROJECT DESCRIPTIONS

Transit service information systems

This project will investigate the use of advanced technologies for providing transit service information to travelers. The overall objective of the study will be to establish the efficiency of transit information systems through a process of review, selection, implementation and operational evaluation.

The project will focus on information technology approaches that can be applied in the public environment. There are four major public areas where information systems can be of great value to the traveler, as follows:

- * within the transit vehicle;
- * at the transit terminal area;
- * at boarding points along transit routes; and
- * at activity centers (shopping malls, tourist areas, etc.).

The information needs of travelers will vary at each of these locations. For example, travelers inside the vehicle will be most interested in knowing their current location, expected arrival time at the next stop or ultimate destination, and information on necessary vehicle transfers. At the transit terminal, important data include time of arrival or departure, departure point and status of connecting services. Boarding point information services should be capable of providing arrival and waiting time for a number of scheduled vehicles. Finally, information required at activity centers will include transit route and mode options for travel planning, as well as timeliness information for a variety of local transit boarding points.

An important first task of this project will therefore be to fully review the requirements of advanced technology information systems at each of the intended application areas. This will involve the definition of the data needs of travelers at various public locations. Required categories of data will be identified, together with appropriate levels of detail for each category.

Following this examination of the information needs of transit users, the next stage of the study will focus on a review of applicable information systems. This will investigate systems that are either currently available or have reached an advanced state of development and could be implemented for demonstration and evaluation purposes. A range of technologies will be reviewed, including the following:

- * flap displays;
- * matrix displays;
- * video monitors;
- * interactive video display systems (e.g., touch sensitive, keyboard entry, etc.);
- * voice synthesis technologies; and

- * production of hard-copy transit service information.

The review of the state-of-the-art in transit information technologies will serve to reveal a number of important aspects concerned with use of the various systems. This information will then be used to identify the preferred approaches for each of the four major application areas. Factors considered in the evaluation and selection of transit information options will include the following:

- * costs of implementing, operating and maintaining the systems;
- * data needs for system operation;
- * equipment reliability, flexibility and accuracy;
- * user-friendliness and complexity involved in any aspects of human interaction; and
- * ability to satisfy the specific needs of disadvantaged travelers.

Significant emphasis will be placed on this last factor in examining alternative technology approaches. Transit systems provide a vital transport service for the disadvantaged, and it is vital that information technologies can cater to their unique needs and requirements. Information services should therefore include facilities for accommodating disabilities such as blindness and deafness. Systems should also be evaluated on their ability to assist non-English speaking travelers in obtaining transit information.

Following the review of alternative information systems, the next stage of the study will involve an operational evaluation of the preferred approaches. The selected technologies will be installed in a number of transit vehicles, as well as at terminals, boarding points and activity centers. The systems will then be used to provide travelers with a variety of transit service data over a demonstration period. During this time, it will be possible to vary the content and format of the information presented to travelers, in order to establish the optimum combination of data categories and level of detail.

The final element of the study will be an evaluation of the efficiency of operating transit information systems. For each of the application areas and selected approaches, this will involve consideration of a number of factors. These will include the following:

- * actual costs of equipment implementation, operation and maintenance over the demonstration period;
- * extrapolation of costs to cover full system operation; and
- * qualitative and quantitative benefits of system operation.

Qualitative assessment of the use of transit information systems will be undertaken to identify benefits that are difficult to value in financial terms. These will include increased satisfaction in the transit service and greater confidence among service users. Qualitative evaluation will place particular emphasis on service improvements and accessibility for disadvantaged travelers.

Quantitative assessment will provide a mechanism for comparing the benefits of the information technologies with their costs of implementation, operation and maintenance. The main quantifiable benefit is likely to be increased ridership due to greater confidence and satisfaction among service users. Assessment will therefore seek to examine farebox revenue increases which have occurred or can be projected due to the transit information systems. The study will conclude with an evaluation of the overall efficiency of the preferred transit information technologies, weighing qualitative and quantitative benefits against overall system

costs.

Transit pretrip planning services

The previously outlined study will examine a number of technologies and approaches for the provision of transit service information to imminent system users. This complementary study will investigate and evaluate information systems that can assist the potential user during the pretrip planning stage. These will primarily be used at the home or in the office, rather than in public locations such as transit terminals or activity centers.

The first **task** of the project will be to review the pretrip planning information needs of transit system users. The results of this task will be used as the basis for the definition of the desired characteristics of pretrip planning services. User needs will be established through a series of interviews and questionnaires. These will address questions such as:

- * what data categories are required by travelers for pretrip planning purposes?
- * in what format and at what level of detail should data be presented to travelers?
- * will travelers be prepared to pay for equipment required to access the pretrip planning database?
- * what technologies are already commonly used in the home or office environment that could provide the necessary access facility? and
- * to what extent should users be required to interact with the system?

Following the review of user needs, the next task of the study will involve an evaluation of the alternative approaches toward the provision of pretrip planning information. A range of technologies will be evaluated, including the following:

- * conventional television and radio broadcasts;
- * cable television transmissions;
- * teletext television transmissions;
- * automated information systems based on touch-tone telephone entry;
- * computer keyboard enquiry systems using telephone and modem links; and
- * dedicated videotext terminals.

In evaluating these alternative approaches, consideration will be given to the costs of supplying information to a large number of travelers, based on the required equipment at the home or office. For example, dissemination of transit service details using conventional television and radio broadcasts would impose no cost on the user, and would have a ready-made base of receivers. However, air-time could be limited and the option could be expensive for the transit operator. At the other end of the scale, the implementation of a videotext service would provide a dedicated data channel, but would require the distribution of terminals to all travelers who wished to use the system.

Inevitably, therefore, the choice of pretrip planning service will affect not only the overall cost of the system, but also the way in which this cost is distributed between travelers and the transit operator. This must be considered in line with the response of potential users concerning willingness to pay for the system. Other factors to be considered in addition to cost will include:

- * the ability of the systems to satisfy the specified user requirements;
- * the potential for the systems to support other, nontransit-related services and hence achieve cost sharing benefits;
- * the data requirements and flexibility of the systems; and
- * the suitability of the systems for use by the disadvantaged, including visually-impaired, hearing-impaired and non-English speaking travelers.

Evaluation of the various pretrip planning technologies will be used to identify the systems showing greatest potential for effective operation. These systems will then be assessed through an operational evaluation. This will require the establishment of a central computer database, containing details of various transit services, routes, schedules and timeliness. The database will be used as the source of information for the selected pretrip planning services, each of which will potentially use a separate communications medium and output device.

For radio- or television-based systems, it will be necessary to integrate the computer database with a broadcasting facility. Computer- or videotext-based systems, on the other hand, will require access facilities using telephone connections. It may also be desirable to distribute suitable terminals to selected users for the purposes of the demonstration.

The operational evaluation will enable the performance, utility and cost- effectiveness of each of the pretrip planning approaches to be assessed. Market research will be used to investigate the benefits of the systems and user reactions. This will consider a number of factors, including:

- * increased use of transit as a result of the pretrip planning services;
- * more efficient use of transit in terms of service and route choice;
- * increased confidence in transit services among travelers;
- * the ability of travelers to operate the systems and comprehend the data presented, and
- * the accuracy and timeliness of the data.

The benefits of the pretrip planning services will be weighed against the overall costs of implementing, operating and maintaining the systems. Conclusions will then be drawn on the practicality of widespread implementation of pretrip planning facilities and operation on a full-time basis.

Transit communication and location systems

A review of previous experience in the transit industry reveals that a number of communication and location systems have been implemented for a variety of purposes. However, the wide range of alternative approaches makes it difficult for transit authorities to decide which technology is best suited for a particular

application. In addition, many communication and location systems implemented in the transit industry are underutilized. In particular, data collected by the systems that could provide a valuable input to pretrip planning and transit information services are often not used to maximum benefit. Furthermore, some communication and location systems have only recently been developed and could provide more cost-effective alternatives to currently adopted approaches.

This study will involve an analysis of communication and location technologies that have been applied or could potentially be used in the transit industry. By examining alternative approaches and applications, the study will aim to develop a preferred technology approach supporting a range of services and functions. The approach will then be implemented throughout a transit fleet for operational evaluation.

The first task of the study will focus on a review of existing approaches toward vehicle communication and location. A number of technologies and systems will be investigated, including the following:

- * automatic vehicle identification;
- * roadside beacon location systems;
- * dead reckoning and heading sensors;
- * land-based and satellite-based trilateration approaches;
- * radio paging systems;
- * conventional analog radio communications;
- * cellular radio systems; and
- * digital radio communications, such as the Radio Data System.

One of the main considerations in evaluating communication and location technologies will be the number of applications that each system can support. Some systems will potentially be dedicated to one specific service, while others may be used in a much greater number of roles. Among the desirable applications of communication and location systems in the transit industry are:

- * selective vehicle detection for signal preemption and access control;
- * provision of real-time vehicle location data at a central control for fleet monitoring and intervention purposes;
- * collection of data for historical analysis in support of management and planning activities;
- * provision of vehicle status and schedule adherence data for input to pretrip planning and transit information systems; and
- * establishment of communication channels for the transmission of routing information, operating instructions and emergency messages between transit vehicles and a control center.

In addition to the potential applications of the communication and location approaches, several other factors will be considered in evaluating alternative technologies. These will enable the efficiency and utility of each approach to be assessed, providing a measure of its suitability for inclusion within an overall system design. The main factors to be considered in the evaluation of the communication and location technologies

will be as follows:

- * the number of applications that each approach can cover;
- * the costs of implementing, operating and maintaining the systems for each application;
- * potential problems associated with radio spectrum availability and broadcasting or communication limitations; and
- * accuracy, reliability and other performance factors associated with the systems.

Based upon the review of available communication and location systems, a preferred technology configuration will be identified. This will represent a combination of approaches, selected to provide the optimum combination of functionality, reliability and cost.

The final stage of the study will involve implementation of the preferred system design for operational evaluation. Vehicles in a selected transit fleet will be equipped with the necessary communications and processing equipment. Compatible equipment will be installed at roadside monitoring points and at a central control location. The system will also be integrated with pretrip planning and transit service information systems, for the provision of up-to-date vehicle status and schedule adherence data.

The operational evaluation will enable a number of factors associated with use of the system to be assessed. This will cover both technical assessment of equipment performance and feedback from the transit authority and service users. The results of the evaluation will be used to draw conclusions on the overall cost-effectiveness of the system and requirements for future system development and enhancement. Investigation of the following factors will provide a major input in drawing the conclusions of the study:

- * actual costs of equipment installation, operation and maintenance incurred during the study;
- * increases in the incidence of on-time arrival of transit vehicles;
- * time savings for passengers as a result of improvements in transit services;
- * increased confidence in the transit service among travelers;
- * increased ridership and growth in farebox revenues;
- * the benefits of providing up-to-date information for pretrip planning and transit information systems;
- * improvements in operating efficiency for the transit operator and potential for staff savings; and
- * benefits of data collected for management and planning activities.

Real-time vehicle condition monitoring

This study will build upon work undertaken in the previous project in developing an integrated transit vehicle communication and location system. The study will connect the communication and location system with sensors installed on transit vehicles. These will monitor a range of vehicle parameters, with data subsequently sent to the control center for real-time review or historical analysis. The principal monitoring

elements to be investigated in the study are passenger counting systems and vehicle component monitoring technologies.

Passenger counting systems maintain a record of the number of travelers entering and exiting the transit vehicle at each boarding point. By communicating in real-time the number of passengers on a transit vehicle, together with its location and schedule adherence data, the system will assist in fleet control decision making and intervention. For example, where a vehicle contains only a small number of passengers, it may be appropriate to deactivate signal preemption measures normally in operation. In addition, real-time occupancy and location data will allow fleet managers to provide extra vehicles or to remove vehicles from service, according to demand. Historical analysis of occupancy levels by route, section and time of day will also allow fleet operators to gain a greater understanding of local travel demands, providing increased scope for service optimization.

Vehicle component monitoring technologies serve to continuously review the condition and performance of various equipment items on the vehicle. These can include the brakes, lights, tachograph and engine components. By transmitting data on these components to the control center, therefore, it will be possible to identify faults and hazards at an early stage and hence take timely remedial action. In addition, historical analysis of the data collected by vehicle component monitoring technologies could greatly assist maintenance scheduling and parts control activities.

As an initial task in the study, it will be necessary to review the state-of-the-art in vehicle condition monitoring equipment. This will include both passenger counting systems and component monitoring sensors. In the area of passenger counting systems, alternative technologies include infrared beam systems and treadle systems. The study will also examine the potential use of fare collection and ticket machines for providing data on passenger loading, including smart cards and automatic personal identification approaches.

A range of vehicle component monitoring technologies will be reviewed in the study. This will establish the capabilities of alternative approaches and therefore their applicability for integration with the communication and location technologies. Factors for assessment of both passenger counting systems and component monitoring sensors will include equipment costs, accuracy and reliability.

Another task of the study will be a review of the data requirements from the vehicle condition monitoring systems. This will focus upon a number of issues, including the following:

- * the frequency of data transmissions to the control center;
- * the level of detail and categories of data required from the onboard equipment;
- * the requirements for storage of data at the control center or on the vehicle, for historical analysis; and
- * the need and method for presentation of data to the driver.

Following the review of available technologies and data needs, the next stage of the study will involve selection of a preferred approach for operational evaluation. Equipment will then be procured and installed on selected transit fleet vehicles. The equipment will be integrated with the vehicle communication and location system, and compatible display and processing equipment will be implemented at the control center. Evaluation of the system will focus on a number of issues, including:

- * costs of implementing, operating and maintaining the equipment incurred during the demonstration;

- * the accuracy and reliability of the system over the evaluation period;
- * improved operational management and intervention potential as a result of system use;
- * increased efficiency of maintenance scheduling and parts control;
- * potential for improved service efficiency and rescheduling through historical data analysis; and
- * reduced operating costs and potential for staff savings.

The operational evaluation of the system will be used to draw conclusions on the utility and cost-effectiveness of integrating vehicle condition monitoring with communication and location technologies. Requirements for additional development and system enhancement will also be identified.

Passenger identification and automated payment systems

A number of alternative technological approaches exist for automatically identifying people for security and building access control applications. Similar systems exist for monitoring equipment and components in factory automation systems. These technologies offer potential for uniquely identifying transit riders for applications including automatic fare collection, automatic reservations, and for automatic passenger counting and surveys. These systems, however, have not previously been widely used in the transit industry.

This project will investigate the suitability of automated passenger identification and payment systems for use in the transit environment. The principal technological options in this area are smart cards and automatic personal identification (API) devices. A major focus of this study will therefore involve a side-by-side comparison of these alternative approaches. This will seek to establish which technology offers the greatest potential for worthwhile application in the transit industry.

As an initial task of the study, it will be necessary to review the range of applications of smart cards and API devices. Although smart cards and API systems operate differently, the overall concept of passenger identification and data communication is essentially the same in both cases. This means that the two approaches can effectively be used to support many of the same functions and services. These include the following:

- * automated fare collection based on pre-payment or post-use billing;
- * automated passenger counting;
- * origin-destination data collection;
- * advance trip reservation and payment; and
- * traveler information services and in-terminal guidance.

The review of potential applications of the smart card or API approaches will be used to define desired system characteristics, as a basis for side-by-side examination. Comparative evaluation of smart cards and API systems will then cover a number of important issues. These will include:

- * costs of implementing, operating and maintaining the systems;

- * ability to support the desired applications;
- * benefits to the traveler and transit operator associated with use of the equipment;
- * accuracy and reliability of the systems under various operating conditions;
- * resistance to tampering and fraud;
- * ability to accommodate concessionary fares or other unusual events; and
- * public acceptance of the equipment.

Examination of the benefits of system usage will be a particularly important element of the evaluation process. For the traveler, benefits will include time savings and increased convenience during payment and reservation activities. These should then lead to benefits for the transit operator through increased ridership and farebox revenue. The automated systems will also provide valuable data to support management and planning activities.

The results of the comparative evaluation will be used to select a preferred technology for automated passenger identification and payment facilities. This will effectively represent a choice between the smart card and API options. However, the recommendation should also define in more detail the desired characteristics of the system beyond this technology selection. This will include consideration of the data storage and transmission capabilities of the equipment, together with definitions of the recommended approach toward each of the various system applications.

Following selection of the preferred approach for passenger identification and automated fare collection, the next stage of the study will be an operational evaluation of the recommended system. This will involve procurement of equipment, installation and operation on an appropriate transit system over a demonstration period. Identification devices will be issued to a number of selected travelers who currently use season tickets, travel permits or multi-trip cards. Compatible reading and processing equipment will be installed on transit vehicles in the selected fleet. Equipment capable of processing data on an historical basis for management and planning purposes will also be procured for use in the demonstration.

The operational evaluation will enable the performance and efficiency of the automated passenger identification and payment system to be assessed. Evaluation of the system will involve consideration of a number of factors, including the following:

- * actual costs of equipment procurement, installation, operation and maintenance incurred during the demonstration;
- * extrapolated costs to cover wider system use on a full-time basis;
- * reaction to the system on the part of users and the transit operator;
- * time savings and other benefits achieved through use of the system;
- * reliability and performance of the equipment over the demonstration period; and
- * the potential for increased ridership as a result of system implementation.

The study will conclude with a summary of the benefits and costs of various applications of automated passenger identification equipment in the transit industry. This will include recommendations on future use

of the system and additional development and evaluation requirements.

Advanced transit operations software

The optimization of transit services to ensure a combination of maximum efficiency for the operator and convenience for passengers requires careful consideration of several operational factors. This has led to the development and widespread application of computer software packages for transit operations design and planning. As advanced technologies are applied within the transit environment, additional data will become available which will potentially be of great value for transit operators. However, current software packages will be unable to use these data, and will also be ill-equipped to deal with the effects of advanced technologies on transit services. This will represent a loss of opportunity, potentially leading to suboptimal transit services for operators and passengers alike.

This study will therefore aim to develop transit operations software capable of accepting input data from a range of advanced technologies. Use of the software will also include full consideration of the effects of advanced technologies on service operation. The software will be developed to cover a variety of activities, including vehicle and crew scheduling, route planning, maintenance, reporting and marketing. Performance of the software will be assessed through use by a selected transit operator, comparing results with those obtained from conventional software packages.

The first task of the study will focus on a review of presently available transit operations software. This will examine a number of aspects of current packages, including the following:

- * applications of the software packages;
- * methods of operation used for service optimization;
- * data requirements and sources of data;
- * requirements for manual interaction in the use of the systems;
- * costs of the software packages; and
- * efficiency of the systems in each of their areas of application.

A second review element of the study will investigate the software needs of transit operators. This will examine the extent to which the requirements of operators are met by currently available software packages. The review will therefore identify software applications and shortcomings in current systems that should be addressed within the context of this study. In examining the needs and requirements of transit operators, factors to be investigated will include:

- * the applications required of transit operations software;
- * acceptable cost levels for software;
- * preferred operating environment (e.g., microcomputer, mainframe, etc.);
- * requirements for manual involvement in use of the software; and

- * control strategies to be considered during software operation.

The review of available software packages and examination of the needs of transit operators will serve to highlight the fundamental characteristics required of advanced transit operations software. It will then be possible to establish the data categories necessary to support these characteristics. The next stage of the study will therefore involve an examination of the potential of advanced technologies to provide software input data. Sources of data to be examined include:

- * conventional data sources, including ridership surveys and farebox revenues;
- * automatic vehicle identification and automatic vehicle location;
- * onboard computers and vehicle condition monitoring systems; and
- * smart cards, automatic personal identification devices or other similar systems.

In investigating these technologies, the study will examine how their resultant data can be used to improve operation of transit services. The study will then seek to achieve these improvements, by developing software capable of making optimum use of the data. Software will be developed according to the specified needs of transit operators, taking account of operating strategies such as traffic signal preemption and real-time service intervention. A further factor to be considered in developing software will be the impacts of pretrip planning and traveler information services on transit deinands and travel efficiency.

The final stage of the study will involve an assessment of the newly developed software. The system will be used to operate services in a selected evaluation area. Results obtained using the software will be compared with previous operation of transit services using conventional software packages. Principal areas for evaluation will include the following:

- + the efficiency of recommended alterations in routes, schedules, etc.;
- * cost savings achieved as a result of use of the software;
- * improvements in management, administration, marketing and maintenance activities;
- * level of service improvements for transit users; and
- * feedback from the transit authority on the user-friendliness and overall performance of the software.

The results of the evaluation will be used to draw conclusions concerning the utility of the software and its potential for wider commercial use. Recommendations on further software development needs will also be developed.

Rideshare management and matching system

This project will involve the investigation, development, implementation and evaluation of a rideshare management and matching system. The system will be designed to assist travelers in identifying ridesharers with similar destinations and travel times. Users will access the system directly, obtaining information from a computer database maintained by the authority responsible for ridesharing operations.

Initially, the system will be accessed from the home or workplace using a computer and modem link. This will enable travelers to review ridesharing options, identify travelers whose needs most closely match their own, and reserve journeys in advance. A real-time element of the system will also permit ridesharers to enter details for an immediate travel request. The central computer will then review the traveler's details and current trip files, providing a rapid response to the enquiry.

In addition to the computer enquiry mechanism using telephone links, the system will be designed to permit future upgrades for different interfaces and dynamic operation at rideshare parking lots. This latter development will accommodate travelers who arrive at the parking lot without having first reserved a ride. Traveler details such as destination and personal preferences will be reviewed on arrival at the terminal. The traveler would then be matched with waiting passengers or drivers, or asked to park and wait for suitable participants to arrive.

The first task to be carried out in the development of a rideshare management and matching system will be a review of the needs of rideshare travelers. This will be used to establish the desirable characteristics of the system. A number of questions will be addressed in the review, including the following:

- * what characteristics would users like to specify in requesting rideshare services?
- * what security features should be included in the system?
- * what home or office technology will be available to interface with the system? and
- * what level of accuracy is required with regard to specified departure and arrival times?

Following the review of user needs and definition of desirable system characteristics, the next stage of the study will involve investigation of the technologies that will potentially form the rideshare management and matching system. These will include home or office computers and interfaces, and the database and processing system at the rideshare matching center. In addition, the technology review will cover systems that can be used to implement dynamic rideshare matching at terminals. Applicable technologies in this area include automatic vehicle identification, automatic personal identification or smart cards, and in-vehicle processing and display equipment.

The technology review will be used to develop an overall design for the rideshare management and matching system. The design will be selected on the basis of considerations of cost, performance and functionality of various alternative approaches. These considerations will result in the recommendation of a specific technology configuration and method of operation. In addition, a user-friendly computer menu structure capable of providing efficient access for users will also be defined.

The final stage of the study will involve the implementation and operational evaluation of the rideshare management and matching system. Initially, computer equipment will be procured and software will be developed to provide the rideshare matching database. This will enable users with suitable home or office computers to access the system and identify compatible travelers. Subsequent system upgrades will introduce the element of dynamic operation at rideshare parking lots. To support this, the selected identification devices will be distributed to a number of regular ridesharers for use during the demonstration period.

The operational evaluation of the rideshare management and matching system will be used to draw conclusions on the utility of the concept and its potential for wider application. Evaluation of the system will focus on a number of aspects, including the following:

- * costs of implementing, operating and maintaining the system;

- * time savings for rideshare participants;
- * increased confidence and satisfaction among ridesharers;
- * accuracy and reliability of the system and its components; and
- * the system's potential to increase the number of ridesharers and thus reduce congestion.

HOV occupancy verification

The objective of this study will be to investigate and develop a system for the verification of vehicle occupancy levels at HOV-reserved facilities. The utility of the system in operating a number of priority measures will then be evaluated. Potential priority measures to be assessed in the study include the following:

- * access to reserved parking lots for HOVs or priority entry lanes for public parking lots;
- * HOV lanes and preferential toll charging at toll plazas;
- * access to highway sections reserved for HOVs; and
- * HOV bypass lanes at ramp metering locations.

The technology configuration envisioned for the HOV verification system will be based around existing AVI technology. Registered HOV travelers will be supplied with AVI transponders for installation on their vehicles. The AVI transponders will then be interrogated by compatible AVI readers as vehicles approach a reserved facility. Detection of a registered HOV will serve to activate a barrier, providing access to the facility without imposing significant delay.

An initial task of the study will therefore involve a review of existing AVI technology. Current AVI systems cover a range of technical approaches and levels of complexity. The review will evaluate alternative approaches, identifying the system that is felt to be most appropriate for the HOV verification application. Evaluation will be based on a number of factors, including the following:

- * costs of the equipment and how these will be divided between the highway authority and the HOV traveler;
- * cost sharing possibilities where AVI has already been implemented, for example in automated toll collection systems;
- * equipment accuracy and reliability; and
- * resistance to fraud and manipulation.

Inevitably, an approach toward occupancy verification which is voluntary and places responsibility for system use with the driver must contain sufficient safeguards against abuse. The most likely form of attempted misuse will be where drivers attempt to gain access to reserved facilities using their AVI equipment when they are not carrying the required number of travelers. The study will therefore investigate ways in which the transponder can be deactivated when the occupancy of the vehicle is below the required HOV level. One potential approach would be to supply regular HOV travelers with smart cards which could be inserted into the transponder. Only when the necessary number of smart cards had been inserted would the transponder

become active. An alternative approach would require the driver to manually activate the transponder at his own discretion.

Both of the approaches outlined above will provide a sufficient disincentive to make them worthy of investigation within the study. Whatever option is adopted toward transponder activation and deactivation, however, it seems likely that drivers will still have the opportunity to attempt to misuse the system if they are prepared to take the risk. Some element of manual monitoring will therefore be desirable in order to detect these drivers. This aspect of the system will also be investigated in the study. The most applicable approaches for consideration in this area are closed-circuit television systems and telephone hotlines for public violation reporting. The study will therefore examine these and alternative options for violation monitoring and enforcement. This will include consideration of the following factors:

- * equipment installation, operation and maintenance costs;
- * equipment accuracy and reliability;
- * operating costs associated with manpower needed for manual monitoring;
- * comparison of continuous monitoring versus random sampling as an effective enforcement approach;
- * the ability of the monitoring system to accommodate compliant HOVs that do not possess the AVI equipment; and
- * methods for dealing with detected system violators.

As a result of the technology review and consideration of enforcement needs, the next stage of the study will involve development of a preferred HOV verification system design. This will be selected to provide the optimum combination of cost and functionality. The preferred design should be flexible enough to deal efficiently with special events, such as the need to open reserved facilities or to provide access for emergency vehicles. The system should also provide a substantial deterrent to potential violators, while maintaining an effective method for detecting drivers who abuse the system.

The performance and utility of the preferred system design will then be assessed in an operational evaluation. This will be performed over a selected metropolitan area offering scope for the introduction of a number of HOV-priority measures. AVI transponders will be distributed to volunteer HOV travelers in the area, together with other in-vehicle equipment specified in the preferred system design. Compatible equipment will then be installed at selected parking lots, toll roads, HOV lanes and bypass ramps throughout the evaluation area. Control center facilities will also be established, including a computer database of registered participants, manual monitoring operations, and equipment required to override barrier systems.

The operational evaluation of the HOV verification system will be used to draw conclusions on the use of the approach, and to identify additional development requirements. Factors to be considered in the evaluation will include the following:

- * time savings for HOV travelers achieved through use of the system;
- * system performance in terms of identification accuracy and reliability;
- * costs of the system, including manpower required for manual enforcement;
- * the system's potential to improve the attractiveness of HOV travel and hence increase the

incidence of ridesharing; and

* the system's ability to deter abuse and detect violators.