Advanced Bus Technologies: Current Practice and Future Projections

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Abstract

This report summarizes the research findings of a study by the Innovations Unit of the Washington State Transportation Commission entitled *Advanced Bus Technologies: Current Practice and Future Projections.* The study was authorized by the Long and Short Term Goals Subcommittee of the Commission in April 1991.

This report describes advanced technologies already in existence and those that are likely to be applied in bus transportation over the next 20 years. Five application areas are examined: (1) bus information systems, (2) fare-payment methods, (3) bus monitoring, (4) bus control, and (5) roadway technology.

Major findings include the following:

Bus information systems. Advanced electronics will make it easier for passengers to obtain information on matters including, but not limited to, schedules, fares, and connections. "Real-time" information, which incorporates current traffic conditions, is expected to become more accurate and more accessible to both transit agencies and bus passengers.

Fare payment methods. A shift from cash-based to "cashless" fare-payment methods is anticipated. Smart cards, magnetic-stripe cards, automatic teller machine cards, and credit cards will be used in conjunction with special fareboxes and debtor machines to make this possible.

Bus monitoring. Automatic vehicle location, which may be accomplished through the use of satellites, radar, and other technologies, is expected to allow transit agencies to track their vehicles while they are out on their routes and to provide "real-time" information.

Bus control. Advanced electronics are expected to refine automatic bus steering and braking. Such systems are already in use for collision warning. More advanced systems, which will automatically alert drivers to collision hazards at the vehicle's front, rear, sides, and blind spots are anticipated.

Roadway technology. Signal preemption for buses and other HOVs is likely to become more widespread—preferential treatment at intersections is already in place for emergency vehicles in many locales. Developments in the roadway itself will depend on the vehicle control technologies adopted—these may include image processing or magnetic guidance.

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Chapter 1. Introduction and Research Approach

Advanced technologies have the potential to dramatically reshape the bus-riding experience from its current state to one that is highly automated. These technologies can benefit the passenger, the bus driver, and the transit agency. Passengers will find bus transportation more convenient and easier to understand. Bus drivers will be able to perform on-board tasks more safely and efficiently. Transit agencies will be able to manage overall bus systems more effectively and will be able to help travelers take full advantage of service and connections.

New technologies will affect not only how individual buses are controlled, but also the provision of bus system information, fare collection, and the types of pathways on which buses will travel. These technologies will also allow transit agencies to monitor their buses' mechanical performance as well as overall system operations.

The anticipated advances in bus transportation technology may also blur the distinction between bus transit and other mass transit modes such as rail transportation. The emerging capabilities of buses that result from advanced technology may change the public's perception of bus transportation, and may make bus transportation easier and more attractive for passengers in the future.

Advances in bus transportation will occur gradually as new technologies are refined, and as transportation agencies adopt and implement them. The purpose of this report is to provide a descriptive overview of the projected evolution of bus transportation over the next 20 years. This overview identifies major technologies that could be implemented by transit agencies, and the impact they may have on bus transportation. For the purposes of this report, *implementation* is defined as use on a wide scale, extending beyond pilot applications in a few selected sites.

This report uses a chronological approach to describe the extent and anticipated effects of advanced technologies on the bus-riding experience. It examines existing technology, illustrated with examples from throughout the world; projected developments organized according to the time frame in which they are anticipated; and current practices in the state of Washington.

This overview begins with a discussion of the relationship between advanced bus technologies and ongoing intelligent vehicle highway systems research. This discussion is contained in Chapter 2. Five applications of advanced bus technology are then presented (see figure 1). Chapter 3 discusses the provision of bus system information to the public. Chapter 4 explores fare-payment methods. Chapter 5 examines the electronic monitoring of bus location and mechanical systems by transit agencies. Bus control, divided into its lateral and longitudinal elements, is described in Chapter 6. Finally, roadway technology as related to bus travel is discussed in Chapter 7. Chapter 8 summarizes the study findings.

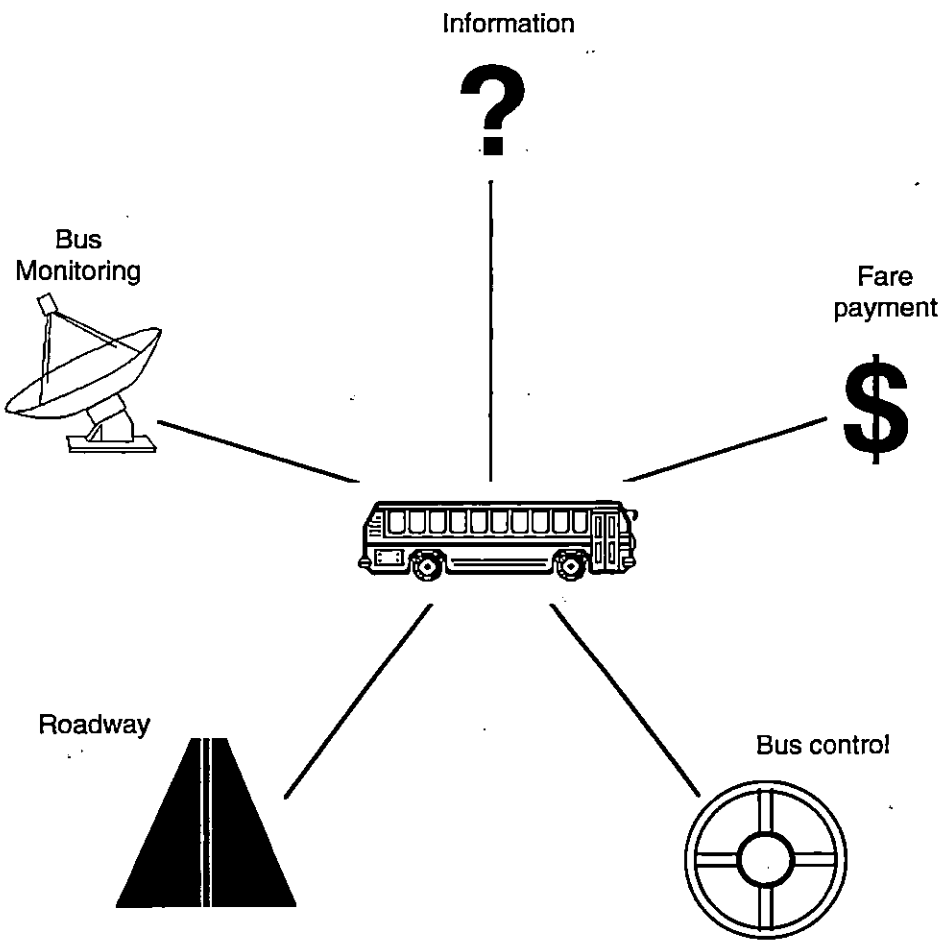


Figure 1. Advanced bus technology research areas

Chapter 2. Advanced Bus Technology and IVHS

Several areas of advanced bus technology draw upon current research on intelligent vehicle highway systems (IVHS). IVHS is "a collection of technological developments that enhance interactions between roads, vehicles, and their drivers so as to improve either highway safety, system operating efficiency, environmental quality, or energy utilization in transportation" (Kamal 1990, 2).

The following IVHS discussion draws on three documents: the *Strategic Plan for Intelligent Vehicle-Highway Systems in the United States* (IVHS America 1992), *Intelligent Vehicles and Highway Systems 1990 Summary* (Mobility 2000 1990), and *Assessment of Advanced Technologies For Transit and Rideshare Applications* (Davies et al. 1991a).

IVHS research is divided into five subdivisions, each of which is briefly described below.

Advanced traffic management systems (ATMS) examines advanced methods of detecting traffic problems, communicating these problems to motorists, and controlling traffic flow (Mobility 2000 1990, 6). ATMS monitors traffic conditions over a wide geographic area and transmits this information to traffic management centers, which then process the data. The processed information is then used to improve system performance by adjusting parameters such as ramp-metering rates and signal timing. It is also used to warn transportation agencies of traffic problems. These actions are intended to improve traffic flow, shorten trip times, save fuel, and reduce congestion (Davies et al. 1991a, 23). ATMS strategies also include management support for traffic incidents such as stalled vehicles, collisions, and other traffic obstructions. These incident management strategies are designed to restore regular traffic conditions as quickly as possible. One such strategy involves sending special "incident management teams" out to the scene to clear the roadway and direct traffic (IVHS America 1992, III-8).

Advanced traveler information systems (ATIS), a second area of IVHS research, uses equipment installed in vehicles, homes, stores, transit centers, and offices to inform travelers of current traffic conditions, routes, and transit schedules (IVHS America 1992, III-20). This information can help travelers plan trips based on information about competing services, modes, and travel times (Davies et al. 1991a, 9).

Commercial vehicle operations (CVO), a third area of IVHS research, focuses on improving efficiency and safety in the operation of commercial vehicles, such as trucks, delivery vans, intercity buses, and emergency vehicles. Commercial vehicles are currently the most sophisticated users of IVHS technology. For example, some trucks are already using a system of on-board text and map displays from which drivers can receive instructions (Mobility 2000 1990, 8; IVHS America 1992, III-45).

Advanced vehicle control systems (AVCS), a fourth area of IVHS research, focuses on controlling vehicle movements. AVCS technology uses sensors, computers, and control systems within vehicles, and within the transportation infrastructure, to warn and assist drivers, and in some cases, to take over the driving task. AVCS research encompasses technologies such as collision warning systems and automatically controlled vehicles (Mobility 2000 1990, 9; IVHS America 1992, III-33). AVCS technology could help improve traffic flow, provide more reliable service, and increase safety (Davies et al. 1991a, 66).

A fifth area of IVHS research, **advanced public transportation systems (APTS)**, applies IVHS technologies developed in the other IVHS research areas to public transportation. For example, ATIS applications can provide timely information to operators and transit passengers, while AVCS technologies may also have the potential to improve the efficiency of transit vehicles. Such technologies are aimed at increasing the use and productivity of high-occupancy public transit vehicles (IVHS America 1992, III-58).

The foregoing discussion gives a brief overview of five areas of IVHS research. Because this report focuses on advanced bus transportation technologies, the APTS component is most relevant. APTS research has focused on developing technologies to allow "transit agencies to provide a more flexible, cost effective, user friendly service to their customers" (IVHS America 1992, III-59). In addition, although previous APTS research has generally not emphasized the automatic control of transit vehicles, the advanced vehicle control systems component of IVHS is also relevant.

Chapter 3. Bus Information Systems

Bus information systems encompass all methods of informing the public about bus service. Both the type of information available and how it is provided are important; these factors affect the public's understanding of the system and ease of access. Bus information systems can also affect user perceptions. For example, if information is limited and difficult to obtain, users may become discouraged and develop negative perceptions of the transit service. On the other hand, useful and easily available transit information can be an important factor in encouraging and maintaining ridership.

In this chapter, information provision is examined chronologically with reference to current, near-, middle-, and long-term time frames. The near term corresponds to a five-year time frame. Middle term corresponds to 10 years, and long term is 20 years. Both pre-board and on-board sources are discussed. On-board refers to bus information that is available *on the bus;* pre-board refers to information provided at *any other location*, including a home, office, or transit information center.

Tables 1 and 2 are summary charts of this chapter. They list the major changes projected in bus information systems for the next 20 years.

Current Status

Pre-board

Virtually all bus system information is currently provided at the pre-board stage because current technology limits on-board information delivery. Most pre-board bus information is static and consists of pre-determined, system-wide schedule information such as arrival and departure times, trip duration, fares, route and bus stop locations, and transfer points. Within 20 years, more on-board information is expected to become available. "Real time" schedule information, which reflects actual arrival times and delays, will become more prevalent.

Travelers currently obtain bus system information before boarding in several ways, including the following:

- **staffed information desks,** where passengers can speak directly with transit service representatives,
- **telephone-based information systems,** that allow passengers to dial a number and speak directly with a transit representative,
- **telephone-based information systems,** that connect passengers with an automated, touch-tone information system that responds with a synthesized or taped voice message,

Table 1. Existing and Anticipated *Pre-board* Information and Information Sources

Information	**Current**	**Near**	**Middle**	**Long**
Arrival and departure times	○✓		✓ (real time)	
Fares	○✓			
Trip length (time)	○✓			
Route number	○✓			
Route location	○✓			
Bus stop location	○✓			
Transfer point	○✓			
Actual bus location			✓	
Actual delays			✓	
Traffic conditions			✓	
Service cancellations			✓	
Reroutes			✓	
Available seating			✓	
Possible connections			✓	
Route selection information			✓	✓ (more precise)
Integrated transit & traffic information				✓

○ = in Washington

✓ = in use

Table 1. Existing and Anticipated *Pre-board* Information and Information Sources (continued)

Information Sources	**Current**	**Near**	**Middle**	**Long**
Staffed information desks	⊘✓			
Live phone conversations	⊘✓			
Recorded touch tone phone systems	⊘✓			
Printed schedules and signs	⊘✓			
Electric signs on buses	⊘✓			
Signs/TV monitors in stations	✓			
Computers in stations/information centers	✓			
Voice recognition phone systems		✓		
TV monitors in homes and offices		✓	✓ (interactive)	
Teletex system/cable TV		✓		
Interactive computers in stations		✓		
Home computers		✓		
Information kiosks			✓	
Talking bus stops			✓	
PDCs - Portable digital communication devices			✓	

○ = in Washington

✓ = in use

Table 2. Existing and Anticipated *On-board* Information and Information Sources

Information	**Current**	**Near**	**Middle**	**Long**
Fares	(✓)			
Arrival and departure times	(✓)		✓ (real time)	✓ (more accurate)
Route location	(✓)			
Bus stop location	(✓)			
Transfer point	(✓)			
Trip length (for bus being used)	(✓)			
Route number	(✓)			
Next stop announcements		✓		
Actual connections information			✓	✓ (more accurate)
Seating availability				✓
Tourist site information				✓
Commercial area information				✓
Point of interest information				✓
Information sources				
Schedules	(✓)			
On-board map display	✓			
Bus driver and other passengers	(✓)			
Automatic voice system		✓		
Automatic text system		✓		
Interactive video displays				✓

○ = in Washington

✓ = in use

- **printed schedules and signs,**

- **changeable electronic message signs**, on the front of buses that display route numbers and destinations,

- **televisions** located in transit stations, that display schedule information, and

- **computers**, located in stations or in transit information centers, that feature interactive, touch-screen information displays.

On-board

Upon boarding a bus, the amount of information available to the passenger diminishes. Although information about fares, schedule frequency, stop locations, and trip duration for the current route is generally available, current technology for providing on-board information is limited. On-board information sources are usually restricted to printed schedules for the route on which the passenger is traveling, maps of the bus system, the bus driver, and perhaps other passengers.

Near Term

In the near term, or within five years, passengers may be able to obtain information in new ways. Telephones, televisions, and computers may be integrated, or further integrated, to provide public information.

Pre-board

The type and quantity of pre-board information available to passengers is not expected to change dramatically in the near term. What *will* change is the way that passengers may obtain that information.

- **Telephone information systems** may employ a voice recognition system capable of interpreting the caller's information requests. The system may then respond with either synthesized or computer-generated speech. The Dade County Transit Authority in Miami, for example, has a passenger information system that uses voice recognition technology to provide information about routes, schedules, fares, and types of service; it also provides passengers with advice on how to access and use the transit system (Casey et al. 1991, 5). This technology is not widespread among North American transit agencies.

- **Televisions in both homes and offices** may display schedule and route information (IVHS America 1992, III-67). This televised information may be broadcast via public access cable or a designated television channel (Casey et al. 1991, 7).

- **Teletext systems** may be used, particularly if cable television is unavailable. Teletext encodes data on a television signal. These data are then read by a decoder attached to the television, which displays the information (Casey et al. 1991, 7). Many western European countries currently provide real-time transit information by teletext. After viewing the information, passengers can adjust their travel plans accordingly (Davies et al. 1991a, 14).

- **Interactive computer display terminals** may be equipped with printers that let passengers print out a hard copy of the information. Such a system is planned in Baltimore (Casey et al. 1991, 7). Transit officials in Houston have installed computer terminals in several downtown locations. These terminals display the bus loop, which is superimposed over a "cartoon-style" city map. Passengers touch their destination on the map; the monitor then shows them which route to take. Passengers can then obtain printed copies of these directions (Kihl 1992, 9).

- **Home computers**, connected to information services such as Prodigy, could also serve as a conduit for specific, tailored information on routes, schedules, and fares (Casey et al. 1991, 7). Using a telephone link between a home computer and a central information center, people can then access services such as home shopping, electronic encyclopedias and travel information (Davies et al. 1991a, 12).

On-board

In addition to the many new sources of information that may become available to passengers before boarding, technological advances within the next five years will give them more information once they are on-board. For example, current and upcoming stops may be announced automatically (IVHS America 1992, III-68). One example of this type of technology comes from the Santa Clara County Transportation Agency in San Jose, California, where buses are equipped with automatic annunciators that keep passengers informed of routes and destinations. This information is audible to people waiting at the curb as well as to those on the bus (Passenger Transport 1993, 12). Two methods can be used to provide automated next-stop and current-stop information: an automatic voice system that uses pre-recorded messages, or an automatic text system that displays information on a dot-matrix sign or on a video screen (Casey et al. 1991, 22; IVHS America 1992, III-106).

Another example of an on-board information technology is the visual communication network (VCN) developed by Telecite Inc. and demonstrated on the Montreal Metro. VCN provides real-time, on-board information both visually and verbally, making it available to passengers with vision and hearing disabilities (Suen and Geehan 1992, 5). VCN also provides continual news, weather, and sports information to passengers. Paid advertisements on the service generate revenue. In Montreal, 88 percent of the passengers surveyed felt that VCN enhanced their trips (Kihl 1992, 11).

Middle Term

Within the middle term (five to ten years from now), real-time information, which is up-to-date and reflects actual conditions, may become available. Examples of real-time information include a bus's actual location or its projected arrival time. Such information may allow commuters to adjust their routines to minimize waiting, an advantage that is not possible with pre-printed schedules alone. The availability of real-time information is a result of automatic vehicle location (AVL) technology, described in detail in Chapter 5. Essentially, AVL will keep transit agencies apprised of the exact location of each bus; these location data will allow transit agencies to project bus arrival times more accurately.

Real-time bus monitoring may allow the provision of new kinds of bus information at the pre-boarding stage, including real-time schedule updates and route selection assistance based on individual travel needs. Real-time information about current bus location, direction, estimated arrival time, traffic conditions, delays, service cancellations, bus-line reroutes, available seating, and connections may also become available.

Route selection information tailored to the passenger's individual travel needs may also emerge. For example, passengers may be able to obtain instructions to a specific destinations, such as tourist attractions. Route selection could be based on any of the following criteria: trip duration, destination, current traffic conditions, scenic and tourist attractions, and mode preference (IVHS America 1992, III-63; Casey et al. 1991, 3). Route selection may even involve multi-modal routing, such as bus-to-train transfers.

Transit agencies in several North American cities already provide real-time information. For example, bus passengers in San Antonio, Texas, and in Halifax, Nova Scotia, can obtain arrival time estimates by dialing a telephone number associated with a particular bus stop. Synthesized speech provides a real-time estimate of the arrival times for the next few buses. The Halifax system features speaker phones at several high-volume stops (Casey et al. 1991, 6).

In Ottawa, roadside sensors monitor vehicle movements, which are reported to a central computer that can determine a vehicle's location, whether it is on schedule, its speed, and how soon it will reach a given location (Cervero 1992a, 5). Passengers access this information by dialing a special phone number associated with a particular stop; calling this number gives arrival times for the next two buses with an accuracy of within 30 seconds. All households in Ottawa are mailed the phone numbers of the two bus stops closest to their homes (Cervero 1992a, 5). The system also provides status reports on delays caused by accidents or storms (Kihl 1992, 4).

In the middle term, several new methods are expected to emerge to distribute real-time information. Some of these technologies are already in existence; their use in providing transit information would simply be an extension of what is already in place. These technologies include interactive cable television in both homes and offices; route displays on both home and office monitors showing actual bus locations; and variable message signs at transit stops projecting actual vehicle arrival times (IVHS America 1992, III-68).

Other means of providing information are considerably more complex, and while they are in place in a few locations, their use is not as widespread as the technologies described thus far. One example is a kiosk-like structure that provides the actual arrival times for transit vehicles and allows interactive route selection by the passenger (IVHS America 1992, III-68). These kiosks may also provide information about nearby restaurants, hotels, and other points of interest. Passengers may also obtain hard copies of the information. The downtown transit station in Denver now has two kiosks that display passenger information as well as the next three scheduled bus departures.

"Talking bus stops" that announce the arrival times of the next three buses, as well as warnings of possible delays, are another advanced technology. A system of this type is being installed in London along the bus route between Sudbury and King's Cross (Suen and Geehan 1992, 5).

A third advanced technology is the portable digital personal communications device (PCD). PCDs are hand-held computers that receive and display real-time traffic and transit information. A test of such a device is being conducted in Minneapolis-St. Paul (Urban Transportation Monitor 1993, 6). A similar device, called "Way to Go," is a touch-sensitive computer the size of a billfold. Way to Go displays a map with the region's major routes. Users touch their trip origin and destination on the map. The device then reports traffic conditions via a generated voice message (Whitely 1992).

In the middle term, real-time information may also be provided on-board, and may include projected arrival times at stops along the route as well as information about transfer connections. In contrast, near-term, on-board information is expected to be limited to the names of upcoming stops (IVHS America 1992, III-68).

Long Term

In the long term (within 20 years), detailed information about traffic conditions and commercial, retail, and tourist facilities is expected to become widely available to bus passengers. Information available at the pre-boarding stage will be integrated and dynamic, reflecting congested or free-flowing conditions in the highway network as they develop. The integration of transit and traffic data may make transit information more reliable, and may possibly encourage transit ridership. The expectation is that commuters will choose reliable transit over automobile travel in congested conditions if they are presented with real-time information about each choice (Kihl 1992, 4).

As an example of integrated transit information, the twin cities of Minneapolis-St. Paul are planning a program which will provide transit service and traffic information to the public in their homes and at their work places. The program will incorporate an automatic vehicle location system and a passenger information system. In addition to its value in allowing commuters to do pre-trip planning, it is thought that providing transit information in conjunction with updates on congestion and delays will alert commuters to the benefits of using transit, and will encourage them to switch modes (Kihl 1992, 6).

On-board information provision is expected to become more accurate. For example, it may become possible to project arrival times and connections more accurately, due to the integration of transit and traffic information. Additionally, transit systems may provide updates on seating availability, as well as information about tourist sites, commercial areas, and other points of interest. A small number of bus systems in Europe and Japan are beginning to provide these features (Casey et al. 1991, 22).

One such system, called MARIA (Mitsubishi advanced real-time information autosystem), is already in use. MARIA was designed for cars, but could be adapted for transit. The system uses on-board interactive video displays to provide specific information geared to the individual passenger's needs and interests. MARIA provides information on tourist sites and other points of interest using data stored on a read-only compact disk. MARIA is also able to "explain" delays to drivers, thereby reducing driver uncertainty (Casey et al. 1991, 22; Davies et al. 1991a, 22).

Bus Information Systems in Washington State

Transit agencies in Washington state currently use advanced technology in a limited way to disseminate information to their passengers, most of whom continue to rely upon pre-printed matter, such as schedules and maps, or on telephone calls to a transit agency for their information needs.

The pre-board information currently available to bus passengers in Washington state does not differ substantially from the pre-board information currently available in other areas. Transit passengers in Washington can obtain pre-board information from several sources.

- They may speak face-to-face with transit service personnel at staffed information desks.
- They may use telephone-based information systems to speak with transit service representatives. In some locations, such as Seattle's bus tunnel, phones are located at bus stops.
- Passengers may dial special phone numbers, associated with particular bus stops, to access taped messages that announce the scheduled arrival times for the next few buses.
- Passengers may also obtain pre-board information from pre-printed schedules and signs and from non-staffed information centers, which often offer maps and other printed materials.
- Additionally, passengers may refer to the electronic message signs displaying route numbers and destinations on the front of the bus.

Several transit agencies in the state are planning to incorporate more advanced pre-board information technology within the next five years. Included are plans for a "tele-viewer," an electronic schedule display device, for Metro's Northgate transit center. Touch-tone, telephone-based information systems are also planned. These systems connect passengers with an automated information system in which passengers use their phone pad to select desired information from a pre-recorded menu listing (Linda Smith, Municipality of Metropolitan Seattle, telephone interview 5 March 1993; Jack Floyd, Community Transit, telephone interview, 23 June 1993). The Bellevue Smart Traveler project, a public/private research effort, is developing and installing a prototype interactive video display at a suburban office site that will provide information on transit and ridesharing alternatives.

On-board information currently available to bus passengers in Washington is similar to that available elsewhere. Passengers may obtain information from bus drivers, who use PA systems or their voices alone to communicate; from printed schedules available on the bus; and from other passengers.

Chapter 4. Fare-Payment Methods

Fare-payment methods affect the overall success of a bus operation. Fare-payment methods that are smooth and easy to understand may attract and retain new passengers. However, cumbersome methods may inhibit ridership, and time-consuming payment methods can hamper operations. For example, passengers paying with cash take more time to board than do token or bus pass users (Strandberg 1992, 47).

Fare-payment methods affect the bus driver directly. Some methods are time-consuming, distracting, and can lead to driver-passenger disputes. In Seattle, for example, the fareboxes currently in use were designed for coins; they require the driver to stuff dollar bills into them with wire probes. New fareboxes, to be installed in 1993, will accept dollar bills as well as coins, and will even count the value of deposits electronically, reducing driver-passenger payment disputes. The new fareboxes will also issue transfers (Lane 1992, B2).

In addition to their value in decreasing distractions and disputes, electronic fareboxes may allow agencies to collect useful information about ridership to be used in strategic planning. For example, electronic fareboxes may be able to count how many passengers board a given route at a particular time of day. They may also be able to indicate the stops at which the largest number of passengers board and the number of transfers issued at particular points.

Depending on the level of technology employed at the farebox, the transit system may also be able to count passengers who use non-cash payment such as bus passes. If the pass is not electronically encoded in some way, drivers push a button on the farebox to manually record each passenger who pays in this manner; if the passes use a magnetic-stripe technology, the farebox may read the pass directly. The former system is currently being used in Snohomish County on Community Transit buses, while the latter system is planned for use by Seattle's Metro following installation of electronic fareboxes in 1993 (Jack Floyd, Community Transit, telephone interview 23 June 1993; Chuck Sawyer, Municipality of Metropolitan Seattle, telephone interview 3 March 1993). In either case, the ability to study passenger counts on targeted routes would allow transit planners to measure the effects of scheduling adjustments and marketing campaigns more easily.

Fare payment, like bus information, can be divided into pre-board and on-board options. With a pre-board system, nothing need be shown, deposited, or given to the driver once the passenger has boarded the bus, while an on-board payment system involves a fare collection device in the bus. Tables 3 and 4 summarize the contents of this chapter. They present the major changes in fare-payment methods expected over the current, near-, middle-, and long-term time periods.

Table 3. Existing and Anticipated *Pre-board* Fare-Payment Methods

Method	**Current**	**Near**	**Middle**	**Long**
Cash		✓		✗
Tokens		✓		
Magnetic cards		✓		
Bus tube	✓ only one application	✓		
Multi-mode magnetic cards			✓	
Smart cards			✓	
Proof of payment system		✓		
Go cards			✓	
Debit cards				✓
ATM cards				✓
Credit cards				✓

○ = in Washington

✓ = in use

✗ = no longer used

Table 4. Existing and Anticipated *On-board* Fare-Payment Methods

Method	**Current**	**Near**	**Middle**	**Long**
Cash	⊘✓			✗
Tokens/coupons	⊘✓			
Passes	⊘✓			
Magnetic cards	⊘✓	✓ (more use)		
Multi-mode magnetic cards		✓		
Smart cards		✓	✓ (more use)	
Proof of payment system		✓		
Go cards		✓		
Debit cards			✓	
ATM cards			✓	
Credit cards			✓	

○ = in Washington

✓ = in use

✗ = no longer used

Current Fare-Payment Methods

Current technology for fare payment varies widely. "Tokens, coins, bills, debit cards, ATM cards, Visa and Mastercard, proof of payment systems, barrier systems—the entire spectrum of fare collection exists here in the United States and around the world" (Strandberg 1992, 47).

Pre-board

Only one bus system in the world, in Curitiba, Brazil, currently uses a pre-board payment system; however, pre-board fare payment may become more common within the next five years.

On-board

In most transit systems, fare payment takes place once the passenger has boarded the bus. There are four ways to pay one's fare: with cash (in the form of dollar bills or coins) which is deposited into the farebox; with tokens, which are similarly deposited; with special passes, which are shown to the driver; and with magnetic-stripe cards, which are passed through an on-board device that deducts the appropriate fare from the card's stored value.

The efficiency of on-board fare-payment methods can depend on farebox technology. Mechanical fareboxes, which are reliable and inexpensive, may accept coins, tokens, and bills (although many are not designed to take paper currency). Electronic fareboxes, which are more secure, can record more information and can reduce driver distraction and responsibility. They accept coins, bills, tokens, and magnetic stripe cards.

Near Term

Within the next five years, several technologies that will facilitate fare collection are expected to become available. Based on advanced electronics, these technologies may result in a "cashless" money flow.

Pre-board

It may soon be possible for passengers to pay their fares entirely during the pre-board stage. This option is likely to be available only at certain locations because it would require installation of additional equipment at boarding areas. Installing such equipment at every bus boarding area would be prohibitively expensive; however, even partial implementation would enhance operations.

Magnetic-stripe cards are an example of a technology that can facilitate pre-board fare payment. Passengers purchase magnetic cards from vending machines that accept cash, credit, or automatic teller machine cards (Casey et al. 1991, 13). Each magnetic-stripe card stores the value paid. Passengers then run their cards through a device at the station, which deducts the appropriate fare and allows them to enter the boarding area. The Bay Area Rapid Transit (BART) system currently employs this type of fare payment. Magnetic-stripe technology is not new; it has been in use on BART since 1972. However, it has not been widely applied on bus systems. Bus stations or transit centers in most areas would have to be redesigned to accommodate this type of technology.

Another type of pre-board fare payment method is used in Curitiba, Brazil. Buses there stop at raised tubes made of acrylic and steel. The tubes, depicted in figure 2, provide level access to the bus. Passenger fares are collected at turnstiles in the tubes prior to boarding. This pre-board fare collection system, combined with level door access, speeds the boarding process by reducing the on-board fare collection time and the need to operate door lifts and ramps.

The turnstiles could also be linked to a computer system to record the number of people passing through. This information could be used by transit officials to plan more effective bus routes. The 100 tubes in Curitiba helped increase bus ridership by 28 percent in a single year (Public Innovation Abroad 1992c, 3).

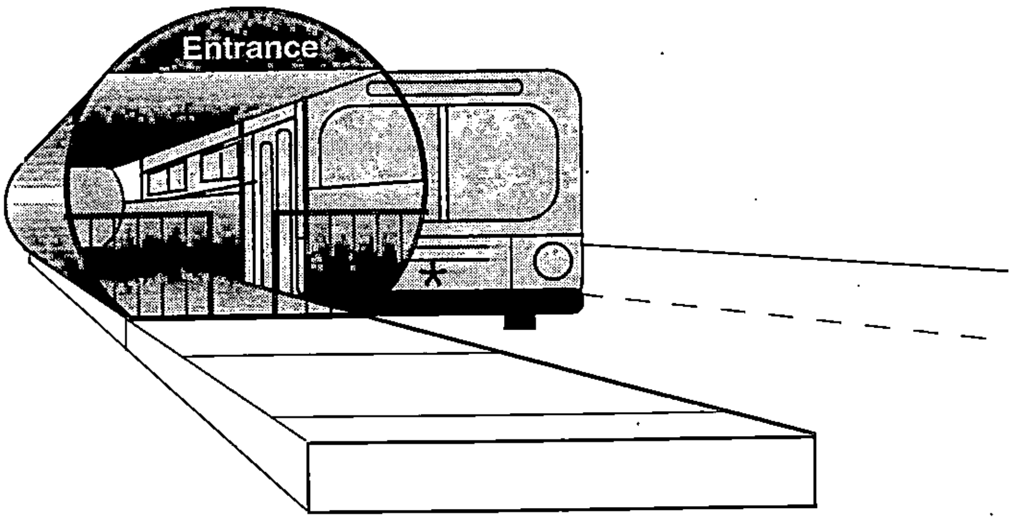


Figure 2. Bus tube concept

In the spring of 1992, four bus tubes like those in Curitiba were installed and demonstrated for a six-week period in New York City. The main purpose of the demonstration was to generate publicity for this new technology. A secondary purpose was to test operational feasibility. In this demonstration, passengers rode for free on a loop route in lower Manhattan that connected South Ferry, the World Trade Center, City Hall, and the South Street Seaport.

After analyzing the demonstration results, it was determined that a bus tube system implementation similar to Curitiba's would cost more to operate than a regular bus system, particularly because each Curitiba tube required an attendant to assist disabled passengers, answer questions, and operate the tube's doors. Full-scale implementation in New York would involve additional expenses because of the need to fortify the tubes to protect the on-site attendant. It was also found that the average dwell time (the time a bus spends at each stop) per passenger was longer for this system than for regular service.

At the outset it was thought that the tubes could reduce loading and unloading time ten-fold. However, this savings was not realized. The *increase* in dwell time was caused by several factors. One was that parked cars often blocked the tube and caused delays. A second was that the doors of the bus had to be properly aligned with the tube doors in order to allow passage (Public Innovation Abroad 1992c, 1; Hevesi 1992; Larry Hughes, New York City Department of Transportation, telephone interview 22 June 1993; Cooper 1992).

On-board

Magnetic-stripe card technology can also be applied to on-board fare payment. For example, passengers may purchase a magnetic card outside the bus, and once aboard, pass it through a device that deducts the appropriate fare. An additional use of magnetic-stripe technology in the near term would be as a multiple-mode ticket, in which case the card would have stored value for use on one mode, but could also be used as a "flashpass" on another. Such a system was tested in San Francisco Bay area from October 1989 to June 1990. The magnetic cards had a stored value for use on all BART trains, but they could also be used as passes for a two-week period on the San Francisco Municipal Railway and on Alameda Contra Costa Transit District vehicles (Casey et al. 1991, 14).

Another way that passengers may be able to pay their fares in the near term is with smart cards. Similar to a credit card in size and shape, smart cards are equipped with a programmable memory chip that can perform several functions, such as holding instructions, self-monitoring, holding value, and creating an electronic billing record (Casey et al. 1991, 23; Davies et al. 1991a, 16).

Smart cards are superior to magnetic-stripe cards for several reasons. Magnetic-stripe cards can be erased accidentally and duplicated fraudulently. Smart cards, on the other hand, can be identified by an electronically unique internal serial number; they cannot be duplicated. Additionally, the smart card can be encoded for additional security (Ognibene 1992, 13).

Smart card users insert their cards into a device on the bus as they board. The device indicates whether the account balance is sufficient to pay for the trip and then deducts the fare. Passengers may add value to their accounts by sending a check to the appropriate transportation agency.

Although they are rarely used in the United States, Europeans have used smart cards for several years (Ognibene 1992, 13). Among the few examples of smart-card technology in the United States was a demonstration project carried out between February and July 1990, by the Port Authority of Allegheny County, in Pittsburgh. In that case, smart cards were good for unlimited monthly service on 15 buses covering three routes. The project was considered successful because it showed that a smart card system would be feasible for buses (Casey et al. 1991, 25).

Smart cards are also being introduced in the Chicago metropolitan area, where a paratransit service is planning to use this new technology to automate fare collection and to identify legitimate paratransit passengers. Paratransit is defined as "public and semi-public transportation services that are more flexible and personalized than conventional fixed route, fixed-schedule service. It utilizes low- and medium-capacity highway vehicles" (Jones and Chambers 1992, 178). Chicago's paratransit service is semi-public in that only the disabled and elderly, of whom there are approximately 17,000 in the service area, are eligible to use it. Smart cards will be used to ensure that only those eligible for the relatively expensive service will be able to board.

The paratransit drivers will be issued smart-card acceptors. At the beginning of each shift, drivers will use their own smart cards to open an electronic log book in the card acceptor. At each pick-up, the driver will enter the passenger's card into the acceptor, punch in the odometer reading, and deduct the fare from the passenger's account. When the passenger is dropped off, the card will be reinserted, and another odometer reading will be taken. At the end of each shift, the acceptor will be placed in an "electronic cradle" to recharge the battery, to transfer the drivers' logbook to the transit agency, and to clear the acceptor for the next day's trips (Ognibene 1992, 12).

A smart-card system was introduced in 1991 for buses in the city of Luneburg, Germany. Passengers insert their cards upon entering the bus and again upon leaving, at which point the fare is registered. The Luneburg system uses two types of cards. The first is akin to a debit card, wherein monthly travel costs are deducted from the passenger's bank account. The second is a card that stores value; the cost of each trip is deducted as it is incurred. The card validator on the bus alerts the passenger with an audio signal when his or her card's value is nearly used up. The Luneburg system gives passengers the freedom to travel without worry about fare zones. Moreover, if lost or stolen cards are reported, fraudulent attempts to use them can be detected (Urban Transport International 1991a).

Another smart-card system used in Germany, "Fahrsmart," relieves passengers of worry about fare structure and the least costly method of payment. At the end of each accounting period, usually a month, passengers are automatically charged the most favorable fare. For example, if a monthly total exceeds the cost of a monthly pass, then the cost of a pass, rather than the actual total, is charged. Several card validators are located throughout Fahrsmart buses, so boarding is not slowed by the payment process (Kraftverkehr GmbH 1992, 7).

Robert Cervero, professor of Urban and Regional Planning at the University of California, Berkeley, suggests that the use of smart card technology could help promote urban density and contain undesirable growth by "allowing for more efficient pricing of transportation resources" and by facilitating a "better integration of transport systems and services" (1992b, 3).

Another type of fare-payment system that may be possible in the near term is a proof-of-payment system. Such systems are used extensively in Europe and are less costly and labor intensive than magnetic-stripe or smart cards. Proof-of-payment systems do not require verification for each passenger. Rather, passengers simply board the vehicle with a pass or a receipt that indicates fare payment. Inspectors board vehicles randomly to check receipts. If inspectors find a passenger without a receipt, a fine is assessed. For example, on the light-rail system in Los Angeles a ticket costs $1.10, whereas the fine for having the wrong ticket is $90.00.

The main disadvantage of proof-of-payment systems is that people may try to ride for free and take the risk of riding without a fare receipt. In addition, bus systems often have so many routes that policing is difficult. As a result, many people do not pay their fares. Nevertheless, according to the president of J.W. Leas and Associates, a transit consulting agency that specializes in fare collection, this system may be gaining acceptance in the United States. Mr. Leas notes that "it has been introduced only on light rail in the U.S. and Canada, and there are a dozen different cities in operation today (e.g., Los Angeles, Buffalo, Vancouver, Calgary, Portland, Sacramento, and San Jose)" (Strandberg 1992, 51).

Another type of fare payment that may become feasible within the next five years is a "go card" or "contactless" card. Passengers carry the cards on their persons, and the cards need not contact the debtor devices directly. Rather, passengers simply walk through sensors that automatically debit their cards (Strandberg 1992, 52).

Ajax Transit, of Ontario, tested go-card technology from September 1991 to June 1992. High school students there were given "ridekeys," similar in size and shape to dominoes. The ridekeys, which contained a microprocessor and memory, were passed through an electric field generated by validators installed on public buses. Each ridekey carried a certain monetary value, and fares were deducted as the students passed through the electric field. One advantage of this system was that when a student transferred from one bus to another, his or her ridekey "told" the validator on the next bus whether the transfer was free, an upgrade, or a new trip start. This feature had the advantage of totally removing the driver from normal fare transactions (Blurton 1992).

The test with the high school students was the first part of a larger assessment of the go-card technology. A second test, which took place between January and May of 1992, evaluated the system's ability to automatically charge passengers the most favorable (cheapest) fare. Few objections to the ridekey system were raised by Ajax passengers or by the bus drivers. A particularly well-liked feature was the system's ability to invalidate and thus identify lost or stolen cards. Ajax Transit plans general usage of the ridekey system in the near future (Blurton 1992).

The city of Turku, Finland, is the first to implement contactless, go-card technology on municipal buses on a permanent basis. Passengers in Turku hold their cards in front of a "reader" for less than one second as they enter the bus. The reader registers the fare and the passenger's account number and then deducts the appropriate amount from his or her bank account automatically. The reader beeps and triggers a green, go-ahead light as long as the card is valid; a red light flashes and a longer tone is emitted if the card is invalid. A flashing yellow light indicates that the card's value is almost exhausted (Public Innovation Abroad 1993, 8).

Middle Term

Although no new fare-payment technologies are anticipated within the next ten years, the technologies already discussed are expected to become more refined and more widely used. During this time period, fare payment will shift from on-board to pre-board locations, and more electronic payment systems may be used. Pre-board payment is expected to make boarding and unloading more efficient, improve schedule adherence, and reduce driver distraction.

Some of the advances in on-board payment methods anticipated within the next ten years include increased reliance on electronic billing, which will be handled directly by banks; the possibility of third-party billing; and the spread of smart card use (IVHS America 1992, III-106). Electronic billing, in particular, is expected to become more widespread as debit cards, automatic teller machine cards, and credit cards are incorporated into the billing process. Currently, it is not cost-effective for banks to process credit card payments for small transactions (such as transit trips). However, according to the president of Almex Control Systems, Inc., "Credit card companies are starting to go after the small transactions...I think the push toward credit card utilization in the transit industry will advance the technology. The average person in the U.S. has $17 in bills and 37 cents in change, so if they want to buy an extended ticket, they'll have to use a credit card. If you want to get ridership up, you have to have the ease of payment and ease of use" (Strandberg 1992, 47).

Electronic billing will also allow employers that subsidize transit costs to be charged only if their employees actually use the services. Transit companies will be able to present employers with bills reflecting the actual charges incurred by their employees, thus eliminating the wasted expense associated with flat-fee cards that go unused.

Long Term

Within 20 years, all reservations, billing, and bus-ticketing functions are expected to be performed electronically, with automated account debiting. Cash transactions will be greatly reduced or eliminated (IVHS America 1992, III-106).

Fare-Payment Practices in Washington State

Although fare payment in Washington state is currently restricted to on-board methods, it is possible to purchase passes, tokens, or coupons in advance.

Once passengers are aboard, there are several fare payment methods to choose from. The first is to simply show the driver a pre-purchased pass. Passes can be obtained for various time increments, up to one year. Pre-purchased passes offer a number of advantages:

- they eliminate cash or coupon handling by both passengers and drivers;
- they allow faster boarding;
- they eliminate fraudulent fares and driver-passenger fare disputes; and,
- they can generate additional revenues based on the investment of pre-payments.

Passengers may purchase passes at designated transit center locations, by mailing a check to the transit agency, or by calling a special phone number designed for credit card payment (Sawyer 1993).

A second payment method is to simply to use cash. This option is convenient for occasional users who do not wish to purchase passes, and for those who are temporarily without a pass. A third payment method is the presentation of a pre-purchased coupon. Coupons are preferable to cash because they represent the exact fare. Coupons may be used at any time; users can present them whenever they decide to ride the bus. They are generally purchased in set amounts, such as books of ten or twenty coupons.

Similar to coupons, tokens are the fourth payment method. In some cases, tokens are purchased directly from transit agencies; in others they may be part of a promotional program between retailers and a transit agency (Sawyer 1993).

The fifth, and most advanced fare payment method currently in use in Washington state is magnetic-stripe card technology, which is in place at Spokane Transit. In this system, passengers slide their passes through a device that checks the passes' validity (Overhauser 1993).

Several advanced farebox technologies are currently in use in Washington state. Fareboxes on Spokane Transit buses count coins (including pennies) accept dollar bills, display the amount deposited, beep when the correct fare has been paid, count token payments, and recognize "free ride" coupons. These fareboxes are also equipped with buttons that allow the operator to count the number of Spokane Transit employees, disabled people, and children on board. These buttons also allow the driver to keep track of short fare payments (i.e., people who do not have enough money to pay the fare), and transfers issued.

Snohomish County's Community Transit also features advanced fareboxes that can count coins, accept dollar bills, count token payments, issue transfers, and recognize bar codes (Floyd 1993). In 1993, Seattle's Metro Transit is installing electronic fareboxes on all its buses. These fareboxes will be able to count coins, take dollar bills, read magnetically encoded passes, deduct appropriate fares from the pass, and issue and collect timed transfers (Lane 1992, B2; Sawyer 1993).

Chapter 5. Bus Monitoring

Technological advances in recent years now make it possible for transit agencies to monitor their buses while they are out on their routes. Two types of bus monitoring are examined in this chapter. The first, bus tracking, involves monitoring the exact location of a bus in a street network. The second, vehicle status, involves monitoring the vehicle's operating conditions while it is on the road. The technology used for bus tracking is also essential in providing the "real time" transit information discussed in Chapter 3.

Current Status

Bus Tracking

Bus tracking uses automatic vehicle location (AVL) to pinpoint a bus's location on the street network. Bus tracking allows real-time monitoring of a bus's movements, control of bus headways, closer schedule adherence (including more effective timed transfers), and the ability to direct maintenance crews in the event of a vehicle breakdown. The real-time location information offered by this technology also allows agencies to provide arrival time updates for commuters waiting at transit centers (Cervero 1992a, 5; Casey et al. 1991, 28).

Most of the technology necessary for bus tracking is already available. Vehicle tracking experiments began as far back as 1958 in South Africa, Japan, Australia, and Europe (Casey et al. 1991, 39). Because most of the technology necessary for bus tracking is already available, this capability could be implemented on a larger scale within five years.

Much of the following discussion of bus-tracking technology is drawn from two documents: *Advanced Public Transportation Systems: The State of the Art* by Robert F. Casey (1991) and *Assessment of Advanced Technologies for Transit and Rideshare Application* by Peter Davies et al. (1991a).

The advent of automatic vehicle location represents the key technological development in bus tracking. AVL determines a vehicle's actual position, which can then be compared to the vehicle's desired position (based on schedule and route information). AVL systems require three components, depicted in figure 3: (1) a method of determining vehicle location; (2) a means of communicating the vehicle's location to a main control center; and (3) a central processor to store and manipulate the information.

AVL is currently being tested and implemented in many locations. The types of technologies used depend on the size of the operation as well as the geographic features and weather conditions of the surrounding area (Casey et al. 1991, 32).

Examples of the major types of AVL are discussed below. Figure 4 illustrates the range of technologies: a roadside signpost/sensor system, a dead reckoning system,

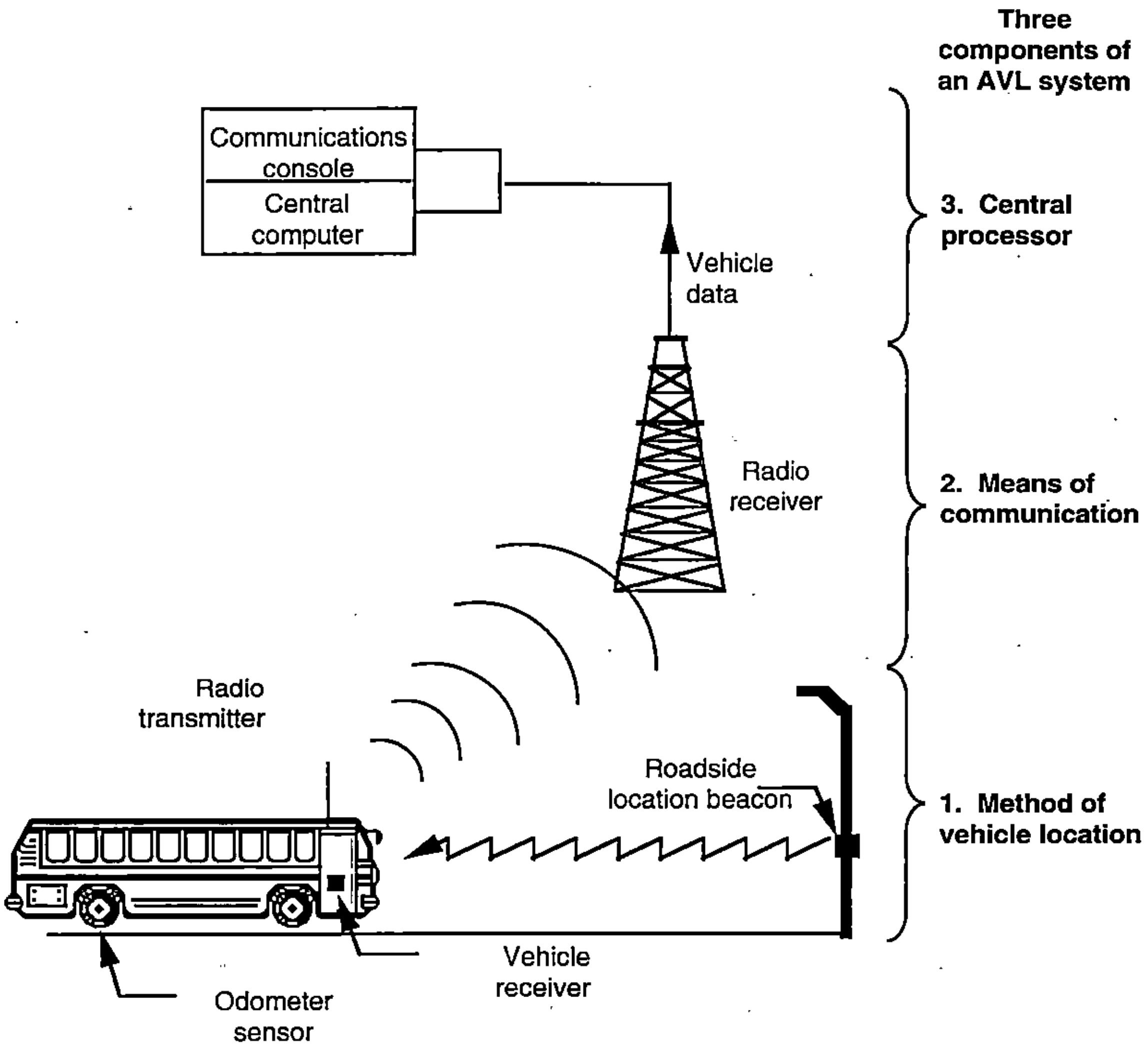


Figure 3. Typical AVL system configuration [Davies et al. 1991, 41]

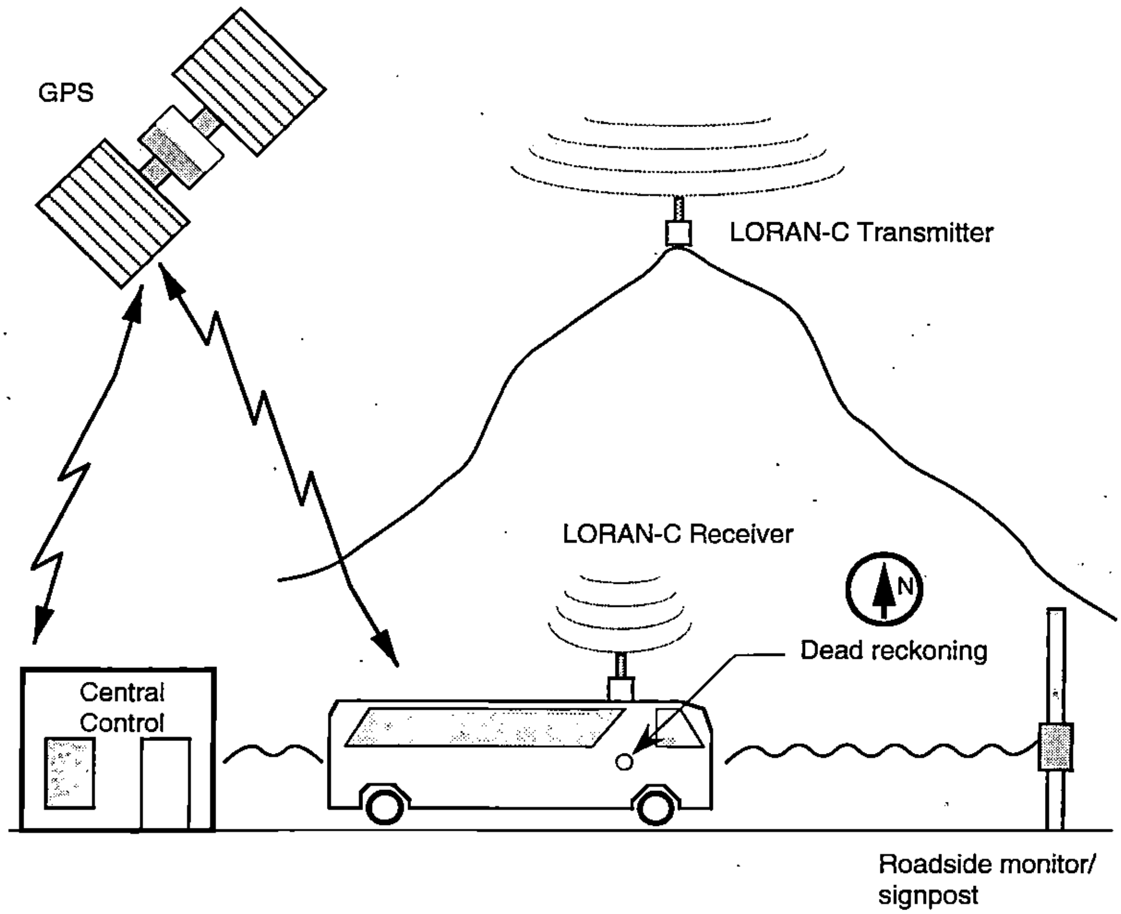


Figure 4. Major types of AVL technology

a LORAN-C system, and a global positioning system.

The **signpost/sensor** system uses fixed transmitting signposts which are detected by passing vehicles. The signpost's transmitter signals are used to determine the vehicle's position, which can then be relayed back to a central control location. This technology is used by the Tidewater Transportation District Commission in Norfolk, Virginia, which relies on signposts and bus odometers. The signposts broadcast their locations to passing buses within a radius of 100 feet. Where there are no signposts, buses use their odometers to measure the distance from the last signpost. The bus's location is communicated by radio frequency to a central processor, which then updates the dispatcher, and in turn the driver, who can then adjust his or her driving speed accordingly (Casey et al. 1991, 33).

Roadside sensors are also used in Ottawa to monitor vehicle movements. These sensors transmit data to a central computer which can then determine the vehicle's location, the extent to which it is out of schedule sequence, how fast it is traveling, and how soon it will reach its destination. Passengers may access this information via a special telephone number. Similar systems are in place in Halifax, Nova Scotia, and in Hull, Quebec (Cervero 1992a, 5).

The Ann Arbor Transit Authority determines its buses' locations using another technique known as **"dead reckoning,"** a technology wherein the bus uses its odometer and an on-board compass to compute its location. Starting from a known position, the system computes the distance and direction traveled, then fine tunes its estimated new position by comparing it to a road map database stored in the vehicle. To correct any location errors that may accumulate because of the limited accuracy of the odometer and compass, the system also takes readings from strategically located signposts (Casey et al. 1991, 34; Davies et al. 1991a, 58).

Location can also be determined using **LORAN-C**, a system originally developed for the United States Coast Guard. Ground-based transmitters, which are already in place, emit a signal that is picked up by buses equipped with LORAN-C receivers. These receivers determine the signals' direction. Buses receive signals from several transmitters, which allow them to triangulate their positions. Triangulation uses three different reference points to determine an object's location. This system has the advantage of working anywhere, not only on designated routes. A disadvantage is that it is less accurate in the vicinity of large buildings or "difficult" topography, which disrupt signals (Casey et al. 1991, 36; Davies et al. 1991a, 57).

AVL can also be accomplished with the **global positioning system (GPS).** This technology uses satellites to locate objects on the earth's surface. Like LORAN-C, GPS also uses triangulation to locate objects. Here, however, the transmitters are in orbit around the earth rather than on its surface (Davies et al. 1991a, 57). One of GPS's advantages is that it can cover a wide area with minimal equipment; a vehicle requires only an on-board device that can be detected by the overhead satellites. A disadvantage is that GPS may have trouble locating buses in "urban canyons" (areas with tall buildings along the streets) (Casey 1991, 40). Because commercial GPS tracking technology is relatively new, few current applications exist. The city of Dallas currently uses GPS technology; Denver and Milwaukee are planning to use it as well (Ken Turner, Tri-County Metropolitan Transit District of Oregon, telephone interview 2 July 1993).

A GPS system designed by Trimble Navigation, Ltd. performs vehicle tracking with a positional accuracy of two to five meters horizontally, and computes velocity to within 0.2 meters per second. Vehicle positions appear on a central display that provides the bus controller with an overview of the system; the controller can then redirect the buses in case of an incident. If buildings block satellite signals, a dead-reckoning sensor is used to maintain tracking (Urban Transport International 1991b).

AVL systems can incorporate a number of additional components to improve service and management.

- **Automatic passenger counters.** In Chicago, a planned AVL system will incorporate a passenger-counting function to communicate real-time information about a bus's load to the dispatchers. This will allow them to instruct drivers to skip stops if a vehicle is full (Casey et al. 1991, 39).

- **HOV identification for signal actuation.** AVL systems can be extended to communicate a bus's presence to a traffic signal's sensor. The signal system then responds by providing the HOV with a green light (see Chapter 7 for examples).

- **Silent security alarms.** The VIA Metropolitan Transit Agency in San Antonio, Texas, has installed panic buttons on its buses. In an emergency, the driver pushes the button, which notifies the dispatcher of a problem. Once the button has been pushed, all communications with the bus are shut off, to keep the perpetrator from knowing that an alarm has been sounded. False alarms prompted transit planners in Ann Arbor to install a "listen in" feature which allows the central dispatcher to hear what is happening on the bus and to send in police if necessary (Casey et al. 1991, 33).

- **Passenger information systems.** The Ann Arbor Transit Authority's AVL system displays each bus's location, represented as a block, on a full-color monitor showing the street network. The block is color-coded according to vehicle type and its on-time status. The information is used by the transit agency's central control to help keep buses on schedule and facilitate timed transfers. Buses can be told to wait for up to five minutes to allow passengers to make transfer connections. This real-time schedule information is also passed on to the public to supplement printed schedules (Casey et al. 1991, 35).

Vehicle Status Monitoring

AVL communications technology also allows transit agencies to monitor the mechanical condition of buses on the roads. Mechanical conditions may be reported to the driver while on the road, via a dashboard display, and to the mechanic, who can plug the engine into a diagnostic computer when the bus is in the repair shop. Mechanical problems may also be communicated directly to central control during operation, where a decision to remove the bus from service to avoid a breakdown may be made (Casey et al. 1991, 31).

In Norfolk, Virginia's AVL system, sensors monitor air pressure in the brakes, engine temperature, and oil pressure. When conditions warrant, an alarm is sounded, and the dispatcher can send out a mechanic with information about the condition of the bus, and if necessary, a replacement vehicle (Casey et al. 1991, 33; Cervero 1992a, 5).

Figure 5 depicts other devices that are not part of an AVL system, but that are currently in use to assess the mechanical condition of buses. They include on-board tachographs to indicate driving time, speed, and distance; taximeters to monitor distance, time, speed, fuel consumption, and engine revolutions per minute; and computer-based systems to monitor additional bus conditions including water temperature and oil pressure (Davies et al. 1991, 39; 1991a, 50).

Anticipated Developments in Bus Monitoring

Although no major technological changes are expected in bus tracking, wider implementation of the methods already available is anticipated. In terms of vehicle status monitoring, transit agencies may be able to check tire condition, traction, braking, and acceleration electronically within ten years (IVHS America 1992, III-42, III-100).

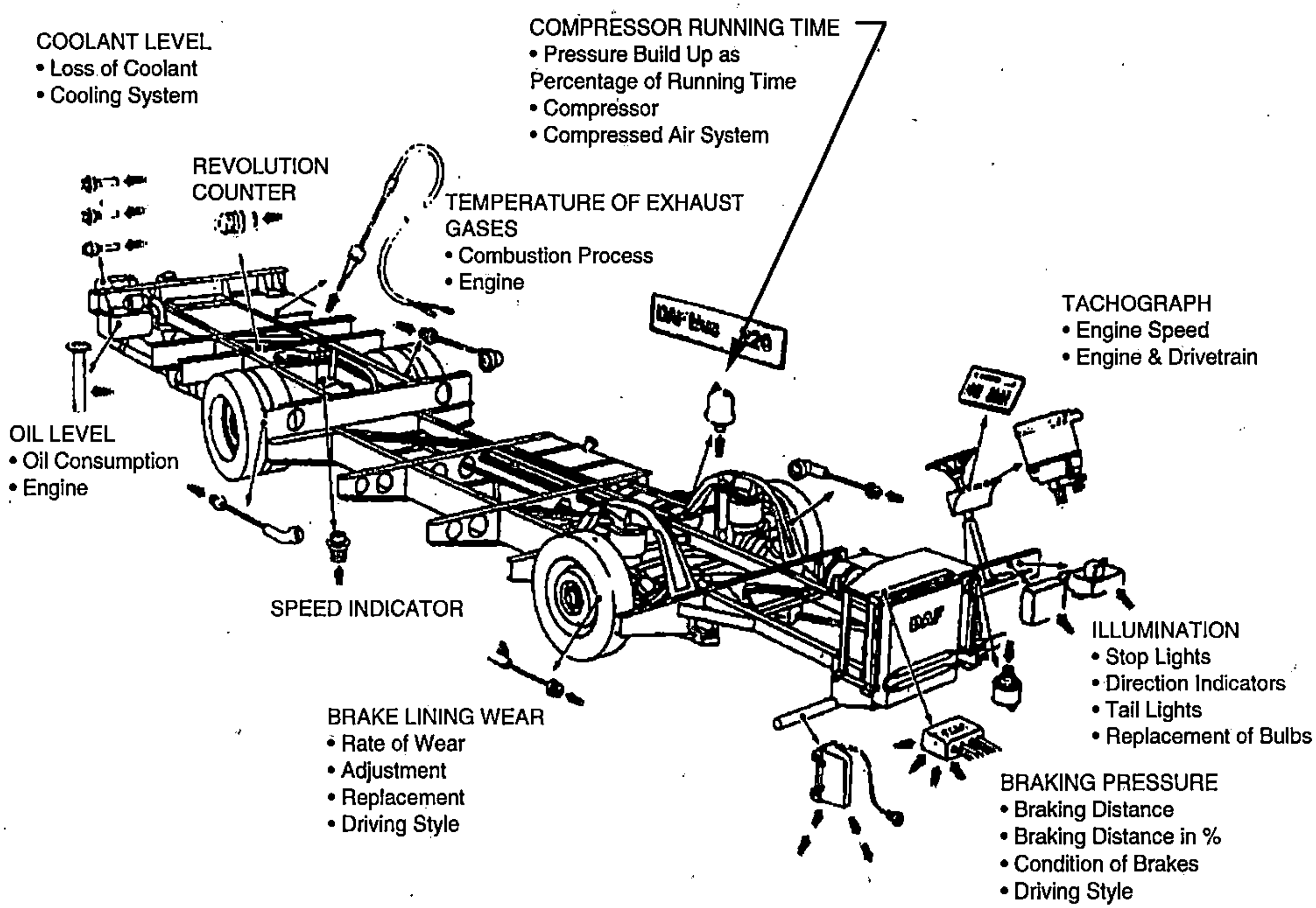


Figure 5. Vehicle condition detection devices
[adapted from Davies et al. 1991, 40]

Bus Monitoring in Washington State

Bus Tracking

In Washington state, bus tracking technology has been applied in several ways. For example, Snohomish County's Community Transit is using an advanced vehicle identification system (AVI) to monitor bus speeds in the HOV lanes on I-5. Approximately 80 Community Transit buses are equipped with transmitter devices. These "hockey pucks" are located on the bottom of the buses and are detected by roadway loop detectors (loops of wire embedded in the roadway surface through which an electric current runs). The loop detectors are used to detect the presence of specific vehicles. As the bus's "hockey puck" travels over the loop detectors, it transmits the bus's identification number, which is recorded with a time stamp (see figure 6). This procedure occurs at several locations along the HOV lane. These time-stamped recordings, combined with knowledge of the distance between loops on the HOV lane, allow calculation of the bus's travel speed.

Community Transit's purpose in using this AVI system is not to monitor its bus fleet, but to assist the Washington State Department of Transportation (WSDOT) in measuring and meeting the "criteria travel speeds" for the HOV lanes on I-5 (Larry Ingalls, Community Transit, telephone interview April 1993). Set by the WSDOT, the criteria travel speeds are part of the Washington State Freeway HOV System Policy. This policy states that "HOV lane vehicles should maintain or exceed an average speed of 45 mph or greater at least 90 percent of the time they use that lane during the peak hour (measured for a consecutive six-month period)" (Washington State Department of Transportation 1992, 12). These criteria travel speeds are meant to ensure that HOV lane users have a speed advantage over other roadway users.

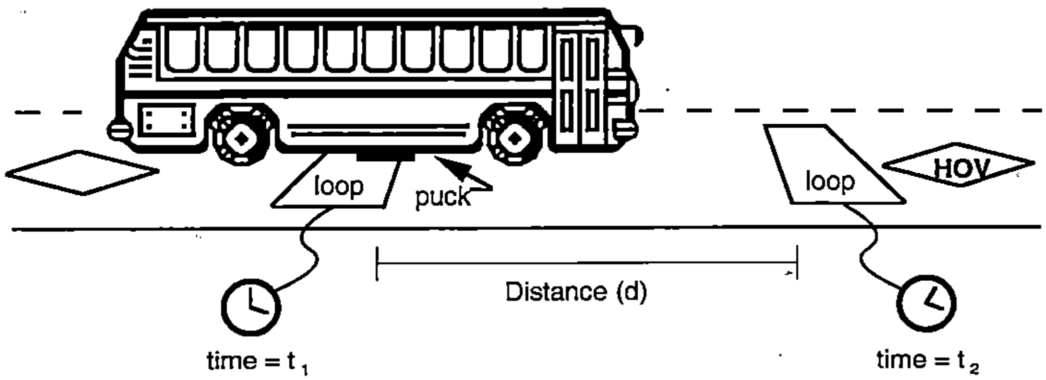
Another type of bus monitoring is used by Seattle's Metro Transit. Metro employs a radio locator system which is similar to one used in Norfolk, Virginia (described earlier in this chapter). Metro's monitoring system uses radios, signposts, bus odometers and a computer at the central control center. The computer stores schedule information and a computer map for all routes.

Drivers begin their day by logging on with a radio number that corresponds to a route on the computer's map. Through the radio system, a poll is taken of the buses approximately every one to one and a half minutes. When the bus is polled, it reports the odometer reading to central control, using the odometer sensor on its right front tire. The computer uses this information to compare the location of the bus to the time schedule (stored in the computer). What results is a central display with a symbol of each bus, color-coded according to its on-time status.

Approximately 250 signposts are also located along Metro's routes. Each signpost transmits an identifying signal which the passing bus records. When the bus is polled by the radio, it reports the last signpost signal received. Central control interprets the signpost signal to determine the bus's location. The system is in effect on all routes and on all Metro buses (Loni Sewell, Municipality of Metropolitan Seattle, telephone interview 4 June 1993; Dan Overguard, Municipality of Metropolitan Seattle, telephone interview 18 June 1993).

Vehicle Status Monitoring

Seattle's Metro Transit buses are equipped with several sensors which monitor the vehicles' mechanical status. Some of these are similar to those found in automobiles; they include engine temperature and oil pressure gauges. In addition, because their suspension and braking systems rely on a certain air pressure, Metro buses feature air pressure gauges as well. If the pressure drops, an alarm warns the driver. Finally, Metro's articulated buses feature another alarm which sounds if the driver overextends the joint that connects the front and rear halves of the bus (Loni Sewell, Municipality of Metropolitan Seattle, telephone interview 4 June 1993).



$$\frac{d}{t_2 - t_1} = \text{average speed between loops}$$

Figure 6. AVI in use in Washington State

Chapter 6. Bus Control

Bus control encompasses any technology used to guide a bus's movement. *Lateral* control involves movements to the left or right (steering), whereas *longitudinal* control deals with forward and backward motion (acceleration or deceleration) (see figure 7). Bus control technologies include not only direct control of bus movement, but warning or advisory systems that allow the driver to control the bus more safely and efficiently.

Much of the technology that is expected to be used to control buses in the future will be based on intelligent vehicle highway systems (IVHS) research. Most IVHS research focuses on automobiles; however, in many instances technology developed for automobiles will be adaptable to buses.

Table 5 summarizes the contents of this chapter. It presents the major changes in bus control that are anticipated for the current, near-, middle-, and long-term time periods.

Current Status

Advanced lateral and longitudinal bus control technologies are already in use in several locations. To date, most of the technology in this area has involved lateral control (movements to the left or right). Longitudinal control (acceleration or deceleration) is still in its infancy, so actual examples are relatively few.

Lateral Control

Currently, there are two types of applications of lateral control: mechanical and electronic. *Mechanical control* uses a guideway that restricts the bus's movement to the guideway itself via a mechanical linkage with the vehicle. For example, guide rollers, attached to either the front or to all axles of the bus, can provide lateral control. The rollers run between a set of guiderails along the roadway; this allows the bus to essentially steer itself (see figure 8).

Mechanical control may also be achieved by embedding a single, slotted rail in the road surface. Bus axles are then fitted with rollers which fit into the slotted rail (Institute for the Future 1992, 84).

The second type of lateral control, *electronic guidance,* is created by embedding a transmitting antenna in the roadway. Buses that travel over such transmitting antennae are equipped with a receiving antenna and an electronic control system. The control system measures how far the bus deviates from the path of the embedded antennae and re-steers the bus with a motor or hydraulic actuator connected to the steering system (Casey et al. 1991, 61). Equipping and modifying a bus for electronic guidance can be more expensive than mechanical guidance. However, track costs may be lower because the embedded antennae are easier to install in a roadway than a retrofitted mechanical guidance structure (Labell 1992, 69).

Examples of Mechanical Control Technology

The first application of mechanical control technology was in Essen, Germany, in 1980. The technology, called "O-Bahn," was

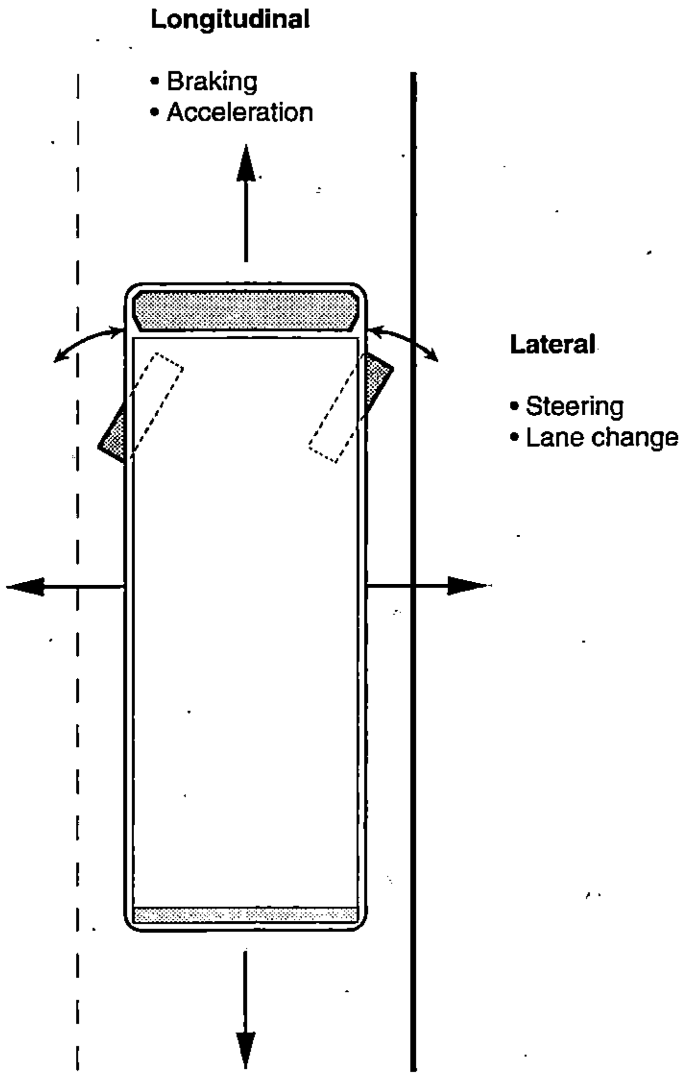


Figure 7. Bus control

Table 5. Existing and Anticipated Bus Control Technology

Bus Control Technology	Current	Near	Middle	Long
Lateral				
Mechanical control methods	✓			
Limited electronic control methods	✓[1]			
Side obstacle warning system		✓		
Blind spot obstacle warning system		✓		
Lane stray warning system			✓	
Merge/lane change warning system			✓	
Automatic steering control			✓	
Intersection warning system				✓
Fully automated vehicles				✓
Longitudinal				
Precursors: anti-lock brakes	✓			
traction control	✓			
active suspension	✓			
four-wheel steering	✓			
"Near" obstacle detection system	✓			
Adaptive cruise control		✓		
Electronic control of anti-lock brakes		✓		
Electronic control of engine speed		✓		
Electronic control of transmission		✓		
Traction control under acceleration		✓		
"Far" object detection system	✓[2]		✓	
Automatic braking system			✓	
Roadway condition detection system			✓	
Automatic collision avoidance system			✓	
Vision-enhancement system			✓	
Intersection warning system				✓
Fully automated vehicles				✓

[1] Demonstrated [2] Not connected to brakes

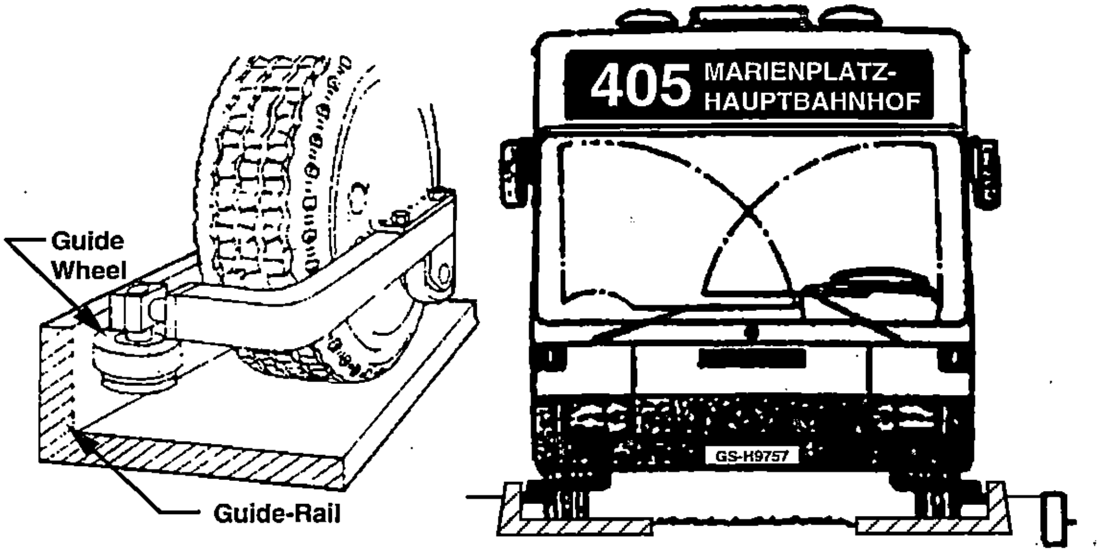


Figure 8. Mechanical bus control technology [Read et al. 1990, 581; Public Innovation Abroad 1992d, 3]

developed by Daimler-Benz and M.A.N. of Germany to allow buses to travel in Essen's light-rail tunnels. As a result, the Essen system features a mixed operation of guided buses and light-rail vehicles along the same right of way. Buses run along a four-kilometer converted tramway in a roadway median as well as through a tunnel under the downtown (Read et al. 1990, 581).

Adelaide, Australia provides another example of O-Bahn mechanical guidance technology. The system features a 12-kilometer, mechanically guided busway. Buses can operate on public streets and then access the grade-separated busway at appropriate locations. The buses' guide wheels allow them to switch quickly from independent, on-street operation to the guided mode. Begun in 1986, the Adelaide system now has approximately 300 buses in service.

Houston Metro, in Texas, is planning a test to incorporate the O-Bahn technology on a prototype bus route. In addition to the O-Bahn technology, an enhanced passenger information system, low floor boarding buses, air conditioned bus stops, and an automated fare collection system will also be tested (Urban Transportation Monitor 1992, 5).

An application of O-Bahn technology has also been considered in Washington state. Seattle's Metro Transit employs M.A.N. buses that are similar to the vehicles used on Adelaide's busway. These buses could be fitted with the appropriate guide wheels if a system like the one in Adelaide were implemented here. In fact, O-Bahn technology was considered for the Seattle bus tunnel.

Guided bus systems offer several advantages over conventional bus operations: (1) Bus operation is safer and more efficient because of the separation from city traffic and congestion. (2) The guideways require less road space; buses can also be used for regular road service when not on the guideway. (3) Finally, the raised entry platforms associated with this technology allow for quick, easy access by all users (Public Innovation Abroad 1992d, 1, 3).

Examples of Electronic Control Technology

While there have been many laboratory tests of electronic guidance, notably by the Transport and Road Research Laboratory in the United Kingdom, there has been only one demonstration project in public service (Labell 1992, 69). Furth, Germany was the site of this demonstration, which began in 1984. The route was 1.5 kilometers long and had three stops. Three buses were used to service the route. The project was discontinued in December 1985, when an underground railway was extended to Furth. The bus route demonstrated the feasibility of electronic guidance (Labell et al. 1992, 69).

One advantage of electronic guidance is that it reduces road space requirements. The German demonstration project indicated that space requirements are reduced by up to 20 percent compared to mechanical guidance. Another advantage is that it does not require the guideway structure needed for mechanical guidance systems (Casey et al. 1991, 62). These advantages would seem to make electronic guidance suitable for environmentally sensitive areas, narrow corridors, or pedestrian areas where guiderails are unacceptable or where buses have to move within a specified area (Read et al. 1990, 586).

Longitudinal Control

IVHS research has not yet advanced to the point of providing fully automated longitudinal control; most longitudinal control systems for buses and other vehicles are still in their infancy. However, the technological precursors of full longitudinal control are already in place in some areas. These precursors include anti-lock brakes, traction control, active suspension, and four-wheel steering (IVHS America 1992, III-36).

Examples of Longitudinal Control Technology

One example of a preliminary longitudinal control technology is an on-board radar system developed by VORAD (vehicle on-board radar system) Safety Systems. Greyhound is equipping 2,400 buses with the system; it is the first widespread commercial transit application of IVHS equipment in the United States. The estimated cost of retrofitting the buses with this system is $5 million, which will add over $2,000 to the price of each bus.

Greyhound is equipping its buses with an antenna on the front grill that produces a radar beam over the road in front of the bus. The radar beam (see figure 9) scans for obstacles in the bus's path while a second wide-angle beam scans the driver's blind spot. The system warns the driver with a dashboard light and a tone when an obstacle is detected. Eventually, VORAD will be able to decelerate the vehicle automatically. VORAD's radar detection system will be connected directly with the brakes. The president of VORAD Safety Systems commented on the potential ability of such a system to reduce the number of lives lost and dollars claimed each year in accidents, noting that "studies have shown that if drivers are given even half a second of additional warning time, more than 60 percent of all rear-end collisions could be prevented" (Public Innovation Abroad 1992a, 6; Popular Science 1992, 22).

A similar laser-based system, designed to prevent rear-end collisions between trucks, was tested in Japan in 1991. The system was developed jointly by a subsidiary of the Nissan Corporation and the Kanto Seiki Company, which operates some 400 long-distance trailer trucks. The system involves a device with a laser radar head that is attached to the front of the vehicle; its purpose is to measure the distance between vehicles. The measurements begin at a maximum distance of 260 feet. If a truck with the warning system starts to gain on the vehicle in front of it, and if the truck is going at least 2.2 miles per hour faster than the vehicle in front, a warning beep sounds. The sound becomes progressively louder if the driver fails to slow down. Inter-city bus lines in Japan plan to adopt a similar system (Public Innovation Abroad 1992a, 6).

Entrained Buses

"Entrained buses" are another possible means of controlling bus operations on the roadway. The principle underlying entrained buses is that individual buses converge at a given location; they are then linked together mechanically or electronically to form a "train" that operates on a dedicated, high-capacity roadway. In the linked mode, fewer drivers would be needed, perhaps only one in the first bus. Trailing buses could function without drivers. Drivers displaced during the linkage would become drivers of other buses from an arriving unlinking bus train (see figure 10).

The lateral and longitudinal motions of an entrained bus would be controlled by the driver of the first bus. This driver would control the trailing buses' steering, acceleration, and braking systems. Alternatively, the trailing buses' operating systems would be shut off, and they would be pulled along by the first bus, much like unpowered passenger cars are pulled by a train locomotive.

An extension of the entrained bus design involves a fully automated system. According to this concept, no driver at all would be needed to control the entrained bus; all control would be performed by on-board automated systems. This type of design would require a grade-separated guideway.

At this point, an entrained bus system is a theoretical possibility. Bus systems that incorporate both lateral and longitudinal controls do not yet exist, at either commercial or test levels. The closest approximation of the entrained bus concept is the trailer bus. Trailer buses resemble 18-wheel trucks, except that the trailer of the vehicle carries passengers (see figure 11). As of 1991, California's Orange County Transit District had 12 of these vehicles in its fleet. Each vehicle "consists of a standard heavy-duty cab over [a] truck tractor as a power module which pulls a passenger module—a specially designed trailer fitted out to carry passengers" (Wilkins 1991, 34). These buses have air suspension, seat 67 with additional standing room for 60, and are equipped with reading lights and overhead racks. Other

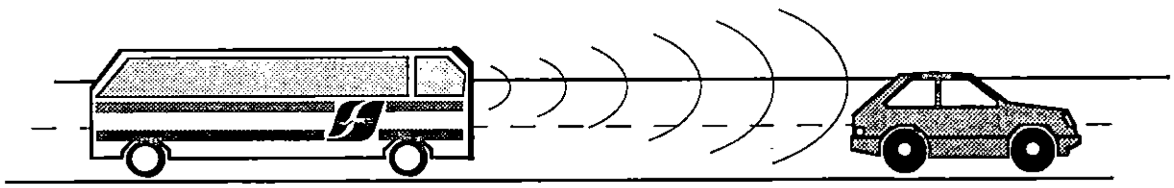


Figure 9. Greyhound VORAD radar warning system

features include low floor boarding for easy access and an automated fare-collection system. In the event of a breakdown, the cab portion can be replaced, thus avoiding the need to take the entire vehicle out of service. Orange County Transit chose these trailer-buses over conventional articulated buses for their commuter service between Fullerton and Los Angeles as well as for local county service (Wilkins 1991, 34).

In theory, the trailers could be linked together like triple-trailer trucks on highways. Thus, a two- or three-car "bus train" could be formed. There are no known examples of such triple-trailer buses at this time.

Near Term

Within the next five years, more technologies that support automatic lateral and longitudinal bus control are expected to become available. These technologies will provide more advanced collision warning systems as well as additional electronic control of vehicle components (see figure 12).

Lateral Control

IVHS technologies for lateral control that are expected to become more common in the near term include systems that warn drivers of obstacles on the side of the vehicle and in the vehicle's blind spot (IVHS America 1992, III-42, III-100). Both types of warning systems will improve bus safety by allowing drivers to control their vehicles' lateral movements with a greater margin of safety.

Longitudinal Control

Several longitudinal control systems are expected to become more widely available within the next five years. The first is a system warning drivers of obstacles near the vehicle. Although the literature on this technology does not specifically define "near," one can infer (from associated diagrams) that this distance is under ten meters (IVHS America 1992, III-42, III-100; Parker 1992, 22).

The second longitudinal control system that is expected to become available

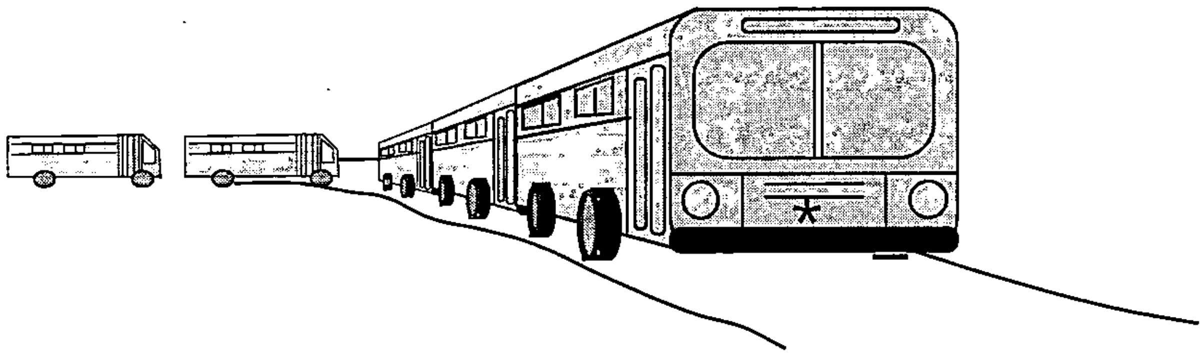


Figure 10. Entrained bus concept

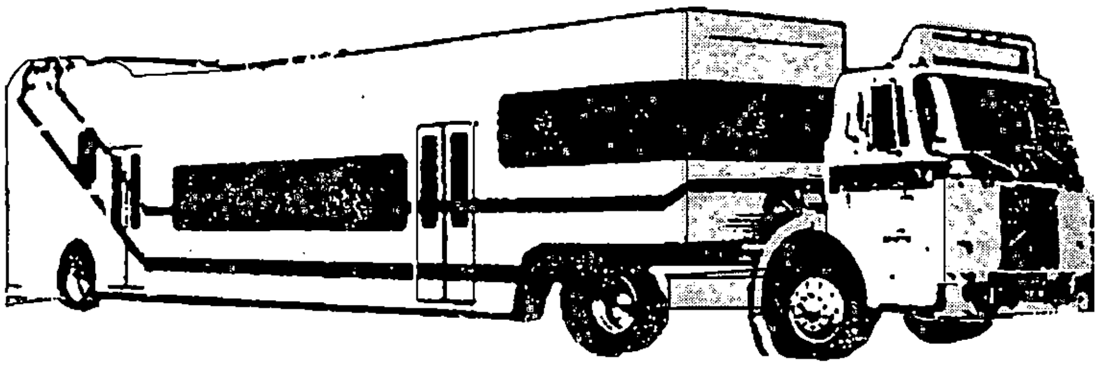


Figure 11. Trailer bus vehicle [adapted from Wilkins 1991, 34]

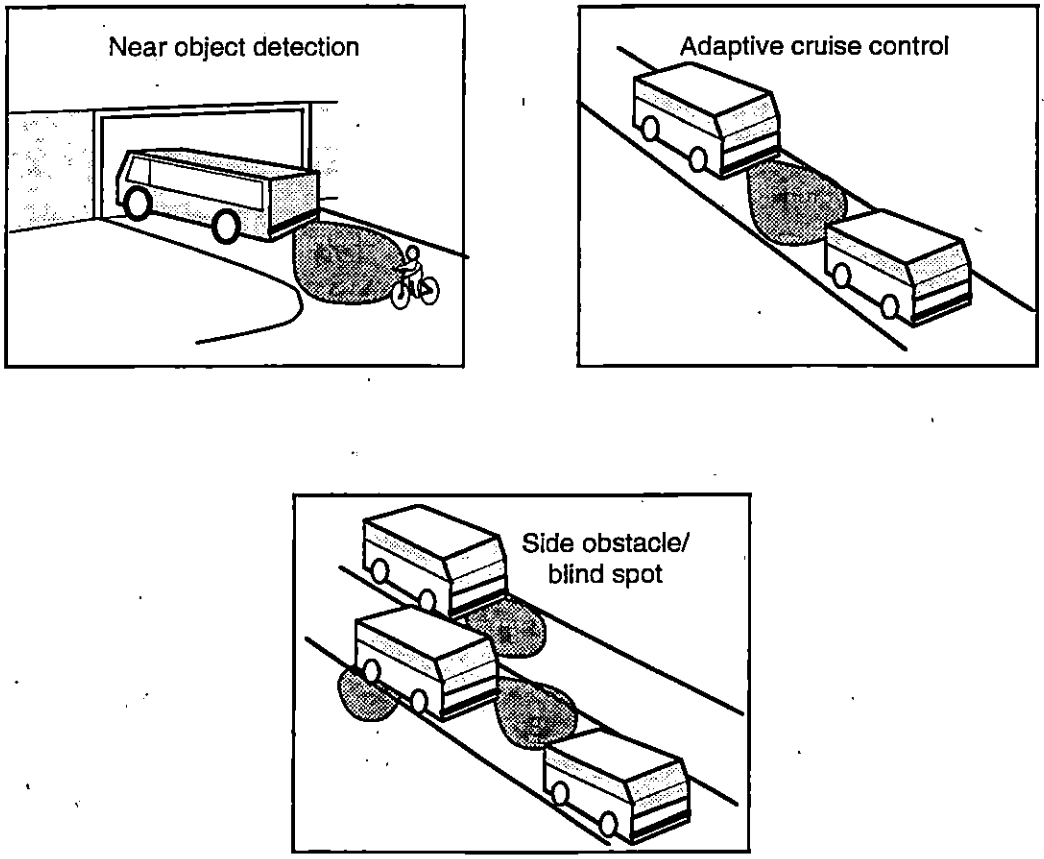


Figure 12. Example of near term bus control technologies
[adapted from Parker 1992, 22]

within the next five years is an adaptive cruise-control mechanism that will allow vehicles to maintain a safe distance from a preceding vehicle automatically (IVHS America 1992, III-42, III-100).

Third, automated or semi-automated electronic control of anti-lock braking, engine speed, transmission, and traction control under acceleration is also expected in the near term (IVHS America 1992, III-41, III-100).

A technical prerequisite for longitudinal control systems, such as near-obstacle detection and adaptive cruise-control, is an on-board detection system. A detection system based on radar, for example, can support a range of potential longitudinal control applications. First, radar systems can send information to cruise control and to anti-lock brake systems, both of which can then adjust to maintain a safe distance from the preceding vehicle. On-board radar can also provide a "forward-looking" collision warning system that alerts the driver to upcoming hazards with audio and visual signals. Finally, a radar system can be used to detect hazards as the vehicle backs up or changes lanes; such features would be activated when the vehicle is put into reverse or when the turn signal is switched on (Brooke 1993, 38).

On-board radar detection systems were touted at the most recent meeting of *Convergence '92*, the annual automotive electronics conference held in Dearborn, Michigan (Brooke 1993, 38; Loren Hall, TRW Inc., telephone interview 16 June 1993). Suppliers of on-board radar systems predicted that vehicles could be equipped with radar-based adaptive cruise control systems and obstacle warning systems within three years.

Middle Term

Bus control systems within the next ten years are expected to incorporate additional warning systems that will continue to improve vehicle safety. Full electronic control of steering and braking is also expected to emerge. However, these improved steering and braking systems are not likely to be integrated into fully automatic vehicles until the long term (within 20 years).

Lateral Control

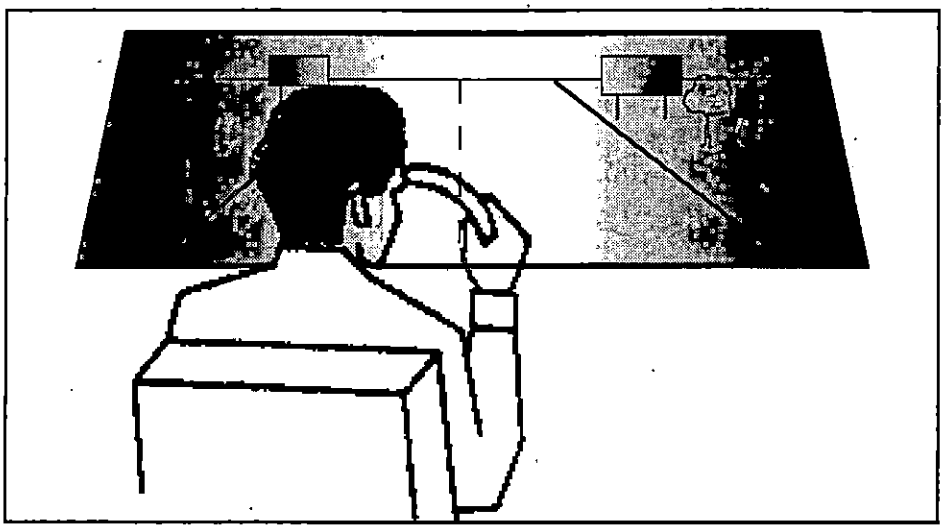
IVHS technologies in lateral control are expected to continue to improve. For example, new lateral warning systems that activate when a vehicle strays from its lane, as well as when a vehicle attempts to change lanes or to merge, are expected (see figure 13) (IVHS America 1992, III-100). Automatic steering control (also known as drive-by-wire) is also expected to emerge within the next ten years (IVHS America 1992, III-100).

Additional improvements are expected in automated vehicle control as well. As shown in figure 14, steering control can be automated in several ways. One approach, electronic control, uses cables buried in the road to create an electric field that can be sensed by equipment on the buses. Lateral deviations from the cable are detected and transmitted to the bus; this information is then used to keep the vehicle centered in the roadway lane. Electronic control was used by buses in Furth, Germany (Davies et al. 1991, 25; Casey et al. 1991, 62).

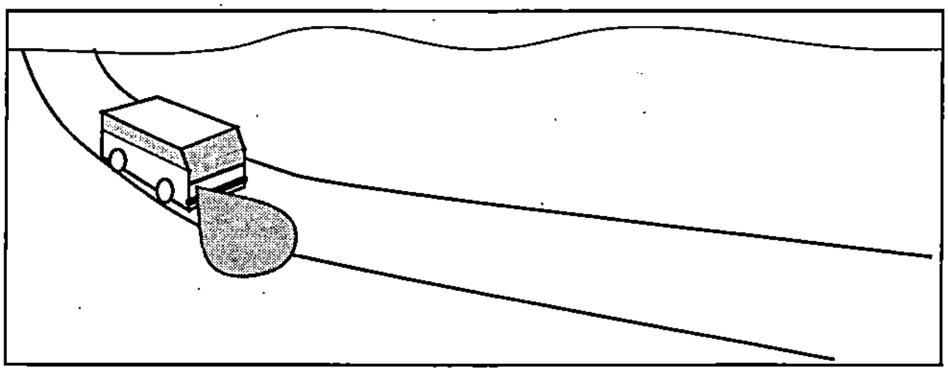
A second method of controlling steering uses magnets embedded in the center of the roadway. In this type of system, vehicles are equipped with on-board magnetic sensors and software systems that detect deviations from the pathway (Shladover 1992, 3).

A third method of steering control involves radar. With this technique, on-board radar uses reference points, such as a fixed barrier, at the side of the roadway, to determine bus position and to steer the vehicle (Davies et al. 1991, 25).

A fourth method of steering control involves an on-board image processing system that uses a video camera and an artificial vision system to interpret visual information, such as lane markers. This type of system adjusts steering based on its interpretation of the image (Okuno et al. 1991, 11). The NEC Corporation, along with Mazda, has been developing such a system. Researchers believe



Night vision



Lane stray

Figure 13. Examples of middle term bus control technologies [adapted from Parker 1992, 2]

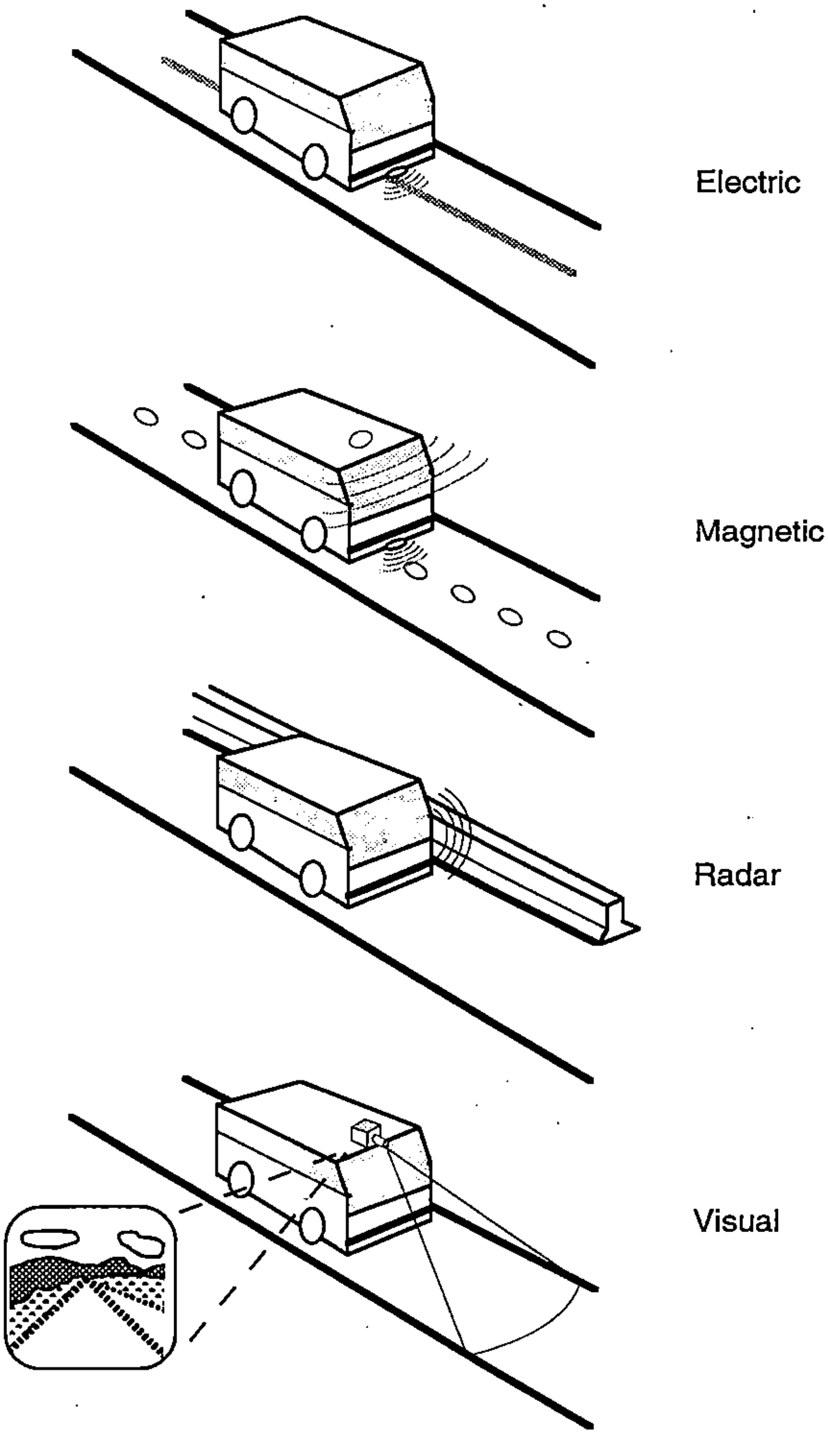


Figure 14. Bus steering methods

that it could be used as a warning device before the year 2000, but that it will be up to 30 years before the system will be refined to the point at which it will be able to drive a vehicle automatically.

The advantage of image-processing over radar-based systems is that they can "see" pedestrians and other objects not perceptible with radar. However, current image processing technology is limited in that it does not work well at night; dirty cameras or lane markers also hamper its performance (Normile 1993, 36).

Longitudinal Control

Advances in longitudinal control within the next ten years include the expected feasibility of fully automated vehicle braking, or "brake-by-wire" (IVHS America 1992, III-100). Collision avoidance systems are also expected to become fully automated; when the vehicle detects a potential collision, the avoidance system will automatically "kick in" to avert an accident (IVHS America 1992, III-100).

Warning systems that provide safety information to the driver are expected to become more common. Anticipated within the next ten years is a system that would monitor roadway conditions and send a warning signal to the driver if a hazardous condition were detected (IVHS America 1992, III-100). The warning could be in the form of an auditory or visual alarm; it could also be a "heads-up" display warning image projected onto the windshield in front of the driver. Heads-up displays would allow drivers to keep their eyes on the road at all times. Roadway conditions that may warrant a warning would include a train approaching a road crossing, ice forming on the roadway, reduced visibility on the roadway due to fog or dust, a work zone, or an emergency vehicle in the vicinity. A device would sent out a radio signal whenever these conditions occurred. This radio signal would be received by the vehicle, and a warning signal would then be delivered to the driver.

For example, an emergency vehicle would have a radio transmitter on-board that would broadcast a signal within a certain radius around the vehicle as it traveled. Other vehicles within this radius would then receive a warning indicating the emergency vehicle's approach. A similar approach would be used for an oncoming train or a work zone location (Gordon Fink, IVHS America, telephone interview, 16 June 1993).

Sensors would be placed in the roadside environment to detect hazardous road conditions such as ice, dust, or fog. When conditions warranted a warning, the sensors would trigger a device located in advance of the hazardous area, which would send out a radio signal or use cellular phone technology to warn drivers of the upcoming hazard. For example, ice on the roadway could be detected by measurement of the temperature on the pavement, and of the dew point. These two measurements allow prediction of roadway ice formation. If conditions were conducive to ice formation, a signal warning of this hazard would be transmitted. The fog detection devices currently used at airports could be used similarly (Gordon Fink, IVHS America, telephone interview, 16 June 1993).

To improve the safety of driver-controlled vehicle movements in the future, vision-enhancement systems may be installed on many vehicles. Vision enhancement will improve driver visibility in poor conditions such as darkness, fog, and rain (IVHS America 1992, III-42, III-100). This technology, which has been used extensively in the military, amplifies low light levels; the amplified image is then displayed on a television screen. In a motor vehicle, it may be possible to display an enhanced image of the road on the front windshield (see figure 13) (Norman Griswold, Texas Transportation Institute, telephone interview, 16 June 1993). Some researchers estimate that such systems will be available as early as the late 1990s (Texas Transportation Researcher 1992, 5).

Long Term

Within the next 20 years, fully automated vehicles are expected to become technically feasible. Implementation, however, is uncertain because it would require substantial changes in the transportation infrastructure, particularly roadways. Automated vehicles would incorporate both lateral *and* longitudinal control. Much of the research in this area is being conducted by California PATH (Partners for Advanced Transit and Highways), a program sponsored by the California Department of Transportation. In the first half of 1992, PATH researchers demonstrated that vehicle steering, speed, and spacing can all be controlled automatically (Shladover 1992, 2).

The National Institute of Standards and Technology (NIST), a division of the United States Department of Commerce, has also been conducting extensive research on automatically controlled vehicles, including a study of on-board image processing. In the summer of 1992, NIST researchers demonstrated a vehicle control system that uses machine vision to follow lane markings (see figure 14). The vehicle in the NIST demonstration could travel at speeds of up to 55 miles per hour on a test track (Inside IVHS 1992).

The fully automated vehicles that are expected to emerge within the next 20 years will also incorporate intersection warning systems which will allow vehicles to "cooperate" at intersections, thus allowing the largest number of vehicles to get through with the least delay and the fewest accidents (IVHS America 1992, III-100). Vehicles approaching an intersection will indicate their approach by sending a signal to a sensor. The sensor will then regulate the movements of all approaching vehicles with the goal of maximizing throughput and safety.

Lateral Control

The feasibility of combining lateral and longitudinal control for automated vehicle operation on specially equipped roadways has already been demonstrated by PATH researchers at the University of California, Berkeley. These researchers have developed an automatic steering and sensing system that detects a vehicle's position to within half a centimeter. This system also "tells" the vehicle about upcoming road geometries. Its components include a set of magnets embedded in the center of the roadway, a magnetic sensor on the vehicle, and a software system that steers the car based on information provided by the sensor (see figure 14) (Shladover 1992, 3).

The embedded magnet technology investigated by PATH researchers lacks several of the advantages of the vehicle control system developed by NIST, which relies on on-board image processing (Inside IVHS 1992, 1). One advantage of a vision-based system is that it is potentially less expensive for private vehicles, because less equipment is required for each vehicle. A second advantage of vision-based systems is that they do not require any changes in the roadway. NIST's vision-based technology simply requires the maintenance of roadway line markings. The PATH system, in contrast, would require that magnetic nails be embedded in the roadway, a procedure that could be very expensive and labor-intensive (Inside IVHS 1992, 2).

The NIST approach is based on a system that processes images of lane markings, which are obtained by a video camera mounted on the vehicle. This information is then integrated into the vehicle's control system. In the NIST demonstration, the vision-processing and vehicle-control computers were not located in the vehicle, but in a lab. The video images and information they contained were communicated between the vehicle and lab via radio. NIST plans to move the computers into the vehicle itself in the near future.

The NIST vehicles were tested under many conditions, including sun, fog, rain, and darkness. The vehicle performed equally well under these conditions. The vehicle was not tested in snow because it is already known that the system cannot handle this condition. Researchers plan to study extreme weather conditions at "some later point" (Inside IVHS 1992, 2, 3).

In early 1993, NIST researchers tested their vehicle on a police vehicle test track in Rockville, Maryland. Originally intended for police driver training, the track was designed with poor road conditions such as sharp curves with poor banking. NIST researchers installed continuous lane markers (painted lines) along this track. The vehicle was able to follow the markings at speeds of up to 30 miles per hour.

Following this successful test, researchers tested the vehicle on a local highway that had been closed off to normal traffic. In this test, the vehicle was able to guide itself along the roadway at speeds of approximately 55 miles per hour. This was possible as long as continuous lane markers were present. At intersections where the lane markers disappeared, the researchers took control of the vehicle. During these two tests, the computers controlling the vision processing and vehicle control were located in a van which followed the test vehicle (Bishop 1993; Marilyn Nashman, National Institute of Standards and Technology, telephone interview, 17 June 1993).

Longitudinal Control

For longitudinal control (acceleration and braking) PATH researchers employ a radar sensor, radio communication, and an engine throttle control actuator. The radar sensor provides data on the spacing between vehicles. Radio communication informs other vehicles of speed changes. Finally, the engine-throttle control device reacts to the radar and radio information through a software algorithm.

PATH researchers have tested this system at speeds ranging from 55 to 75 miles per hour. They have found that vehicles are able to follow one another while maintaining a set distance over different grades and during both acceleration and deceleration. In fact, "the precision of the performance gave riders the reassuring sensation of the vehicles being rigidly coupled to each other" (Shladover 1992, 6). PATH researchers believe that it will be possible to combine these longitudinal and lateral controls, and that an automated highway system equipped with these technologies could be implemented within 20 years (Shladover 1992, 6).

NIST researchers have also been working to develop longitudinal control. Recall that their automated vehicle uses an image processing system to control lateral movements (to the left or right). To control the vehicle's longitudinal movements (acceleration and braking), NIST researchers are studying a technique that also uses video images to monitor the distance between vehicles. This information is then used to adjust vehicle speed to avoid collisions (Inside IVHS 1992, 3).

Bus Control Technology in Washington State

Although some buses may be equipped with the "enabling technologies" for bus control, or may be capable of adaptation, there are no known examples of bus control technology in Washington state. "Enabling technologies" include anti-lock brakes, four-wheel steering, traction control, and active suspension (IVHS America 1992, III-36).

Washington state now has roadway monitors to detect hazardous conditions such as ice formation. These monitors are located at Snoqualmie Pass on I-90 and at several other areas throughout the state, including one in Seattle at the interchange of 130th Street and I-5. These monitors can determine the temperature of the pavement, whether ice or water is present on the roadway, and whether the surface has been chemically treated (salted). The State Department of Transportation uses this information to determine when crews should be deployed to treat the roadway surface.

The Washington State Department of Transportation is planning a system called Travel Aid in the Snoqualmie Pass area; its purpose is to improve roadway safety under poor weather conditions in the mountain pass. As part of this system, eight display signs will be posted along the road to warn travelers of adverse road conditions (FAME 1993, 1). These signs will also be used to display variable speed limits, based on road conditions. These (lower) speed limits will be enforceable.

Chapter 7. Roadway Technology

Special roadways may be constructed to improve bus movement through an urban network. These roadway treatments may involve the construction of new facilities; they may also involve the addition or alteration of traffic control devices or modification of an existing roadway. This chapter examines the characteristics and design of such facilities.

There has been little research to predict the types of roadways that may be used in the future. There are two reasons for this. First, the roadways of the future will depend upon the type of vehicle control technology that is adopted. For instance, if embedded magnets become the accepted method of vehicle control, then magnetic roadways will be necessary. Second, the type of bus roadway adopted will depend on many local factors. Environmental, political, geographic, and economic considerations will all influence roadway type.

Because it is not yet known what type of roadway will be used in the future, this chapter consists of a simple taxonomy of possible roadway types, some of which already exist. Table 6 shows some of the major characteristics of existing roadway types that could be used within the next five years. The five types—signal preemption, high-occupancy vehicle (HOV) lanes, bus-only lanes, busways, and guided busways—are described in the following sections.

Signal Preemption

The goal of signal preemption is to maximize the flow of buses through an urban network. At intersections equipped with the appropriate technology, buses are given preferential treatment (a green signal) while other vehicles wait for a separate signal to change.

Several types of detection methods can initiate signal preemption. An inductive loop detector or a piezoelectric axial sensor can be placed in the roadway to detect all buses. Alternatively, more advanced automatic vehicle location (AVL) technology can be used for preemption. Vehicle strobe lights can also be used for this purpose. Many emergency vehicles are equipped with a flashing strobe. The flashing is detected by the traffic light, which then adjusts to give the vehicle a green light.

While this technology is currently used in many cities in the United States and abroad for police, fire, and other emergency vehicles, signal preemption has not been implemented on a large scale for buses for two reasons. First, signal preemption can adversely affect smooth traffic flow by interrupting synchronized traffic signals. Second, buses are still subject to general congestion unless provided with preferential roadway space (Labell et al. 1992, 66). One way to alleviate this problem would be to give buses a special travel lane, such as an HOV lane.

Table 6. Characteristics of Existing Roadways

	In use today	Automatic steering	Separate right of way	Grade separated	Use standard buses	Illegal access possible	Able to maneuver in roadway easily	On-line stations	Off-line stations
Signal Preemption	○✓ (limited)					N/A	✓	✓	✓
HOV Lanes	○✓				✓	✓	✓		✓
Bus-only Lanes	✓		✓		✓	✓	✓	✓	
Busways	○✓		✓	✓	✓		✓ (in some cases)	✓	✓
Guided Busways	✓	✓	✓	✓				✓	✓

○ = in Washington

✓ = in use

N/A = not applicable

In 1991, a signal preemption system was established for 1,000 London Transport buses, which were fitted with transponders. This system produced "a 'green wave' effect through traffic lights and [speeded] up bus journeys" (Urban Transport International 1991c, 7). Seventy-two signals in London's outskirts were fitted with the equipment, and plans were made to equip an additional 280. Downtown London traffic signals were not fitted because it was believed that the complex traffic flow in that area would inhibit the green wave effect (Urban Transport International 1991c, 7).

Signal preemption has also been used in the Netherlands; there it has reduced variations in travel times. This improvement has allowed some transit agencies to reduce operating costs, as it has reduced the number of vehicles needed in operation. Increases in ridership have also been reported (Davies et al. 1991a, 83).

In addition to speeding up bus travel, signal preemption could also improve fuel efficiency and decrease brake wear. Travel speed and the number of stops and traffic signals along a bus route affect fuel efficiency. Buses traveling on routes with more signals and turns have been found to require more fuel than those traveling on routes with fewer signals and turns (Williams 1993, 20).

HOV Lanes

High-occupancy vehicle (HOV) lanes, which are restricted to bus and other HOV use, provide a quick and simple way of improving bus movement through an urban network. Usable by standard buses, HOV lanes allow travel without the congestion of general-purpose lanes.

When HOV lanes are located on a freeway, buses must leave the lane to make stops to avoid blocking the lane for other HOVs. In some cases, a bus need not have to travel far; it can use a "flyer stop" along the freeway adjacent to the HOV lane (see figure 15). Another disadvantage of HOV lanes is that non-HOV vehicles can access them. On the other hand, lane-changing ability is beneficial for buses in situations where the HOV lane is blocked by a stalled vehicle (Institute for the Future 1992, 77).

Bus-Only Lanes

When designated lanes on streets and highways are reserved exclusively for buses, they are called bus-only lanes. Because bus-only lanes are not used by non-bus HOVs, congestion is much less likely. They are also advantageous compared to normal HOV lanes in that buses may not have to leave the lane to make stops. On-line stops, where the bus does not leave the lane, are possible on a bus-only lane if the headway (the time between buses) is sufficient (a long headway would allow a bus to stop in the lane without delaying other buses).

One disadvantage of bus-only lanes is that they are not completely exclusive, because of the lack of physical dividers. Other traffic can cross into bus-only lanes at grade, introducing possible conflicts between buses and other urban traffic, or lane blockages due to parked or disabled automobiles (Institute for the Future 1992, 77).

Busways

A busway is a set of bus-only lanes that is grade-separated from all other traffic. Busways (shown in the bottom half of figure 15) can be designed at street level, at an elevation, or in a tunnel. A busway's separation from other traffic frees it from urban congestion. Another advantage of this design is that illegal access is easily monitored because busways feature special entrances (Institute for the Future 1992, 77).

Busway stations may be located on-line, in which case buses do not have to leave the lane to access the station, or off-line, in which case buses *do* have to leave the lane to access the station. These two options offer flexibility in locating stations. For example,

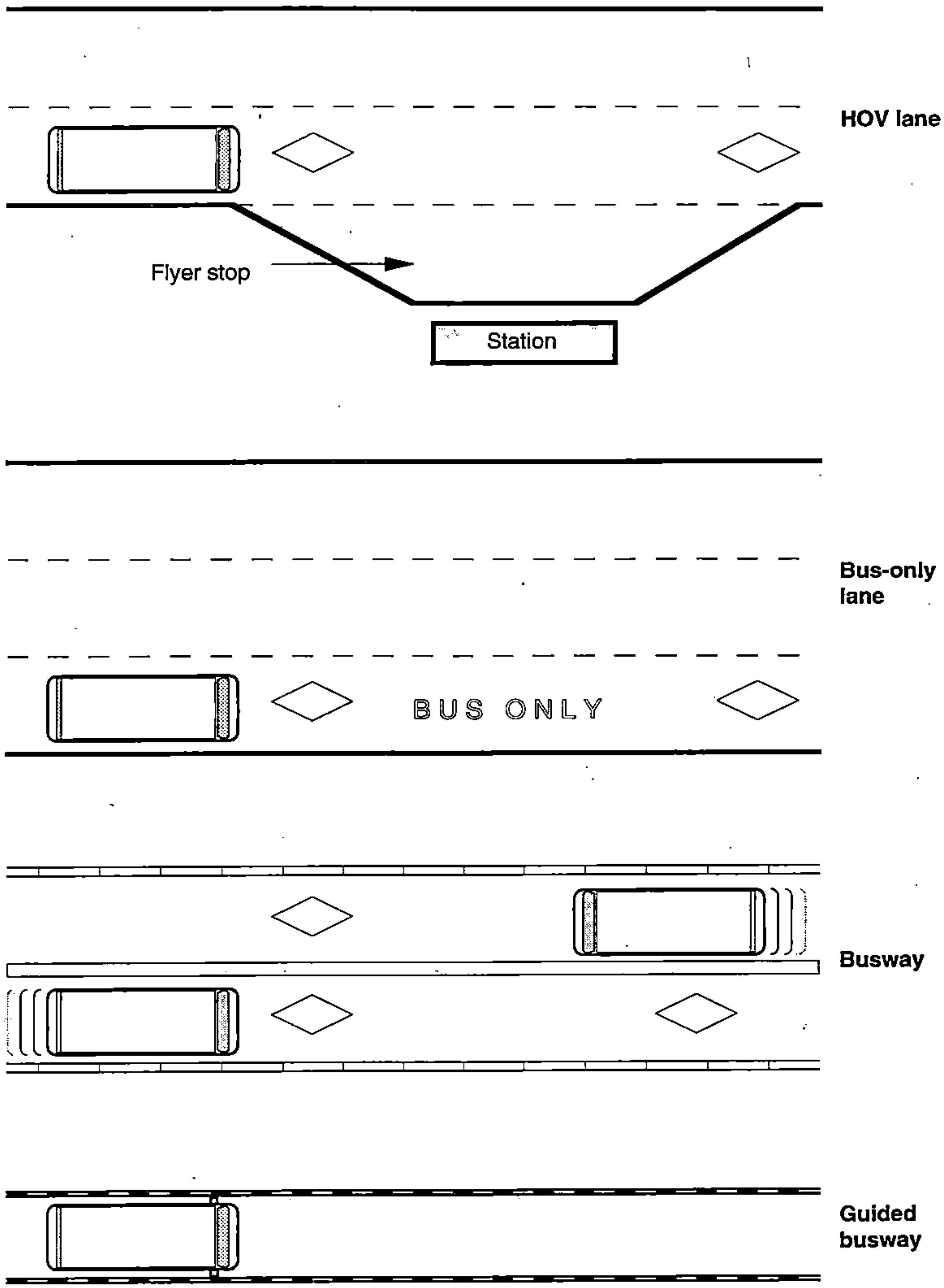


Figure 15. Transit roadway alternatives

off-line stations allow buses to bypass stations undelayed if a stop is not requested or required. If a bus breaks down along a busway with either type of station, other buses can pass the stalled vehicle on other busway lanes or along the busway's shoulder.

The Japanese, who built a 10.5-kilometer busway in Nagoya in 1985, pioneered this type of roadway. Bus speeds in Nagoya rose from six kilometers per hour to 20 kilometers per hour along this route, and bus ridership rose to its capacity of 35,000 passengers per day. Buses from different routes use this busway, operating with a 60-second headway during the rush hour and every three minutes during off-peak periods (Public Innovation Abroad 1992b, 4).

In North America, busways in Pittsburgh, Houston, and Ottawa provide examples of this type of design. In 1990, the Houston busway added a 13.5-mile section running from the downtown to a northwestern suburb at a cost of $117 million. Houston now has over 44 miles of busway in operation and plans to extend the system to 95.5 miles (Urban Transport International 1990, 8).

While busways are more expensive than either HOV or bus-only lanes, the additional cost can be worthwhile. In Le Mans, France, a 1.2-kilometer busway that carries 60 buses an hour during peak periods provides a savings of four minutes per trip. Consultant Jacques Roulet believes that this time savings is worth 300-350 francs per trip to the transit agency. At an exchange rate of 5.4710 francs per dollar, this is equivalent to approximately $55 (USA Today 1993, 3B). The Le Mans busway now carries 13,200 passengers per day on routes that previously carried 9,000 (Urban Transport International 1991d, 9).

Guided Busways

Guided busways represent a more advanced type of busway. As shown in figure 15, they are grade-separated and built exclusively for buses. In addition, they are designed to allow automatic steering. Because control of the buses' lateral position is constrained, right-of-way requirements and construction costs are reduced. These cost savings can be greater than the cost of retrofitting buses to run on the busway (Institute for the Future 1992, 77).

Guided busway stations may be located on-line or off-line. Off-line stations in this design also allow buses to bypass stations undelayed if a stop is not requested or required. Vehicle breakdowns on guided busways can be problematic if all buses travel along the same track. The other buses cannot then "switch tracks" as is possible in other design configurations, because the mechanical guidance technology restricts the buses to one travel lane. When a disabled bus blocks the lane it can either be pushed to the next off-line station by other buses, or it can be removed by a specially equipped breakdown vehicle that can access the guideway at any stop (Institute for the Future 1992, 77; Read et al. 1990, 586).

Anticipated Developments in Bus Roadways

Four other types of bus roadways could be developed in the future.

- **Magnetic roadways**, which would use inexpensive ceramic permanent magnets buried beneath the road surface along the lane center (Shladover 1992, 2). Magnetic roadways would be necessary if the control technology being developed by California PATH (see Chapter 6) were implemented on a wide scale.
- **Radar roadways**, which would use a roadside reference, detectable by the vehicle's radar, to keep the bus on the roadway. Such a reference could be a metalized strip, a series of reflectors, or a sidewall. For example, a fixed barrier at the side of the roadway could be detected by a passing vehicle, which would determine its own position in relation to this barrier with its on-board equipment. Such a reference function would allow the vehicle to maintain its lateral position on the roadway (Davies et al. 1991, 25). This type of roadway would be required if radar con-

trol technology were implemented on a large scale.

- **Electric roadways**, which would contain "energized cables running along the desired vehicle path, usually buried below the pavement surface" (Davies et al. 1991, 25). This type of system would be necessary for the implementation of electrified vehicle control like that demonstrated in Furth, Germany (see Chapter 6).

- **Visual-imaging roadways**, which would require maintainable roadway markings such as painted stripes or other delineating signs to indicate lane and roadway barriers. Stop signs or other painted markings on the road surface could also act as visual clues. This type of system would be required for the implementation of the on-board image processing system under study by the National Institute of Standards and Technology (see Chapter 6).

Roadway Technology in Washington State

Washington state offers four examples of bus roadway technology: signal preemption, loop detectors, HOV lanes, and a bus tunnel, each of which is described below.

Signal Preemption

Buses in the city of Bremerton, located on the Kitsap Peninsula, are currently using a signal preemption system. Although the state generally restricts the practice to emergency vehicles, an exception was made for Bremerton because the city is isolated and geographically confined.

Bremerton buses are equipped with strobe lights that emit an infrared signal. This signal is detected by a cone-shaped device located on top of the traffic light, which alters its signal timing in response; it either gives the bus a green light or minimizes the waiting time.

This system employs two levels of preemption: low and high. The strobe light's flash rate determines the preemption level (John Clausen, Kitsap Transit, telephone interview April 1993). The low preemption level, on which buses operate, reduces, but does not eliminate, the green signal time for cross traffic. The low preemption level also maintains a minimum green time for pedestrians in the cross direction to walk through the intersection. The low level can preempt the signal to green for one bus. Multiple preemptions, which could occur if one bus arrived within 30 seconds of another, are not allowed. After one preemption, the cross traffic receives a minimum green time.

The high preemption level is for emergency vehicles only. At this level, a green signal can be preempted more than once, as when two emergency vehicles pass in rapid succession. After the first vehicle preempts the signal and moves through the intersection, the signal changes to allow cross traffic. A second emergency vehicle can then preempt the signal again, cutting short, or totally eliminating, the cross traffic's green time. The higher preemption level also eliminates the allocation of a minimum pedestrian cross time (John Clausen, Kitsap Transit, telephone interview April 1993).

A study of the Bremerton signal preemption system was recently completed. Its purpose was to assess the impact of signal preemption on bus travel time and automobile delay at cross street intersections. The nine-month study focused on four bus routes and eight intersections; data were gathered over a three-week period (Williams et al. 1993, 1; TRANS NOW 1993, 4). The results of the study indicated that the average travel time for buses *not using* signal preemption was 48.991 minutes. The average travel time for buses *using* signal preemption was 44.071 minutes. This is a statistically significant difference of about ten percent. Travel time savings varied from five to sixteen percent, depending on the route (Williams et al. 1993, 14; TRANS NOW 1993, 4).

Findings were inconclusive with regard to automobile delay at intersections. Four of the eight intersections experienced increased delay while the other four experienced decreased delay. Researchers felt that this result could be due in part to the low use of signal preemption at the signals during the study period. Preemptions occurred at a rate of three to four per hour (Williams et al. 1993, 17; TRANS NOW 1993, 4).

Loop Detectors

Loop detectors are wires embedded in the roadway that can detect the presence of vehicles via electric fields. Employed at several intersections in Seattle, the loops identify the presence of a bus by its "electronic signature." Once a bus has been recognized, the signal begins the process of minimizing the bus's waiting time at the intersection (Ellen Bevington, Municipality of Metropolitan Seattle, telephone interview 3 March 1993).

HOV Lanes

As of 1992, the Washington State Department of Transportation had constructed over 70 miles of HOV lanes along the primary interstate and state highway corridors in the Seattle area; plans call for an eventual network of 273 lane-miles (Eldon Jacobson, Washington State Department of Transportation, interview, August 1993). Several transit agencies throughout the metropolitan area take advantage of this HOV lane network. Transit agencies have developed a number of flyer stops, which allow buses to stay close to the HOV lane. Flyer stops eliminate travel to off-line stops, which can be time-consuming because of local traffic and traffic signal delays.

HOV lanes are also located along several arterials in the Seattle area. At some arterial intersections, HOV lanes provide a "queue jump," in which the bus in the HOV lane receives a green signal before the rest of the traffic, giving the bus a head start and allowing it to merge into the roadway more easily. This type of HOV treatment is depicted in figure 16.

Bus Tunnel

The two-kilometer bus tunnel in downtown Seattle provides a grade-separated right-of-way for Metro buses operating downtown. The busway's five underground stations are open until early evening. Dual powered buses (electric and diesel) travel the two-kilometer route; the electric power mode is used in the tunnel to minimize air pollution.

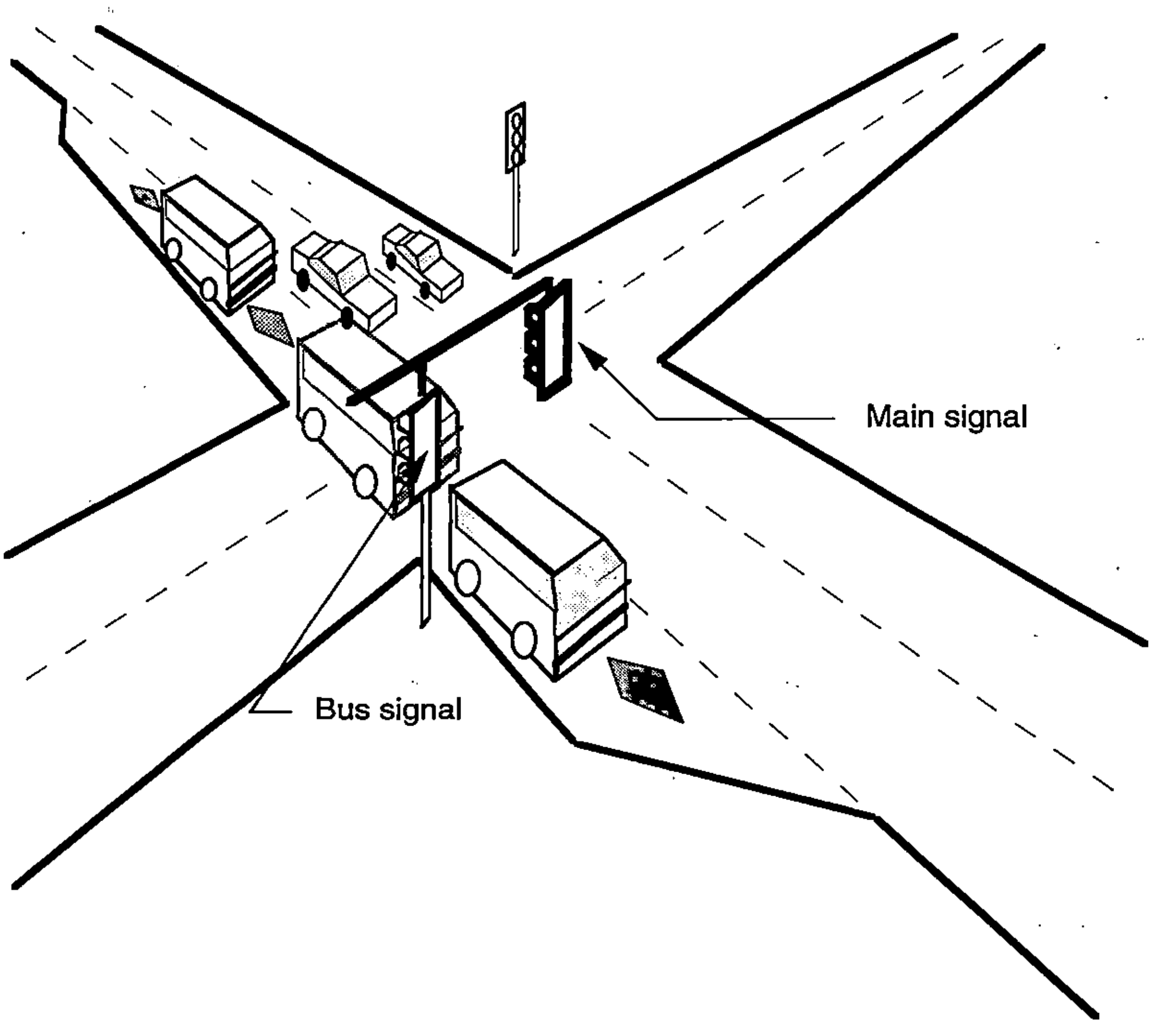


Figure 16. Arterial queue jump

Chapter 8. Summary

The results of this study indicate that bus technology will change significantly over the next 20 years. Some of these changes may occur within the next five years because the requisite technology already exists and is implementable. Other changes may not occur for at least 20 years, because the corresponding technology is complex or still evolving. This chapter summarizes the projected developments in bus technology during the near term (the next five years), middle term (five to ten years from now) and long term (ten to 20 years in the future).

Bus Information Systems

Several advances in bus information systems are likely within the next 20 years. First, over the next five years (the near term), information is likely to become significantly easier for passengers to obtain, due in large part to advanced electronics. In particular, during the pre-boarding stage of tripmaking, home computers, telephones, and televisions are projected to become major sources of transit information.

The middle term will see new or expanded uses of existing technologies such as interactive cable television, television monitors and kiosks at transit centers, and portable communications devices that people carry with them. These technologies will make travel by bus transit easier for passengers by providing travel information at many more locations. In some instances this information will literally be "at their fingertips."

Also during the middle term, five to ten years from now, real-time transit information will become increasingly available and accessible to both transit agencies and the traveling public. Real-time information services will be further refined ten to 20 years from now, in the long term, when real-time traffic conditions are projected to be integrated with real-time transit information to provide the public with an even more accurate "up-to the-minute" picture of the multimodal transportation system. The advent of real-time information, during the middle and long term, is expected to enhance public transit's reliability and attractiveness.

Fare-Payment Methods

During the next 20 years, fare-payment methods are likely to undergo two major changes. The first is a shift from a cash-based to a "cashless" system, made possible by advances in electronics; the second is a shift from on-board payment to pre-board payment.

Over the next five years (the near term) electronic fare payment technologies expected to be implemented on a larger scale include magnetic-stripe cards, smart cards, and "contactless" go cards. In addition, the implementation of advanced bus-stop designs, such as the bus tubes used in Curitiba, Brazil, may also make these shifts more likely by facilitating boarding.

In the middle term, five to ten years from now, electronic card technologies are expected to become more widely used, further encouraging cashless fare payment. The trend towards "cashlessness" is likely to continue into the long term, 10 to 20 years from now. During this period cash transactions may be greatly reduced or even eliminated.

These two changes in fare-payment technology are expected to increase boarding speed, which in turn will make overall operations more efficient. Technologies like contactless fare payment are expected to make the entire fare collection process faster and easier. Concern over how to pay one's fare so as to receive the lowest fare will also be eased; advanced electronics will allow passengers to be charged the least expensive rate for which their trips qualify automatically. Cashless systems could handle any additional charges previously collected with transfer fares. The use of "electronic cash" would also reduce the number of people required to handle cash, and thus reduce "cash shrinkage."

The shift to electronic fare payment will also relieve the bus driver of fare collection tasks. Advanced farebox technology, preboarding fare payment, and "electronic cash" will allow the driver to concentrate on vehicle operation, thus reducing driver-passenger conflicts.

Bus Monitoring

The use of bus monitoring systems is expected to increase gradually over the next 20 years, largely because such systems will be essential in gathering the data needed to support real-time bus information. All of the technologies for bus monitoring described in this report, ranging from roadside monitors to global positioning systems (satellites), are currently feasible and in use in some locations. It is possible, though not likely, that a significant increase in the use of these systems will occur within the near term (the next five years). However, in the middle term (five to ten years from now) and into the long term, ten to 20 years from now, the use of satellite-based systems and roadside detectors is expected to become more widespread. The appearance of these systems would coincide with the provision of real-time travel information, which is expected to become available beginning in the middle term.

In addition to the ability to monitor schedule status and location, bus monitoring technology is also expected to allow transit agencies to better gauge the physical condition of vehicles in their fleets. Thus, it can be projected that beginning in the middle term, five to ten years from now, the continuous operational assessment provided by such systems will allow agencies to maintain a higher level of service by monitoring the working condition of vehicles while on the road, and by anticipating the need for repairs before an in-service malfunction occurs.

Bus Control

The implementation of bus control technologies based on IVHS is expected to expand during the next 20 years. In the near term, initial applications are expected in the area of safety warning, such as the collision warning systems that are already in use on some bus fleets.

During the middle term, five to ten years from now, more advanced collision warning systems are projected to be implemented. These systems will automatically alert drivers to collision hazards at the vehicle's front, rear, sides, and blind spots.

Also during the middle term, information about roadway conditions is projected to become available to bus drivers. This information may be in the form of an enhanced image of the roadway when visibility is poor, or warnings of hazardous conditions.

Although automated mechanical bus control technology is already used in several locations worldwide, there is no clear indication that this technology, or the more advanced electronic control technologies, will be widely implemented within the 20-year time frame of this report. Implementation depends in part on continuing evolution of a control technology, as well as the accompanying modification of the road network to accomodate that technology.

Roadway Technology

Roadway developments that are implemented over the next 20 years are likely to reflect an increase in the use of technologies that currently exist in limited settings. During the near term (the next five years), the use of high-occupancy vehicle (HOV) lanes on both arterials and highways is expected to increase. This strategy for enhancing bus transportation is likely to continue into the middle term, five to ten years from now.

During the middle term, signal preemption may also become more widespread, particularly along arterials in urban areas. The use of signal preemption will depend on cities and states relaxing laws which currently restrict the technology to emergency vehicles. In the middle term, queue jumps at intersections may also become more widespread, and may be coupled with signal preemption to further expedite the movement of transit vehicles in urban traffic. The use of signal preemption, queue jumps, and HOV lanes can improve bus travel times and schedule adherence on mixed-use roadways; these strategies are inexpensive when compared with infrastructure improvements such as exclusive busways.

In the long term (ten to 20 years from now), and, most likely, beyond the 20-year scope of this report, advanced roadway developments will depend on the vehicle control system technology adopted. Recent research on automated roadways has focused on image processing or magnetic guidance systems. Large-scale implementation of such systems is beyond the scope of this report (20 years). However, limited applications may occur ten to 20 years from now in self-contained sites such as airports, malls, or recreation areas.

Conclusion

This report covers five broad subject areas as they relate to bus system operations: bus information systems, fare-payment methods, bus monitoring, bus control, and roadway technology. The probability of implementation of advanced technologies in each of these areas is not equal. Technological developments, the extent to which research focuses on buses, and the prevailing philosophies on the role of transit all affect the likelihood of implementation.

The areas most likely to implement advanced technologies in the next 20 years are fare payment, bus information systems, and bus monitoring. Bus monitoring is a necessary component of any advanced information system that provides real-time information. Thus, bus monitoring and bus information systems are likely to be implemented together.

The use of advanced roadway technology seems less likely. This is due to the still-evolving nature of bus control technology, which will determine the roadway type. Instead, roadways will most likely experience an increase in the use of technologies already in limited use. HOV lanes, signal preemption, and queue jumps are expected to be further integrated into standard bus operations.

The use of advanced technology to control the movements of buses is projected as the area least likely to experience widespread implementation within 20 years. Such technology would involve a significant modifications in the transportation infrastructure, as well as a demonstration of public confidence in the new control technology. It is more likely that components of the control technology will be implemented selectively to provide bus drivers with information that will allow them to drive their vehicles safely and efficiently.

This report focuses on the importance of advanced bus technologies for the transportation professional. However, the implementation of these technologies will affect not only those who operate bus systems, but the larger society as well. Additional research to assess the societal impacts resulting from advanced bus technologies is suggested.

Acronyms

APTS	Advanced public transportation Systems
ATIS	Advanced traveler information Systems
ATMS	Advanced traffic management Systems
AVCS	Advanced vehicle control systems
AVI	Automatic vehicle identification
AVL	Automatic vehicle location
BART	Bay Area Rapid Transit
CVO	Commercial vehicle operations
GPS	Global positioning system
HOV	High occupancy vehicle
IVHS	Intelligent Vehicle Highway Systems
MARIA	Mitsubishi advanced real-time information autosystem
NIST	National Institute of Standards and Technology
PATH	Partnership for advanced transit and highways
VORAD	Vehicle on-board radar system
USDOT	United States Department of Transportation

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Glossary

Advanced vehicle location (AVL)	Technologies to track the position and movement of vehicles. AVL technologies include ground-based triangulating systems; on-board odometer- and compass-based systems; and satellite tracking.
Bus-only lanes	Traffic lanes that are restricted to bus use.
Busway	Grade-separated, bus-only lanes.
Global positioning system (GPS)	A multiple-satellite AVL system that determines vehicle position by triangulation.
Go card	A card payment system in which sensors detect the presence of the card on the passenger's person. Also known as a **contactless card**.
Guided busway	Busways containing a lateral or longitudinal vehicle guidance system.
HOV lane	Traffic lanes that are restricted to HOV use.
Intelligent vehicle highway systems (IVHS)	"(A) collection of technological developments that enhance interactions between roads, vehicles, and their drivers so as to improve either highway safety, system operating efficiency, environmental quality, or energy utilization in transportation" (Kamal 1990, 2).
Loop detectors	Electric current-carrying wires embedded in the roadway that detect the presence of vehicles.
LORAN-C	An AVL system that employs ground-based transmitters and on-board vehicle receivers to determine vehicle position by triangulation.

Magnetic-stripe card — Credit card-like fare payment devices that store dollar values. The cards are typically placed in a detector, which determines that sufficient value remains in the card to pay the fare, and deducts the fare from the stored value.

O-Bahn — A system that provides lateral control of vehicles by means of a mechanical linkage to a guiderail. First developed and tested in Germany.

Proof-of-payment system — Fare payment system that does not require verification of payment by every passenger. Passenger carry proof of payment in the form of a pass or receipt. Random passenger checks verify payment.

Queue jump — Vehicle detection and intersection signal system that allows HOVs to bypass intersection queues.

Real-time information — Traffic and scheduling information that reflects actual traffic conditions and travel times, as opposed to typical traffic conditions or pre-defined arrival and departure schedules.

Signal preemption — Intersection technology that detects HOVs and gives them preferential signal treatment.

Smart cards — Credit card-like fare payment devices that are equipped with a programmable memory chip that can hold instructions, hold value, and create an electronic billing record. Electronic encoding prevents duplication.

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About the Innovations Unit

The Innovations Unit is an advisory group to the Washington State Transportation Commission that conducts technology and policy research on emerging transportation developments and opportunities in Washington State. The goals of the Innovations Unit are to

- provide long-range program development support to the Transportation Commission,
- generate unfiltered visions of a wide range of future short-term and long-term transportation technology and policy options, and
- establish a research methodology that fosters development of innovative transportation concepts.

The Innovations Unit has three objectives representing successively more detailed and focused studies:

Objective 1. Monitor emerging technologies and strategies. Compile and synthesize up-to-date information about emerging and innovative transportation technologies, strategies, and policies.

Objective 2. Research selected topics of Commission interest. Conduct detailed background research of specific technology and policy issues, under the direction of the Commission's Policy Development Subcommittee. Produce a series of white papers outlining technology and policy implications germane to the Washington State transportation system.

Objective 3. Support in-depth technology and policy research. Conduct and/or coordinate detailed research of key enabling technologies, strategies, and policies.

The research activities of the Innovations Unit emphasize early, preparatory studies of emerging potential transportation solutions, and include interaction with elected officials, public agencies, university researchers, the private sector, and members of the public. Its activities are intended to complement and support in-depth applied research and implementation by the Washington State Department of Transportation (WSDOT), and reinforce ongoing State Transportation Policy Plan activities.