SECTION **4**

STATE OF THE ART IN TTI

4.1 REVIEW OF TECHNOLOGIES

TTI systems are key technology applications within the transit industry, designed to provide timely and accurate information to help transit riders make decisions on modes of travel, routes, and travel times. This information generally includes transit service areas and routes; scheduled vehicle departure times; projected vehicle arrival times (through AVL); service disruptions and delays; information on fares, transfers, and other transportation services; and information on the various activities and events in the region. This information is used to assist customers and potential customers in making pre-trip and en route (including in-vehicle) trip decisions. Such a TTI system not only assists riders in their trip planning, but also improves the visibility of transit agencies within their communities. Often, access to this information is through various media, including the Internet, wireless PDAs, electronic displays at stops and stations, kiosks (at bus shelters, office buildings, shopping centers, and other locations), and land or mobile telephone.

Given that a basic level of information can be disseminated easily to the user via these media, the next level of information requested will be tailored to meet a particular user group's or individual's travel needs. This level of information may be provided by a private entity (sometimes known as an information service provider [ISP]).

Before describing the types of TTI and available technologies, it is important to note that underlying data of good quality is required in order for quality TTI to be generated. A comprehensive bus stop inventory is the most basic data required for applications that provide the basis for developing and disseminating information, such as an AVL system. Developing and maintaining this type of inventory is considered a challenge by many agencies for several reasons, including the fact that one agency may have several bus stop inventories that contain conflicting data on characteristics, such as exact latitude and longitude, and that resources necessary for maintaining such a database are scarce. In any case, an AVL system's accuracy and reliability is directly dependent on an accurate and reliable bus stop inventory, among other important factors, such as the accuracy of positioning technology.

4.1.1 Types of TTI

While there are any number of ways to categorize TTI—for example, based on the medium of communication used or the type of information that is received—the most common classification scheme is one that simply groups TTI services according to the stage of the journey at which the information is received. It has become an industry standard to classify TTI as being: (1) pre-trip; (2) en route (and in-terminal/wayside); or (#) in-vehicle.

One issue that must be addressed with all types of TTI is the accessibility of this information to individuals with disabilities. Technologies that provide accessibility of traveler information include DMSs at stops and stations for persons with hearing impairments (providing en route information); automatic annunciators and signage to provide in-vehicle information for persons with visual and hearing impairments, respectively; and talking signs and kiosks for passengers with visual impairments. Several transit agencies have deployed remote infrared signage systems (RISSs)—that is, hand-held devices that convert informational signs into a spoken message. RISSs provide persons who have visual impairments with significantly improved abilities to understand transit signage, navigate around a transit stop or station, and board a transit vehicle at a busy stop or station (*1*).

4.1.1.1 Pre-trip Transit Information

Pre-trip information is information that a rider accesses before embarking on his or her trip. It covers an array of areas such as route alignments, schedules, arrival times, delays, itinerary planning, and multimodal information. Hence, pre-trip transit information plays a critical role in the user's decision on which mode to take, what route(s) to take, when to make the trip, and how to get to his or her destination.

Pre-trip information includes static information on routes, schedules, fares, and system policies, and itinerary planning (also known as trip planning). This information includes timetables for individual train and bus routes and system maps and schematics. Information of this type, while updated periodically to reflect service changes, does not reflect the current operating conditions of the transit service. Historically, the main source of this type of information has been printed schedules, maps, and other materials displayed at rail stations, at bus terminals, and (often very sparingly) at bus stops. Pocket versions of these materials are distributed by many transit agencies either in the system or through local shops and other outlets. However, static information such as route, schedule, fare, and other information is now provided via the telephone, Internet websites, wireless media, and public kiosks. The systems needed to provide this information include automated telephone-answering systems, which allow passengers to access information on the route of their choice using the telephone keypad or speaking their responses; websites containing electronic versions of transit schedules and route maps; and computer kiosks with this information either preinstalled or available through an Internet connection. Providing static information using the Internet allows the user to select the specific type of information required, and, in some cases, this selection process can be more interactive than just selecting a specific schedule for a specific route. For example, the user may select a route by clicking on a specific place on a map of the transit system. He or she can then obtain the schedule associated with this route. Also, this selection process can be linked to real-time information about when the next few vehicles on that route are expected to arrive at specific stops or stations.

Improvements being made to static information include bus stop schedules that provide information about vehicles leaving from one specific stop and spider maps, which show all the transit services emanating from one specific stop. Transport for London has deployed these improved forms of static information for buses via its website (www.tfl.gov.uk/buses/). A detailed description of these improved forms of static information is provided in Section 8.

Itinerary planning allows passengers to plan a door-to-door (or station-to-station) trip using one or more transit services. This feature enables travelers who are making a one-time or atypical trip, for instance, to plan their transit journeys before leaving. Itinerary planning also allows tourists, visitors, and others who are less familiar with the transit services to plan complete routes to their destinations, reducing the stress of trying to navigate an unfamiliar transit system. Users can request a trip plan based on such variables as least travel time, minimal walking distance, lowest cost, least number of transfers, modal preference, and need for paratransit service.

Historically, most North American transit systems have provided itinerary-planning services by means of a telephone information service operated by knowledgeable staffers with (1) a good geographical knowledge of the system; (2) schedule and route information; and (3) in the most recent decades, software resources to interrogate a database rapidly and to find the itinerary or itineraries most responsive to the inquirer's constraints. Currently, the use of trip-planning software, which can calculate a number of alternative itineraries for each door-to-door or station-to-station trip, is quite common. The software can be accessed internally by agency staff and the information relayed to callers, or it may be made available to passengers directly through an automated telephone service, an Internet website, or a kiosk.

As mentioned in Section 3.1.2, many transit websites now provide itinerary planning. WMATA's RideGuide system is one such itinerary-planning service, which is provided on WMATA's website (www.wmata.com). This system, along with several others, will be described in detail in Section 4.2.

4.1.1.2 En Route (and In-Terminal/Wayside) Transit Information

The importance of providing transit information does not stop once the traveler embarks on his or her trip. Quite often and for various reasons, transit vehicles do not run according to the pre-trip information the traveler has received. En route travelers may experience anxiety if their vehicles do not arrive on time according to the schedule, if they are not sure where to go to catch their intended vehicles, or if they have missed the last vehicle (or do not know if they missed the last vehicle). Providing en route transit information plays a significant role in keeping travelers informed about the status of their vehicles; reducing their anxiety; and directing them to the right stops, platforms, and bays. Real-time or dynamic information describing current transit operations includes updates on delays, incidents, and service diversions along transit routes, as well as estimated vehicle arrival and departure times for stops along the routes. In contrast to static information, this dynamic information needs to be updated on a frequent basis if it is to be useful to passengers.

Real-time updates about transit operating conditions can be relayed to passengers in a number of ways. At transit stops and stations, DMSs, video monitors, and public address systems can report the estimated arrival (or departure) times of trains and buses and information about conditions or incidents that cause the buses or trains to operate in unscheduled ways. Updated information on vehicle arrival times and delays can also be placed on the agency's website or automated telephone answering system or on a cable television channel. An even more "interactive" system can send updates or alerts on transit operations to passengers via e-mail, pagers, portable phones, or PDAs.

In recent years, several transit agencies have deployed en route transit information systems. These real-time transit information systems are the subject of several current projects, including the aforementioned FTA and TCRP Synthesis projects. Information on these systems will be presented in detail in Section 4.2.

4.1.1.3 In-Vehicle Transit Information

In-vehicle transit information provides important information to travelers while they are en route. In-vehicle information such as automated annunciator systems help transit agencies comply with the Americans with Disabilities Act (ADA) by providing train stations and major bus stop locations in both text and audio formats. Furthermore, in-vehicle information reassures passengers that they have taken the right vehicle and route. Onboard displays are also used for informing passengers about transfer points, service disruptions, and other events.

Most transit operators that are implementing these systems are supplying some combination of audible and visual information on next stop, major intersection, and transfer points to achieve both objectives. Two primary media are used: automated audible annunciators and in-vehicle displays. Both can communicate location-related information to customers based on location data from the AVL system, data that is typically processed using an onboard microprocessor that is often used to support other onboard systems.

Another development in in-vehicle transit information is integrating bus destination signs with AVL systems to ensure that destination information displayed for waiting passengers is accurate. This integration is particularly important on multiroute corridors or multibranch routes and takes the responsibility away from the vehicle operator by automating destination sign changes with the AVL/computer-aided dispatch (CAD) system. Perhaps the most sophisticated examples of in-vehicle information involve transit agencies that are enhancing their fleet management systems so that passengers who are already on board can request and get confirmation on transfers to other transit services. This technology, called transfer connection protection (TCP), has been and is being deployed in several agencies in the United States.

4.1.2 Available Technologies

Static information on routes, schedules, and fares is typically provided via relatively low technology means such as printed timetables, information booths, and telephone systems. Augmenting this manually provided static information with real-time updates about transit service—for example, by giving bus locations or estimated arrival or departure times—requires specific technological infrastructure. These underlying technologies include AVL systems, communication systems, prediction algorithms, and media that disseminate TTI.

4.1.2.1 AVL Systems

Providing real-time information about transit vehicles (arrival and departure times, location, delays, etc.) requires that the location of the vehicle be determined. An AVL system is necessary for determining the location of vehicles, and, in some instances, it can also provide other operational parameters such as vehicle speed and direction. In addition to providing the data that is the basis for TTI, AVL systems are important from a safety and security perspective: dispatchers can respond more quickly to incidents, accidents, or other emergency situations because they know exactly where the vehicles are.

There are numerous types of AVL systems, each utilizing different technologies. Currently, the most common AVL technology is based on GPS. Other technologies include the signpost/odometer method and tag and tag-reader systems.

GPS-based AVL system: GPS is a series of satellites flying in geosynchronous orbit that emit signals that are received by vehicles equipped with GPS receivers to provide very accurate geographic location. By receiving signals from no less than three different satellites, the GPS receiver computes a vehicle's location by triangulation. GPS is often augmented by adding a transmitter tower of known geographic location (latitude and longitude): the GPS receiver and processor on a vehicle use the tower to provide error correction in case one of the three satellite signals is lost because of topography or urban canyons. This is called differential GPS (DGPS). Because selective availability—error that was introduced into the GPS system—is no longer used, DGPS may not be necessary. Further, the Nationwide DGPS System supported by U.S. DOT provides accuracy between 3 to 10 meters.

As mentioned earlier, GPS-based AVL systems are the most common of all AVL technologies. The Central Ohio Transit Authority's (COTA's) real-time bus arrival system (i.e., Ride Finder) uses such a system. In an effort to avoid duplicating equipment on board buses, COTA interfaced the Ride Finder interface with the newly acquired DGPS-based AVL system in order to obtain bus locations and other necessary data.

There are other examples of real-time information systems using GPS technology that are provided by a third party. A third-party company installs its GPS receivers on transit vehicles or it uses information from an existing AVL system. Some agencies that already have a GPS-based AVL system and do not choose to integrate it with the third-party's real-time information system end up with a second GPS receiver. Also, unlike other real-time information systems in which data processing is done at the agency's site on agency-owned computer equipment, a third-party system utilizes the third-party's servers at its own location. All data processing utilizing this type of third-party system is done at the third-party's servers. City-University-Energysaver (CUE)—a transit system in Fairfax, Virginia—has been using this type of system to provide its passengers with real-time arrival information at bus stops and on the web since 2001. Currently, at least seven other transit agencies are using this type of system.

Another interesting example is Virginia Railway Express's (VRE's) Train Brain system. Train Brain provides trains' locations on a system map on the Internet as well as information about major problems and delays. Although Train Brain utilizes GPS technology to determine the location of trains, the system is not entirely automated. Customer service agents receive train locations and then make the decision whether to report the delay of a particular train based on a certain threshold (10 min or later). This information is also used in a sister project called Train Talk, which provides e-mail alerts about VRE train status and delays or problems.

Signpost/odometer method: Using this AVL technology, information about a vehicle's location is determined by knowing the fixed location of a wayside signpost, when a vehicle passes this signpost, the current odometer reading, and the vehicle's scheduled route. Wayside equipment reads a tag/transponder placed on the vehicle as it passes by. A variation of this system is using loop-detectors rather than a tag reader to detect when a vehicle passes a certain point. Signposts are located at specific points along the route, and they transmit to a central point (usually dispatch) the identification (ID) of a vehicle that has passed by, or the vehicle's tag/transponder reads the ID of the signpost and transmits that ID back to a central point. Determining location between signposts is interpolated by using odometer readings. Upon receiving the data transmitted from either the signpost or vehicle, the central computer would compute the vehicle location by cross-referencing the data with the geocoded location of the signposts.

The Los Angeles County Metropolitan Transportation Authority (LACMTA) provides real-time arrival information on its Metro Rapid bus rapid transit system by using loop detectors throughout the route to determine bus location. The Los Angeles DOT (LADOT) developed this real-time system. As a Metro Rapid bus passes by one of the loop detectors, the bus number, time, date, and loop detector number are transmitted to the central computer using cellular digital packet data communications. The central computer looks at the time it took the last bus to traverse the same segment that the approaching bus is about to traverse. The approaching bus is assumed to take that much time to traverse that segment. The central computer will then transmit to the appropriate DMS the anticipated arrival time of the next bus.

Alternatively, in Seattle, Washington, King County Metro utilizes the signpost/odometer method to provide real-time arrival information. Signpost transmitters that broadcast a signal are distributed throughout King County. Buses pick up these signals and transmit them to the central computer, which in turn computes the buses's location. Transport for London also uses the signpost method for its vehicle location system.

One of the largest signpost-based AVL systems is used in London to monitor all buses in the London Buses division of Transport for London. The London Countdown system is based on this signpost (also called a beacon) AVL system. An onboard AVL unit receives the identity of a roadside beacon as the bus passes the beacon. Since each beacon has a unique identifier, the bus can then determine its location, and the location information is forwarded directly from the vehicle to a central system via the onboard radio. Currently, there are 5,000 beacons deployed in the London Buses service area. Figure 5 describes how the AVL and Countdown systems function.

WMATA's Metrorail system uses a fixed-block system, which could be considered another form of a "loop detector" method. Each block has a fixed running time. When a train passes by a certain block, the train information and block code are sent to the Rail Operations Computer System central computer. Using this information, the system calculates estimated arrival time at the downstream stations. The estimated arrival time, the line (which is designated by color and destination), and number of cars are sent to a group of signs at each station.

4.1.2.2 Communications System

The effective and efficient operation of transit systems depends on a sound and reliable communications system. Such a communications system also provides the necessary backbone for the operation of an AVL and other ITS systems (such as a real-time transit information system). The most common communication technology for transit ITS is wide-area wireless. Other technologies include dedicated short-range communications and local area networks (LANs).

There is considerable variation in the capabilities of each communication technology applied to transit. The technology can support voice communication, data communication, or both. Further, the technology can be one-way or two-way. Finally, the coverage of each technology is a critical factor.

Wide-area wireless: Wide-area wireless (WAW) networks are communication networks based on radio frequency technology. These networks are different from conventional, private, land mobile radio systems, which typically require larger and more powerful transmitters and towers.

There are two types of WAW systems: generic and proprietary systems. Generic technologies include services such as analog cellular, digital cellular, cellular digital packet data (CDPD), and personal communications systems. Proprietary technologies include the Advanced Radio Data Information Service (ARDIS™), EMBARC, MobileComm, Nextel, RAM Mobile Data, Ericsson, MTEL™, and others. European systems in particular may make use of protocols such as global systems for mobile communications, Radio Data System–Traffic Message Channel (RDS–TMC), digital audio broadcasting, and general packet radio service. CDPD has become an important data communications technology for transit because it supports relatively high data transfer rates (of up to 19.2 Kbps); it allows Internet protocol (IP) multicast (one-to-many) service—meaning that a base station can broadcast a message to many recipients simultaneously; and it utilizes unused space on existing cellular networks. However, CDPD often costs more than conventional communication technologies because charges are normally calculated based on the number of data packets sent per time period.

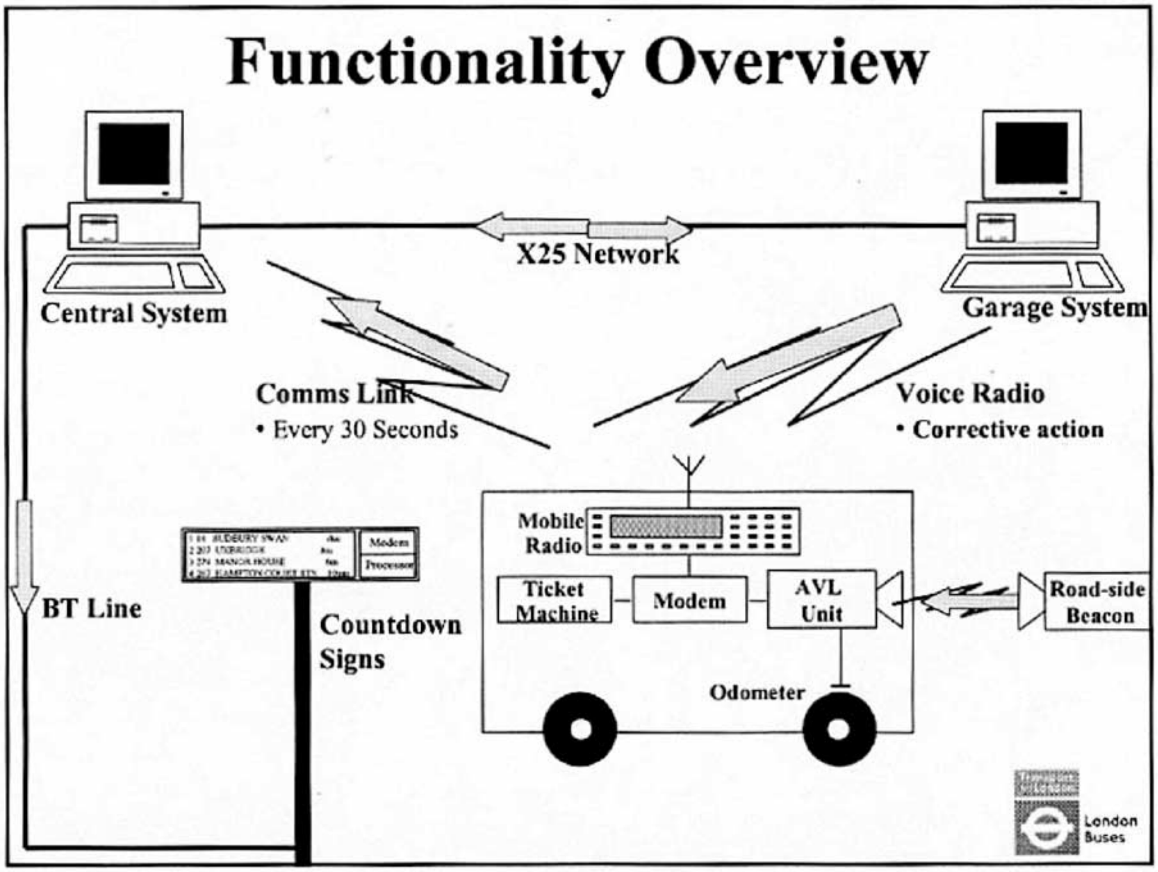


Figure 5. London Buses AVL and Countdown systems.

As mentioned earlier, LACMTA uses loop detectors to determine the location of its Metro Rapid vehicles. Using the bus number, time, date, and loop detector number received from the field, the central computer computes a bus's estimated arrival time. Once the estimated arrival time of the bus is computed, this information is transmitted to a display at bus shelters. The message travels from the LADOT's traffic-control center to AT&T's nationwide cellular data network, which relays it to a wireless CDPD/IP modem built into the electronic display at the target bus stop.

COTA's Ride Finder in Columbus also uses CDPD communications between the AVL central computer and DMSs at bus shelters. After the central computer computes the predicted arrival time of a bus, the information is sent to Verizon's cellular data network, which in turn sends it to a wireless cellular CDPD modem in the DMS. Each DMS has its own cellular subscription and messages are sent to a particular DMS.

Unlike COTA's Ride Finder, San Luis Obispo Transit wanted to lower the operational cost of communicating with the DMS units deployed at the bus stops. These units have a built-in intelligence module that allows all deployed signs to listen to a single, bundled text message sent by way of a pager. This one message contains the updated data for all signs at all stops. Each Smart Transit sign is easily programmed to know the bus stop(s) and bus route(s) it is servicing. Once the text message is received, the "smart" sign strips out and uses only the information meant for its specific location. The sign then uses this information to inform the waiting passengers of the time remaining until the bus arrives at that specific bus stop. This technique allows the transit agency to limit its Smart Transit sign communication link costs.

Dedicated short-range communications: Dedicated short-range communications (DSRC) have a somewhat limited application to transit. The most commonly used form of DSRC is the beacon/tag combination used for toll collection on bridges, tunnels, turnpikes, and parking facilities. The electronic tag, or transponder, contains a small radio transmitter that is used to emit a short-range radio signal that the beacon, or tag reader, receives. The beacon then transmits the data to the necessary computer hardware and software via radio frequency. The short-range radio signals are transmitted at a special frequency designated by the Federal Communications Commission for these short-range communication needs. The tags can be either active or passive. In Europe, DSRC are used for communications between transit in-vehicle equipment and roadside beacons to determine schedule adherence and to calculate the estimated time of arrival at the next stop (e.g., London Buses).

Tags and tag readers are also used in passenger rail systems for a variety of purposes. These purposes include automatic vehicle identification, tracking and control, and communications-based signal systems that can replace outmoded block-signal systems.

One agency that uses a short-range communications system is River Valley Transit (formerly CityBus) in Williamsport, Pennsylvania. Because bus bays were not preassigned for a particular route, buses had to select an available bus bay upon arriving at the transfer center. This arrangement made it a challenge for customers to find their buses. The solution to this challenge is a system that uses two variable text message signs to display the bay number for each bus as well as to warn when a bus is about to depart (see Figure 6). Each bus is equipped with a mobile data terminal (MDT), which the driver uses to send a message to the dispatch center indicating the selected bus bay. The mobile data communications use spread-spectrum antennas; bus antennas use unlicensed radio-frequency spectrum to communicate with transfer center antennas over a limited range on a "line-of-sight" basis. The original number of spread-spectrum antennas proved insufficient to communicate with the many different locations of buses around the transfer center (this short-range communications method requires a substantially clear line of sight), but this was addressed by adding antennas at various locations.

4.1.2.3 Prediction Algorithms

TTI systems that provide arrival and departure time predictions depend on a prediction model or algorithm to process vehicle-location and related information. The accuracy of the predicted arrival time is contingent on the accuracy of the model or algorithm being used. A variety of data is used as input to the prediction models or algorithms. These inputs typically include vehicle identification, vehicle location, cur-

Figure 6. CityBus Transit Transit Center sign.

rent traffic conditions, historical traffic conditions, and real-time operating data from the last several buses on that route that passed that stop.

LACMTA's Metro Rapid real-time information system contains a prediction model that was developed by LADOT. The model operates by recording bus arrival time at every bus detector, then estimates bus travel time using previous bus information, and finally calculates arrival times for approaching buses to all bus stops (*2*):

> TPM [Transit Priority Manager] first tracks every data that is generated when a bus traverses through a detector in the system. It consists of two real-time lists—the Hot-List (HL) and the Run-List (RL) objects. The HL tracks movement of every bus operating along a TPM corridor, which contains the bus attributes, position, and running status. The RL stores the detail time point table and detector attributes, including bus scheduled arrival time-points, and actual arrival time-points.
>
> Bus travel time is a function of distance and prevailing bus speed. TPM employs a Dynamic Bus Schedule Table technique (DBST) using an innovative algorithm approach called the Time Point Propagation (TPP) method, which dynamically builds the Schedule Arrival Time Point table with run-time information from the prior bus arrival time for the same locations plus the active headway value of the current bus.
>
> The actual arrival time point is also used for the prediction of Estimated Time of Arrival (ETA) of the next bus. ETA is calculated based on the previous bus travel time under the assumption that the current bus would experience the same or similar traffic conditions in the same segment of the corridor. The predicted bus arrival information is then transmitted through Cellular Digital Packet Data (CDPD) services to LED display signs at major bus stations. According to a field survey, the accuracy of the bus arrival information is relatively high.

The King County Metro bus arrival information system (MyBus) employs an algorithm that uses time and location pairs with historical statistics in an optimal filtering framework to generate estimated arrival times. The algorithm relies on assumptions that "allow the problem to be formulated in a statistical framework and fulfill the requirements necessary to use the Kalman filter to make optimal estimates of the predicted time until arrival for individual vehicles" (*3*). A set of mathematical equations, the Kalman filter provides an efficient computational (i.e., recursive) solution of the least-squares method. The Kalman filter is powerful: it supports estimations of past, present, and future states, and it can do so even when the precise nature of the modeled system is not known (*4*).

4.1.2.4 Information Dissemination Media

AVL, communications, and other key underlying technologies are necessary systems to collect and process the data that is used in TTI systems. However, these systems are not very useful without a dissemination mechanism to communicate the TTI to travelers. Not long ago and aside from printed media, traveler information was accessible only by telephone. The technological advances that have taken place in communications in the past few years have greatly impacted how TTI is distributed to users. Currently, transit agencies are using a variety of media to better inform their riders about their services. These media include mobile phones, pagers, PDAs, DMSs, video monitors, kiosks, and the Internet.

Not only did the advances in communications impact how the information reaches the users, but it also revolutionized when the user can access the information and the type of information that is available. Wireless communications make it possible for travelers to receive information anywhere and anytime through wireless devices such as PDAs, WAP-enabled cell phones, and DMSs at stops and stations. The introduction of the Internet and kiosks for providing detailed traveler information, customized itineraries, interactive maps, and real-time information allows users to access TTI on their personal computers and at key activity centers.

Information dissemination media can be divided into four categories: personal communication devices, noninteractive displays, interactive wayside devices, and the Internet and e-mail services.

Personal communication devices: This category includes traditional land-line phone and wireless devices such as cellular phones, pagers, and PDAs. Wireless communications devices are becoming more and more popular with transit agencies because they provide a better level of customer service at a very low cost. Wireless devices are not limited to accessing real-time information: they are also being used to provide static schedule information. For example, Zero-Sixty, which will be described in Section 6, provides transit schedules that can be downloaded to a subscriber's PDA. Another example is using a WAP-enabled cell phone to receive an itinerary from Transport for London's Journey Planner.

Noninteractive displays: These devices can be divided into DMSs at bus stops and train stations, DMSs on board vehicles (automated annunciation system signage), and video monitors. DMSs are more popular than are video monitors because DMSs come in a variety of shapes and sizes and are more versatile. Video monitors and wayside DMSs are mainly used to display arrival times, bay information, and service delays; onboard DMSs are mainly used for announcing and displaying next stop information.

Interactive wayside devices: An example of an interactive wayside device is a kiosk. Kiosks are being deployed at major bus centers, train stations, and other public places such as hotels, airports, and commercial centers. The single most important advantage of kiosks is that they are interactive devices. This feature allows the users to access the information they need in a relatively short time. Moreover, kiosks can provide an infinite amount of information when they are connected to the Internet by providing links to a host of sites such as sites on weather, traffic, and other local information.

Internet and e-mail services: Through the Internet, users can access a variety of TTI at any time to obtain schedules, real-time arrival information, itineraries, and other TTI. E-mail services, on the other hand, are usually limited to information on delays, incidents, emergencies, or real-time arrival information. Furthermore, unlike the Internet, e-mails are not interactive and are one-way messages. Given the importance of the Internet in providing TTI, the current state of TTI deployment on the web is reviewed as follows.

The Transitweb website (transitweb.volpe.dot.gov/introduction.asp) provides comprehensive information on transit websites that were reviewed in July and August 2001. A total of 637 websites were reviewed, with 520 from urban areas and 117 from rural areas. This review examined the frequency of specific website features, as shown in Table 7.

The Transitweb review conclusions included the following (*5*):

- There is wide variation across websites in content and presentation of information. This variation is present within groups of websites from similar rural or urban areas or within groups that are eligible for the same category of federal funds.
- The most common features are fare and schedule information, but they are not universally present. Since this information is essential to using a transit system, it seems that significant improvements could be made by adding the information to the sites that lack it. There was no significant change between last year and this year in the percentage of agencies with fare and schedule information.
- The main area of improvement in the past year is for route-choosing content. System maps have been improved so that more show transfer points clearly. Itin-

TABLE 7 Frequency of specific website features

Feature	Percentage of Websites with Feature
Route-choosing content:	
Any system map	44.0
With clear transfer points	27.9
With point-and-click	15.9
With "you are here"	.05
With itinerary planner	7.6
Route-specific information:	
Route maps	49.7
Schedules	81.0
Fares:	
Comprehensive information	88.4
Online purchase of fare media	6.7
List of purchase locations	43.0
Multimodal information:	
Traffic information (real-time or construction notices)	1.1
Park-and-ride lots	15.0
Bicycles	29.0
Information for tourists (highlighting common tourist destinations on maps, etc.)	10.8
Links to websites with related content:	
Other transit	41.0
Traffic	7.4
Intercity public transportation (bus, train, air)	21.5
Government	28.4
Current news, service updates, or real-time information:	
Current info (temporary re-routing notices, special events, etc.)	21.5
Real-time info (transit vehicle locations, incident information, parking availability, etc.)	1.9
Sign up for e-mail or other alerts	4.7
Rules and restrictions	52.0
Contact information (e-mail/telephone)	76.2/89.6
Website	24.5/.08
Transit	21.1/36.9
Unspecified/general/multiple	29.9/51.5

erary planners are still rare, but are becoming more common.

- A fair number of transit websites have links to other sites (although they are not necessarily the complete set of sites that users may find helpful) or to a comprehensive set of websites providing information on all modes of transportation available in the area. The links frequently include sites that are irrelevant and sometimes imply transportation options that are not available.
- The most common type of information on other modes of transportation is information about the use of bicycles in conjunction with transit. Information that might facilitate a decision about whether to drive or take transit—such as traffic conditions, links to traffic sites, or information on park-and-ride lots—is rare.

4.2 CURRENT EXAMPLES OF DEPLOYMENT

In this section, key examples of deployed TTI systems are presented. These examples can be distinguished from the information presented in Section 5 in that these examples briefly illustrate the use of the technologies described in Section 4.1. The systems described in Section 5 do not necessarily focus on the technological aspects, but provide an overview of key TTI systems throughout the world.

It is important to note that providing traveler information is not the only reason (and in many cases, is not even the main reason) why transit systems deploy the various ITS technologies. Equipping vehicles with AVL and communication technology and monitoring vehicle locations typically are driven more by operational efficiency and concerns of public safety and security. For example, knowing where the buses are at any point in time and being able to communicate with them permits operational policies that can improve the general level of service to passengers under both routine and extraordinary circumstances. Prior to using these technologies, many transit systems would use road supervisors to make decisions about, for example, taking a bus out of service mid-route and turning it to operate in the opposite direction or on another route. Such decisions would typically also have to be made with very imperfect information about the locations of other relevant buses.

The business case for investing in these technologies is most often made on grounds other than to provide TTI, not because that is not considered an important product of the underlying technologies, but because the returns on improved TTI may be far less tangible and quantifiable than the cost savings and benefits from an operational viewpoint. In this sense, the additional investment to make AVL-derived information available to the traveling public may well have a relatively low cost, viewed in terms of both the total infrastructure investment and the incremental cost per ride. However, not all AVL systems are capable of generating continuous, real-time data that can be used for passenger information purposes.

It is also worth noting that the technologies summarized in Section 4.1 are not the only components of current initiatives to add enhanced monitoring and communications capabilities to transit vehicles and stops. Security and safety concerns are leading to, for instance, greater use of technologies such as closed-circuit television systems at stops or in stations or terminals and video cameras and audio recording devices on board vehicles. The deployment of these technologies may have limited benefits in providing information to passengers. The urban transit analog of the traffic website offering real-time camera images of highway conditions might, for example, include images of the current level of crowding on subway platforms.

4.2.1 Pre-Trip Information

WMATA's RideGuide system provides pre-trip itinerary planning on the Internet and by telephone (using interactive voice response technology). Users are prompted to enter the origin and destination of their trip (see Figure 7). Next, they enter a time when they plan on making the trip. They then select whether they want to minimize time, walking, or number of transfers and whether they want to travel by rail only, bus only, or by both (see Figure 8). Once all this information is entered, the system provides not one itinerary, but multiple itineraries, giving the user a number of alternatives from which to choose (see Figures 9 and 10). Itineraries also include walking directions and fare information (see Figure 11).

Ventura County Transportation Commission (VCTC) is another agency that provides an itinerary-planning application. Similar to WMATA's application, VCTC's application accepts addresses as well as landmarks for origin and destination. Users also select the time of their trip, type of fare they will be using, special accommodations, and mode of travel. The resulting itinerary not only provides the users with exact directions and fare information, but also displays the direction of travel in a map format, making it easy to understand how to get to the intended destination. Another significant feature of this particular application is that it encompasses various modes of travel such as buses, ferries, and trains (including AMTRAK).

VRE is another transit agency that provides pre-trip transit information to its customers. VRE is a commuter rail service operated along two lines (Manassas and Fredericksburg) from the Virginia suburbs to downtown Washington, D.C. VRE offers two real-time transit information innovations—Train Brain and Train Talk. Train Brain, implemented in 1999, is a schedule-based JAVA Applet program that displays the location of VRE trains on a map on the VRE website. The Train Brain webpage on the VRE website displays the trains operating according to schedule. The display is periodically updated with information about delays from the Communications Center, which derives the information from the GPS-based AVL system or from the train conductor. The

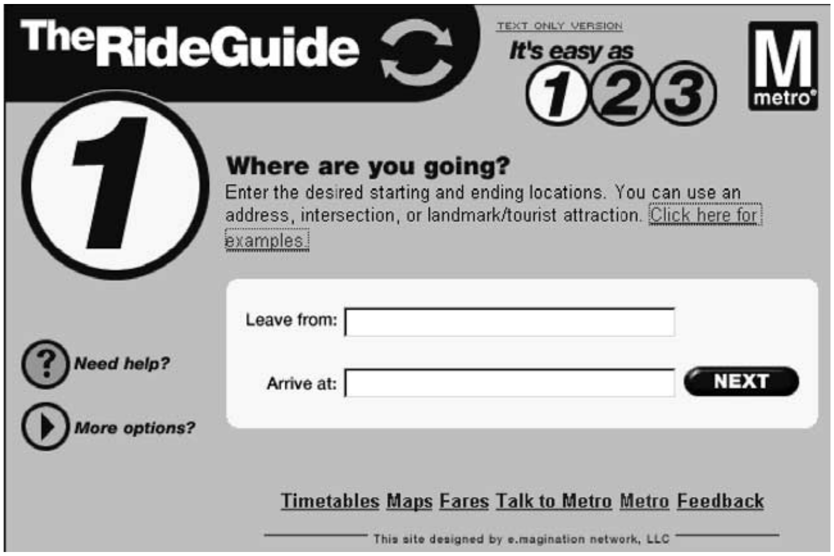


Figure 7. RideGuide origin and destination entry screen.

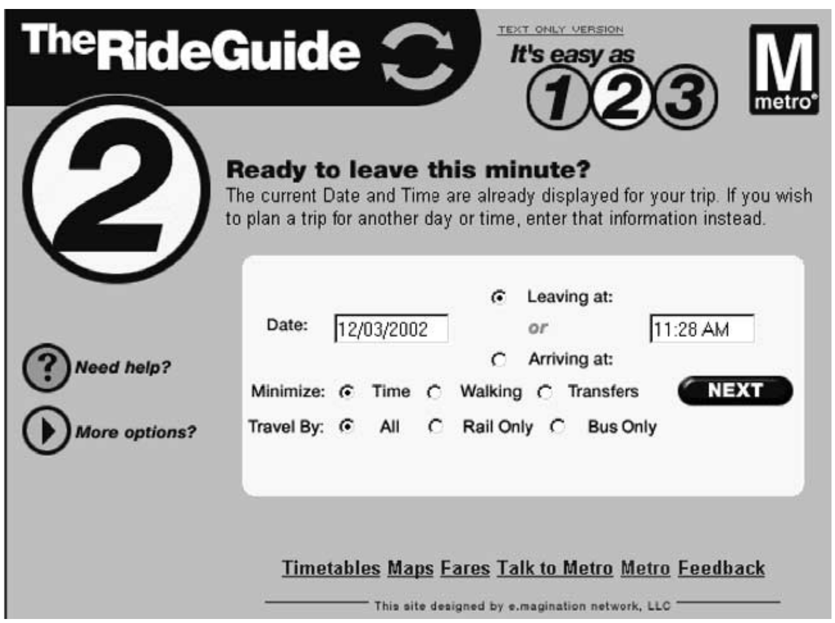


Figure 8. RideGuide entry screen for other parameters.

system is not fully automated as Train Brain only shows the delays that Customer Service decides to reveal.

Train Talk, on the other hand, provides e-mail alerts about VRE train status to riders who register for this service. As of December 2002, 6,500 passengers were registered on the Train Talk e-mail list (out of daily ridership of 12,000 to 14,000 one-way trips). Train Talk is not route- or station-specific, that is, the same e-mails are sent to all Train Talk customers. Train Talk information largely reports significant service disruptions, potential disruptions, and potential equipment changes.

Denver's Regional Transportation District's (RTD's) Bus Locator, implemented in 1999, is an Internet application that provides the ETA for the next two to three bus/rail arrival times based on the route and direction selected (see Figure 12). When real-time data is not available, the Internet application displays scheduled arrival times instead. Another real-time application being used at RTD is Talk-n-Ride. This system

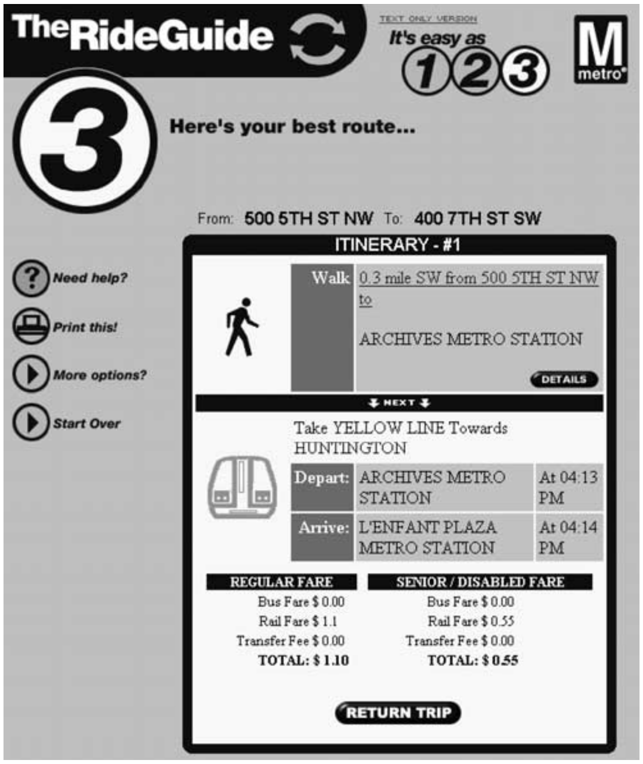


Figure 9. RideGuide first itinerary alternative.

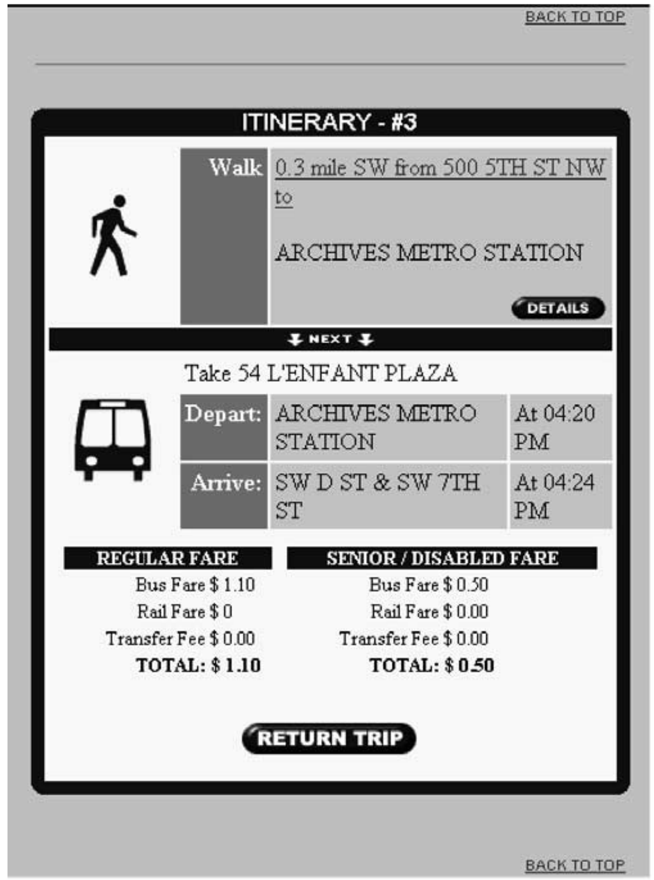


Figure 10. RideGuide third itinerary alternative.

is an interactive voice response (IVR) system that provides real-time "next bus/rail" arrival information for RTD buses and light-rail routes and stops. The user has the option to enter basic information on route and direction and then the option to choose real-time or scheduled time. The resulting information is then presented for arrival times for the next three buses/light-rail vehicles. The basic technology used for this system is a text-to-speech system, in which schedules in Extensible Markup Language (XML) format are translated into voice schedules. The real-time information is taken from the same server that is used to provide arrival information for the Internet application. A more detailed description of Denver's TTI Systems is presented in Section 5.

Portland Tri-Met's Transit Tracker real-time transit information system (next bus and train arrival) is presented to users through two types of media: the Internet and light-emitting diode (LED) signs at the stations and bus shelters. The Internet application (www.tri-met.org/transittracker/index.htm) currently provides information on all TriMet's bus stops (8,000 bus stops). This system allows the user to choose a route, the direction, and a specific bus stop and then provides the user with the next few bus arrivals in a countdown fashion (see Figure 13). The user has the option to view more arrivals for different bus routes and stops.

In Seattle, BusView and MyBus are two additional applications that help King County Metro's users make travel decisions before they start their trip. BusView is an Internet application that provides information on the location of the King County Metro buses by tracking them and displaying their real-time location on a map (see Figure 14). Bus progress along a specific route is shown in the progress window, which can be viewed by clicking on a particular bus and choosing the progress view (see Figure 15). The real-time vehicle location is provided by Metro's signpost-based AVL system. The map is updated every 1 to 3 minutes. One relatively new feature in BusView is an "alarm feature." A user can set an alarm to have BusView alert him or her when it is time to leave to catch the bus. The user chooses a specific time point (designated points along a route) and sets an alarm. When the bus reaches that point, a message is sent to the user alerting him or her that the bus has reached the requested destination.

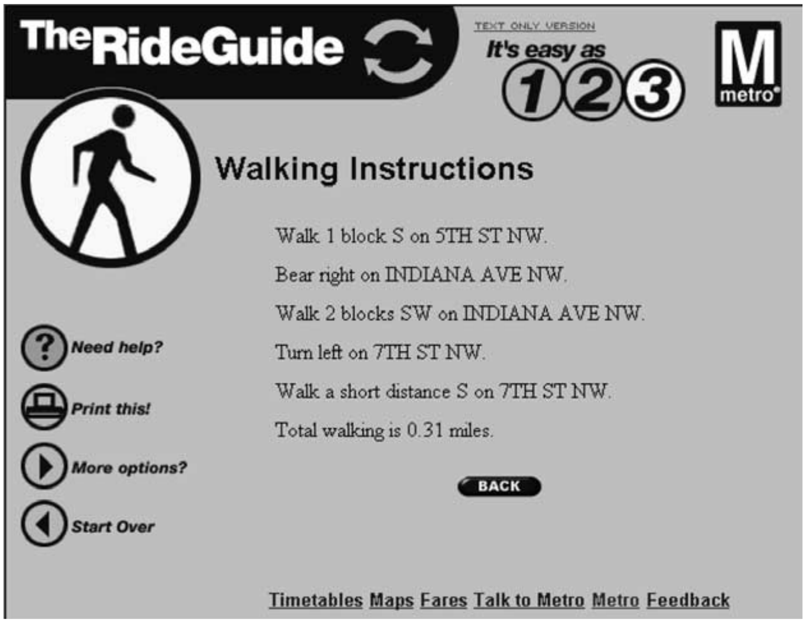
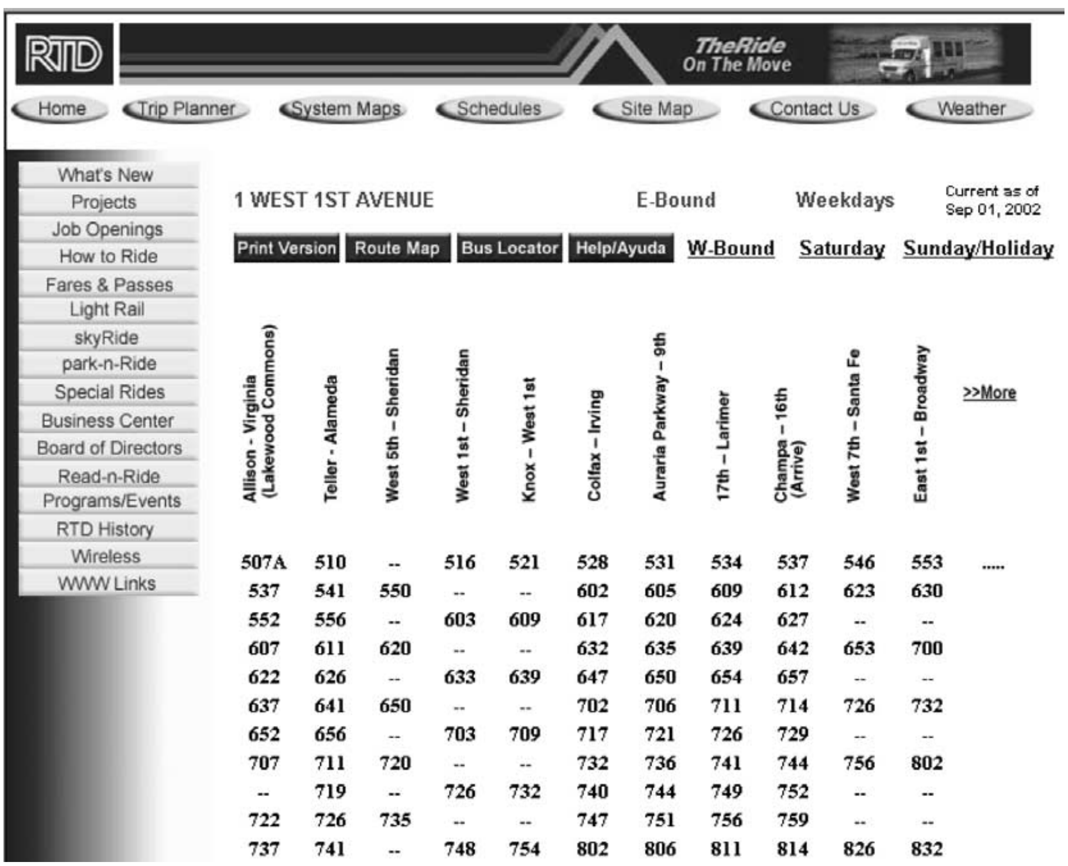


Figure 11. RideGuide walking instructions.



Allison - Virginia (Lakewood Commons)	Teller - Alameda	West 5th – Sheridan	West 1st – Sheridan	Knox – West 1st	Colfax – Irving	Auraria Parkway – 9th	17th – Larimer	Champa – 16th (Arrive)	West 7th – Santa Fe	East 1st – Broadway	>>More
507A	510	--	516	521	528	531	534	537	546	553	.....
537	541	550	--	--	602	605	609	612	623	630	
552	556	--	603	609	617	620	624	627	--	--	
607	611	620	--	--	632	635	639	642	653	700	
622	626	--	633	639	647	650	654	657	--	--	
637	641	650	--	--	702	706	711	714	726	732	
652	656	--	703	709	717	721	726	729	--	--	
707	711	720	--	--	732	736	741	744	756	802	
--	719	--	726	732	740	744	749	752	--	--	
722	726	735	--	--	747	751	756	759	--	--	
737	741	--	748	754	802	806	811	814	826	832	

Figure 12. RTD's schedule page, with bus locator option.

Figure 13. Tri-Met Transit Tracker on the Internet.

A different King County Metro Internet and wireless application provides detail on the real-time bus arrival of Metro buses. This information is presented in a tabular form, and it uses the data from the AVL system along with a prediction algorithm to determine the time when the next bus will arrive at a particular stop. Historical operational data is also used by the prediction algorithm to predict the arrival times. MyBus also provides status information on each bus (i.e., departed, 10-minute delay, etc.).

Another agency that provides pre-trip traveler information is Washington State Ferries (WSF). This real-time Internet application (www.wsdot.wa.gov/ferries/), called Vessel Watch, provides the location of the WSF vessels by displaying their real-time location on a map (see Figure 16). The vessels are represented as colored arrows (directional) on the map when they are moving and as colored circles when they are stopped. The vessel locations are shown based on the route selected from a drop-down menu. The route names are also represented on the map alongside the moving arrows. The Vessel Watch information is updated every 3 minutes. The Internet application was developed in-house with help from contractors from Washington State DOT.

4.2.2 En Route Transit Information

The real-time transit information system implemented by San Francisco Municipal Railway (MUNI) in 1998 started as a demonstration project by a private provider. The private provider demonstrated the capability to provide real-time next train arrival information using AVL data from MUNI trains in 1996 on LED signs installed at train station platforms (see Figure 17). The demonstration turned into a pilot in 1998, and MUNI implemented this system for the whole rail fleet by 1999. The system includes signs on the station platform that provide next train arrival information for the next 2 or 3 lines. An audio component was added to this system by another vendor.

Using the same real-time data that is provided via Bus Locator and Talk-n-Ride, Denver RTD implemented an application to provide real-time next arrival information to

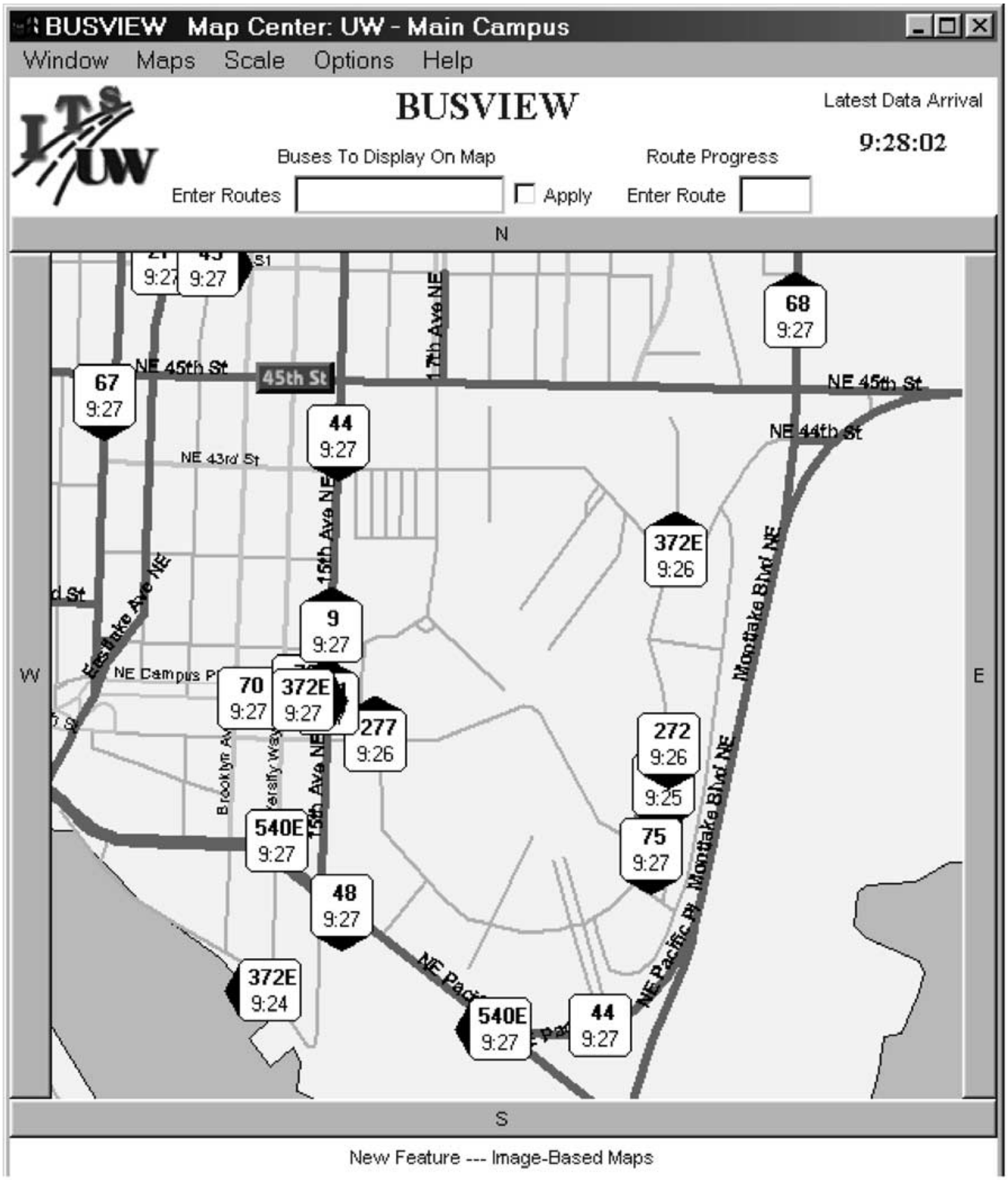


Figure 14. BusView main window.

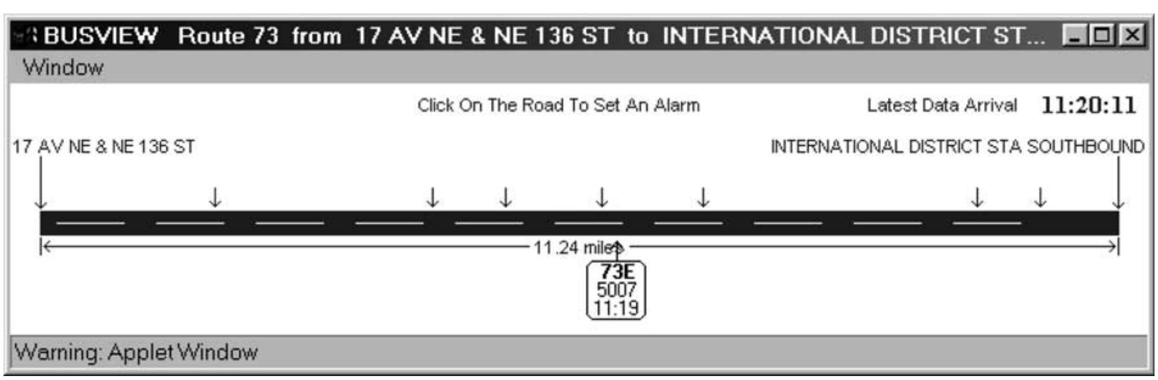


Figure 15. BusView progress window.

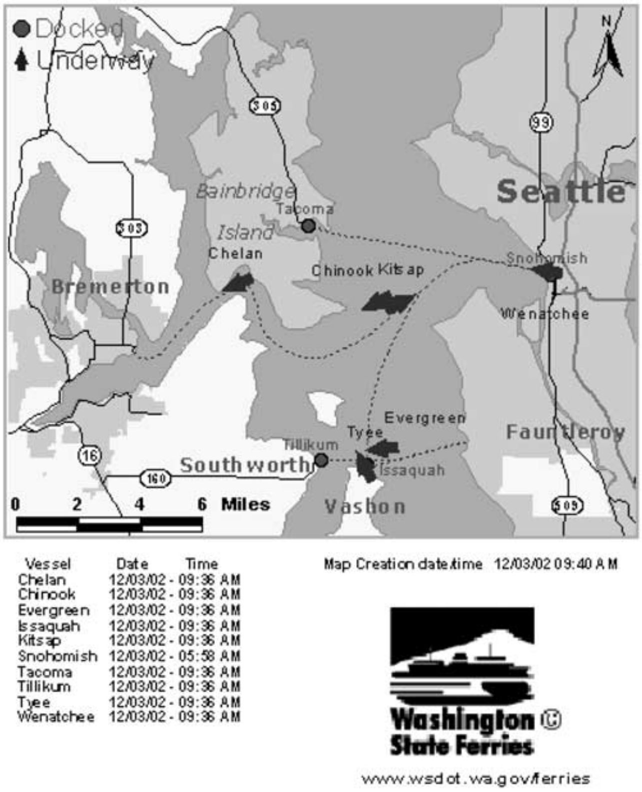


Figure 16. WSF Vessel Watch for Seattle-Bainbridge Island route.

wireless devices, including PDAs and WAP phones. This application is called Mobile-n-Ride (www.gortd.com). Once the user connects to the Internet web page via mobile device, he or she enters a route number, a direction, and a stop. When all the parameters are entered, a message containing the ETA for the next two to three vehicles is sent to the mobile device using the same operating system as the device that requested the information.

In Pompano Beach, Florida, when the double-tracking work was first being planned, Tri-County Commuter Rail was concerned about the varying train delays that would be caused by the construction and the impact these disruptions might have on its ridership. Hence, it deployed a real-time arrival system in 1996 to address this potential problem. The system provides real-time information on arrival times of trains, location of trains, and service delays and disruptions. LED DMSs display arrival times of the next train in a countdown fashion (e.g. "Train in *X* Minutes"). Messages at train stations are also provided in audio format to accommodate passengers with visual impairments. Audio messages are automatically played whenever text messages are updated.

As part of its long-range plan, COTA in Columbus, Ohio, implemented a real-time bus arrival system in August 2001 called RideFinder. The initial demonstration was conducted on the Downtown Link and the Hotel/Airport circulator routes. The purpose of this system is to provide COTA's customers, at certain bus stops and hotel lobbies, with the actual arrival time of the next bus. The arrival time for the Down-

Figure 17. San Francisco MUNI shelter with LED sign.

town Link is displayed on DMSs. The signs display the route number, estimated arrival time, time, and date. The Hotel/Airport circulator uses touchscreen interactive kiosks for displaying the information (see Figure 18). The kiosks display a map of the route with the actual location of the buses as well as the estimated arrival time of the bus at that stop (see Figure 19). The user can also access weather information and information on COTA's service and fares at the kiosk. In addition, arrival time is provided in audio format. Users with visual impairments can push a button on the kiosk to hear the estimated arrival time of the following bus.

In an effort to provide better service to its customers, WMATA introduced a real-time passenger information display system (PIDS), which provides actual arrival times of trains, elevator and escalator outages, incident information, and security alerts. DMSs at Metrorail stations display arrival times of the Metro trains in a countdown fashion, as shown in Figure 20. The DMSs are also used to provide information during an emergency or terrorist situation. Time is also displayed on the DMSs when the ETA information is not being displayed. WMATA uses the DMSs to disseminate events messages, especially on weekends when there is more time between trains and therefore greater opportunity for other messages to be displayed.

Customers of River Valley Transit (formerly CityBus) in Williamsport, Pennsylvania, faced a dilemma as to how to inform passengers at their Transit Center about how to locate their buses (i.e., which bus bay had which bus). Incoming buses must select an available bus bay upon entering the facility, making finding the right bus a challenge for passengers. The implementation of a unique information system was needed to inform customers about the location of their bus. The system, deployed in 2000, uses two variable text message signs to display the bay number for each bus as well as to warn when a bus is about to depart (see Figure 6). Each of these variable signs has 10 rows of 2-in.-high characters. Each row is labeled for 1 of the 10 different bus bays and indicates the route name for any bus currently occupying that bay. There is also a public address system that provides audible announcements for the sign messages.

San Luis Obispo Transit (SLO Transit) in San Luis Obispo, California, provides another example of a real-time bus arrival system. In 2001, SLO Transit completed the installation of Efficient Development of Advanced Public Transportation Systems (EDAPTS) prototype ITS equipment on its buses and at bus stops to test the operational suitability of ITS technology in a small transit agency environment. The EDAPTS concept and the prototype equipment were designed and developed by California Polytechnic State University researchers and undergraduate engineering students under a research contract funded by the California DOT's (Caltrans's) Division of New Technology and Research and by FTA. EDAPTS is designed for small and rural public transportation agencies and focuses on providing basic functionality that is affordable for small agencies and that can be expanded. EDAPTS was developed with special attention given to providing low, post-deployment operating and maintenance costs. The current system provides real-time information on arrival times of buses, location of buses, and service delays and disruptions. DMSs at selected bus stops display arrival times of the next bus in a countdown fashion (e.g., "Route 34 Here in *X* Minutes") (see Figure 21). Vehicle locations are available only on the dispatchers' monitors because the DMSs do not have the capability to display graphics. The electronic signs are in compliance with the ADA as they have 3-in.-high characters; however, there are no audio announcements available.

Portland's Tri-Met installed Transit Tracker LED DMSs at several bus stops with shelters and light rail (Metropolitan Area Express [MAX]) station stops to provide real-time arrival information to its customers. Tri-Met is in the process of installing more signs (scheduled to install 50 by 2003) and has planned to install a total of 250. The LED signs at the MAX stations currently display "next scheduled arrival time" and not the "next train arrival." In the bus shelters, the LED signs display the real-time next bus arrival in a countdown fashion. In one transit mall area where there is more than one bus and one route served, there is a multiline LED DMS, which shows the route number, direction, and countdown time for three or four buses (see Figure 22).

Figure 18. RideFinder kiosk.

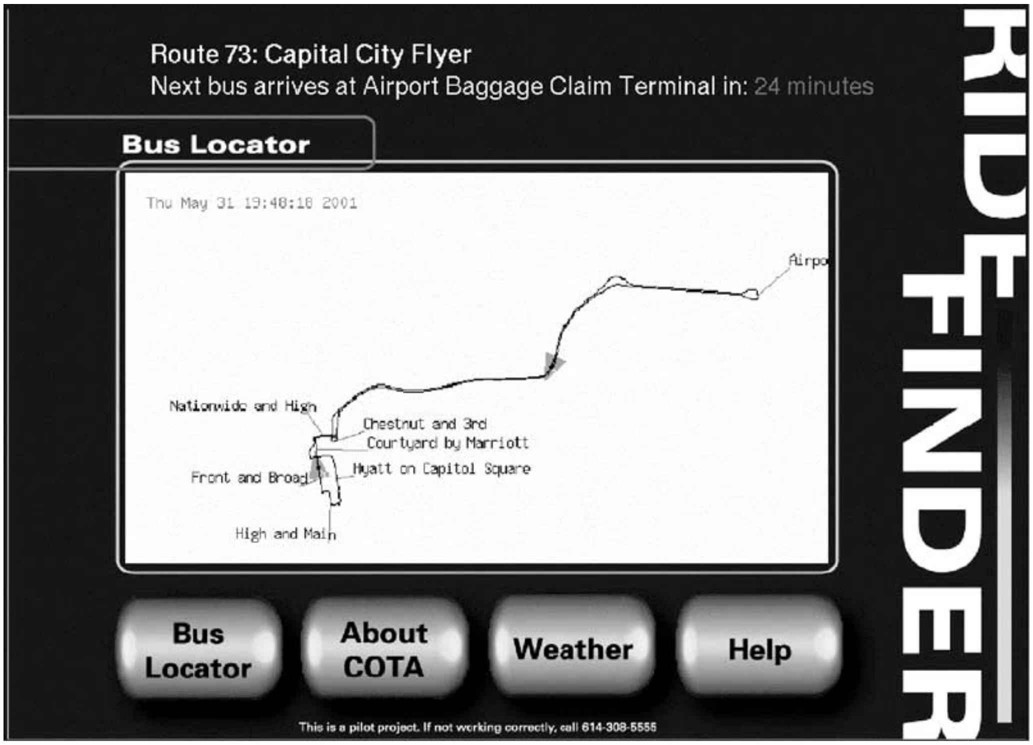


Figure 19. RideFinder real-time bus location screen.

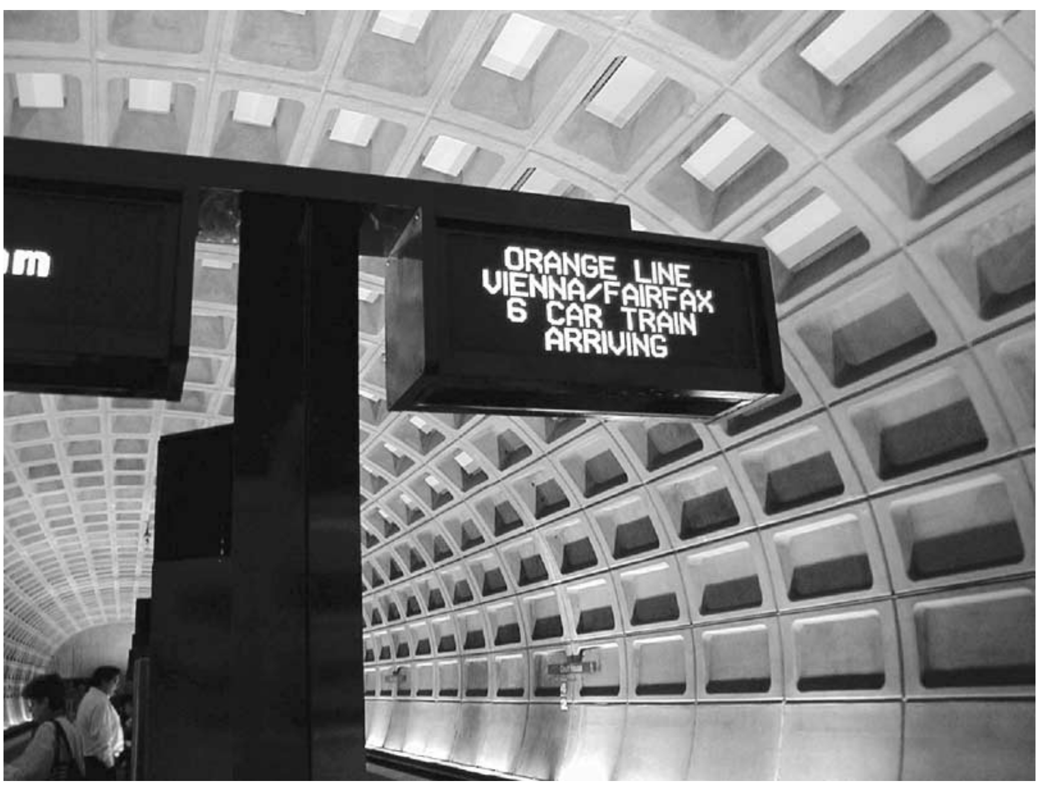


Figure 20. WMATA's passenger information display system.

Figure 21. SLO Transit smart transit sign.

4.2.3 In-Vehicle Transit Information

An example of an automated annunciation system providing displays that are more sophisticated than the typical display on in-vehicle electronic LED signs is the system implemented on one long-distance, limited-stop bus route in Orlando, Florida, called Lynx. This system provides the following information on multiple high-resolution video screens in the bus: (1) real-time activity information, including route information, time, and date; (2) next-stop announcement and display; (3) public service announcements; (4) scrolling headlines and text advertising; and (5) actual video (e.g., short films, newscasts). See Figure 23 for a photo of this onboard annunciation system.

Figure 22. Portland Tri-Met Transit Tracker multiline DMS.

Figure 23. Automated annunciation system on board Lynx bus.

4.3 REFERENCES AND ENDNOTES FOR SECTION 4

1. Marston, J. R., and R. G. Golledge. "Improving Transit Access for the Blind and Vision Impaired," *Intellimotion,* Vol. 7, No. 2: 1998: www-path.eecs.berkeley.edu/PATH/Research/Featured/1098/Featured10-98.html.
2. Hu, K., and C. K. Wong. "Deploying Real-Time Bus Arrival Information and Transit Management Systems in Los Angeles," abstract prepared for the ITS America 12th Annual Meeting, Long Beach, CA; April 29–May 2, 2002.
3. Dailey, D. J., Z. R. Wall, S. D. Maclean, and F. W. Cathey. "An Algorithm and Implementation to Predict the Arrival of Transit Vehicles," available at www.mybus.org.
4. Welch, G., and G. Bishop. "An Introduction to the Kalman Filter," March 11, 2002; available at www.cs.unc.edu/~welch/kalman/kalman_filter/kalman.html.
5. Transitweb: transitweb.volpe.dot.gov/introduction.asp.