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Future Ride: Adapting New Technologies to Paratransit in the United States

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The University of California Transportation Center

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Berkeley, CA 94720

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INTRODUCTION

For the average American, the overwhelmingly popular first choice in trip mode is to get into the private car at point A and drive it directly to point B. In the San Francisco Bay Area, for example, 82 percent of all work trips and 76 percent of all non-work trips are solo car trips The total share of transit trips is 10 percent and steadily declining, in spite of massive operating subsidies for these modes Short of a drastic change in the cost of car travel (e g , a long-term doubling of gasoline prices), current transit modes cannot hope to compete with the private automobile for passengers

Why is transit so unattractive to most potential passengers compared to the private automobile? The two major modes of transit in large U S. metropolitan areas are rail and bus Rail systems, whether heavy rail (such as BART), commuter rail (such as CalTrain), or light rail (such as Santa Clara County Light Rail) by definition operate only along a few fixed corridors. Although they generally run on exclusive rights-of-way, they have a number of time and cost disadvantages. The main time disadvantages are the wait times and the access and/or egress times to and from the station (rail stations are typically accessible on one end by car, but the passenger must usually rely on bus service for transport from the other end to the final destination). Also, a round-trip train ticket is often more expensive (or perceived to be so) than the cost of using the private car. While bus fares are generally lower than those for rail, buses also operate only on fixed routes, and often have even greater headways than trains

Paratransit can be considered as any transit mode with the following characteristics (1) rides are shared by more than one person, (2) vehicles range in size from taxis to large vans or small buses (i e , vehicles with capacities of between 4 and 25 persons), and (3) routes need not be fixed. Paratransit as a general transit mode is not offered in most U.S cities A number of paratransit services have existed in U S. metropolitan areas, but have failed to survive (in Los Angeles, due to a great lowering of bus prices through public subsidies [1]), never came into being because they could not survive under regulations favoring transit monopolies, or have succeeded but under highly special circumstances (e g., illegal vans operated largely by and for persons of Caribbean descent in New York City [2]).

Even when allowed to compete freely with current modes of public transit, paratransit services may find it hard to find a profitable niche in low-density, suburban U.S. metropolitan areas. As with any other transit mode, a successful paratransit service will have to provide cost, convenience, and time benefits comparable to those of the private car, particularly the ability to immediately access the vehicle and drive it straight through to the final destination. It is therefore unlikely that taxis, vans, or small buses would be able to provide these benefits in low-density suburban areas. Perhaps their only useful niche would be as competitors with bus or rail along highly traveled corridors.

An increasing number of researchers, however, believe that certain high-technology enhancements can greatly improve the range of paratransit services, and hence the demand for these services. Most tests of this hypothesis have involved service for American with Disabilities Act (ADA) populations who generally make regular service requests on a subscription basis or at least 24 hours in advance of the trip. However, a few projects are testing this hypothesis for the general trip-making population as well.

This paper will investigate the possibility that the application of technological innovations can make paratransit into a mode that is cost- and time-effective for both passengers and operators, relative to the private car. Section I creates a typology of potential paratransit services by listing particular characteristics of paratransit and particular niches for which these characteristics are especially suitable. Section II describes the four principal high-tech components that have been proposed for "smart" paratransit, and how various degrees of integration of these services can serve the niches described in Section I. Section III outlines three particular types of paratransit service for which these high-tech components seem especially suited: parataxis, ADA service, and general public transit.

To date, no major tests have been conducted on the parataxi concept The Winston-Salem Mobility Manager is the most highly integrated and longest-running operation that uses advanced technologies to improve service for its ADA service area. The German Ruf-Bus/FOCCS experiment is the main example to date of using these technologies for general public transit Apart from these two examples, there is very little empirical data on which to make any sort of quantitative assessment of cost-effectiveness for these technologies Furthermore, there are no standards for designing such projects or for evaluating their outcomes. in large part because there are so many potential types of services with different combinations of the technologies Section IV discusses the issues involved in evaluating applications of the new technologies to paratransit Section V concludes by speculating on the future of high-tech paratransit, and suggests further studies.

I. A TYPOLOGY OF POTENTIAL SERVICES OFFERED BY HIGH-TECH PARATRANSIT

The specific technologies that constitute "high-tech paratransit," either separately or in combination, will be described in Section II. This section lays out a map for assessing the different types of services that these technologies will either enhance or make possible in the first place. The map consists of combinations of choices among the nine characteristics shown in Table 1. Each of these nine characteristics will now be briefly described.

I.1. Scheduling Type: Fixed-Scheduled vs. Demand-Responsive vs. Unscheduled

At first glance, it would seem obvious that all transit services are scheduled, and the applications of high-tech to paratransit are no exception to this rule. However, the private car is just as obviously an "unscheduled" mode, and therein lies one of its greatest attractions — it is simply there whenever it is needed. In major cities of many developing countries (e.g., Mexico City, Bangkok) the quantity and frequency of paratransit service are so high that schedules are neither needed nor used [3]. U.S. metropolitan

Characteristic	Alternatives
1. Scheduling Type	Fixed-Schedule Demand-Responsive Unscheduled
2. Route Type	Fixed-Route Route-Deviation Flexible-Route
3. Client Type	Specialized Population (e g , ADA) General Public
4. Number of Trip Segments	Transfer(s) No Transfer
5. Ride-Sharing	Shared Ride Exclusive Ride
6. Origin and Destination of Service	Door-to-Door Checkpoint
7. Origin and Destination Relationship	One-to-One One-to-Many Many-to-Many
8. Real-Time Information Access	Accessible Not Accessible
9. Service Goals	Efficiency Equity

Table 1. Paratransit Characteristics

areas are considered to have densities too low to support this kind of service, although in theory advanced computer algorithms and good trip distribution data could be used to approximate such service [1]

Exclusive ride taxis generally don't have a scheduling problem — a request is serviced by the nearest available taxi, which provides the service and then responds to the next request. The shared-ride characteristic of most paratransit modes makes scheduling much more complicated. If a given day's requests are known at least one day in advance, then computerized scheduling algorithms can be used to determine the most efficient and/or effective route for each vehicle in the fleet (depending on the criteria used), subject to the constraints of passenger origin and destination points and the requested time of service, other constraints, such as the need for a vehicle equipped with wheelchair lifts, may also apply, especially for special-service populations such as ADA clients. Most ADA service requests are for "subscription" service; i e. a series of regularly scheduled trips determined well in advance (such as a doctor's appointment at the same medical center every Tuesday at 3:30). If real-time requests are allowed, the scheduling problem becomes vastly more complicated, since each vehicle which could potentially service such a request is subject to all the constraints of the passengers currently on board, plus all

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[1] This is the subject of the forthcoming Ph D dissertation of one of the authors (Round) .

passengers who are subsequently scheduled to be picked up. Furthermore, there is no way to anticipate the trip parameters of the next real-time request. Thus, if the scheduling algorithm has just computed the optimal route based on all requests up to the present moment, there is no way to know the extent to which the next request will make this route sub-optimal; if the next request had been known at the time of route optimization, a very different route might have been configured. For these reasons, few paratransit services that are primarily demand-responsive have been attempted.

There are currently no formal tests of unscheduled paratransit (although the illegal jitney services of New York City and Miami might fall into this category). Numerous experiments are being conducted in the improvement and integration of both fixed-schedule and demand-responsive ADA service, a few such experiments for general public transit have taken place, are in process, or have been proposed.

All current theoretical and empirical work on advanced technology paratransit deals strictly with scheduled trips. The purpose of the technologies is typically to decrease the amount of time between trip request and actual pick-up, or the average total passenger delay, depending on how the problem is formulated.

I.2. Route Type — Fixed-Route vs. Route-Deviation vs. Flexible Route

Fixed-route service involves scheduled arrivals at given checkpoints along pre-defined routes. This is the type of service that is normally offered by buses. Route-deviation service extends fixed-route service by permitting a certain amount of deviation from the fixed route. This deviation can be measured in terms of distance or time, and may be subject to other constraints. For example, a vehicle may be required to pass through all checkpoints even if it deviates from its route. If this is the case, then the vehicle will arrive "late" at the checkpoints beyond the deviation, thus requiring other vehicles to fill the slack. The inability to perform this kind of time coordination among vehicles through traditional manual dispatching has hampered the development of route-deviating bus or paratransit services.

A further extension of the route-deviation is flexible routing, in which the vehicle can literally go wherever the demand takes it[2]. Taxis frequently operate in this manner. If the taxi dispatcher receives a request for service, the dispatcher typically broadcasts the location of the request to the drivers in the currently operating fleet. Based on the response, the dispatcher will order a particular driver (probably the one closest to the requestor's location) to service the request. The reason that transit does not operate in this way is that all transit modes are inherently shared-ride, in contrast to the exclusive-ride nature of most taxi services. The shared-ride characteristic of transit operations puts a totally different set of routing constraints on these services compared with taxi services. The complex interaction between the scheduling, routing, and ride-sharing characteristics of paratransit, and the ways in which technology might impact these interactions, are discussed in the section on automated scheduling in Section II.

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[2] Subject to the inter-jurisdictional constraints discussed in previous chapters.

I.3. Client Type — Specialized Service vs. General Public Service

The vast majority of proposed or actual projects involve service for ADA populations. The emphasis of these projects has been on improving the efficiency (e.g , lower costs per vehicle mile) and/ or effectiveness (e.g , increase in number of trips that otherwise would not have been made) of the service, rather than changing the actual service offered. For example, while the automated computerized scheduling systems described in Section III do allow for unexpected schedule changes, the majority of trips are still scheduled at least 24 hours in advance. A service for the general public would have to be much more demand-responsive.

I.4. Number of Trip Segments — Transfer vs. Non-Transfer Service

Vehicles have a carrying capacity between those of the private car and the bus. This intermediate carrying capacity poses a dilemma. It is unlikely that a general public paratransit service can operate profitably outside of high-traffic corridors, where it would compete with buses, especially in the absence of policy incentives for these services (such as employer cash-out of free parking or congestion pricing [4]) In low-density suburban areas, it would be difficult to find a set of passengers whose endpoints (or nearest checkpoints) and desired trip times were such that a single paratransit vehicle could pick them up and drop them off while (1) serving enough passengers to be profitable, (2) delivering each passenger all the way from origin to destination, and (3) causing minimal delays, especially for passengers picked up earlier along the route. It would seem that paratransit might find a more useful niche along one leg of a multiple-segment trip, where the paratransit leg is between two large trip generators (e.g , a rail station and an office park several miles apart). However, people generally perceive transfer times between vehicles as particularly onerous.[3] In either case, paratransit is unlikely to succeed on a large scale outside of major corridors due to long real or perceived delays. It is thus of interest to investigate whether technology can be used to minimize delays, either for direct trips taken entirely on a single paratransit vehicle or for trips in which paratransit is one leg of a multi-segmented trip.

I.5. Ride-Sharing — Shared Ride vs. Exclusive Ride

At first glance, it would seem obvious that paratransit is inherently a shared-ride mode. However, there is an interesting technological application that makes paratransit an exclusive-ride variation on both the single-passenger taxi and ride-sharing. For a given trip by single-passenger taxi, the passenger arrives at the destination. The driver does not have a destination per se: he simply transports the passenger for a profit. For a given trip in a two-person carpool, both the driver and the passenger have the same destination, but the driver is not normally paid for the service. Experience with various incentives (such as Southern California's Reg 15 [5]) have shown that it is very difficult to get people to carpool in significant numbers.

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[3] The City of Emeryville shuttle seems to be an exception.

"Parataxi" is the name given to the mode in which instantaneous, real-time trip matches are made between a driver about to depart for a destination and one other person (or party) who (1) has the same or nearly the same destination as the driver, (2) has a current location that would cause minimal delay for the driver, (3) has time constraints that closely match the time that the driver could arrive to pick up the person (or party), and (4) is willing to pay the driver for the service. Unlike the taxi, the driver has the same destination as the passenger. Unlike ride-matching services, the driver gets paid for driving the passenger. In theory, more than one person/party could be picked up, however, the limited capacity of the private car along with the high probability of substantial delays make it unlikely that a parataxi service would take more than one person or party. For this reason, it is called an "exclusive ride" service The hypothesis that improved technology for ride-matching plus the ability to earn extra income will lead to significant increases in ridesharing remains to be tested [4]

I.6. Origin and Destination of Service — Door-to-Door Service vs. Checkpoint Service

Dial-a-ride service is mandated by ADA legislation for transit services at a distance of 0.75 mile on either side of their operating corridors Since the vehicles that provide this service are typically vans, the term "paratransit" is often used synonymously with this ADA-mandated transit service. Dial-a-ride services for the general public, however, have not been successful. As pointed out in the section on transfers above, it is likely that door-to-door paratransit services in low-density suburban areas would either be under-utilized or cause substantial delays. Furthermore, demand-responsive dial-a-ride service presents formidable scheduling challenges

Checkpoints are fixed points at which pick-ups occur (drop-offs may or may not be limited to checkpoints). Buses normally pick up passengers only at certain checkpoints along their routes (a checkpoint might be any intersection along the route). For paratransit, as for buses, checkpoint service along heavily travelled corridors increases the likelihood of filling the vehicles, but decreases the proportion of the metropolitan area that is covered by the service. The door-to-door vs checkpoint characteristic interacts with some of the other charatericstics described above; for example, parataxi is inherently a door-to-door service while a paratransit operation that requires transfers is likely to be a checkpoint service.

I.7. Origin and Destination Relationship — One-to-One vs. One-to-Many vs. Many-to-Many Services

Another important characteristic of paratransit services is the set of origins and destinations they serve. A one-to-one service operates strictly between two points, along with possible pick-ups and drop-offs at intermediate points. For example, BART has vans that operate exclusively between the Coliseum BART station and the Oakland International Airport two miles away; these vans allow no intermediate

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[4] This hypothesis will be tested in the city of Ontario, CA (see Section III below).

pick-ups or drop-offs. A fixed-route jitney service, such as the one operating on Mission Street in San Francisco, also operates between two end points but picks up and drops off passengers at intermediate checkpoints A one-to-many service delivers passengers from multiple origins to a single destination or vice versa The best-known example of this type of service is airport shuttle, which transports passengers from most points in a metropolitan region to an airport.

A many-to-many service transports passengers between any two reasonably accessible points in the service region. The great dispersal of origins and destinations in major U.S. metropolitan areas, along with limited vehicle capacity, the shared ride nature of paratransit, and passengers' reluctance to transfer between vehicles have precluded the development of many-to-many paratransit services.

I.8. Real-Time Information Access vs. No Real-Time Information Access

All other things being equal, a paratransit service will attract more passengers to the extent that it minimizes their delays. New technologies have the potential to deliver real-time traffic and routing information directly to drivers, enabling them to avoid congestion and hence minimize delay. This information can consist solely of traffic condition updates, leaving it up to the driver to determine the best route given prevailing conditions; or it can include the actual route that the driver should follow. As discussed in Section III below, a large experiment is currently being conducted in the Chicago area that provides drivers with on-demand optimal routing information based on their present location, their destination, and current traffic conditions. In theory, this provision of real-time information is useful to paratransit modes to the extent that they are flexibly routed. However, such information would also be useful for fixed-route paratransit services that pick up drop-off passengers at timed-transfer points, as the drivers of the waiting vehicles could at least be informed of the delays. Such information would also be useful to route-deviating services, which could order additional vehicles to service the off-corridor requests rather than further exacerbating the delays of vehicles already in service.

I.9. Service Goals and Constraints

Finally, the type of paratransit service, and the impacts that technology has on that type of service, are largely dependent on the goals of that service and the constraints that these goals impose on the service. An ADA service has as its primary goal the delivery of specialized (e.g., requiring special equipment such as wheelchair lifts), door-to door service for a relatively fixed clientele that typically has a pre-defined schedule of trips. A general public checkpoint service, on the other hand, has net profit maximization as the primary goal. These different goals in turn imply different constraints. For the ADA service, equity constraints are likely to be of greater importance; no passenger should have a delay of 15 minutes more than any other passenger, no matter where the passengers live in the service area. For the general public service, efficiency constraints are likely to be more important than equity constraints, and routes are selected to maximize fares generated per hour of operation.

Summary

The above characterization of paratransit services shows an enormous number of potential types of operation. In theory, there are numerous niches for a large variety of paratransit services, all of which vary by the goals and characteristics of the service as well as by the characteristics of the area served (e.g , distribution of residences, employment and commercial centers, schools, government agencies, etc). Given this potential to fill the many gaps in bus- and train-dominated transit, why have paratransit services remained largely confined to airport and employer shuttles? Part of the answer lies in the regulatory obstacles to private sector development of these services. And even in the absence of such regulatory obstacles, the market for these services may simply be non-existent or highly limited, due to the relative cost- and time-effectiveness of the private automobile. It may turn out that paratransit is inherently limited to very narrowly defined markets such as the ADA population, or it may be that paratransit has been limited by the technical inability to realize the flexible routing, many-to-many routing, real-time information acquisition, and other characteristics that would create demand for these services. The next section explores a number of technologies that might make the large number of potential paratransit services cost-effective competitors with the private automobile.

II. NEW TECHNOLOGIES FOR PARATRANSIT

There are many different technologies, based on advances in computers and communications, that have the potential to enhance existing paratransit services or create new ones. The examples below will give some idea of the variety of such services. In order to discuss these technologies within a common framework, a general model for advanced paratransit will be presented, such that each particular application is a subset of the general model.

The general model can perhaps best be introduced by considering an example of current paratransit service. the dispatcher for an ADA broker has compiled the ride lists for the next day and distributed them to the drivers. During the next day, the dispatcher receives a call from an ADA-qualified client requesting service for that same day. The dispatcher currently has two choices. First, she can reject the call, reminding the caller that requests for rides must be made 24 hours in advance. Second, she can realize that there are a number of vehicles currently on the road that are carrying few passengers, so that it would be cost-effective to satisfy the caller's request, even though it was previously unscheduled. If the dispatcher chooses the second option (which is unlikely to be the case for most current ADA services), then the following questions present themselves: (1) which vehicle should service the call, (2) at what time will this vehicle arrive to pick up the caller, and (3) how will this deviation from the scheduled service affect the passengers already on board or those to be picked up by the same vehicle after the caller is serviced?

To make intelligent decisions that answer these questions, the dispatcher should know three types of information. First, he should know the current location of all vehicles currently in operation. Second, for each of these vehicles, he needs to calculate the expected pick-up time for the caller and the effects that servicing this call has on the vehicle's other passengers Third, in order to make this calculation, he would need to have readily available data to help determine the best route for a vehicle (including street layouts, speed limits, current traffic conditions, etc.) as well as information about the caller and the other passengers (their destinations, whether they require special equipment such as wheelchairs, etc.). Thus, the dispatcher needs an extensive database that includes both static information (e.g , the street grid) and dynamic information (e.g , current traffic conditions)

The general model addresses these questions through the integration of four components. First, Automatic Vehicle Location (AVL) technology gives the dispatcher knowledge of the location of all currently operating vehicles Second, automated scheduling technologies take all currently available vehicle and passenger information into account in order to determine the best vehicle to pick up the new passenger, as well as the best route for that vehicle to satisfy this passenger's request Third, the automated scheduling component needs extensive static and dynamic data pertaining to the roads, vehicles, and passengers in order to make optimal decisions This information is stored in databases that are immediately available to the automated scheduling component. Fourth, the three components described above are useless unless there is a means of communication that connects the passenger, the dispatcher, and the driver. The initial request starts as a call from the passenger to the dispatcher. The dispatcher must then have a means of entering this request into the integrated system and getting feedback from the system that helps make the best decision for servicing the request. This decision then needs to be communicated to the appropriate driver Furthermore, any special conditions, such as a vehicle breakdown or delay, need to be communicated to the appropriate individuals.

The general model, illustrated in Figure 1, therefore consists of four components:

A. Automatic Vehicle Location
B Automated Scheduling
C Database Technology
D. User Interfaces

Each of these components will now be described in more detail.

A. Automatic Vehicle Location

Automatic Vehicle Location (AVL) refers to the ability of the system to accurately pinpoint the location of each vehicle in the fleet at any given moment. If all trips in the system are known in advance, the automated scheduling software can compute the optimal routes for each vehicle. Since the routes are pre-determined, there is no need to know the position of the vehicle real-time (except, perhaps, for exceptional situations, as discussed below). However, to increase the market for paratransit, the scheduling software must be able to respond to real-time passenger pick-up requests. To reduce passenger waiting time and system costs, the system must select the most appropriate paratransit vehicle to service the particular

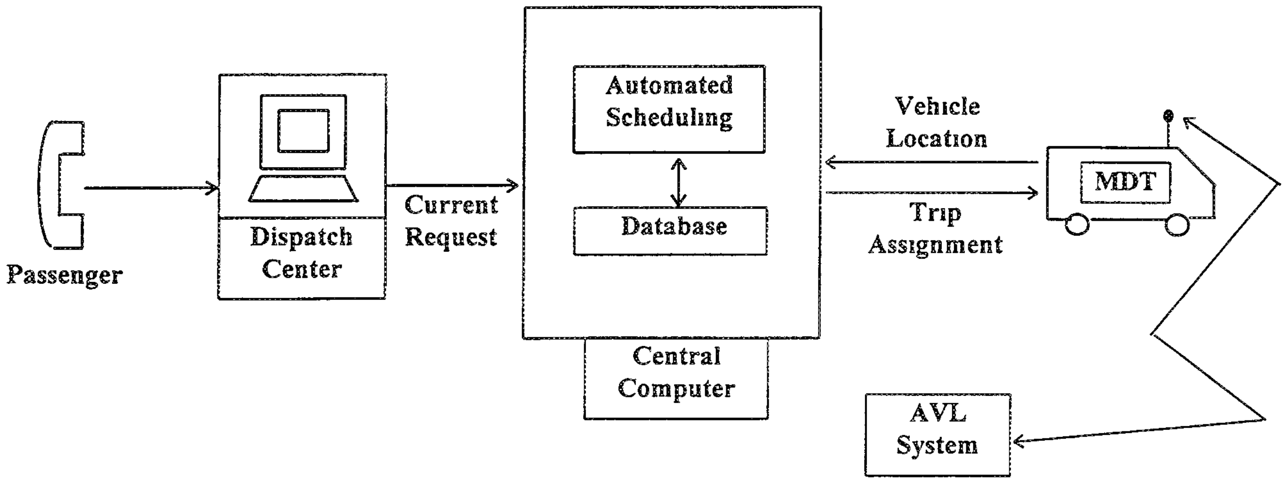

Figure 1. General Model for an Integrated Advanced Technology Paratransit System

request (probably, but not necessarily, the vehicle that is closest to the location of the requestor) To make this selection, the system must know the location of all the vehicles at the moment the request is made

AVL can also be used to help the passenger make timely transfers. For example, ADA requires paratransit service up to 0 75 mile on either side of a long-haul transit corridor. If the corridor is served by a bus, then the paratransit vehicle must drop off passengers at the bus stop in time to make the connection, yet not so early as to make the passengers wait for a long time at the bus stop AVL makes this possible by knowing the locations of the two vehicles at any moment. If the system detects that the bus is likely to arrive at a connection stop ahead of schedule (before the paratransit vehicle arrives), then a message can be sent to the bus driver's terminal requesting a "slow-down." Likewise, if the paratransit vehicle is experiencing significant delays, the system can inform the driver of the bus that is to make the connection not to expect that group of passengers, and inform the driver of the next bus to pick them up.

Finally, AVL adds a measure of safety through its ability to automatically notify the appropriate agency of the vehicle's location as soon as it detects an emergency condition (e g., a breakdown, accident, violent behavior by a passenger, etc.).

AVL Technologies

The four principle AVL technologies that have been used to date are fixed beacons, radio navigation location systems, global positioning systems, and on-board navigation and route-guidance systems.

1. Fixed Beacons

This type of system requires a transmitter/receiver aboard each vehicle, and a series of signpost devices that are mounted on utility poles about 11 to 16 feet above street level [6]. The signpost devices constantly emit a low-powered signal (beacon) along with a unique identification, both of which can be detected by the vehicle's transmitter/receiver. The vehicle, in turn, relays the signpost's identification to a central station, so that the dispatcher knows which signpost has been passed at which time (see Figure 2) In addition, the distance traveled between signposts can be approximated because the signpost devices also monitor electric pulses emitted by the vehicle's odometer. A variation on the beacon method has the transmitter/receiver attached to the vehicle operating in "transmit" mode, so that the vehicle's signal is detected by the signpost device, which relays its identification, along with the time the vehicle passed, to the central dispatch station

The main advantages of this approach to AVL are (1) low cost, and (2) considerable experience. The main disadvantage, as far as paratransit is concerned, is that it precludes tracking vehicles along routes other than fixed, pre-determined ones The technology is therefore more appropriate for fixed-route buses than for demand-responsive, route-deviating, or flexibly routed paratransit. However, most AVL systems currently installed in U.S. and Canadian metropolitan areas (including Toronto, Tampa, San Antonio, and Norfolk) are of the fixed beacon type.

2. *Radio Navigation Location Systems*

Land-based radio navigation location systems such as Loran-C track vehicles by emitting low-frequency radio waves from a series of stations [6]. Each station transmits pulses of timed signals, and a receiver mounted on the vehicle can calculate distance traveled by comparing the times it receives different signals from the different origins In this way, vehicles can be tracked to within an accuracy of 500 meters (see Figure 3) Baltimore uses this technology to successfully track 50 of its buses within the city's 650-square-mile operations area

The main advantage this technology has over fixed beacon systems for paratransit services is its flexibility — any paratransit vehicle equipped with the proper receiver can be tracked no matter what its route, assuming the signals can be read throughout the service area The main disadvantage is that numerous sources cause signal interference, including power lines and substations, tall buildings, and even fluorescent lights within the vehicles

3. *Global Positioning Systems (GPS)*

In this type of system, a GPS receiver mounted on the vehicle locks onto at least three satellites in order to determine its position [7]. Twenty-one satellites owned and operated by the Department of Defense are available for this purpose. Each of these satellites moves at approximately 3,500 meters per second and constantly transmits two types of data. The first type of data is the instanteous position of the satellite; this position data consists of 1,500 bits transmitted at a rate of 50 bits per second. The second type of data is called "range data"; it is used to correct for the fact that the satellite will have moved from its transmitted position (the first data type) by the time that position is received. The GPS receiver mounted

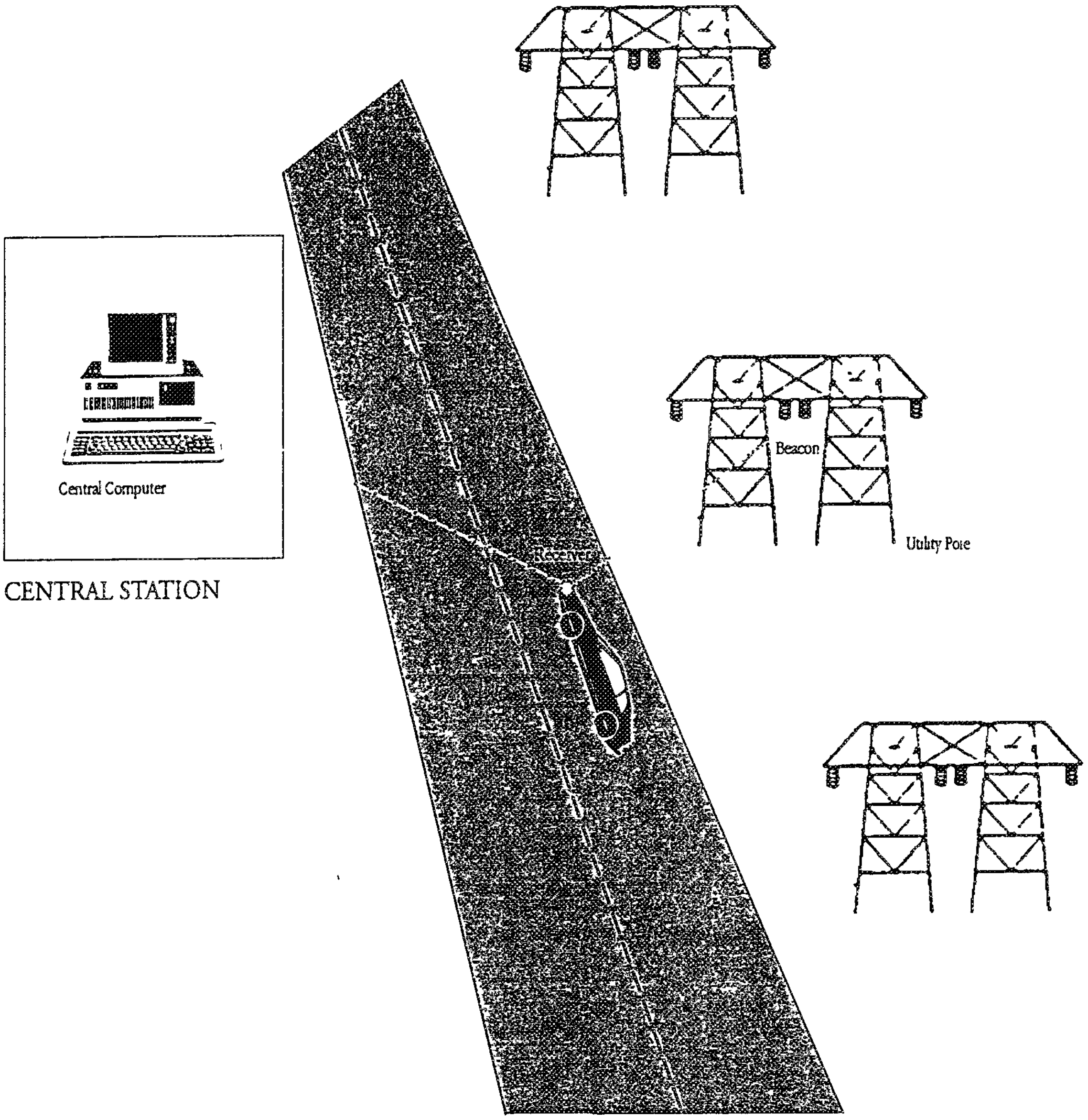

Figure 2. Automatic Vehicle Location: Fixed Beacon System

on the vehicle receives the position and range information from each of the three satellites, then uses mathematical and statistical techniques to calculate its own location, along with the maximum error in that location. The location is then communicated to a central dispatching station, much as in the case of fixed beacon and radio navigation systems, which can display the location on a map. Figure 4 shows the components of a GPS system.

The location of moving vehicles can be established to an accuracy of within 60 feet. Tests in Dallas have established accuracy to within 14 feet. GPS offers maximum flexibility with a minimum of interference and other problems that affect fixed beacon and radio navigation location systems. (It should

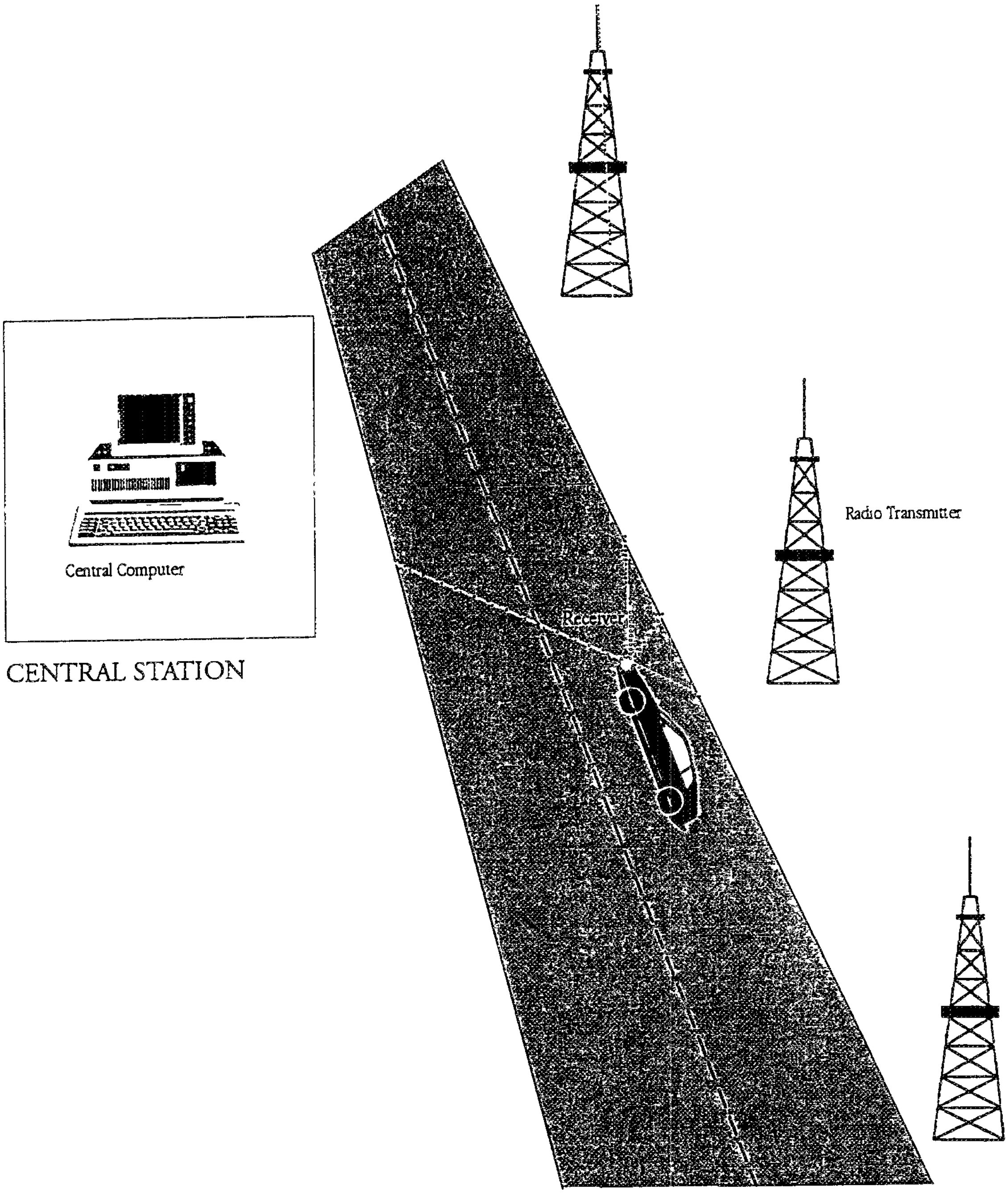

Figure 3. Automatic Vehicle Location: Radio Navigation Location System

be mentioned, however, that satellite signals are not free from distortion due to tall buildings and urban foliage. GPS is therefore supplemented in affected areas by other techniques such as "dead reckoning".) For this reason, most AVL pilot test projects in the U.S. (including Des Moines, Denver, Milwaukee,

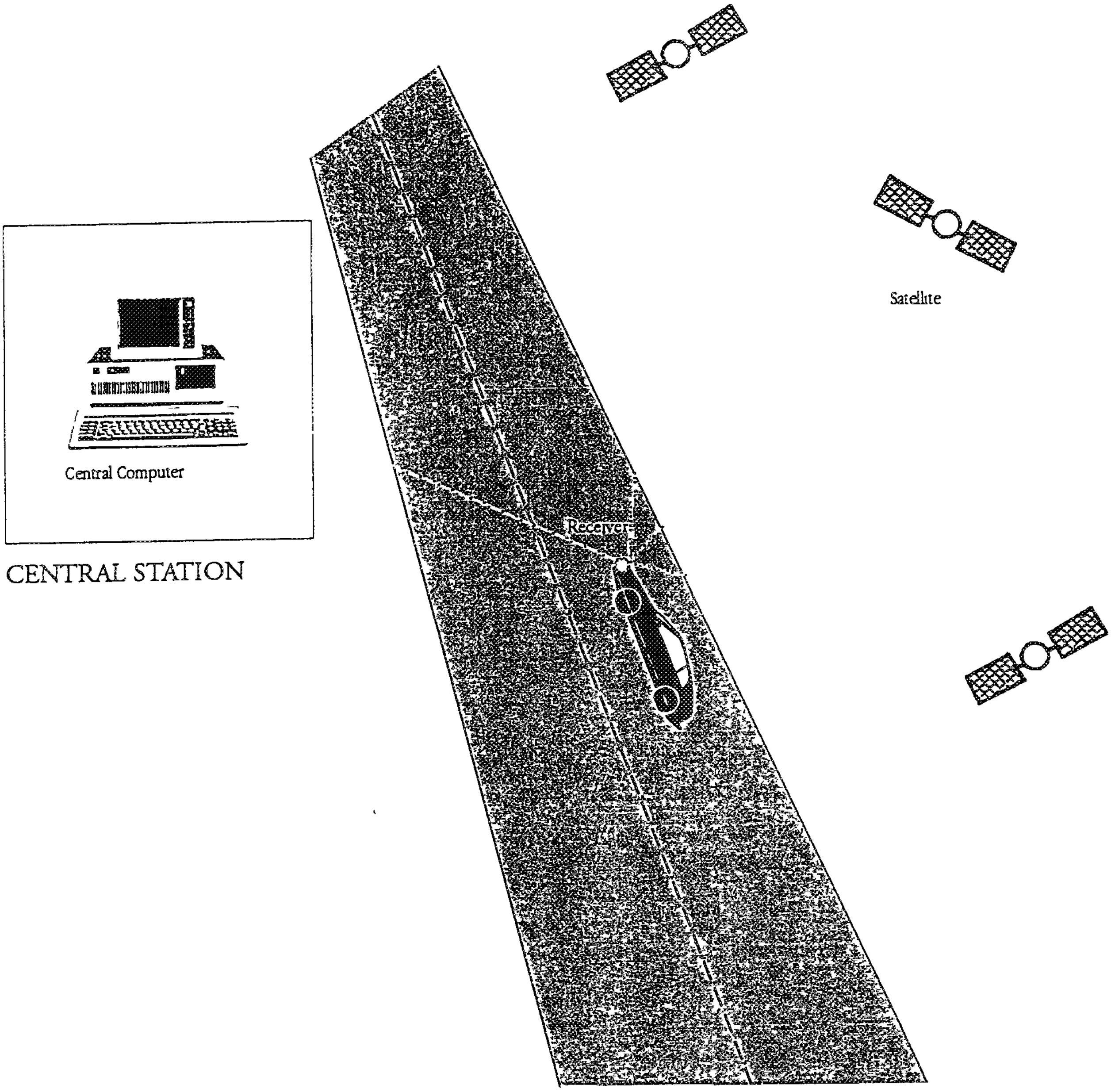

Figure 4. Automatic Vehicle Location: Global Positioning System

Dallas, Chicago, Minneapolis, Baltimore, Tulsa, and Tampa) are for GPS systems. The subsequent discussion of AVL technologies will therefore focus on GPS.

Requirements for GPS

To be useful for paratransit operations, a GPS must be able to:

- Determine a vehicle's position to an acceptable accuracy
- Communicate that position to a central dispatcher in real-time
- Store that position so that it can be used for display

Accuracy of Position

What constitutes "acceptable accuracy" depends on the situation. For timed transfers between two vehicles (such as an ADA van and a public bus service), the timing constraints may be so narrow that accuracies of less than 100 feet may be necessary. For determining the paratransit vehicle that can most quickly respond to a real-time service request, the accuracy demands can perhaps be relaxed — either one vehicle is by far the closest to the origin of the requestor, or else it is likely to make little difference which of several vehicles services the request. The high accuracy and robustness of GPS makes it adaptable to a wide variety of situations in which paratransit vehicles are deployed.

Communication to Central Dispatcher

The locational information obtained by a vehicle's GPS receiver can be transmitted to a central dispatcher once per second. If every currently operating vehicle transmitted its location at this rate, the central dispatching computer would be overwhelmed with largely useless data, as there is rarely a need to track any one vehicle at this rate The central dispatching computer controls the rate at which positional information is received from each vehicle through a technique known as polling. With this technique, the central dispatcher determines how frequently to sample the vehicles. For example, if there are 10 vehicles currently on the road and the sampling rate is once per minute, then each of the 10 vehicles will be sequentially "polled" at 6-second intervals Thus, vehicle 1 transmits its positional information at t seconds, vehicle 2 at t+6 seconds, vehicle 3 at t+12 seconds, etc. A key advantage of being able to control the sampling rate is that the dispatcher can more effectively focus on "exceptions" such as late arrivals and breakdowns. For example, if a vehicle has not changed position between two 1-minute samples, and the vehicle is not at a signalized intersection, then the dispatcher can increase the sampling rate to 1 second to determine as quickly as possible if there is a problem with the vehicle

Storage of Positional Data

In order for positional data to be useful to a dispatcher, it must be displayed in a format that allows the dispatcher to make the best decision possible. The position of the vehicle must therefore be correlated with a digital map display (e.g., based on U.S. Census Tiger files or data files from private firms such as ETAK). In addition, the dispatcher needs to be able to zoom in and out of the display and control the level of detail shown. For fixed route bus service, the names of all streets in the displayed service area are probably not necessary. For demand-responsive, flexibly-routed paratransit services, such detailed information may be necessary, as many alternate routes are possible for servicing a given request.

3. On-Board Navigation and Route Guidance Systems

A variation on the GPS approach to vehicle tracking is demonstrated by the ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) project currently being implemented in the Chicago area [5] Each of the 5,000 participating vehicles is equipped with a Mobile Navigation ssistant (MNA), a device containing an on-board navigation computer, a GPS receiver, a digital road map stored on CD-ROM, and a transmitter/receiver for communicating with a Traffic Information Center (TIC) Each vehicle acts as a probe of the traffic conditions in which it is currently embedded, by continuously sending data on its position (from GPS) and speed (from the time taken to traverse loop detectors) over a radio frequency network to the TIC. The TIC, in turn, is constantly creating a composite summary of the current regional traffic situation through the information it receives from the probe vehicles. This composite summary is then broadcast to all the probe vehicles, so that each vehicle has the same view of the current regional traffic situation. The on-board computer then combines this real-time view with road information from the CD ROM and with the known destination in order to continuously update the best route to take. The overall architecture of an ADVANCE-type system is shown in Figure 5 [5].

The difference between this system and the AVL systems described previously is that the "intelligence" resides in the vehicle itself, not in the TIC. Thus, each vehicle is capable of independently calculating the best route, as opposed to having a central computer perform route optimization for all vehicles at the TIC and then transmit each particular route to each targeted vehicle. The theory is that the high cost of the on-board computers, CD-ROM, and transmitter/receivers is more than offset by the savings in the communications infrastructure and the TIC.

With respect to paratransit, such a system allows vehicles to independently route themselves in order to pick up and drop off passengers in the most efficient manner possible. This allows flexible routing for the entire fleet of vehicles, thus opening up the general public paratransit market beyond the high-traffic corridors it has traditionally served. It also has the effect of largely eliminating the need for human dispatching, as the real-time scheduling is performed on board the vehicle itself.

Other Potential Forms of Vehicle Tracking

It has been suggested that the AVL technologies described above are "overkill" — that much simpler means can be used to provide vehicle position information to a central dispatching station. In particular, the use of two-way pagers has been proposed as a means by which the driver can communicate the current position of the vehicle through a few simple menu selections on a paging device. For example, an ADA van driver can start the day with the van's pager pre-programmed to that day's schedule. The driver can simply make a menu selection on the pager from the series of pre-programmed stops when a particular stop is reached. If the vehicle will be late arriving at a stop, the driver can transmit the time or distance from the last stop through the paging device. Such a system would be much cheaper than using beacons, radio-based navigation stations, or GPS satellites.

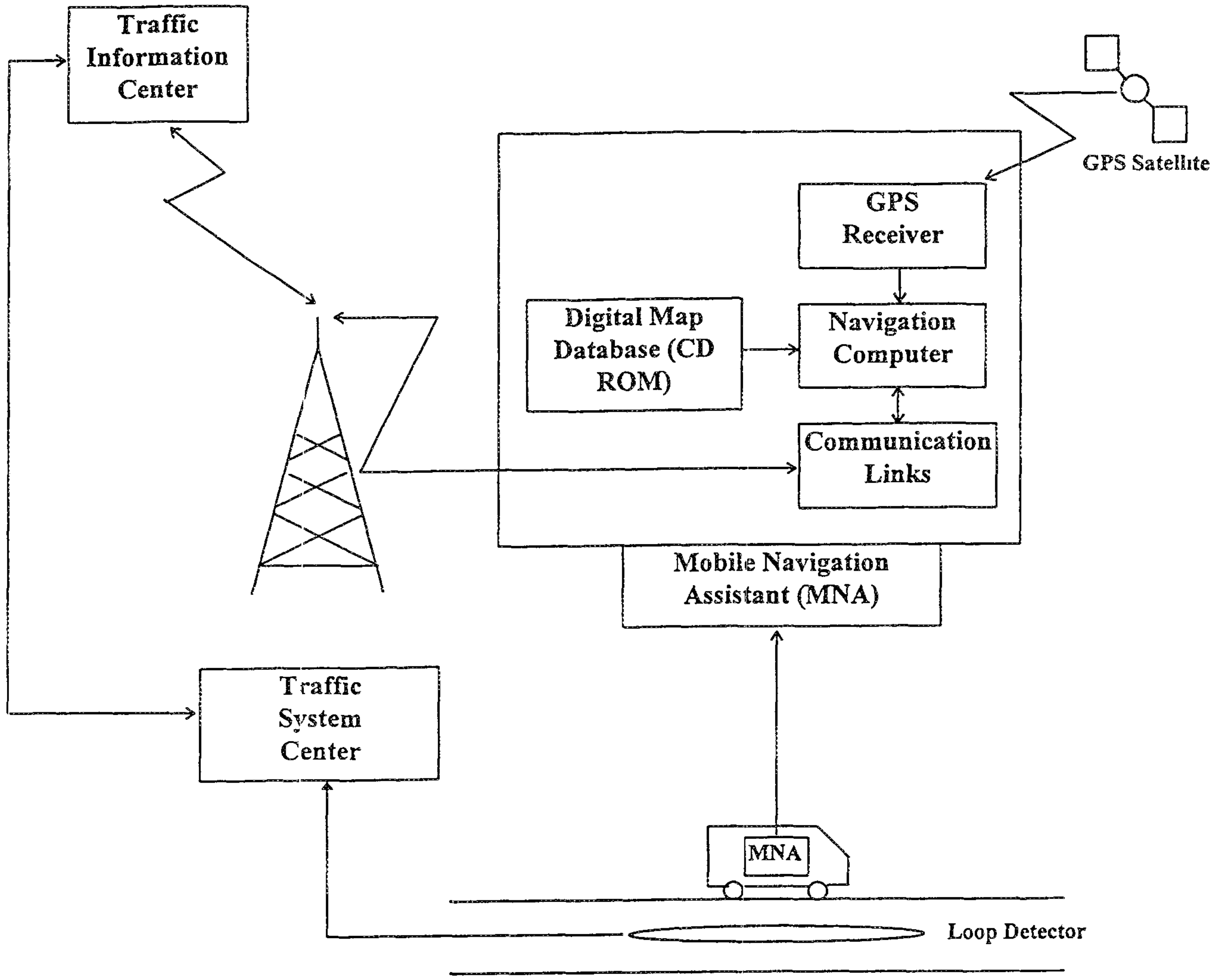

Figure 5. Automatic Vehicle Location: On-Board Navigation System

B. Automated Scheduling

Automated scheduling first became widely used in the taxi industry [9]. Up through the 1970s, most taxi companies had sufficiently small request volumes and fleet sizes, and requests could be matched to vehicles through a human dispatcher who took telephone requests and broadcast those requests to the fleet. A wave of consolidations in the taxi industry during the 1980s made both request volumes and fleet sizes too large to handle manually. Early automated scheduling systems amounted to using computers to assist in the record-keeping associated with taking trip request information and storing it in a convenient manner so that the human dispatcher could decide which taxicabs should get which calls. In recent years, however, these early efforts have been supplanted by more sophisticated systems that automatically make the dispatch decisions and communicate the information for a given trip to the selected taxicab. Figure 6 sketches the components of such a system [9].

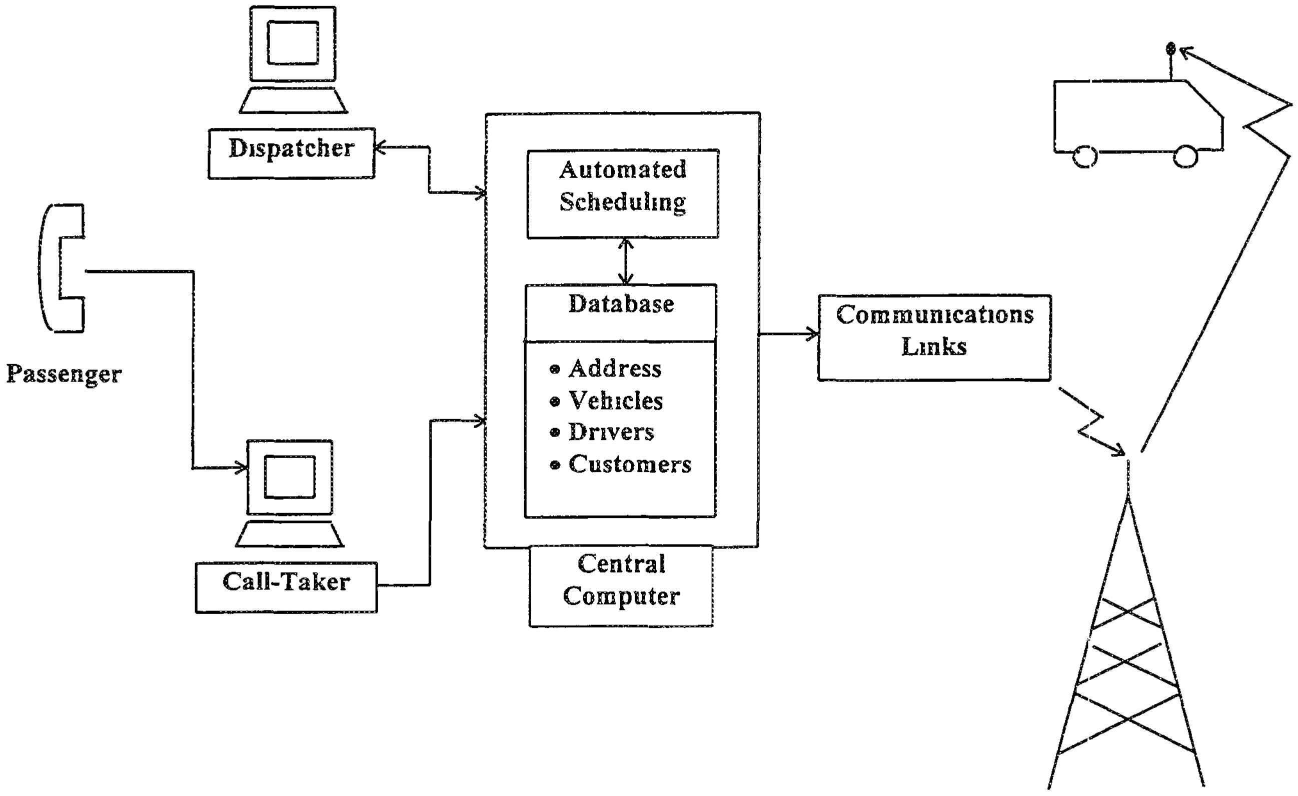

Figure 6. Computerized Scheduling: A Taxicab System

The requirements for automatically making the best match between passenger request and vehicle are more stringent for paratransit than for taxicabs. Taxicab services generally take one person or one group at a time, and have no special equipment requirements (e.g., wheelchair lifts) or time constraints (e.g., patients with doctor's appointments). Payment is generally cash (as opposed to, say, billing an agency in the case of ADA-qualified passengers), which simplifies record-keeping. Traditional paratransit services such as dial-a-ride, shared ride taxis, and airport/employee shuttles require a more complex scheduling algorithm since multiple trips must be scheduled in a logical sequence for specific vehicles, but in such a way as to satisfy certain overall goals (e.g., minimizing total cost or total passenger delay). A paratransit service having a full range of flexibility (e.g., real-time demand responsive, flexible routing, many-to-many matching of origins and destinations, connections to long-haul services, and ability to respond to cancellations and other schedule changes) has even more complex requirements for its scheduling algorithm. Apart from the scheduling itself, a large automated scheduling system is likely to include functions such as reservations and billing.

Once the trip request has been entered, the computer's scheduling software figures out which paratransit vehicle should be route-deviated (if necessary) in order to service the call. The computer's decision on the next route is then transmitted to the appropriate vehicle.

An automated computer scheduling system operates as follows [10]. Trip requests are made by telephone to a dispatching center. Two people are involved in handling the trip request at the dispatching center: the call-taker and the dispatcher (these two roles can be taken by the same person if the demand for service is not too great) The call-taker receives the call and enters information about the request into the computer. For ADA services, it is likely that a given caller is already in the computer's database, with information such as address, physical condition, name of doctor, and any particular instructions for that person.

The scheduling algorithm then optimizes the route based on all current trip requests for the day, including the one just entered. The actual route generated by the scheduling algorithm depends on the criteria used for optimization. For example, a route that gives priority to equity criteria (e.g , no passenger has a delay of 15 minutes more than any other passenger) will likely be different than a route that gives priority to efficiency criteria (e.g., minimum total delay or minimum total cost) The routes also depend on constraints relating to the vehicle capacities (i e number of seats) and provision of special services on board the vehicles (e g., wheelchair lifts).

The route generated by the scheduling algorithm is then presented to the dispatcher for approval or modification. The dispatcher always has the ability to override the computer-generated route This override ability is necessary, since subjective criteria must often be taken into account when assigning passengers to vehicles. For example, certain combinations of passengers may want or not want to travel together The route generated by the scheduling algorithm is therefore seen as complementing and assisting, rather than replacing, the dispatcher's decisions.

Traditionally, a driver receives a schedule sheet listing all the pick-ups and drop-offs for the shift about to be started, along with the route to follow. However, with the combination of computerized scheduling and digital on-board displays, real-time trip requests can be inserted into the schedule, and the resulting modified route can be broadcast to the driver over the display. The driver can use the display to see the location of the next pick-up or drop-off, as well as the route to follow. The driver therefore does not need to be concerned about changes to a fixed schedule; the current on-board information is always accurate. Figure 7 shows the components of a computerized paratransit system [9].

C. Database Technologies

Databases for advanced paratransit contain both static and dynamic data. Static data includes "permanent" data about roads (their names, number of lanes, directionality, configuration in the network, etc.),

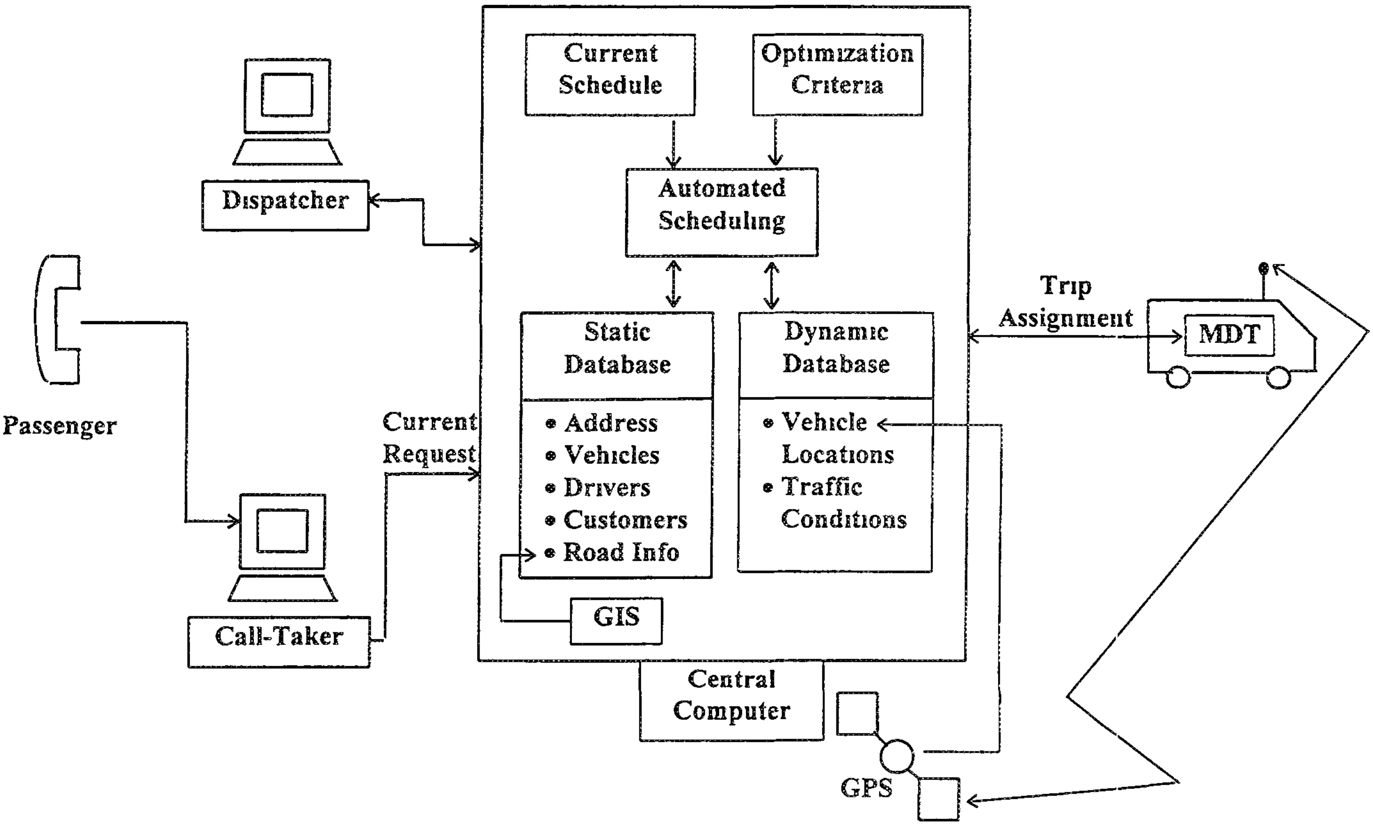

Figure 7. Computerized Scheduling: A Paratransit System

vehicles (their models, capacities, equipment, top speeds, etc.), passengers (characteristics of "regular" passengers such as name, address, typical destinations, special needs, ADA eligibility, billing agency, etc.), and drivers (names, years of experience, etc.). Dynamic data includes "temporary" data about roads (e.g , current conditions such as congestion or blockages due to construction), vehicles (their current locations, the locations of the next passengers to be picked up/dropped off, any problems, etc.), passengers (the current schedule for pickups/dropoffs, etc.), and drivers (e.g., which driver is currently driving which vehicle). The database is typically implemented as a combination of a GIS (e.g., ArcInfo, Map Info) which has static data about roads, and a commercial relational database (e.g., dBase, Oracle) that stores the rest of the data.

Two types of data of special importance to advanced technology paratransit systems are static road data and dynamic traffic data.

Static Road Data

The data that describe the roads in the operational area of the vehicles are of two types: locations of the roads, and attributes that describe the roads. The roads themselves are represented as a series of nodes and links. Nodes are located at positions that define the geometry of the road system (e.g., intersections, changes in direction, road end points). The physical location of each node is defined by its geographic coordinates (e.g., latitude and longitude). Each consecutive pair of nodes is connected by a link The road attributes describe each node and link of the road network. Examples of these attributes include road name, address range, number of lanes, direction of lanes, speed limit by time of day and by type of vehicle, distance along a link, average speed along a link by time of day, average traversal time along a link by time of day and by type of vehicle, type of signalization at the node, turn restrictions by time of day, height restrictions, etc.

The two most popular sources of data for describing roads and their attributes are digital map files produced by the U.S. Census Bureau (e.g , Tiger files) and Quadrangle maps produced by the U S Geological Survey.

Dynamic Traffic Data

Dynamic data are the constantly changing pieces of information relevant to the process of assigning the most appropriate vehicle to service a trip. One type of dynamic data that is frequently incorporated into smart paratransit applications is real-time traffic data. Data about current traffic conditions throughout a region's road network helps the scheduling software to avoid heavily congested routes and thereby minimize total passenger delay. This data comes from a number of sources, including (1) loop detectors installed at regular intervals along freeways, (2) "probe" vehicles equipped with transmitter/receivers that broadcast their position and time at various intervals, enabling a central computer to track their changing velocities, and (3) traditional sources such as radio reports from helicopters. Another important type of dynamic data is the location of all vehicles in a paratransit or combined paratransit/bus fleet at a given time As described above, a variety of AVL technologies serve to locate the vehicles and then simultaneously transmit these locations to the central computer. The central computer's database organizes this data in such a way that it can be queried in order to determine the vehicle that should be dispatched to service the latest real-time request. The query combines current vehicle location information with static data about trips that have already been scheduled for the vehicles; this latter type of data tells where each vehicle should be at any given instant, thus giving the dispatcher a means of determining the extent to which any vehicle is off schedule.

D. User Interfaces

The term "user interfaces" refers to the manner in which data is input to and output from the integrated system for each person who plays a role in the system: the passenger, the call-taker, the dispatcher, and the driver.

The passenger interacts with the system by initiating a request for service. This request can take a number of different forms. A subscription request (i.e., a series of trips at regular times scheduled relatively far into the future, such as weekly doctor appointments or daily commute trips to a rail station) can be made by mail or telephone. A disadvantage of making subscription requests by mail is that there is no immediate confirmation of the request for the passenger On the other hand, a complex set of subscription trip requests may be difficult to convey over the telephone. A request for a single trip, whether made in advance or for immediate service, is also typically made over the telephone. In theory, the request can be made through a number of different "videotex" modes, such as computer terminals (possibly via the Internet) or checkpoint kiosk (the Ruf-Bus system described below is an example). Another type of interface that is potentially available to the passenger is computer displays of real-time traffic information. Such information would be useful for determining the relative duration of car vs. transit trips, and of transit trips on different modes It might even lead to a decision to postpone a trip if congestion was particularly severe at a given moment. Appendix I shows the output of a computer display of actual conditions on the Seattle freeway system.

The call-taker interacts with the system by receiving the passenger request and entering that request into a computer. The passenger request is typically received via a phone call, though other means (mail, Internet, kiosk) are also possible Telephone has the advantage that a human provides immediate confirmation of the request. The data for the request is then typed into a database form on the screen. If the passenger has already "registered" with the system (i.e., an ADA client), then information about this passenger is automatically brought up onto the screen. The system verifies that all information necessary to process the trip has been entered, or else prompts the call-taker to supply the missing information.

The dispatcher interacts with the system by looking at three kinds of display outputs (1) a digital road map of the service area overlaid with the current location of all vehicles in service, (2) a text display of the passenger request for which the dispatcher must make a vehicle assignment, and (3) a text display of the recommended vehicle assignment and route update for that vehicle produced by the scheduling software. The dispatcher then must input the passenger address and route-updated information for the selected vehicle into the system in such a way that it is sent to the appropriate vehicle. The entering of this data may require nothing more than confirmation that the dispatcher accepts the scheduling software's decision, or it may require typing the data into a database form.

The driver of the selected vehicle interacts with the system by receiving the new passenger address and updated route information. This data can be received as a (1) printout, (2) display on a mobile data terminal (MDT), (3) display on a paging device, or (4) a direct voice communication from the dispatcher. MDTs (and potentially pagers) have the advantage of allowing the driver to "scroll forwards" to see the overall route that is currently planned for the vehicle. Another type of driver interaction with the system is the conveyance of information about the location of the vehicle or about exceptional conditions (such as breakdowns or schedule deviations). Although most or all of this location and exception information reporting could be automated through the AVL technologies described above, they could also be transmitted directly by the driver through a MDT or two-way beeper (see II.A, AVL).

One other type of user interface should be mentioned: the "smart card" for paying fares. A smart-card reader would read the identification information on the card, wherever the card might be on the person of the passenger, enabling a passenger to board without having to do anything. The fact that a given passenger boarded or alighted would automatically be transmitted back to the central computer, which could check the passenger boardings and alightings against any scheduled trips.

III. APPLICATION OF THE NEW TECHNOLOGIES TO PARATRANSIT SERVICES

How have the technologies described in Section II matched up with the paratransit characteristics listed in Section I to provide or improve actual service? Three types of paratransit services can be identified that either owe their existence to these technologies or are substantially enhanced by them: parataxi, special services paratransit, and general public paratransit. Parataxi has yet to be implemented, although plans to do so are underway. Special services paratransit will be illustrated with the case of the Winston-Salem Mobility Manager, which to date is the case most often cited as the most advanced application of paratransit technologies for serving a local ADA population. General public paratransit will be illustrated by the case of the Ruf-Bus/FOCCS system implemented in Germany starting in the mid-1980s; this system has accumulated by far the most experience of any technology-driven paratransit application

To date, there has been no extensive test of AVL technologies for either specialized or general public paratransit services. The two most extensively documented examples of the other three technologies (automated scheduling, database, and user interface) are the German Ruf-Bus/FOCCS system and the Winston-Salem Mobility Manager. The German system is unique because it was in operation for a number of years and because it served the general public in its service corridor. The Winston-Salem system, like most smart paratransit systems, serves an ADA clientele, however, it seems to have the most thoroughly laid-out analysis of costs and benefits of any smart paratransit project. Although no parataxi project has yet been implemented, a test of the concept is being prepared for Ontario, California.

A. Winston-Salem Mobility Manager

The Winston-Salem Mobility Management system is repeatedly cited as the most advanced project of its kind in terms of the duration of its operation, the amount of data collected, and the extent of the analysis of costs and benefits [11]. Like most pilot projects which use high technology to improve the efficiency and effectiveness of paratransit operations, this system serves ADA clients. The agency responsible for this paratransit service, called TransAID, is the Winston-Salem Transit Authority (WSTA), which contracts out the day-to-day operations to a private company (ATC/Vancom). TransAID carried about 170,000 passengers in 1993 in Winston-Salem and the surrounding area of Forsyth County.

The project has recently completed the first of two phases. The first phase involves the use of computer-aided dispatch and scheduling (CADS) to test the efficiency and effectiveness of the TransAID service. The second phase will build upon the first phase by incorporating AVL, MDTs, and smart-card readers for all vehicles. The goals for both phases include the following.

- Improve the quality, timeliness, and availability of customer information
- Increase the convenience of fare payments within and between modes
- Increase service reliability.
- Minimize passenger travel and wait times.
- Improve schedule adherence and incident response.
- Improve the timeliness and accuracy of operating data for service planning and scheduling.
- Provide integrated information management systems and develop improved management practices.
- Facilitate the ability to provide discounted fares to special user groups
- Improve the mobility of users with ambulatory disabilities.

All of these goals seem to apply to Phase I, for which the client population is limited to those who are ADA-certified. In particular, a major goal of Phase I is to improve the ability of the system to handle on-demand requests for service. Phase II is currently in progress, so the subsequent discussion refers exclusively to Phase I

The technologies deployed for the purpose of improving service were installed in two parts. First, a computerized scheduling system called PASS was implemented to help automate dispatching, reporting, and billing. This system was tested on 17 TransAID vehicles starting in August 1994, and evaluation of the performance of this system (by WSTA and North Carolina State University) took place during the six months between September 1994 and February 1995. Second, three of these vehicles were equipped with automatic vehicle location (AVL) transmitters, mobile data terminals (MDTs), and smart card readers Evaluation of the performance of these three vehicles is still in progress, so the subsequent discussion refers to the evaluation of the computerized scheduling system.

There are five roles that people play in the operation of the Winston-Salem CADS: the client who requests a ride, the receptionist, the dispatcher, the scheduler, and the vehicle driver. There are two types of scheduling that involve these players. First, a "skeleton" schedule is created by the scheduler using PASS. This skeleton consists of regular trip requests (e.g , Mrs. Smith has a doctor's appointment every Thursday at 3). Second, on-demand calls alter the skeleton. When a client makes an on-demand trip request over the phone, the receptionist takes the call and enters the information into PASS. The dispatcher then uses the output of PASS to make a decision about the most appropriate vehicle to handle the request. The receptionist then informs the client of the expected pick-up time, and the dispatcher informs the driver of the schedule modification. PASS takes into account all constraints (e.g., current scheduling commitments, current and projected number of riders, availability of special equipment such as wheelchair lifts, etc.), then runs an optimization algorithm to select a vehicle. The dispatcher is free to assign a vehicle to the ride other than the one chosen by PASS. This happens frequently as the dispatcher often knows the personal circumstances of the clients and makes a decision based on human factors not considered by PASS (e.g., grouping together kidney dialysis patients). The dispatcher then directly informs the driver of the selected vehicle of the schedule change. PASS automatically handles all billing and data collection requirements generated by the trip request. The same sequence of events happens in the case of a cancellation.

The results of the benefits evaluation of this CADS are summarized in Table 2 below (reproduced from [11], p. 4).

Performance Measure	Pre-CADS	Post-CADS	Change
Operating Expense	$346,578	$399,475	+15.2%
Passenger Trips	61,185	71,910	+17.5%
Vehicle Miles	167,040	208,928	+25.1%
Vehicle Hours	12,431	16,406	+32.0%
Operating Expense/Passenger Trip	$5.78	$5.64	-2.4%
Operating Expense/Vehicle Mile	$2.11	$1.93	-8.5%
Operating Expense/Vehicle Hour	$27.03	$24.70	-8.6%
Vehicle Miles/Passenger Trip	2.79	2.94	+5.4%
Vehicle Hours/Passenger Trip	0.21	0.23	+9.5%

Table 2. Evaluation of Performance Measures for Winston-Salem CADS System

The following results are especially noteworthy.

- The number of passenger trips during the six-month test period increased 17.5 percent over the same six-month period one year previously. This represents an average of almost 12,000 trips per month
- Based on a conservative projection of 10,000 trips per month, and distributing the $100,000 capital cost of the CADS system over 5 years, the cost per passenger trip attributable to the CADS system is about 20 cents This is about 3.5 percent of the operating cost per passenger trip of $5.64.
- Total operating costs increased 15 percent between the two six-month periods This is due mainly to the increase in service; the client base doubled from about 1,000 to 2,000 as the service area expanded and two additional dispatchers were hired
- Operating expense per vehicle mile dropped by 8.5 percent to $1.93. Operating expense per passenger trip dropped by 2.4 percent to $5.64 Operating expense per hour dropped by 8.6 percent to $24.70.
- Vehicle miles per passenger trip increased 5.4 percent to 2.94. Vehicle hours per passenger trip increased 9.5 percent to 0.23. These increases are attributed to the expanded service area, including some rural areas.
- During the six-month test period, about 10 percent of all requests were for same-day trips Prior to this period, almost all trips were booked at least 24 hours in advance
- Passenger wait time decreased by more than 50 percent

In addition, the CADS system seems to be well accepted by all the five types of players mentioned above, as well as by the WSTA management In particular, it cuts the amount of time required to process a call by more than half, and greatly facilitates insertion of same-day demand-response trips into the existing schedule.

As discussed more fully in Section V below, some caution should be taken in interpreting figures like those in Table 1. For example, efficiency criteria such as operating expense per passenger trip might have decreased even without CADS, perhaps because there were decreasing marginal costs per additional passenger trips in any case. Likewise, effectiveness measures such as total passenger trips, or cost measures such as total operating expenses, might have increased even without CADS due to the expansion of the service area. Thus, it is difficult to pinpoint the effect of CADS on these criteria However, it is indisputable that CADS has greatly facilitated the call-taking, scheduling, and dispatching functions, especially with respect to demand-response calls.

B. German Ruf-Bus/FOCCS Sytems

In 1977, a service called Ruf-Bus ("Call-A-Bus") was initiated in the city of Friedrichshafen, Germany, for the purpose of testing the concept of demand-responsive transportation service for the residents of this area. In particular, the system attempted to put into practice the following ideas, as stated in ([12], p.34):

- The term "buses" should include large buses, minibuses, and microbuses (i e., three- or four-passenger buses with no standing room, commonly known as taxis).
- Small, flexible-route buses could be more cost-effective in low-travel situations than big, fixed-route buses.
- To manage a fleet of buses efficiently, a central computer should know the location of each vehicle at all times.
- Each bus should be equipped with a computer terminal and a digital radio to permit regular data communications to and from the central computer
- The system should focus on checkpoint-to-checkpoint service rather than door-to-door service for the general public.

An overview of the Ruf-Bus system is presented in Figure 8 The user interacts with the system through checkpoint kiosks (telephone requests for on-demand service as well as subscription requests by mail are also allowed). To request an on-demand ride, the user undertakes the following steps at the kiosk:

- Enters the three-digit code number of the destination bus stop
- Enters the number of passengers.
- Inserts a DM 0.20 coin or a Ruf-Bus card.
- Waits for a display of the bus number and arrival time, then accepts or rejects the pick-up
- Removes the confirmation ticket that is printed if the pick-up is accepted.

If the user accepts the pick-up, then the trip information is sent to the central computer, which in turn updates the schedule for the selected vehicle and transmits the updated information to the computer terminal on the assigned bus. The schedule is stored on board the bus in such a way that at each checkpoint where a pick-up or drop-off occurs, the driver simply looks at the display to determine the next checkpoint to go to.

The Ruf-Bus was therefore a flexibly routed paratransit system that provided on-demand service between fixed checkpoints. The service was continously expanded in the Friedrichshafen area over the next four years. By 1981, ridership on the Ruf-Bus was 44,300 per month, an increase of 36 percent over

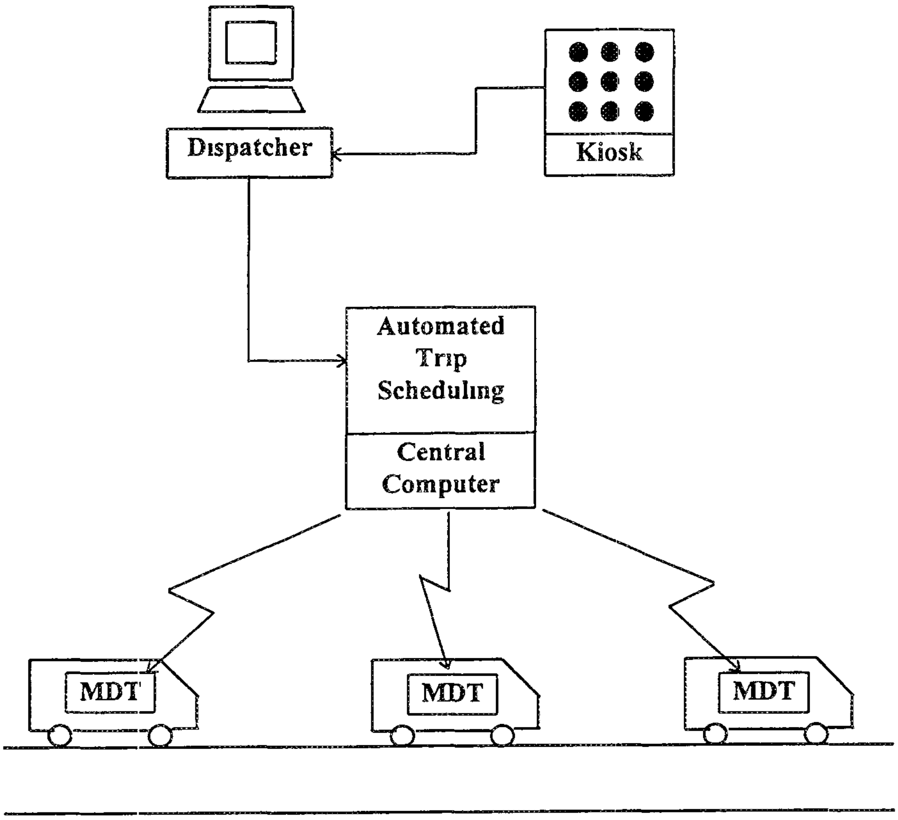

Figure 8. The Ruf-Bus System

the fixed route bus services it replaced However, the system operated at a financial loss, partly due to high operating costs and partly due to the relatively large number of monthly pass holders (who obtained discounted fares) among the population of Ruf-Bus users

In order to make the Ruf-Bus more cost-effective, it was integrated with fixed-route and route-deviation services. The new system was named FOCCS (Flexible Operations Command and Control System). Like Ruf-Bus, the FOCCS system used a mix of buses, vans, and taxis (again all referred to as "buses" in the discussion) equipped with data terminals (12). Unlike Ruf-Bus, the vehicles operated along fixed-route corridors between fixed checkpoints, with route deviations or flexible routing allowed depending on real-time demand. Thus, "a transit agency could operate the same vehicle in 1) fixed-route mode during the morning and afternoon peak commuting periods, 2) route deviation mode during the mid-day, and 3) demand-responsive mode during evening hours or on weekends or holidays" [12], p. 46).

The replacement of the pure demand-responsive services of Ruf-Bus with the multi-modal FOCCS reduced monthly ridership and monthly fare revenues slightly (in real terms). However, it also reduced monthly operating costs significantly (in real terms) between 1981 and 1987. Performance and cost data for Ruf-Bus and FOCCS are summarized in Table 3 below:

Year	Operation Mode	Vehicle Kms per Month	Number Passengers per Month	Monthly Cost (1993 DM)	Cost per Trip (1993 DM)
1977	Line Haul Bus	29,300	32,600	95,000	2 91
1981	Ruf-Bus	83,000	44,300	229,000	5 18
1987	FOCCS	47,200	37,800	130,000	3 44

Table 3. Performance and Cost Data for Ruf-Bus and FOCCS

The service characteristics for the two systems are summarized in Table 3.

	Ruf-Bus	FOCCS
Year	1981	1987
Service Area Size, sq. kms.	75	300
Service Area Population	36,000	100,000
Number of Checkpoints	90	180
Number of Call Boxes	16	13
Maximum Number of Vehicles	24	40
Average Number of Passengers per Day	44,300	5,000

Table 4. Service Characteristics of Ruf-Bus and FOCCS

The great increase in per trip costs of Ruf-Bus vs. line haul bus has been attributed to the increased operating costs of the Ruf-Bus system and to the capital costs of the kiosks. The cost increase per trip between line haul FOCCS is much less; in fact, the cost per additional passenger is DM 0.35, or 12 percent of the average cost per passenger of the line haul system. The massive decrease in the number of passengers in going from Ruf-Bus to FOCCS has been attributed to the following factors. 1) the marginal Ruf-Bus services were eliminated, 2) residents preferred the demand-responsive Ruf-Bus service to the line haul and multi-modal FOCCS services, and 3) there was a general decline during the 1980s of the transit-using proportion of the population in the Lake Constance area of Germany.

While FOCCS went through several other incarnations after 1987 (including attempts to install GPS receivers on board the vehicles), none of the Ruf-Bus or FOCCS systems ever broke even financially. They did prove, however, that substantial numbers of new passengers could be generated through demand-responsive, flexibly-routed paratransit service.

C. Parataxi

The Winston-Salem Mobility Manager is used for a client population that still primarily schedules trips through subscriptions or at least 24-hour advanced reservations. The German systems did induce substantial numbers of the general population to switch to transit, but lost ground to rising automobile use. Neither system solved the problem of providing transit service for the general public that approached the demand-responsive nature of the private automobile. Parataxi is a proposed technological attempt to address this problem.

The basic premise behind parataxi is that unused private automobile space can be filled by matching drivers with passengers. At first glance, this would seem to be a repeat of numerous failed attempts to get urban Americans to rideshare. Parataxi provides two unique approaches to overcoming this resistance towards shared rides: 1) it uses technology to minimize the delay in picking up the passenger, and 2) provides financial compensation to the driver for the service.

The theoretical justification for providing compensation comes from a survey conducted during the 1978-79 oil crisis by the Department of Energy. This survey asked drive-alone commuters two questions: 1) at what level of compensation would they be willing to serve as vanpool drivers, and 2) how much would they be willing to pay to be vanpool passengers. The results are summarized in Figure 9 below ([112], p. 77).

The "supply" curve in Figure 9 shows that 12 percent of those surveyed would be willing to serve as vanpool drivers at no compensation; thereafter, the proportion of willing drivers increases at the rate of about 1 percent per increase in fare of one cent per mile. The "demand" curve shows that 53 percent of those surveyed would be willing to be vanpool passengers if the service were provided for free, thereafter, the proportion of willing passengers decreases at the rate of about 1 percent per increase in fare of one cent per mile. The two curves intersect at a fare of about 20 cents per mile; at this fare, about 35 percent of those surveyed would serve as drivers, and about 35 percent as passengers This result indicates a substantial potential for ridesharing if financial compensation for drivers is priced right.

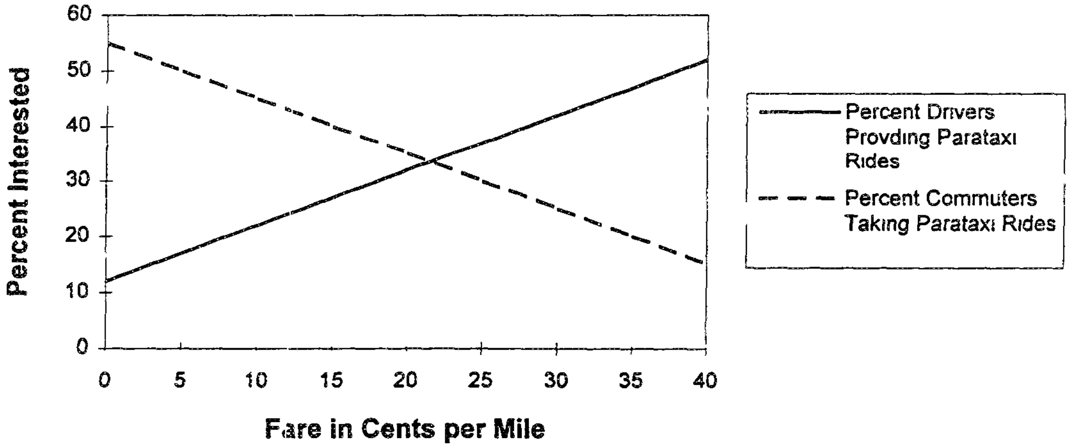

Figure 9. Interest in Parataxi Service by Fare

The ridesharing potential of parataxi would be even further enhanced if wait times for both drivers and passengers were minimized. Originally, a number of videotex, computer-based modes were proposed for performing ride matching (e.g., by placing real-time requests on the Internet) The current thinking, however, is that by far the cheapest and most direct way to match up drivers and passengers is through two-way paging devices linked to modems that transmit real-time requests to a central computer and receive the real-time "best match " The computer would have to have access to information on the entire road network of the service area, including distances, average velocities on links, and current congestion information In principle, the operation of such a system is simple. All drivers about to leave for a trip send a message to the central computer giving the trip origin, trip destination, and start time of trip All passengers desiring trips give their present location, trip destination, and time of request. If there is a critical mass of requests from both drivers and passengers, then the computer can easily make large numbers of matches. When a match is made, the computer creates and transmits a message to the paging devices of both driver and passenger

Whether the critical mass needed to support parataxi can be achieved depends on a number of factors· (1) some sort of certification of the drivers, (2) some sort of uniform and automated billing policy, so that both drivers and passengers always know the exact amount of payment, (3) some form of insurance, and (4) sufficiently low costs for the pager technology and for use of the ridematching service provided by the central computer

Two very recent developments indicate that the conditions for developing parataxi services may be here. First, the city of Ontario, California has approved a pilot parataxi project Second, a number of electronics firms are developing paging devices that may be suitable for parataxi operations

D. Other Applications of Technology to General Public Paratransit

Three other projects in the pre-evaluation stage are worth brief mention because their intended goals extend somewhat beyond those for the cases already described

Des Moines AVL System

The Des Moines, Iowa, Metropolitan Transit Authority is currently testing a GPS-based system to improve timed-transfers between 100 long-haul buses and 17 paratransit vehicles which offer complementary door-to-door service for ADA passengers [13]. The paratransit system is underutilized, accommodating about 1,000 trips per day, and is not amenable to demand-response requests. By providing the dispatcher with the location of the paratransit vehicles at all times, they hope to increase overall ridership, service demand-response requests more efficiently, and minimize delays through timed transfers between paratransit and bus modes. This project expands the boundaries of previous work by explicitly using AVL as a means of improving intermodal transfers

Potomac-Rappahanock Transportation Commission SaFIRES System

The SaFIRES (Smart Flexroute Integrated Real-Time Enhancement System) is currently being implemented in a part of Prince William County, Virginia, about 25 miles southwest of Washington,-

D C [14] This system is unique in three ways. First, it is the first system in the United States that attempts to integrate AVL, automated scheduling, database, and user interface technologies for general public transit. Second, it is a multi-modal system, incorporating new routes along with existing long-haul bus and train routes. Third, it makes flexible use of vehicles; a given vehicle can operate in a fixed-route, flexible-route, or demand-responsive mode, depending on real-time circumstances. Service has already begun along three major corridors, with flexible routing up to 0.75 mile along the corridors and feeder service to two rail stations

Alameda/Contra Costa County Integrated ADA Services

Another potentially interesting case is that of Alameda/Contra Costa County ADA services, because a single vendor (Comsis of Dallas) has been contracted to develop an automated scheduling application that replaces the 15 separate services that currently exist [15]. Although this vendor currently has no intention of using AVL, this application might prove interesting because it addresses an issue that no one in the literature seems to have addressed so far: how technology can be used to ramp up a paratransit operation to serve larger regions. This "ramp-up" issue is discussed at greater length in Section IV

IV. EVALUATION OF THE SMART PARATRANSIT TECHNOLOGIES

Based on the empirical evidence to date, the most that can be concluded is that "smart" technologies have the capability of providing substantial improvements in both efficiency and effectiveness for paratransit services that (1) serve clients whose trip needs can mostly be scheduled at least 24 hours in advance, or (2) provide flexibly-routed, demand-responsive service over relatively small geographical areas The Ruf-Bus/FOCCS experience leads to the reasonable hypothesis that such a system can be operated in a much more cost-effective manner with today's technology, but this hypothesis has yet to be tested There is no evidence that the "high-end" technologies, including AVL, communications networks, and Internet-based information systems, provide any net benefits to either specialized-service paratransit or to paratransit for the general public. Further, there is no evidence that any of the current projects that use these technologies are being conducted in such a way as to quantitatively assess the net benefits and compare these assessments with comparable projects that use other means to achieve similar ends.

While the number of projects that attempt to employ "smart" paratransit keeps increasing, there is very little empirical evidence to date as to the relative benefits provided by the technologies described in this chapter, compared to both the status quo and to non-high-tech alternatives. In fact, it is probably accurate to say that these projects were not designed with such evaluations in mind In particular, these projects

- are primarily technology-driven as opposed to demand-driven
- lack an evaluation framework, either internally or in comparison with other projects, as well as a set of standards by which to make such an evaluation
- do not address any of the issues concerned with ramping up the technologies to a scale at which they can induce large numbers of solo drivers to switch to transit.

evidence that the information gathering and distribution technologies it describes perform any better. Instead, the article goes on to give a list of numerous installations of these information systems, as if their existence were a self-sufficient justification.

As far as can be ascertained, there has been no research designed to rigorously test hypotheses such as "accessibility of real-time information on traffic conditions will result in significant reductions in congestion of Seattle's freeways " Without such hypothesis testing under controlled conditions, it is somewhat difficult to believe that this particular hypothesis is correct, for three reasons First, any real-time information is at best correct at the moment in which it is accessed, it becomes obsolete very quickly. In any given trip, "commitments" have to be made at certain times beyond the one in which the information was accessed. For example, a choice between Interstate 90 and state highway 520 as an east-west link for trips in the Seattle area is likely to be based on real-time information accessed many minutes before the choice actually must be made, by which time the traffic conditions may have completely changed. Second, even if the information did not become obsolete (traffic conditions remain the same between the time of information access and the time of commitment to a major link), it s likely to be impossible to predict which of the potential options is "best." Suppose that a trip is pre-planned from Mill Creek to Tukwila. Looking at the screenshot of real-time traffic conditions in Seattle (see Appendix I), it is unclear whether route 5 or route 405 should be taken, especially as distance information is not provided Third, even supposing that the real-time traffic data did not become obsolete and that the options were throroughly analyzed by the system and presented to the traveler (such is not a feature of any of these systems at this time), the fact is that there are very few options in reality. As far as mode is concerned, there simply are no transit options that approach the private car for most trips, especially suburb-to-suburb tips There is no evidence that travelers will switch from the private car to transit or some other ridesharing mode even with "perfect" information. Even for private car trips, there are very few options, especially for trips across a region. The San Francisco Bay Area, for example, has four bridges that traverse the Bay, spaced at intervals of 15-20 miles. It is highly unlikely that a traveler would choose to go to the "next" bridge, even knowing that traffic on the "nearest" bridge is backed up. Ironically, if travelers did make such choices, it is likely that the "next" bridge would soon become as congested as the "nearest" bridge, thereby defeating the purpose of the information system

B. Evaluation Standards for Smart Paratransit Projects

New technologies can be categorized by whether they create a new product or service that could not have otherwise existed, or in some way enhance or improve a service that already existed before the application of the technology. The applications of high technology to paratransit discussed in this chapter clearly belong to the second category (with the possible exception of parataxi). The purpose of all these technologies is to improve the provision of existing transportation services by some measure, whether it be minimizing passenger delays or operator costs, maximizing the number of passengers or car trips switched

Each of these considerations will be addressed in turn.

A. The Technology-Driven Nature of Smart Paratransit Projects

An extensive literature review of the theoretical and empirical literature on the potential application of IVHS technologies to paratransit or paratransit-like services is striking for the almost complete absence of any sort of demand modeling or analysis of social costs/benefits The questions posed are in the nature of "how is the technology implemented" rather than "to what extent can the technology reduce congestion, pollution, accidents, etc., and at what cost to drivers and passengers, service providers, taxpayers, etc." An example of this technology-driven approach is provided in a recent "Innovation Brief" from the Urban Mobility Corporation called "Applying ITS Technologies to Travel Demand Management" [16]. While not dealing with paratransit per se, this article does discuss some of the information-providing technologies referred to in Section III above

The article summarizes "regional traveler information systems" as follows·

> Perhaps the best known examples of the application of advanced communication technologies to pre-trip planning are the traveler information systems, which enable commuters to make informed travel decisions by providing accurate, up-to-the-minute information about traffic congestion and highway incidents. This information is often bundled with information about other travel options, such as transit routes and schedules, intermodal connections, parking availability and airline departures

The means by which this information is accessed are then summarized:

> This information can be conveyed to people in their homes, offices, transportation terminals and public places, using a variety of communication channels, ranging from cable television and computer modems to touchscreen kiosks and hand-held devices.

The article goes on to describe the case of Riderlink for the Seattle area, which communicates pre trip traveler information over the Internet to

> 15,000 employees of (Riderlink) member companies with information about a broad range of travel options: bus routes and schedules, ridesharing services and ridematching assistance, ferry schedules, biking information, as well as real-time freeway congestion updates and road construction reports . . . . the same information is also accessible at several touchscreen kiosks located at employer sites.

This article was cited at length because it clearly illustrates the tendency of high-tech transportation projects to have the implementation of the technology itself as the criterion for evalution. The implicit premise behind the Seattle example is that the provision and distribution of static information (e.g , transit schedules) and dynamic information (e.g., current levels of freeway congestion, demands for rides among fellow employees) will yield unspecified benefits (increased ridesharing, increased transit use, spreading out of congestion over the freeway system, etc.). However, there is no *a priori* reason to assume that the availability of this information will lead to any of these improvements to any significant degree. The "Innovation Briefs" article correctly states that regulatory command-and-control approaches to travel demand management such as Reg 15 have not worked, but gives no theoretical or empirical evidence that the information gathering and distribution technologies it describes perform any better. Instead, the article goes on to give a list of numerous installations of these information systems, as if their existence were a self-sufficient justification.

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The report states that

> . . .the various operational tests implemented under the APTS Program are meant to serve as learning tools and/or as models for other locales throughout the country. In order for these tests to have maximum effectiveness in their respective operational capacities, a consistent, carefully structured approach to project evaluation is desirable. This document has been prepared to provide a common framework and methodology for developing and then executing the evaluation of individual operational tests ([17], p. 1).

However, the document is essentially a listing and description of the project variables to be evaluated, without an actual methodology for assigning values to those variables. The following quote ([17], pp. 27-28) and Table 5 (excerpted from [17], pp. 31-33) give an idea of this descriptive, as opposed to methodological, approach to evaluation:

> Central to an operational test evaluation is the performance of the APTS system and its individual components. Questions surrounding the costs and functional characteristics (including reliability, usefulness, maintainability, adherence to specifications) should be addressed, and the relationship between these APTS characteristics and overall operational test objectives should be examined. Examples of such questions are.
>
> - What are the life cycle costs (including fixed and recurring expenses) of the APTS system and its individual components? Which are "start-up" costs associated with the newness of the system and might be avoided in future applications?
> - Is the automated vehicle location system easy to use and are vehicle positions determined quickly and accurately so that on-time scheduling can be carried out and passengers are provided with timely information?
> - Is the smart card system reliable, and does the system meet the required design specifications?

The way these questions are to be answered is indicated by the measures described in Table 5 Unfortunately, both the questions and the answers are largely rhetorical. For example, what is needed is a **methodology** for measuring life cycle costs; otherwise, there is no clear way to know which parts of the system get included in the accounting, and hence no standard for comparing life cycle costs between projects. Questions relating to the ease of use of AVL systems or reliability of smart cards beg the issues "ease of use and reliability," for what purpose? for whom?

The "answers" given in the table likewise fail to offer methodological guidelines. Transit system effectiveness is to be measured by criteria such as "time to answer telephone queries," "response time,"

	Sub-Objective				
Category of Measure	Improve Timeliness and Availability of Customer Information	Increase Convenience of Fare Payments	Improve Safety and Security	Reduce Passenger Travel Time	Enhance Opportunities for Customer
Transit System Efficiency			Changes in Vehicle Downtime		
Transit System Effectiveness	Time to Answer Telephone Inquiries	Changes in Transfer Wait Time, In-Vehicle Time, and No of Passengers Transferring	• Response Time • Accident Rate • Incident Rate • Perceptions of Drivers on Safety and Security	• Actual Travel Time Changes • On-Time Performance	No of Suggestions, Complaints re Improvements
Impacts		• Ease of Use, by Riders, of New Fare Payment Options • Ease of Use by Drivers and Other Staff			

Table 5. APTS Program Objectives and Examples of Corresponding Measures

and "number of suggestions, complaints re improvements." The interpretation of any of these criteria depends on the particular way the entire system is configured and operated. For example, if response time has decreased, then two interpretations are possible. (1) the system enables requests to be handled more rapidly, or (2) demand has dropped, so that it is possible to respond to each request more quickly on the average The first interpretation would indicate an improvement, all other things being equal, while the second interpretation would indicate a worsening of overall performance, since at the very least the system should not cause demand to drop! Likewise, if time to answer telephone queries has increased, it could mean that (1) the technology has actually worsened response time, or (2) so many new people are attracted to the system that the number of queries has saturated its ability to respond to queries Again, these two interpretations have opposite implications for the true net benefits of the system

Any methodology that allows comparisons between projects must deal with three considerations

1. Different projects have different goals
2. Each system has a unique blend of technologies
3. Each system functions in a unique institutional context
4. Feasibility of ramping up the project to a larger scale.

This fourth consideration is so important that a separate section is devoted to it below.

Comparisons Among Projects Having Different Goals

The way in which projects such as the Winston-Salem Mobility Manager (WSMM) and the Ruf-Bus/FOCCS system have been carried out makes it difficult to compare them. For example, the WSMM project has clearly shown that automated scheduling improves certain performance criteria, including pick-up delay times. However, it would be extremely difficult to compare this improvement in performance to similar improvements with similar systems, since the results depend on:

- the particular scheduling algorithm that is used by the software (these algorithms are proprietary, so by definition no comparison can be made between them)
- the way in which the scheduling software is used by the dispatcher (are its recommendations interpreted literally or with a great deal of flexibility)?
- the integration of the scheduling software with other components of the system (e.g., does the scheduling software provide a visual display of the location of the vehicles and the client?)
- the extent of interaction with the dispatcher (e.g., does it present the dispatcher with choices about different scheduling options?)
- the ability to set global parameters to specify particular service goals (e g , can the system be "set" so that it performs scheduling with the goal of "no passenger on-board times of greater than 30 minutes" vs. the goal of "have as few unused seats as possible"?)

The last item in the above list emphasizes the point that performance can be evaluated only in the context of the problem to be solved — it is unrealistic to develop and compare performance characteristics for AVL as a cost-reducing technology for private ADA operators vs. AVL as a means of minimizing passenger pick-up delays — two very different goals. It would be even more unrealistic to evaluate AVL among entirely different applications, e.g., ADA service with 24-hour advanced reservations vs general public, demand-responsive service.

Unbundling the Mix of Technologies

The general trend for projects that apply high technology to paratransit is towards **integration** of the four major components shown in Figure 1. Ideally, evaluation of an integrated system should assess the effects of the different components, both individually and together. For example, it might turn out that for an ADA semi-demand-responsive, route-deviating service, all things being equal,

- the automated scheduling program reduces average passenger trip time by three minutes,
- the GPS system without automated scheduling (the location of all vehicles is displayed on a screen and the dispatcher has to choose a vehicle) reduces average passenger trip time by two minutes,
- the automated scheduling program and the GPS system **together** reduce average passenger time by eight minutes.

Unfortunately, the ability to discern exactly which features of the integrated system, either individually or together, contribute to its performance is extremely difficult. For example, the above scenario indicates that GPS added on top of automated scheduling has a synergistic effect on overall system performance. However, suppose that the automated scheduling software could easily be "tweaked" to predict where all the vehicles in the fleet are at any moment, given the schedules they already have, and that these predictions may be almost as effective as the GPS system in minimizing average on-board passenger time This distinction of functionality vs. technology might be completely masked if an evaluation is not done correctly. None of the proposed integrated systems projects to date is being designed, tested, and evaluated in such a way as to bring out these distinctions.

The Institutional Context for Operating an Integrated System

One of the biggest problems in the transfer of any new technology is training users, not just in the mechanics of operating the technology, but in getting them to understand what it can and cannot do, how to use it most effectively, and how to improve its performance. If the agency that purchases an integrated system has cost-cutting as highest priority, then the system could be used as justification for firing a call-taker and having the dispatcher take over the call-taker duties as well. On the other hand, if service provision is the highest priority, the agency might not only keep both the call-taker and the dispatcher, but might hire someone full-time to maintain the system as well. As another example, one dispatcher might accept unquestioningly the vehicles and routes recommended by the system, while another dispatcher might look at these recommendations as simply "opinions" to be used in conjuction with his or her intuition and knowledge of the served client base As a final example, the agency "rules" may forbid a dispatcher to experiment with the software in order to optimize its performance, while another agency might encourage such experimentation. The performance of the system clearly depends on these institutional factors

C. Ramping Up the Prototype System

All of the projects described in this section are "prototypes " This fact raises the question of the extent to which the scale of these projects could or should be increased. Would the deployment of a ramped-up, integrated system cause significant numbers of solo commuters to switch to transit? Or are benefits limited to relatively small, primarily advanced-schedule and fixed-route ADA services? These questions cannot currently be answered, since theoretical research as well as empirical evidence is lacking Particular questions that need to be answered deal with·

Economies of scale. For which technologies and which markets do the marginal costs of an integrated system decrease (or increase?) The same set of GPS satellites might be used by a large number of ramped-up AVL applications, while automated scheduling software might need to be upgraded to much more expensive versions for each substantial increase in the customer base Do the integrated technologies increase or decrease the marginal cost of putting each additional vehicle into operation?

Measurement of Marginal Costs. As indicated above, an integrated system incorporates many components whose cost characteristics are quite different. How do these differences in marginal cost affect the design of the integrated system? What are the trade-offs, for example, between "a little more AVL" and "a little better scheduling algorithm"? There is also the standards issue — are marginal costs of the system and its components to be measured per passenger mile? per hour of service?

Technical Requirements for Ramping Up. This issue is related to economies of scale It could be that the technical requirements for extending a prototype project for optimally routing buses would simply mean adding MDTs and AVL transmitter/receivers to the new buses, or it might require extensive redesign of the whole system (e.g., because the transmissions from the new buses might saturate the original system).

System Reliability and Robustness. For example, a scheduling algorithm that successfully handles 10 vehicles might significantly degrade at 100 vehicles. Also, the processing time for handling real-time demand-responsive requests might go up exponentially in the number of such requests, especially if they occur with high frequency. Also, what happens if a component of a system fails? If the component is a transmitter/receiver on a vehicle, the system should be able to make routing choices as if the "silent" vehicle isn't there, and performance should not degrade much. However, the whole system might crash if a GPS satellite or scheduling computer goes down.

Personnel Requirements. The more complex the system, the greater its maintenance needs, hence the greater the number of personnel involved. Also, it is difficult to predict the extent to which automation reduces the need for other personnel. In theory, automated scheduling reduces the need for dispatchers; however, as the service area widens, there will undoubtedly also be an increasing number of exceptional or difficult cases that need personal attention by a dispatcher.

Ability of operators to finance projects. If transit agencies and/or private operators cannot afford to expand beyond the prototype stage, then the value of the prototype itself is questionable.

Potential for Increase in Regional Transit Demand. This issue concerns the amount of money people would be willing to pay, and how much time they would be willing to wait, if smart paratransit services were available.

Institutional Implications of Ramping Up. Would there be one integrated public system for each metropolitan area, or would there be competing systems? If there is a single integrated public system for a given area, does that system control all aspects of service? If there are competing systems, which aspects of service are competitive? The electric utility industry is facing a similar issue under the current environment of deregulation. The "unbundling" of services does not imply that all aspects of the electricity business are up for grabs; for example, private firms are largely free to generate electricity in Northern California, but transmission still occurs along Pacific Gas & Electric power lines.

V. CONCLUSIONS

1. Automated scheduling has resulted in improved all-around performance for systems that provide primarily fixed-route, advanced-scheduled ADA service (e.g., the Winston-Salem Mobility Manager), and in increased ridership, but not increased cost-effectiveness or cost-efficiency, for small general public paratransit service (e.g., the German Ruf-Bus/FOCCS systems).
2. There is otherwise little evidence by which to evaluate the advanced technologies discussed. In particular, there have been very few prototype transit systems for the general public.
3. The projects to date have been largely technology-driven, as opposed to market-driven.

4. There are no standard methodologies for performing and evaluating smart paratransit projects
5. There is little attempt to design prototype smart paratransit projects in such a way that the ability to ramp up such projects to a larger scale can be evaluated.

The recommendations for future research are briefly outlined as follows.

1. Perform a theoretical analysis of the potential market for paratransit Such an analysis would use regional travel data for a given metropolitan area, along with other empirical data (such as price- and time-elasticities and cross-elasticities of demand for different modes), to estimate this market for each of the various paratransit services outlined in Section I
2. Based on the theoretical analysis, identify particular source-destination pairs that would have high demand for paratransit services. Create a model of the demand for such services (e g., the demand might be great in relatively high-density, low-income areas). Start a few pilot projects without the technology , then use the results to theoretically determine whether the technologies would improve performance. In particular, how many commuters would switch from solo driving to paratransit, and at what price? What features are lacking in the "no-tech" service that would increase the numbers of these commuters and/or lower the price they are willing to pay? The starting point for the incorporation of any of the technologies should be the answers to these questions, not the features of the technologies per se
3. If the pilot projects indicate that a genuine demand exists for some of the niches described in Section I, then make a judgment as to the technologies that would prove most effective in each case. Incrementally add these technologies, making sure that a standard evaluation methodology has been agreed upon before embarking on the additions, including a theoretical analysis of the feasibility of ramping up the project to larger scales.

Finally, it is essential that we not take the reductionist point of view and look at paratransit as one of many potentially competing transportation services, but rather investigate how paratransit in general, and advanced technology applications in particular, can be integrated with existing transit systems to provide net social benefits

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[16] "Applying ITS Technologies to Travel Demand Management," Innovation Briefs, Urban Mobility Corporation, Vol. 6, No. 6, December 1995.

[17] Casey, Robert F. and John Collura. 1994. "Advanced Public Transportation Systems Evaluation Guidelines," Office of Technical Assistance, Federal Transit Administration, U.S. Department of Transportation, DOT-T-94-10, January.

Appendix I

Metro Seattle Transit and Traffic Information Displays over the Internet

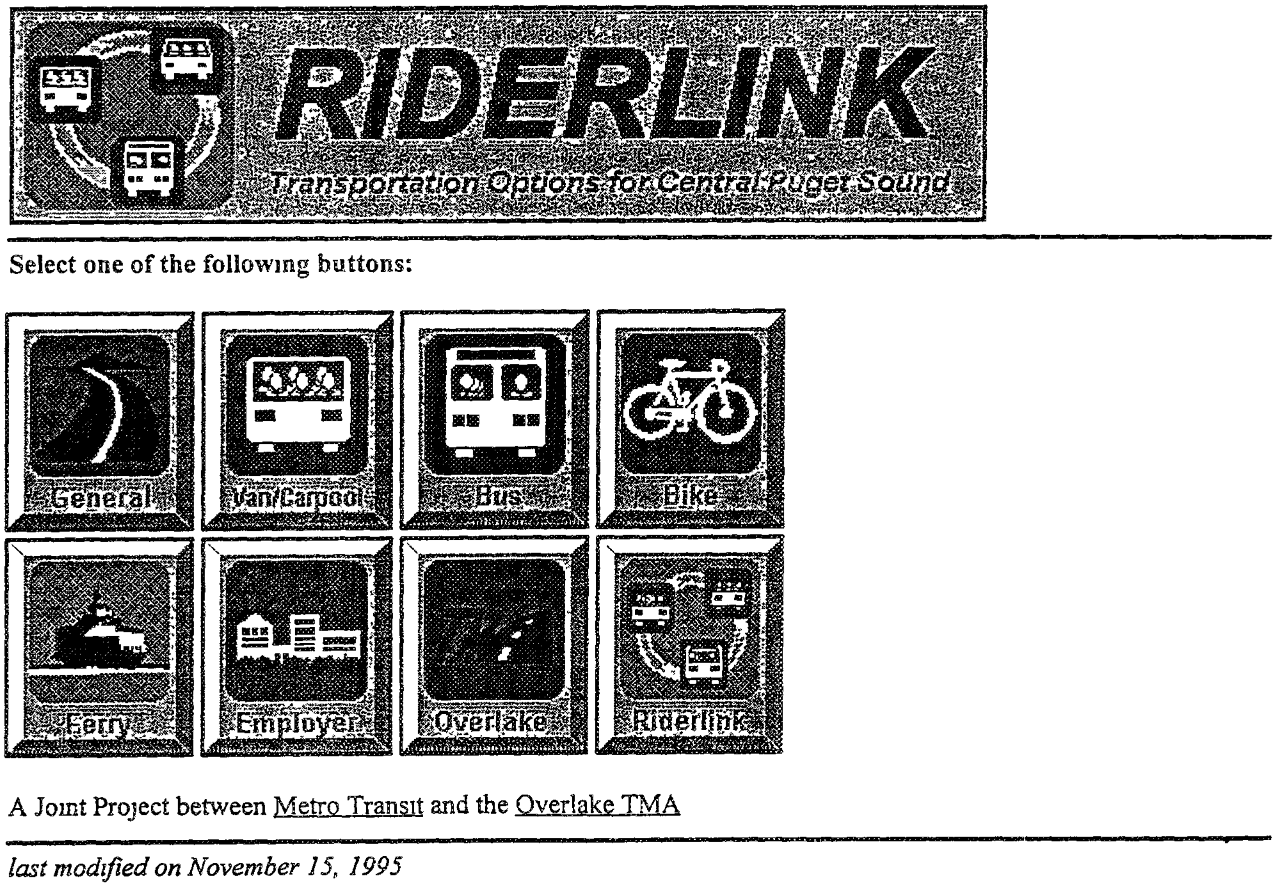
The following pages show how both static transit information and dynamic traffic information can be obtained for the greater Seattle area by accessing the following home page on the Internet: http.//transit metrokc gov Page A-1 shows the home page, i.e. the top-level menu. The sequence on pp A-2 through A-4 is initiated by selecting "bus," while the display on p A-5 is initiated by selecting "General."

Transit Route Information

Pages A-2 through A-4 show the key parts of the sequence for getting schedule information about Route 78 near the downtown Seattle area. By selecting "Seattle" from the map on p. A-2, both the schedule information (p. A-3) and a route map (p. A-4) can be displayed.

Current Traffic Conditions

The map on p. A-5 shows current traffic conditions on the main thoroughfares of the greater Seattle area. This data is updated once per minute.



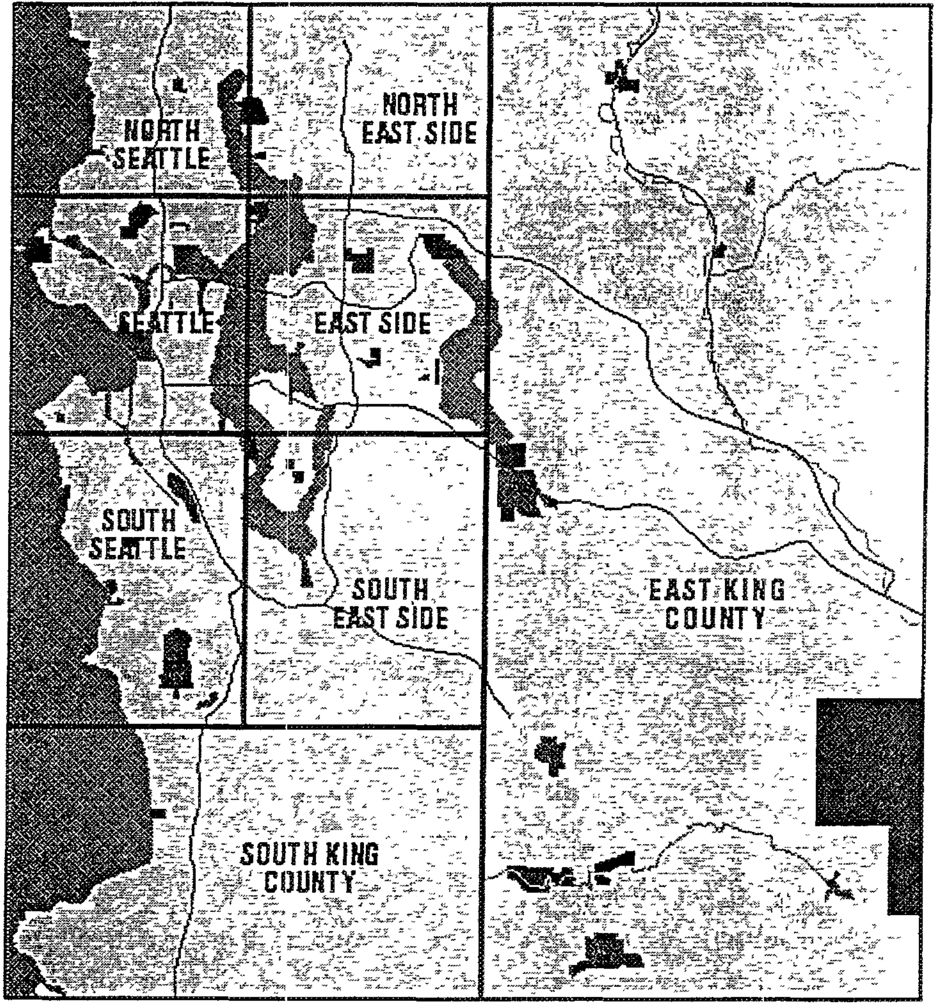
Select one of the following buttons:

A Joint Project between Metro Transit and the Overlake TMA

last modified on November 15, 1995

Regional Map

Select the section of the map in which you are interested



Home Page | Bus Menu

date last modified June 13, 1995

Route 78

UW Campus, University District, Maple Leaf, Lake City, Jackson Park
(Weekday service only)

Route Map

Trips equipped with wheelchair lifts are indicated with an "L"
Express service trips are indicated with an "E"

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to University of Washington Campus (Weekdays):

	20 Av NE & NE 146 St	15 Av NE & NE 125 St	15 Av NE & NE 80 St	U of W HUB
EL	6 15am	6 30am	6 37am	6 48am
EL	7 12am	7 28am	7 39am	7 50am
EL	7·45am	8 00am	8 11am	8 22am
EL	8 45am	8 59am	9 10am	9 21am
EL	9 45am	9 59am	10 08am	10 19am

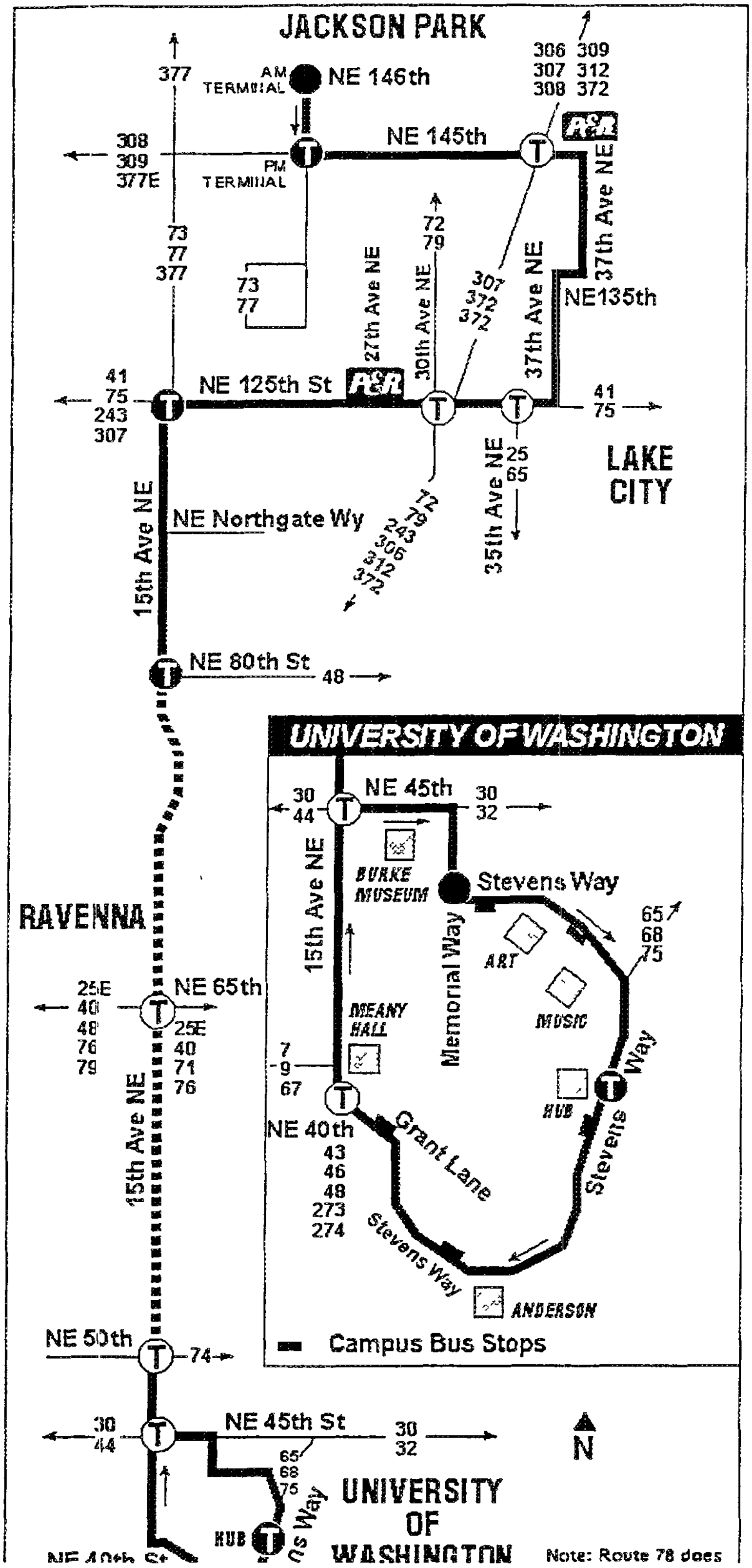
to Jackson Park (Weekdays):

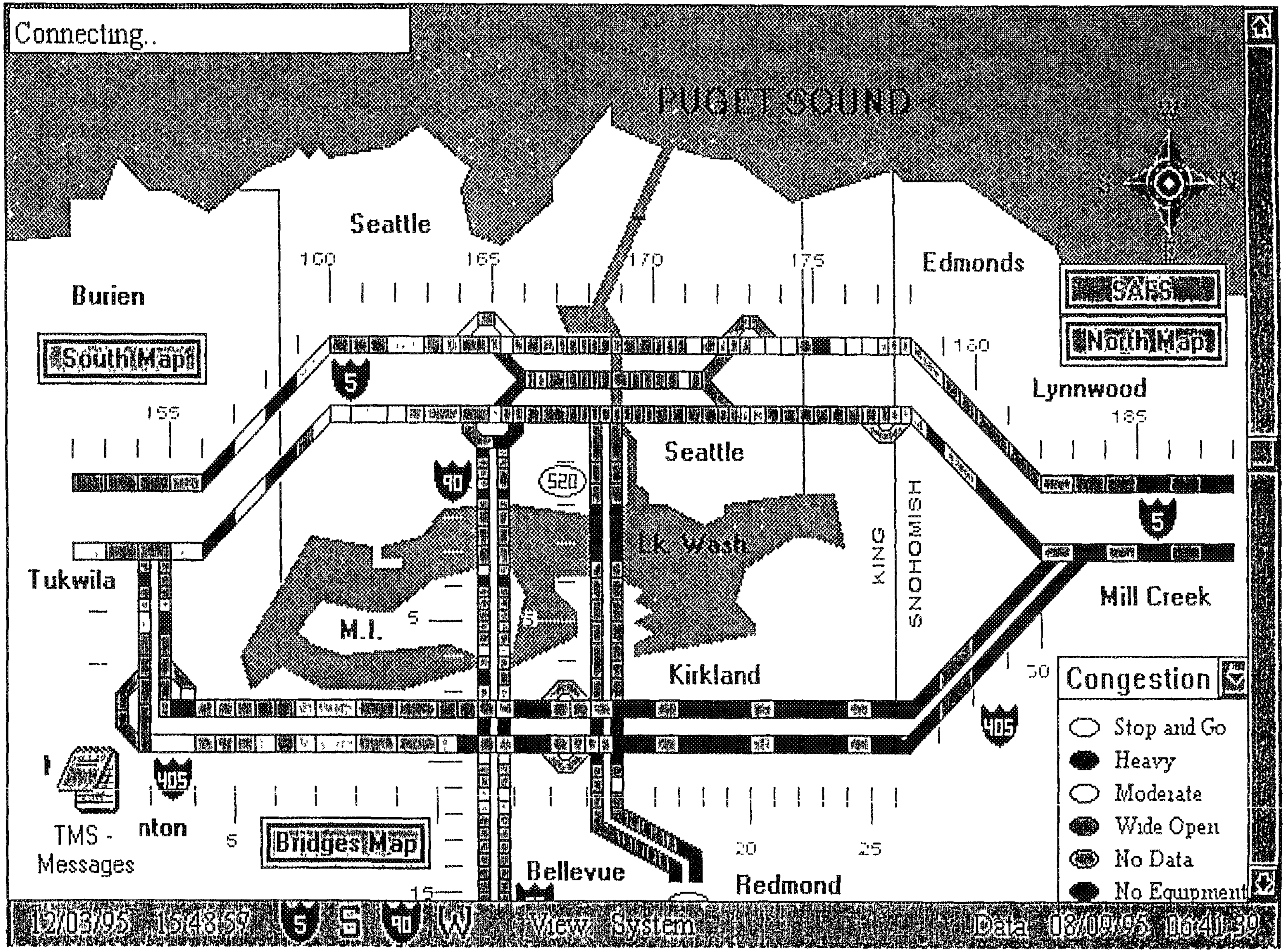
	Memorial Wy & Stevens Wy	U of W HUB	15 Av NE & NE 80 St	15 Av NE & NE 125 St	20 Av NE & NE 145 St
EL	1 30pm	1 33pm	1 50pm	2 01pm	2 14pm
EL	2 30pm	2:33pm	2:50pm	3 01pm	3 14pm
EL	3 28pm	3 31pm	3 48pm	3 59pm	4 12pm
EL	4.28pm	4 31pm	4.48pm	4 59pm	5 12pm
EL	5 33pm	5·36pm	5.53pm	6 04pm	6 17pm

Home Page | Bus Menu

last modified on August 15, 1995

Route 78


JACKSON PARK
AM TERMINAL
NE 146th
PM TERMINAL
NE 145th
P&R
377
308
309
377E
306 309
307 312
308 372
73
77
377
73
77
72
79
27th Ave NE
30th Ave NE
37th Ave NE
37th Ave NE
307
372
372
NE135th
NE 125th St
P&R
41
75
243
307
41
75
LAKE CITY
25
65
35th Ave NE
72
79
243
306
312
372
15th Ave NE
NE Northgate Wy
NE 80th St
48
RAVENNA
UNIVERSITY OF WASHINGTON
NE 45th
30
44
30
32
15th Ave NE
BURKE MUSEUM
Memorial Way
Stevens Way
65
68
75
ART
MUSIC
MEANY HALL
HUB
Way
7
9
67
NE 40th
43
46
48
273
274
Grant Lane
Stevens
Stevens Way
ANDERSON
Campus Bus Stops
NE 65th
25E
40
48
76
79
25E
40
71
76
15th Ave NE
NE 50th
74
NE 45th St
30
44
30
32
65
68
75
HUB
UNIVERSITY OF WASHINGTON
N
NE 40th St
Note: Route 78 does



Congestion
- ○ Stop and Go
- ● Heavy
- ○ Moderate
- ● Wide Open
- ● No Data
- ● No Equipment

12/03/95 15:48:57 View System Data 08/09/95 06:41:30