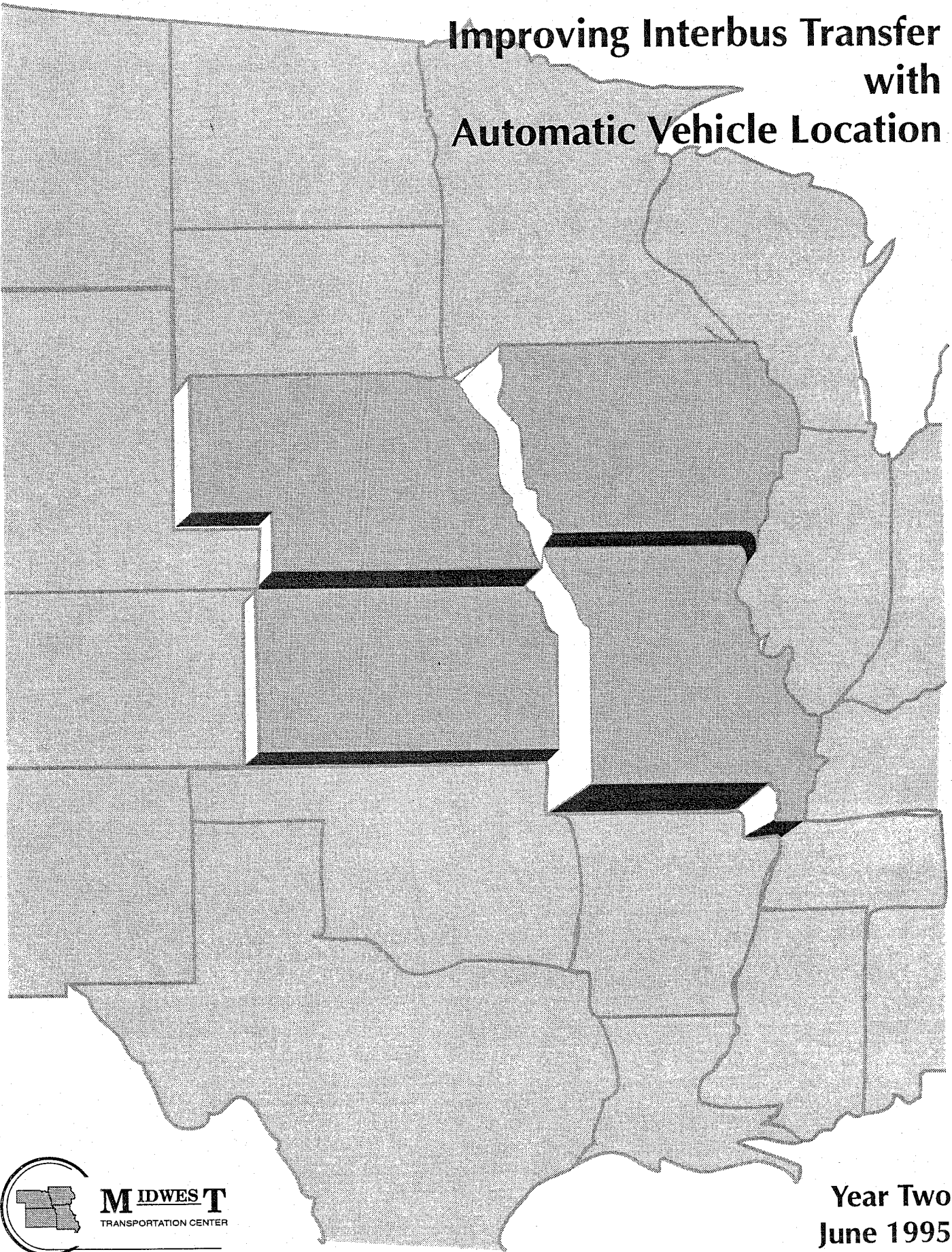# Improving Interbus Transfer
with
Automatic Vehicle Location

M **IDWES** **T**
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IMPROVING INTERBUS TRANSFER WITH AUTOMATIC VEHICLE LOCATION

Year 2 - Final Report
June 1995

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INTRODUCTION

One of the most consistent public frustrations with bus systems is their perceived, and frequently actual, lack of schedule reliability. Patrons nervously fidget with their watches as they peer down the street in hopes of catching a glimpse of the bus. Those who have been late for work or an important appointment or have stood out in the rain or snow are unlikely to be repeat transit users. For travelers who must transfer between buses the potential for missing a connection becomes a major point of concern.

While annoying to any passenger, a missed connection can be critical for a disabled passenger, especially in adverse weather conditions. Yet in the best of systems, schedule adherence is difficult given traffic, road construction, or unexpected problems with vehicle maintenance. When the required transfers are between different types of travel modes or different types of transportation services, a precise transfer becomes even more difficult. This, however, is required if a transit operation is to institute the type of feeder service envisioned in the Americans With Disabilities Act (ADA) legislation. The concept is for a paratransit vehicle (demand-responsive service) to pick up eligible passengers at a point of origin within three-quarters of a mile of a fixed-bus route and transport them to the nearest accessible bus stop. If successful, such a system should increase the efficiency of the whole operation by enabling paratransit to serve more prospective passengers with shorter advanced reservation requirements. To date, however, the feeder concept has not been widely tested. A major reason is the difficulty in guaranteeing a timely transfer.

One promising approach to facilitating the critical transfer is the use of Automatic Vehicle Locator systems (AVL). AVL systems can accurately pin-point all available vehicles, display locations on a map, and greatly assist a dispatcher in assuring a successful transfer. On-board warning light systems can notify both drivers as to whether they are early or late for a key stop and the drivers can then take appropriate measures before they ever get to the stop—either slow down or gradually increase speed. Ultimately, on-board real-time display maps in paratransit vehicles will enable drivers to adjust their own route and schedule to effect a transfer.

Understandably, pressure to move forward with advanced public transportation technologies have generally come from heavily congested areas, especially those concerned about deteriorating air quality. The application to smaller cities and to more rural environments is just being explored. Cost is a major factor. Most cities where AVL is now being deployed are relying on heavy federal subsidies. This is particularly true of the use of Global Positioning, the form of AVL attracting the most interest. For smaller transit companies to explore the potential of using AVL will require gradual implementation as funding becomes available. They will also need to be assured that they will have a workable system at the various stages of development and that all portions of the operation can later be incorporated into a unified system covering the whole fleet.

The current study will contribute to the discussion regarding applicability of AVL, specifically GPS, by addressing:

- the application to a smaller transit operation
- the potential for using AVL to effect transfers between fixed-route and paratransit vehicles
- the modifications required to adapt AVL for paratransit in rural areas

The primary test site for the project is Des Moines, Iowa, where the Metropolitan Transit Authority operates a fleet of about 100 vehicles along 12 fixed routes and a fleet of 17 paratransit vehicles which offer complementary door-to-door demand-responsive service. The Des Moines metropolitan area is the major urban hub for the largely rural state of Iowa. Not only is it the state capital and the home of several major insurance companies, a large publishing company, and several other major service industries, but it also has four major hospitals and three extensive shopping malls. Two major interstate highways cross in Des Moines which is also the home of the state's major commercial airport. As such, Des Moines is a major attraction for residents in the surrounding rural counties. Demand-responsive vehicles operating in surrounding counties bring out-patients to the Des Moines hospitals while a new commuter bus line is bringing in workers from the surrounding small towns. The opportunities for transfer, therefore, exist both within the Des Moines MTA system and between rural to urban operations as well.

This report reflects a two year study sponsored by the Midwest Transportation Center and conducted with the helpful cooperation of the Des Moines MTA and an active advisory group including representatives of the Iowa Department of Transportation and the Des Moines Metropolitan Planning Organization. The project included:

- a review of existing literature
- a review of the current national experience of transit operations developing and considering AVL applications
- assessment of components required for the application of a GPS AVL system to a small urban system
- development and assessment of a Geographic Information System (GIS) display for a GPS AVL system
- development of recommendations for small urban and rural systems considering AVL systems
- a test of prototype equipment needed for a small urban operation

The following report provides an overview of these efforts. It includes:

- an overview of automatic vehicle location
- an assessment of the application to the Des Moines MTA
- a review of issues associated with application to a rural demand-responsive system
- an assessment of components for an AVL application and a set of recommendations.

AUTOMATIC VEHICLE LOCATION

Automatic Vehicle Location (AVL) holds considerable promise for both increased operating efficiency and reliability of schedule information. Although there are few reports documenting increased operational effectiveness as a result of AVL, the Toronto Transit Commission (TTC) which installed an Automatic Vehicle Location and Computer-Aided Dispatch system several years ago, reported increased usage of their fleet at a level of between 5 and 25 percent. In addition TTC has reported multi-million dollar operating cost reductions and passenger revenue increases (Trimble Navigation, 1992). Further evaluation of installations supported by the U.S. DOT are currently underway. They will be conducted by the Volpe Transportation Assistance Center of the U.S. DOT.

The application of AVL vehicle tracking systems to public transit has been tested in a variety of large and small cities in the United States, Canada, the European continent, and Japan. The goals of transit operations in selecting AVL applications are described in a recent publication by the Ontario Ministry of Transport, "Automatic Vehicle Location and Control Systems for Small Ontario Properties":

- improve the safety and security of drivers and passengers
- provide more reliable service to the public
- allow for more efficient transit resource management
- provide real-time schedule information to the public

This is accomplished through monitoring and recording the location of vehicles in the transit fleet as they progress through their routes and comparing their progress, in terms of time and distance, with a master schedule. Data collected can enhance real-time identification and handling of incidents and major delays as they occur. Any vehicular malfunction will be immediately apparent to the control center (dispatcher) which can quickly dispatch a replacement vehicle. Bus hijacking or other criminal activity can be immediately noted as an emergency switch, usually a silent alarm, is tripped and security officers can be dispatched directly to the correct location. If a vehicle is seriously delayed in traffic, another can be dispatched to finish the route. That concept is being successfully tested in London, England, which is notorious for its traffic jams.

AVL also facilitates the collection and storage of route travel time information so that schedules may be refined to reflect on-street travel times. The on-time scheduling resulting from AVL can potentially increase public confidence in the reliability and level of service provided by the transit system.

Before developing any AVL system it is essential to consider the goals and objectives which it is intended to address within the context of the individual transit operation in both the short and long term. Goals may include:

- increased schedule reliability
- increased schedule efficiency and responsiveness

- enhanced safety for drivers and passengers
- greater service to special populations
- enhanced traveler information

Associated objectives might include vehicle performance monitoring, schedule monitoring, and/or route assessment. While these goals are certainly not mutually exclusive, they do represent differences in system focus and differences in the complexity of systems design.

For example, if the goal is primarily to increase reliability, the bus company may opt for the simplest design, one that will track and report the location of the buses in the fleet. That information could be used to monitor the vehicles and assure on-time arrivals. Data acquired from a basic AVL system could also be used to meet the goal of increased efficiency by enabling schedule updates and route modifications. The addition of passenger counters which would record the number of people boarding at each stop could provide further valuable information for updating routes and schedules. Similarly, linking an electronic fare box with AVL would permit associating passenger characteristics with the individual stops at which they boarded. This would also help in further refining routes and schedules.

The goal of enhanced safety would require adding a silent alarm to the basic AVL system. The alarm would be triggered by the driver in an emergency situation, immediately notifying the dispatcher of the exact location of the vehicle. A concealed microphone would be turned on immediately allowing the base station to monitor the situation while the appropriate emergency vehicle was dispatched to the scene.

One way to provide greater service to those with limited sight would be to install an automatic enunciator system which would announce major stops and transfer points. This feature would also help meet the requirements of the Americans with Disabilities Act.

To meet the goal of providing more accurate traveler information it is possible to relay real time (AVL-generated) vehicle location information directly to a passenger information monitor, a kiosk, or even to a personal computer.

Since these various features require additional investments, the goals would be used to indicate priorities in system development. It is critical, however, that a focus on a short term priority not preclude a longer term objective.

One objective that is often cited along with others is data collection and verification. AVL systems can generate extensive amounts of data. Since it is possible for a system to be overwhelmed by data, it is essential to determine what data are needed and for what purpose. AVL can potentially generate reams of data regarding schedule performance, driver efficiency, vehicle engine performance, passenger counts and passenger characteristics, all in relationship to real-time and location. What data are to be collected and how often, what data is to be analyzed, and what data are to be retained and for how long are significant decisions and may help in setting priorities regarding features to be added to the basic AVL system.

For paratransit, objectives and data requirements are significantly different from those of a fixed-route. For example, data related to individual passengers is important to paratransit, but not to fixed-route systems. What is important for an integrated fixed-route paratransit system is that the objectives remain complementaryallowing for differences in emphasis, but not precluding aspects of importance to the alternative type of operation. A temptation has been to develop objectives and to make decisions for the fixed-route independently and then to attempt to add on the paratransit system. What are needed are simultaneously and mutually determined objectives guiding decisions relative to vehicle tracking.

Operational Challenges of Inter-system Linkage

The operational challenges associated with inter-connecting fixed-route and paratransit vehicles are manifested in the fundamental differences between the systems. Fixed-route service is characterized by regular schedules, pre-established headways, and an organized dispatch procedure while paratransit is characterized by demand-responsive shared ride service. Automatic Vehicle Location (AVL), however, begins to address the challenges associated with providing reliable, efficient service for both types of service.

Fixed-Route

For the fixed-route service, problems associated with schedule reliability are the result of: 1) operating environment, 2) driver performance, 3) vehicle malfunction.

The operating environment with traffic congestion, road construction, or weather related factors are most problematic. When possible, the challenges imposed by the operating environment are met with more vehicles with tighter headways, thereby making the schedule less critical, particularly in peak periods. When that is not possible, routes are shortened or tightened up so as to have better control and back-up plans are activated. Monitoring driver performance is the task of street supervisors, often few in number. Reporting vehicle malfunction is the responsibility of the driver with a two-way radio who must wait with the passengers until help arrives.

AVL can assist in addressing all three of these types of challenges. On time performance can be much more closely monitored and warnings about early or late arrival at a location can be conveyed to the driver who can take appropriate action. Unauthorized route deviation can be quickly noted. Knowing the precise location of stalled vehicles or other on-board emergencies can direct the quick response of appropriate assistance. The schedules can be monitored and waiting passengers notified of delays. Serious problems resulting from congestion can be addressed by injecting an additional vehicle into the route above the congestion so as to inconvenience as few passengers as possible.

Paratransit

The characteristics of paratransit are markedly different from those of the fixed-route bus. Paratransit provides "many-to-many" service with a variable

schedule that depends on the particular riders aboard. Although similar in some ways to a taxi, paratransit is made more complex by the shared ride concept. Unlike the taxi which retrieves and deposits each passenger individually, paratransit retrieves several passengers from different locations and takes them to different destinations. Complexities develop because of the way the system must operate. In addition to the challenges to schedule reliability associated with the operating environment, driver performance, and vehicle malfunction, paratransit must also contend with trip patterning that is not consistent or predictable. To respond to these and to get at least some control over schedule, paratransit dispatchers currently have as many trips as possible pre-established and urge twenty-four hour advance call-ins. To minimize the problems associated with the operating environment, paratransit dispatchers limit the number of trips per hour to accommodate potential delays. Drivers report vehicle malfunction on two-way radios and, like the fixed-route drivers, wait for help. There is no standard procedure to monitor driver performance except in response to reports of missed or delayed pick-ups.

With AVL tracking, however, paratransit dispatchers would be able to monitor the vehicles' real-time positions. This would allow reduced call-in time and schedule variation. Dispatchers could also monitor vehicle and driver performance effectively and more accurately note the locations of disabled vehicles.

For many paratransit operations there is also the potential for increased efficiency. Since it is difficult to gauge the time required for individual trips, many paratransit operations pre-plan trips to fit into a standard envelope of time. For example, they typically plan two or three trips an hour. There is no simple procedure to slip in extra last minute calls if the planned trips take less time than expected. This process establishes a de facto limit on the number of riders that can be accommodated even though there might be some points in time when the vehicle is empty between pick-ups.

In Des Moines, Iowa, for example, the MTA paratransit system with 17 vehicles operates 12 hours a day with a total of only 408 half-hour blocks of time available for pick-ups during the day. Several of these time blocks are utilized by multiple riders for the same trip, but the system only accommodates about 1,000 persons a day because some time-blocks are underutilized.

If a paratransit dispatcher were provided with a computer display of the real-time locations of the various paratransit vehicles, he or she could type in the address of a new caller and then signal the closest vehicle to make the extra stop. That would make it possible to accommodate impromptu transit trips for any number of purposes and to respond to the ultimate goal of the ADA, i.e., integrated complementary service. A more elaborate system would also build in a networking concept which would route the demand-responsive vehicles more efficiently. To date, however, as many as 80 percent of the paratransit trips performed in Des Moines and elsewhere are for "subscription" or regular riders, generally to the same regular locations. This limits the opportunities for broader complementary service and makes return trip (will call) requests complex to handle.

AVL TECHNOLOGIES

The Signpost Approach

Within the last few years, the technology used in AVL has gone through some dramatic changes. The signpost concept which had been state of the art has now encountered a number of detractors, although both large and small systems are continuing to install it. That type of system uses a series of proximity signposts mounted about 11 to 16 feet above the street on utility poles or other posts to detect the presence of a vehicle within the 300-600 foot range of the sensor. This provides a geographic position fix for the vehicle since each signpost has its own ID. The vehicle's transceiver relays each signpost's ID to the control center (dispatcher). The dispatcher can then plot the location of the vehicle in relation to the signpost. Electrical pulses emitted by the vehicle's odometer are monitored between posts to determine distance traveled. Some systems work in reverse by having the signposts fitted with wayside readers which can read and record the passive transponder tags attached to each vehicle as they pass by and then relay the information to a central site (Ontario Ministry of Transport, 1991).

Problems with the signpost approach rest primarily with maintenance. For example, Kansas City had to replace all the batteries in its signposts within two years of initial installation and all such changes and adjustments had to be made by using a "cherry picker." Other concerns relate to the maintenance of the devices mounted on the vehicles themselves. They can be easily dislodged during regular maintenance or even during vehicle washing. Therefore, they need to be regularly tested and replaced. Vandalism is a concern in other cities. Weather-proof cabinets are needed for signposts in the colder climates in Canada. Other concerns rest with the limited flexibility of the system. Signpost systems have limited flexibility since they are placed along a pre-established route and can only be used effectively to monitor fixed-route buses that are locked into a specific route. Signposts are not effective for tracking demand-responsive paratransit operations. When used in conjunction with odometer reading, they act as "point-in-time locators" rather than as continuous reporters of real-time data.

Nevertheless, the lower costs involved with signposts as well as established consultant experience in using this type of system encourage new cities to elect this approach. For example, Tampa, Florida, has recently installed an AVL signpost system. In fact, most North American cities with AVL including Halifax, Hamilton, Hull, Toronto, San Antonio, and Norfolk all currently use signposts. The chart in Table 1, provides more detail on cities and the type of AVL being used (FTA State of the Art Update '94).

Loran-C

Land-based radio navigation location systems such as Loran-C use low frequency radio waves to provide signal coverage on land for up to 1,500 kilometers. Loran-C signal coverage is provided using sets or chains of three to five Loran stations. Each

TABLE 1

North American Transit AVL Systems *

City, State/Province	Vehicles	$M	Status (as of 9/30/93)	Principal Contractor	Location	Freq.	Poll
Ann Arbor, MI	67/67		*In Bid Process*				
Baltimore, MD	235/1200		*RFP Out*		GPS		
Urbana, IL	69/69		*Abandoned*	II Morrow	LC		
Chicago, IL	?/1900		*In Second Round of Bidding Process*			8	
Dallas, TX	1200/1300		*Resolving Software Issues*	ElectroCom	GPS	8/3	*
Denver, CO	833/833	10.4	Installation/Resolving Additional Issues	Westinghouse	GPS	?/2	*
Fort Lauderdale, FL	192/192	2.3	*System Installed/Resolving Issues*	Motorola	SO	2/1	*
Halifax, Nova Scotia	168/168	1.0	In Regular Use	(agency)	SO	1/1	30
Hamilton, Ontario	284/284	6.0	*In Regular Use/Resolving Additional Issues*	RMS Ind Controls	DR	3/1	30
Houston, TX	1000/1000		*Designing/Building System*	(agency)	GPS		
Hull, Quebec	162/162		*In Regular Use*	(various)	SO		
Jacksonville, FL	0/180		*Withdrew Plans for AVL*				
Kansas City, MO	275/275	2.1	In Regular Use/Under Re-assessment	F & M Global	SO	1/1	15-30
Louisville, KY	300/300	2.5	*Installation to begin early 1994*	Glenayre	SO		40
Miami, FL	550/550		*Install. about to begin/Operational late '95*	Frederick R. Harris	GPS		120
Milwaukee, WI	550/550		*Under Installation*	Westinghouse	GPS	2	*
New Jersey Transit	1900/1900	8	*Pilot Test in Progress with 300 Buses*	Motorola	SO	25/3	

Sources: the agencies; Pekilis, B. and G. Heti, Automatic Vehicle Location and Control Systems for Small and Medium Ontario Transit Properties: Phase I Report (Final), Transportation Technology and Energy Branch, Ontario Ministry of Transportation, January 1992.

Text in italics represents new information since the last state-of-the-art report.

FTA, Advanced Public Transportation Systems: The State of the Art Update '94

Key:

Vehicles - Number equipped/Number owned

$M - System cost in millions of $, when purchased. US Agencies - US$, Canadian Agencies - Canadian $.

Location - The location technology: *SO* - Signposts + Odometer; *LC* - LORAN-C; *GPS* - Global Positioning System; *DR* - Dead Reckoning + signposts; *GBR* - Other Ground-Based Radio.

Freq. - The number of frequencies dedicated: numbers in the format *a/b*, indicate *a* voice channels and *b* data channels.

Poll - Time between polls (seconds). * = exception reporting strategy employed.

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station transmits timed signals in the form of pulses. A Loran receiver can calculate the distance a series of radio waves has traveled from their origin by knowing the amount of time during which they were delayed from a reference system. Location is computed after receiving each transmission and its associated timing. Under normal conditions, it provides an absolute position accuracy within 500 meters. This is adequate for tracking buses in all but the most congested cities. (Ontario Ministry of Transport, 1991).

Baltimore has 50 buses being tracked by the Loran-C system. When Baltimore installed its system, Loran-C offered the best response to the need for providing greater safety and security on its bus system. The system can track any equipped vehicle within the 650 square mile operations area. In the two major 1/4 mile areas of the city where coverage is not adequate, the system is supplemented by a dead reckoning system which charts forward movement using odometer readings. Baltimore is, however, in the process of moving to a GPS (Global Positioning System) for installation on the full fleet of 900 vehicles.

Few other cities have experimented with the Loran-C approach. Until recently, adequate signal coverage was not available to communities in the southern part of the United States or for cities in the interior. Traverse City, Michigan, does continue to track paratransit vehicles with Loran C. The system operator is very satisfied with the accuracy of the tracking effort, but communications difficulties have prevented full utilization of the system for tracking purposes. One other city which has used the Loran system is Champaign-Urbana, Illinois. However, Champaign-Urbana discontinued their AVL program because of equipment problems. There are some problems with reception using Loran-C. Overhead power lines and power substations cause significant interference with the radio signal, distorting the location reports as much as 1,000 meters. There are also blank spots in the reporting in urban areas in which high rise buildings block signals. It has also been suggested the florescent lights on buses interfere with the ground-based radio signals. Ultimately, however, cities have lost interest in Loran-C, primarily because reception with long radio waves is much slower than with the newer Global Positioning System (GPS) technology.

GPS

Currently, most cities which are considering AVL are looking toward Global Positioning System (GPS) as a vehicle tracking system. At latest count, at least 21 cities are either formally considering GPS or have already installed it on part or all of the fleet. The COLTS system in Scranton, Pennsylvania, is in full operation with its 35-bus fleet being tracked with GPS. An enunciator was installed at the same time to announce stops in compliance with the ADA (Americans With Disabilities Act) requirements, requiring greatly increased accuracy in reporting locations. The Denver system has 900 fixed route buses involved in an operational test. Plans call for accomplished route-schedule adherence by fall, 1995 and subsequently linking AVL to information kiosks at transfer points. After a series of software upgrades Milwaukee anticipates completing the test phase in summer 1995. Dallas has installed GPS receivers on its entire fleet and is working to resolve issues which will increase accuracy. The Chicago CTA let bids for a demonstration of an AVL

system. Plans are to install it system-wide if it is successful. In Minneapolis, Minnesota, operational tests involve tracking fixed route buses along the I-394 corridor. A contract will be awarded in fall 1995 for installing GPS, dead reckoning and module data terminals on 300 buses and GPS and MDTS alone on an additional 1,300 buses. CTA buses will also experiment with signal preemption at its locations. Tulsa, Oklahoma, hopes to procure an AVL system within the next few years. In addition to these plans for fixed route bus installations, there are a number of functional GPS systems being used to track emergency vehicles and taxis. Cedar Rapids, Iowa, has plans for installing a common GPS system which would track fixed route and paratransit buses as well as emergency vehicles.

GPS refers to a U.S. military positioning and navigational system now available for civilian use. A full component of 24 satellites are now installed with 21 available for such civilian purposes as tracking buses and three others are reserved for exclusive military use. The Department of Defense expects that there will be over 12,000 land-based uses of these satellites. The signals can be received continuously regardless of weather virtually anywhere in the world. However, the U.S. military stills retains control of the satellites and periodically applies what is known as "selective availability" (SA) which scrambles the signal somewhat, leading to some loss of accuracy in reading positions. GPS functions by using a GPS receiver to lock onto at least three satellites and the axis points are then read to confirm the location. Often it is possible to lock onto four or five satellites, enhancing the accuracy of reporting a location. That location is then communicated to a base station where it is compared with the expected location of a vehicle at that point in time.

Location data can then be recorded on a display map and updated using Geographic Information system (GIS) software. According to the U.S. Defense Department, accuracy of moving vehicles can be assured to within 60 feet by using this system. By employing differential correction, however, accuracy can be increased considerably. This allows the position recorded by GPS to be verified in relation to a standard location point and corrected, and then the corrected position report is transmitted back to the base station. With the aid of differential correction, accuracy for a moving vehicle has been recorded at within 3 to 5 feet. Tests for stationary vehicles are even more precise.

Despite some reported problems with coverage using GPS, specifically in areas with tree canopy or tall buildings, it does appear to represent a major step forward both in terms of effectiveness and in reporting vehicle locations. It permits maximum flexibility and minimizes the complexity involved in maintaining a field-based system like signposts. This flexibility permits tracking of demand-responsive vehicles as well as those which travel along a fixed route.

Given the general enthusiasm which the transit community holds for GPS, as well as its apparent applicability to tracking paratransit as well as fixed-route buses, the current study focuses exclusively on GPS. To provide a realistic focus for the study, the Des Moines Metropolitan Transit Authority was selected as a target site. Hence the study emphasizes the potential application of GPS to the transit operation in the city of Des Moines, Iowa, a mid-sized city in a predominantly rural state.

THE DES MOINES MTA

The Des Moines MTA is a mid-sized bus operation with a fleet of about 100 vehicles in passenger service. This fleet size is fairly typical of other mid-sized bus operations. The routes which traverse the city and the half-hour headways are fairly typical of mid-sized cities and quite different from large operations in more densely populated urban areas where GPS is also being considered. The MTA operates both a fixed-route and a complementary paratransit system and hence provides a logical test environment for considering potential feeder bus transfers between paratransit and fixed-route. The interest and enthusiasm of the management is critical to the success of this type of experimental project.

The expectation is that many of the findings of the project will prove to be valuable to Des Moines as well as to other mid-sized bus properties which are operating with limited funding and a stable ridership. The purpose of the study is to provide guidance as they consider moving toward acquisition of AVL systems.

The Des Moines MTA has a long history of service to the community. It's predecessor, rail car operations, began service in 1868, soon after the founding of the city. At the height of the street car company's activity in 1920, it operated about 100 cars and had 900 employees. Gas powered buses were first introduced as feeders to the street car lines. Gradually they replaced the street cars and by 1951 the last street car made its final run. The Des Moines Transit Company became the successor to the Des Moines Railway Company in 1954. The new freeway did not have electric trolley lines so, the new company converted to diesel motor coaches, causing severe financial problems. Ownership was transferred to the Iowa Regional Transit Corporation (IRTC) in 1971. Despite this change, ridership decreased considerably in the 1960's due to increased use of the private automobile. In 1962, ridership stood at 8,202,762 and then dropped to 4,411,022 ten years later in 1972. With this loss in ridership, the private provider could no longer provide service. In 1973, five cities in the Des Moines metropolitan area signed an intergovernmental agreement, creating the Des Moines Metropolitan Transit Authority (MTA) and took over all assets of the IRTC. With government subsidies, it was possible for the MTA to replace the aging bus fleet, acquire a new facility, and increase the productivity and efficiency of the system. (Baumhover, 1993). The system recently expanded operations by offering commuter express service to surrounding communities.

The current Des Moines fleet includes the following buses:
>8 GMC buses (1974)
>25 GMC RTS03 buses (1979)
>5 GMC RTS04 buses (1981)
>30 Gillig Phantom (1989)
>15 Bus Industries, Orion (1992).

All but the oldest of these buses have power sufficient to accept the equipment being considered for AVL tracking. Modifications would be needed to install AVL on the earlier equipment. Nevertheless, each of the bus types has its own properties. A pilot project would, therefore, focus initially on the Gillig Phantoms since they represent the largest number of buses in the fleet.

ISSUES INVOLVED IN GPS APPLICATION

There are a number of elements involved in an AVL application. Some of them are essential for operation and others are potentially useful additions to the basic system that can be added as needed or as funding becomes available. According to the FTA Update on Smart Transit (FTA, 1992) the basic technologies include:

- a method of position determination
- a means of communication with the dispatcher (in real-time)
- a central processor capable of storing and using the transmitted information

As the term implies, the vehicle location component measures the position of each vehicle within a certain tolerance. The tolerance is dependent on the technology chosen, how that technology is implemented, and the environment in which the system is operating. Real-time communication between the bus and the central control is essential. The positional data generated by the vehicle location subsystem is transmitted from the bus to central control at a predetermined rate and then compared with the pre-established bus schedule.

Optional components could include:

- passenger counters
- engine component monitoring/mechanical alarms
- security alarms
- connections to passenger information systems
- enunciators

In an effort to develop a system that will be as low-cost as possible, the current study will focus exclusively on the basic technologies with the determination not to foreclose any of the other options as additional resources become available. Even the three essential elements encompass a number of key issues as they relate to GPS for a fixed-route and complementary paratransit integrated system in Des Moines.

Issues Related to Position Determination

The fundamental issues related to position determination include:

- level of accuracy required
- consistency of position reporting required
- frequency of polling required

Each of these issues must be addressed in terms of the unique qualities of the individual transit operation and its city, the type of service involved, and the associated costs.

Level of Accuracy

Each transit agency is unique, having its own operational characteristics and requirements. Hence the parameters for an AVL system need to be defined in its specific operational context. For example, the level of accuracy needed to track fixed-route buses varies from 15 meters to 100 meters, depending on the layout of the streets, the number and proximity of the bus routes, and the headways of operation.

It is generally possible to track a bus within 100 meters of accuracy by using basic GPS. This may be adequate for a city with half-hour headways and no concern about vehicle bunching. To be assured of greater precision would require use of a differential base station with line-of-sight to all active vehicles in the fleet. A differential base station applies a correction factor to signals being received from global positioning satellites. With such a system, receivers on individual buses would pick up satellite signals corrected for accuracy by the differential base station. Purchasing and maintaining the differential base station and acquiring more sophisticated on-board equipment obviously increases system costs above that of a simpler GPS that uses the satellite signals directly. But as the military activates selected availability (SA) more frequently, the use of differential base stations becomes more cost effective. Further analysis of the relative merits of a differential base station for a mid-sized transit operation is still needed.

For all AVL systems, operational requirements distinguish tracking procedures for fixed-route and for paratransit operations. Generally, the precision required for tracking demand-responsive paratransit vehicles is generally not as critical as for fixed-route vehicles on fixed schedules. With paratransit, the significant issue is the relative position of a vehicle vis-à-vis an on-call pick-up or other paratransit vehicles which might be diverted. The location of a paratransit vehicle traveling along a specific street is not as significant as its arrival at origin and destination points. In the future, when paratransit operates with full dial-a-ride service and in-vehicle displays, greater accuracy will be required so that drivers can find their way to less familiar locations. But basic tracking of paratransit vehicles does not require a differential base station.

In the Des Moines test case, the issue of precision in tracking was fairly similar to what would be the case in other small or medium sized cities. Fixed-route buses operate at approximately half-hour headways over some multi-stop routes and several additional peak hour express routes. (The only variation is the 15-minute headways in rush hour and the one-hour mid-day headways on a few routes.) The routes cross the entire city, but all connect at a down-town transit mall which is the one common transfer point. When GPS tracking was tested on fixed-route buses without using a differential base station, fixes within +/- 15 meters of actual location were reported in all areas except for a two block area downtown. See Figure 1 for plot of GPS Tracking of Buses in Des Moines. This approach proved to be very satisfactory for vehicles operating on half-hour headways. Differential GPS could insure greater accuracy but, for a fixed-route system with scattered routes on one-half hour headways, the marginal benefits would have to be closely weighed in light of costs.

FIGURE 1

ACCURATE TRACKING OF YELLOW FIXED ROUTE

14
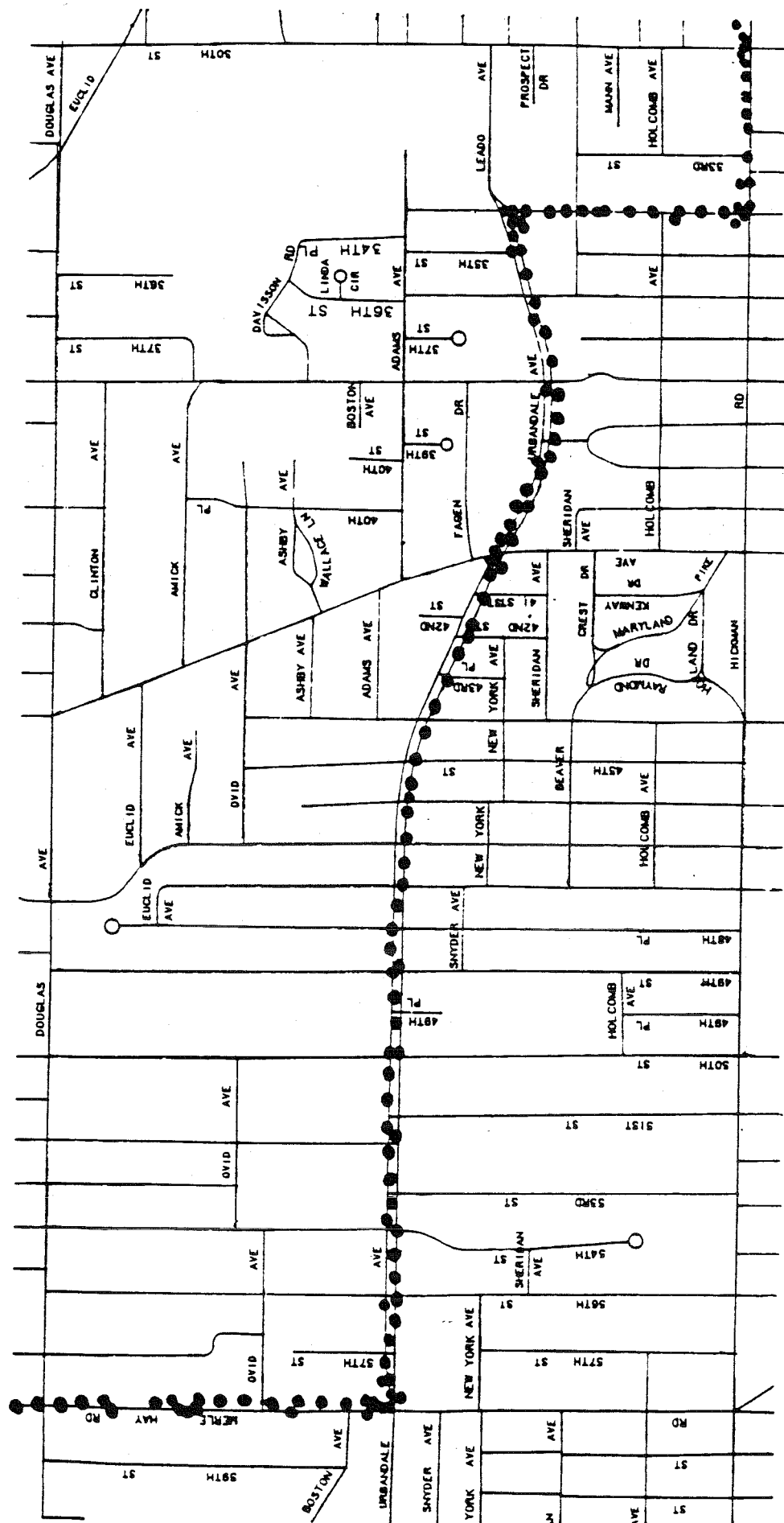
Given the fairly small fleet of paratransit vehicles, no compelling reason to track them with greater precision than the fixed route buses emerged. Two pre-planned pickups per hour, per vehicle, is the current norm. If more on-call stops were added, tracking of position relative to unprogrammed pick-ups would be of higher priority than location per se. Hence +/- 100 meter location accuracy would be satisfactory.

Consistency of Reporting

For many cities, it is not possible to use a GPS receiver alone to accurately report positions. Gaps in GPS reporting are caused by blocked GPS signals or by an inability of a receiver to lock onto satellites consistently. This problem is generally reported in urban chasms where tall buildings absorb/distort GPS signals or more suburban areas with heavy foliage which also tends to reduce signal strength. In these areas, dead reckoning has successfully supplemented and bridged gaps in GPS-deriven tracking data.

The increase in the application of Selective Availability (SA) by the US Defense Department provides another reason to consider systems that back up GPS in urban areas. Selective Availability introduces an intentional degradation of the code signals from the satellites called Position Dilution of Precision (PDOP). PDOP produces receiver noise and significant fluctuations in a sequence of position fixes. The problem is made more complex in urban areas where street orientation, street width, and building height already make it difficult to receive or track the same configuration of satellites consistently. The combination of PDOP and the signal degradation can lead to considerable fluctuation in position recording. This can lead to "spiking" rather than a smooth and accurate track. In a test conducted in Paris by Jean-Claude Fantou and reported in GPS World (July, 1993), three satellites were visible for 88 percent of the traveled distance even when there was no effort to mask or otherwise correct for the PDOP. Greater consistency in tracking required an additional type of back-up system. Since two satellites were useful for 97 percent of the distance traveled in Paris, it was possible to consider dead reckoning as that support system. It is possible to initialize a dead reckoning support system with only two satellites (Fantou, 1993).

Simple dead reckoning systems use the vehicle odometers and on-board compass and assume the forward progress of the vehicle to project the track from the last known good position. Systems range from this simple odometer/compass arrangement to costly gyroscope and accelerometer components. All require on-board data processors to calculate and plot vehicle location. Tracking errors in dead reckoning systems are cumulative and appear as drifting of the reported fix positions along the track plot. Dead reckoning systems using odometer data assume that tire rotation indicates forward vehicle motion. It does not typically account for variation in tire pressure, tires spinning on ice or wet leaves or for minor route diversions. The Ann Arbor transit company, for example, found that a system relying largely on dead reckoning was very inaccurate even when corrected with occasional signposts.

Hence, dead reckoning cannot be used alone and requires either a signpost or other location method for periodic recalibration. When used by fixed-route buses to supplement GPS, dead reckoning can smooth and bridge GPS coverage gaps in urban canyons. In the Paris tests indicated above, dead reckoning was to fill in GPS gaps and GPS was used to recalibrate the dead reckoning system. That would seem to provide the ideal system. The problem is that switching back to GPS from dead reckoning often produces sharp discontinuities in the track plot. Fantou suggested using dead reckoning as the primary positioning method with periodic use of GPS position fixes to smoothly resynchronize the system (Fantou, 1993). Such a system is being tested in Paderborn in Germany.

The value of a dead reckoning system as a back up for GPS is dependent upon the length of the urban route segment where the vehicle cannot receive consistent GPS signals. In Dallas, for example, tall towers interfere with GPS signals for only a block at a time. So the vehicle could report its position both on entering and departing those sections of the route. A routine polling interval of two minutes is often sufficient for a vehicle to enter and emerge from a high PDOP area and re-acquire access to the satellites. Whether it will lock onto the same satellites and, if not, whether that will create a jump or a spike in the track, must be tested in specific urban environments.

The benefit of dead reckoning for a paratransit demand-responsive vehicle is less apparent. Paratransit does not travel specific routes and may deviate from the shortest path for a variety of reasons. Paratransit dispatchers need information on the distance between vehicles and/or specific pick-up or drop-off points. The benefit to be gained from adding dead reckoning to paratransit (or fixed route) systems must be weighted against the additional cost.

In the case of Des Moines, a city with a limited number of taller buildings, it was possible to access at least four satellites at almost all times when following a fixed-route bus route through the heart of the city. This was reassuring since only three satellites are required to complete a triangulation and determine position. Acquiring the fourth satellite does not improve position accuracy, but offers a better choice of satellites and lowers the PDOP level (Fantou, 1993). The only location where spiking or drifting in reported fixes occurred was a two block area in downtown where there are several tall buildings. See Figure 2 for plot of GPS reporting in this two-block area. Post test analysis suggests plotting errors may be attributed to the equipment used rather than an indication of degradation in signal quality. At the present time, it does not appear that the relative refinement in position accuracy would justify the cost of adding a dead reckoning back-up system in the Des Moines setting.

Frequency of Polling Required

Polling is the process by which the central control or dispatcher requests information on the position of a vehicle.

When polled, each bus generates a "packet" of data. The packets from the various buses are communicated sequentially so that the records are written into a relational

FIGURE 2

TRACKING AT DOWNTOWN DES MOINES

Fixed Bus Route

GPS Locations at 5-second Interval

17
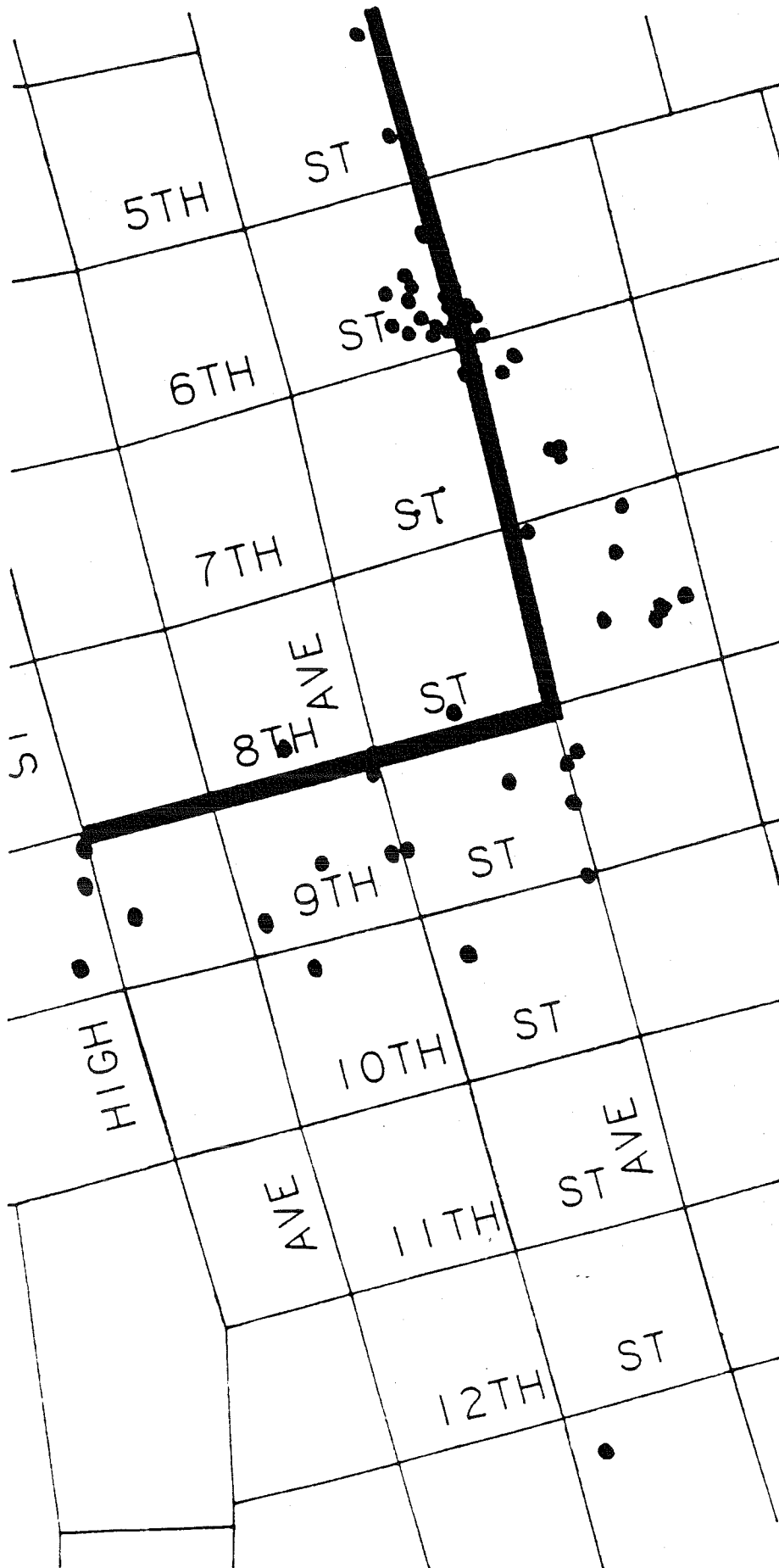
database management system (RDBMS) at the base station. An identifier is associated with each data packet and is used to isolate packets for individual buses.

Polling also eliminates excessive data by allowing the dispatcher to sample data from buses at desired intervals. A constant flow of data would inundate the base station with far more information than can reasonably be communicated, filtered, and processed. This could slow up all related operations.

Polling permits user focus in case of emergency. Typically, buses are being polled every two to three minutes. Buses in an emergency status can be polled more frequently (every second, if required) and the remaining buses can be tracked at longer intervals.

The polling schedule is generated by a controller at the base station. The controller can be a dedicated PC linked to the radio at the base station or a single-board computer. This board controls the base station radio which initiates calls to the mobile radios in the active fleet in a regular sequence. For example bus 1, bus 2,...bus 100 and again bus 1, bus 2, bus 3, etc.

GPS generates a record of position every second; hence it is technically possible to track a single vehicle every second. Limitations on frequency of polling are more often a function of the number of radio frequencies available to the transit company.

The frequency of polling desired by a fixed-route system depends on bus headways, the interlocking of routes, and the number of transfers required. Some fixed-route bus companies poll vehicles only every 15 minutes. Typically, polling every two minutes would be sufficient for buses with half-hour headways operating at ten mph along city streets. A viable plan is to poll every two minutes, but to suppress the data unless there is a special reason to look at the progress of a particular vehicle. Any vehicle operating outside a given set of parameters (too early, too late, or experiencing mechanical or security-related problems) can be flagged with a special icon on the display. Most transit companies do not permit early arrival and most allow about a two minute window for lateness.

Recently more transit companies are turning to exception reporting because of the shortage of available radio frequencies. This concept involves an on-board comparison of actual real-time location with scheduled location. Company policy would determine what variation would be within tolerable limits. (For example, the bus cannot be early for a stop, but it can be up to two minutes late.) If the bus's computed fix is outside these parameters a message is sent by the bus to the base station. Parameters could be changed for snow days or other weather-related difficulties. This type of reporting reduces transmission to a fraction of what would be reported using standard polling procedures. In addition to saving on radio traffic, exception reporting avoids an overly cluttered display screen and directs full attention to vehicle with problems. The understanding is that by the time a minor variation in the progress of a bus would be detected in the base station, the driver would have already corrected the situation. Exception reporting would not, however, allow for precise tracking of vehicles along routes, if that were a requirement.

Paratransit vehicles could also be polled every two minutes, but their progress through city streets would only become important if an extra stop were required. Hence, they would only be polled on command or by exception if they missed or were late for a prearranged stop.

Issues Associated with Vehicle Intelligence

The concept of exception reporting relates to one of the fundamental issues associated with AVL: whether to provide intelligence on the mobile units, the buses, or to retain the intelligence at the base station. Seen in terms of AVL, the issue is whether to establish a "smart bus" or to maintain all the intelligence at the "smart central" base station. A "smart bus" would have a microcomputer on-board capable of doing routine analysis while the "dumb bus" would act as a type of probe and relay all data to the base station for analysis.

While the "dumb bus," ("smart central") concept was the one initially developed, the "smart bus" is becoming more popular in recent efforts at GPS installation. The availability of rugged and inexpensive on-board digital processing is reducing the need for continuous reporting and the number of radio channels required.
The "dumb bus" concept is certainly less expensive. The on-board equipment for each bus would be simply a GPS receiver, modem, and a transmitter. All GPS locational data would be communicated to the base station where it would be processed in a central computer and then conveyed to the dispatcher. The function of an on-board computer, if any, would be for data compression so that only essential information is sent to the base station. In this case all schedule monitoring would be done centrally with the aid of a computer which would compare reported locations with expected locations according to the pre-established schedule. Regular polling of all vehicles in the fleet, every fifteen seconds, or every five minutes, or any established interval, would be a variation on the "dumb bus" concept but would require a two way radio for control and reporting.

"Smart Bus"

The "smart bus" presented in Figure 3, would have a computer on-board with processing speed equal to at least an Intel 386. (Data storage would require power equal to an Intel 486.) This computer would hold pre-established time schedules for the routes, review the real-time locational data in light of those, and only relay to the base station discrepancies or "exceptions" that exceed a pre-established set of limits. Specifically, the on-board computer would perform the following functions:

- Select data from the GPS receiver output, reducing the requirements for transmission and storage. Time, latitude, longitude, and heading are examples. In most cities, altitude and other projections can be discarded.

- Convert Latitude/Longitude (lat. long) data to map coordinates. This must be done before a display is possible and before comparing real-time locations with the pre-established schedule.

- Compare GPS-derived locations to the scheduled locations/times. If differences exceed established operational parameters, activate an exception report packet.

- Reporting exceptions for operating activity outside established parameters.

- Develop packets for transmission. A header and location data are packaged with an end-of-file so that the packet can be sent in a burst to the base station. The location packet for transit includes a header, time, an "x" coordinate, a "y" coordinate, and heading. Standardized messages can be handled in the same way. Display of a signal can be made directly from a RS233 port at the base station when the conversion from lat/long to x/y coordinates is made on the bus.

- Store data required by the bus company. This could include a report of exceptions transmitted and/or any additional data associated with the basic vehicle location information. This might include a report of vehicle maintenance, passenger counts by location, and location specific safety information and can be used as a history to analyze the system's operation.

Despite the added cost of equipping each bus, the advantages of the "smart bus" concept include:

- major reduction in data transmission
- larger number of buses could be covered with a standard base station
- fewer radio frequencies would be needed
- reduction of data storage at the base station
- dispatcher panning of the base computer display for exceptions would be possible
- allowing for immediate information on the extent of problems with the operation

While this would add to the cost of equipping each bus, it would also limit the use of scarce radio frequencies and not overwhelm the base station with extra data. It would also be possible for the driver to be notified directly of his or her progress vis-à-vis the printed schedule so that corrective measures could be taken immediately before too far outside acceptable limits.

To establish on-board verification of schedule deviation requires a process for relaying the preprinted schedule to the respective on-board computers. This could either be accomplished by reading the pre-established time points into each bus' computer directly in the garage or by communicating the schedule over a half-duplex radio to each bus once a day.

"Smart Central"

In contrast to the "smart bus" concept, the "smart central" ("dumb bus") concept would reduce the on-board bus requirements and increase the transmission of data and the need for dedicated radio frequencies. The results would include delays in

FIGURE 3

GPS : Tracking Model
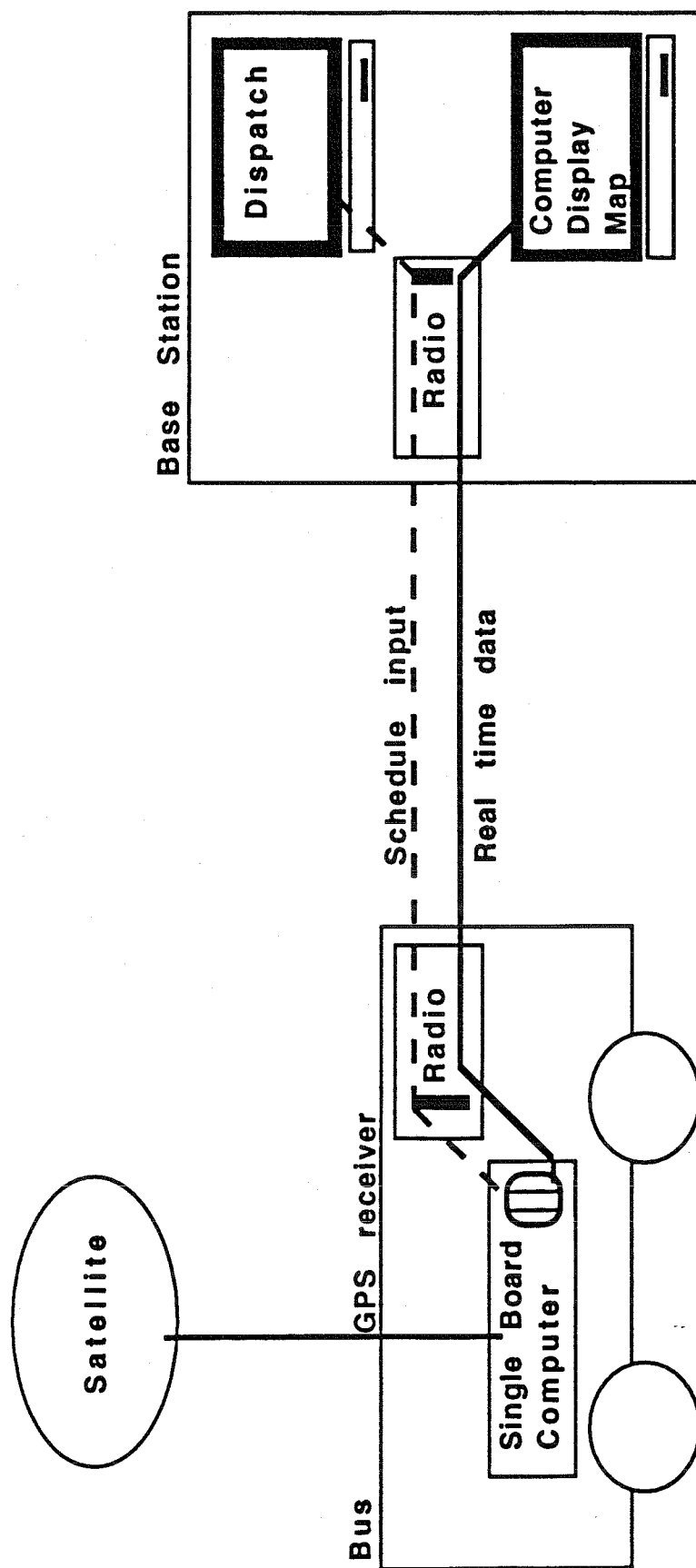
data reception. The "dumb bus" would still require some on-board computing. This would include extraction of data from the GPS receiver and development of packets for transmission to the base station. Reporting to the base station would be at regular intervals with each bus allotted a specific point in time to transmit its packet in rotation. Conversion of lat/long data into x, y coordinates for a particular software and a particular map projection would be done on a central computer and all comparisons with pre-established schedules would be done by the central computer. All data would be displayed at the base station, possibly requiring a dedicated monitor at the base station to highlight exceptions. Data storage would be large; it would include every location for every regular interval for every bus.

Advantages of the "smart central" system would include:

- reduction in the cost of on-board bus computers
- elimination of the need to load and reload bus schedules on-board the buses
- regularized time slots for transmitting data, overridden if a driver pushed the panic safety button
- a single location for schedule verification and hence a full history of travel for each vehicle, facilitating route analysis and post operation schedule improvement

Study Team Assessment

After reviewing the two approaches, the study team opted for exception reporting and the "smart bus." The primary benefits of this approach became apparent during efforts to secure increased radio frequencies. Although the cost per vehicle would be higher, this approach would be more viable given the scarce supply of radio frequencies and the need for simplicity in reading and responding at the base station. Dispatchers are typically very knowledgeable about operating a bus system; the objective here would be to enhance their effort by conveying data already screened for importance.

Issues Associated with Communication

With a GPS receiver providing fixes at an acceptable level of accuracy and reliability, the study now focused on the process of communicating vehicle position to a base station or dispatcher. This involves radio transmission. Issues associated with selection of a radio include both legal and technical inquiries. Primary issues relate to obtaining frequency allocations, radio type (analog or digital, simplex vs. duplex), and the data rate in bits/sec. Cost tradeoffs must be evaluated.

Frequency

An issue of increasing importance is the availability of radio frequencies for licenses and the length of time required to process a request for a license. Most transit systems use 400-Mhz Land Mobile band for voice communication with the drivers. Such communication is on an "as needed" basis and is not seriously affected by the congestion caused by the high number of other users of 400-Mhz radio frequencies in the metropolitan area. Transmission of GPS positions, on the other hand, must be

frequent and consistent across the whole fleet (depending on the agreed polling frequency).

Noise from other users would interfere with the accurate and regular transmission of data points. In addition, the range of reception of 400-band radios is limited. Typically, repeater stations are needed to amplify the signal to communicate reliably across a city. Although some transit companies try to transmit both voice and digital information over the same 400-Mhz radio frequency, by allowing a voice override, this is not very successful with a large fleet. When voice overrides the digital signals it interrupts the regular reporting schedule. This becomes more problematic for larger fleets.

The use of 800-Mhz radios is the direction of the future, despite the increase in cost for the radios. The problem is the limited number of licenses available in the 800-Mhz band and the lengthy review process required to acquire one. Some cities are using 800-Mhz trunk lines to serve several city services including power companies, medical facilities, and police. If the trunk is to include heavy users like the police, it is difficult for the transit company to secure a sufficient number of bands for regular transmission of GPS locations. The issue of an available radio spectrum has, in fact, determined the frequency of polling of vehicles and has prompted a number of transit operators to opt for exception reporting. This assumes that most vehicles are operating within an acceptable range of schedule accuracy. Vehicles operating outside a pre-established set of parameters for schedule or route are identified and only those are polled frequently. With more transit companies adapting GPS, the issue of available channels in the 800-Mhz frequency bands will become increasingly important.

Bps Rate

The second set of issues associated with the radio are technical. GPS receivers typically transmit data at 9,600 bps (bits per second). Lower cost radios usually transmit at lower levels (4,800 bps or lower). This leads to requirements for data reduction, compression, or buffering (storage). One factor that may prove to be significant is that, in general, the higher the bps rate used, the lower the range of reception. Other things being equal, a system using a baud rate of 1,200 has a broader range of reception than a similar system attempting to communicate at higher rates, a factor that might prove to be significant in a rural setting.

Basic GPS, reporting only the x, y coordinates of the buses in association with time or schedule, can be transmitted using a 1,200 bps data rate. Transmitting other data for an expanded GPS system (passenger counting, engine monitoring, and data to passenger information systems) may require a radio with a faster data rate. This leads to a trade-off between cost for a more expensive radio system vs. the amount of data which is to be transmitted. A security system with a silent alarm is considered essential to flag the location of a vehicle in difficulty and direct emergency vehicles to it immediately. Transmitting distress signals would interrupt regular sequential polling and would require more sophisticated radios. The Denver GPS test has discovered the complexity of this issue.

In Des Moines, one proposal is to retain the existing voice communication radio and add additional 1,200 bps radios to transmit location data only. The silent alarm would activate the microphone of the existing voice communication radio so the dispatcher could hear activity on the bus in question. Meanwhile the GPS radio would continue to display the exact location of the vehicle. This would direct and inform the emergency response.

Radio Type

Here the issues are complexity and mode.

Simplex/Duplex
Simplex is defined as alternating transmissions between two or more stations using a single frequency. Duplex indicates simultaneous transmissions between two stations using two frequencies. Half-duplex radios allow two directional flow of information but not simultaneous transmission between two stations. Table 2 shows that the simplex radios are less expensive, but can they ultimately do the job. Polling is possible using simplex radios, but duplex radios are needed if two-way simultaneous communication is needed.

At the Des Moines test site, the use of simplex radios would seem to be sufficient for most purposes. The buses talk to the base station only and are not expected to communicate with each other. In addition, data from each bus would actually not be needed more frequently than every five seconds. This would allow sufficient time for simplex radios to receive the data packets. The only potential need for digital communication from the base station to the bus would be to load, change, or verify the schedule to be performed on a given day by a specific vehicle.
The basic concept behind vehicle tracking is to compare real-time location with expected or scheduled location. It is, therefore, essential to communicate the expected schedule to each bus to permit this verification. The standard practice in the Des Moines MTA is to assign each bus and bus driver to a different route every day. This means that the appropriate run and route schedule for each bus needs to be changed daily. Inserting a floppy disk with the appropriate schedule into the on-board computer of each bus was ruled out because of susceptibility to anticipated shock and vibration levels on a bus. Daily communication of the appropriate schedule to each vehicle before it left the garage was also ruled out given the time involved and the necessity to have all vehicles on the streets for the morning rush hour.

Given the relatively small size of the full schedule for the Des Moines MTA (1,500 time points) it will be possible for the on-board computer on each bus to store the full schedule with codes to indicate specific routes. Digital radio communication with each bus can then use those codes to quickly activate the appropriate portion of the schedule for a specific day. Relaying schedule information from the base station to each bus, as well as the regular communication of real-time locational data from the bus to the base station, can be accomplished with half-duplex radios.

TABLE 2
RELATIVE COSTS SCHEDULE

Radio	Mhz	Baud	Dollars	Repeater(s)
Simplex	400	1,200	600	5,000
Simplex	800	1,200	900	
Duplex	400	1,200	1,500	10,000+
Duplex	800	9,600	2,300	

Issues Related to the Base Station

Decisions on what data to collect and how often, what to analyze, what to store and for how long need to be made before the central processor is selected. Transit properties which already have AVL are often inundated with data exceeding their capacity for analysis. For example, one property has the capacity to collect data in real-time on eighteen aspects of bus performance plus bus location. However, only the oil pressure and fuel gauge are monitored because there is no staff to review the rest of the data on a regular basis. This information is generally downloaded once a day when the buses return to the garage.

The base computer selected depends on the number of vehicles to be tracked, the specific equipment components in the GPS system, data requirements, and the type of display desired. Hence it is logical to reach agreement on these parameters before deciding on a computer for central processing. A major consideration is the future objectives of the system in using GPS as well as current plans. It is most important to be able to interrelate databases associated with fare collection, maintenance, scheduling, and tracking. Many transit companies have acquired separate software to address each of these areas. They also have separate data processing systems for fixed-route and paratransit systems. The result is limited systems integration and redundancy of data collection.

These issues become important when considering the type of platform required at the base station. A UNIX workstation would potentially allow greater speed in refreshing the screen and greater computing power. This becomes important when several data streams need to be interrelated and associated with a display map. The extensive files needed for display maps require substantial computer power to be used effectively in tracking. Networking software which allows for dispatching is largely UNIX-based.

PC computers are more frequently found in transit dispatch centers, however. An additional alternative is provided by the new Windows NT operating system which offers a PC of the speed and of computer power generally found in a workstation. For the Des Moines system, high speed computers would be required to handle serial communication, display management and refreshing, and maintenance of file systems and databases. Databases alone usually take more Central Processing Unit (CPU) time than anticipated or estimated.

For paratransit, objectives and data requirements are significantly different from fixed-route systems. Passenger origin and destination and personal attributes are of fundamental importance and require computer-based scheduling programs for efficient handling. These issues are not significant for fixed-route buses. What is important for an integrated system is that the objectives remain complementary allowing differences in emphasis, but not precluding aspects of importance to the alternate type of operation. The tendency has been to develop objectives and make decisions independently for the fixed-route service and then attempt to add on paratransit. What is needed are mutually determined objectives guiding decisions relative to vehicle tracking and the type of data to be collected, analyzed, and stored.

Display Systems

While not a basic requirement of an AVL system, a map display provides an important communication device for the dispatcher and others associated with the tracking function. Although a number of transit companies operate AVL without using map displays, all systems currently installing GPS systems are including map displays. These displays use icons to represent bus locations, provide updates on schedule adherence, vehicle malfunction, and the location of vehicles with security problems. The displays can also make real-time additions to paratransit scheduling a feasible concept. Display maps are graphic and symbolic of the nature of the new AVL systems. The decision to use a display map, however, affects the selection of a central processor and the software and revisits basic questions raised in determining the purpose of an AVL system for a transit company.

Information needs of AVL applications vary with operations. Indeed, just locating the buses may satisfy many transit operators. Retrieval of information about a specified proximity, connectivity to another location, and routing via a network are examples of information needs that surpass location.

Displaying the GPS tracking data in such a way as to be meaningful and readable requires an accurate, seamless base map. There are an increasing number of transportation-related GIS mapping software programs becoming available including InFoCAD, MapGraphix, Intergraph, and GDS. Although most operate on UNIX-based workstations, several companies are also introducing personal computer versions. The issue will be to determine whether these PC versions have sufficient capacity to display an entire bus system and to display the real-time location of the buses in operation. Tests are being conducted on several of these in connection with the Des Moines project.

The paratransit dispatcher must be able to scroll from one section of the city to another. It is important to observe both the origin and destination points of demand-responsive requests and for the dispatcher to be able to insert additional stops. For the fixed-route system, it is also important to be able to observe the entire route and then to zoom in on particular problematic locations as needed. The level of detail required for fixed-route displays is far less than that required for demand-responsive vehicles. For fixed-route, even a display with the street names suppressed and only showing the bus routes would be appropriate. This would reduce the amount of time needed to refresh the computer screen. Some cities bring in landmarks to orient dispatchers while others simply show the routes. Greater detail is important for a paratransit dispatcher to pan and zoom the origin and destination points and to consider alternate travel routes. To facilitate transfers will require adjacent display screens or a window interted into the paratransit display to show a map of the closest accessible fixed route. The maps should be in the same coordinate system and be of equivalent accuracy. A computer with the new Windows NT operating system would have sufficient memory to permit a virtual pan of the entire city and display both origins and destinations of paratransit passengers.

While any GPS verified map could serve as base for the fixed-route bus display, a paratransit display would require a far more complete map, such as the U.S. Census

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Tiger Map with street addresses. Tiger maps are, however, notorious for blank spots in address ranges. Other maps such as those provided by ETAK and others are more complete, but not available for all cities. A major requirement is to associate the map with available verified GPS points so as to insure an accurate record of GPS vehicle tracking on the display.

Specific street names are essential for paratransit scheduling. They enable the dispatcher to zoom in to one area of town and identify the street location of the caller requesting a ride. For a display to be useful for paratransit networking it would also need to reflect topology and major intrusions into traffic patterns, i.e. one-way streets, construction zones, prohibitions on left turns. With such information, it is possible to plan the shortest possible trip and make most efficient use of the paratransit fleet. In the absence of such a map, most demand-responsive systems rely on the personal knowledge of an experienced dispatcher.

Two maps, available locally, were used for the Des Moines project, a very detailed map (Figure 4) constructed by the Central Iowa Area Mapping (CIAM) group which includes local county and metropolitan agencies. The other is an Intergraph map developed by the Iowa Department of Transportation. (Figure 5) The CIAM map had been verified for accuracy through comparison with known GPS points. The CIAM map, however, was developed for the utility companies, public works departments, the police, and other city agencies. It includes far more detail than was needed for a display of either the fixed-route or paratransit services, (e.g. curb lines rather than center lines for each street). The map was so large and complex that it absorbed extensive computer memory and CPU time to refresh the screen. Hence the Intergraph map was used for the project since it proved to be easier to manipulate and the CIAM map was used to verify the accuracy of the Intergraph map.

Neither map available to the study team included topology. Hence, no attempt was made to relate a paratransit networking program to the actual map of Des Moines. Instead, the study team developed a simulation program using the GIS software package, InFoCAD. This was intended to demonstrate the type of networking which would assist paratransit dispatchers in deciding which paratransit vehicle to dispatch to a call. The program, entitled "Dispatcher Enhancement," built in impedance based on one-way streets and variable travel speed to propose an optimum path for paratransit trip dispatching. Other factors (such as topography) could be incorporated as well. Expectations were that such a program would be used in conjunction with real-time tracking to insert "will call" trips.

A lower cost option to a full networking program is the nodal approach to the demand-responsive trip assignment. Trip nodes associated with major trip generators (points of origin of regular riders) would be placed on a map of the service area. The travel times between these nodes (known as links) are used as standardized trip references. The links are then cross-referenced by street and attractor and posted in a look-up table. Dispatchers could rapidly connect a series of links to construct ad hoc routes that best satisfy the needs for each paratransit trip for quick selection of "routes." Paratransit vehicles would travel between nodes on pre-established routes and maintain the times associated with each link in the trip table. More detailed maps would be prepared and keyed with the nodes to assist the

CIAM BASE MAP
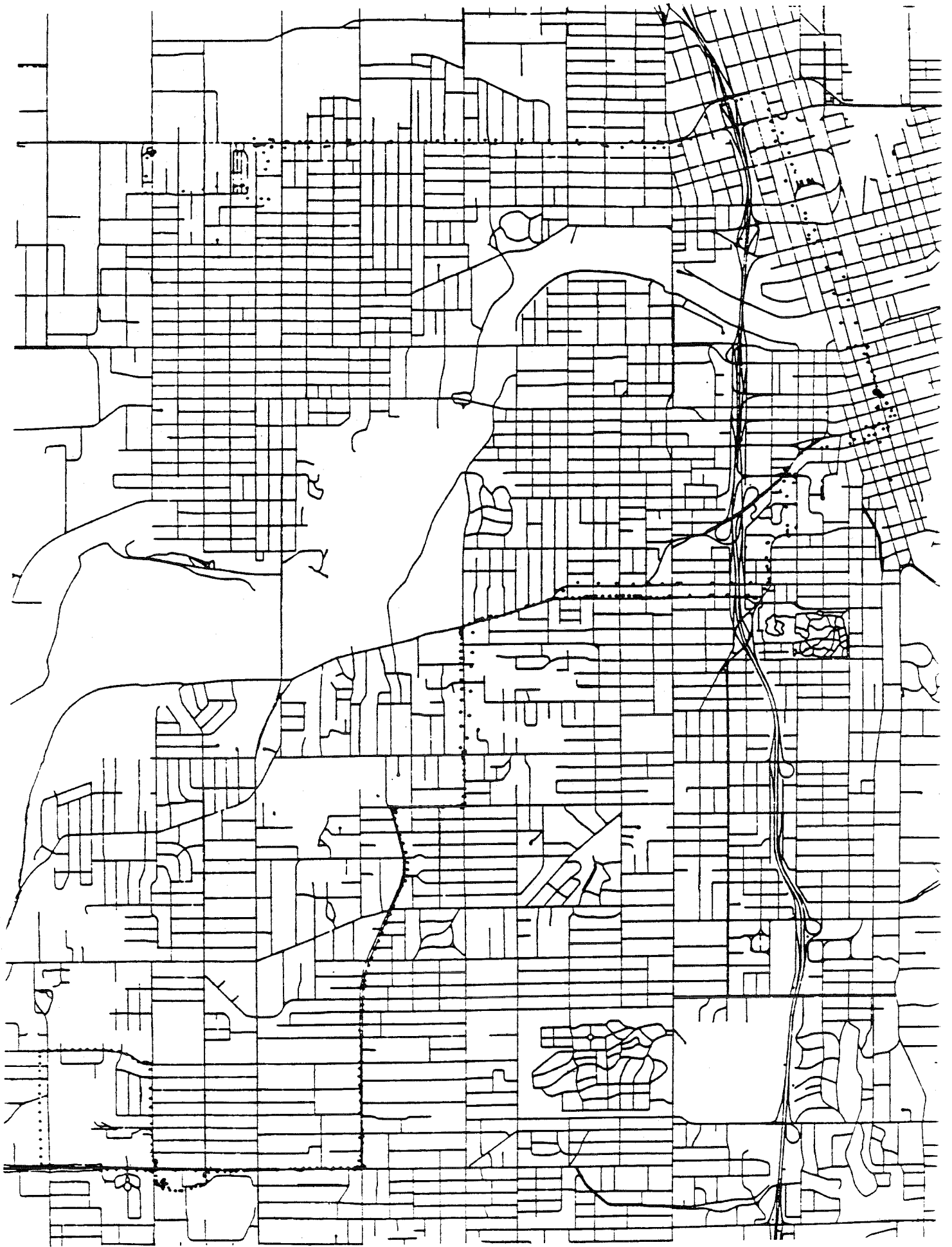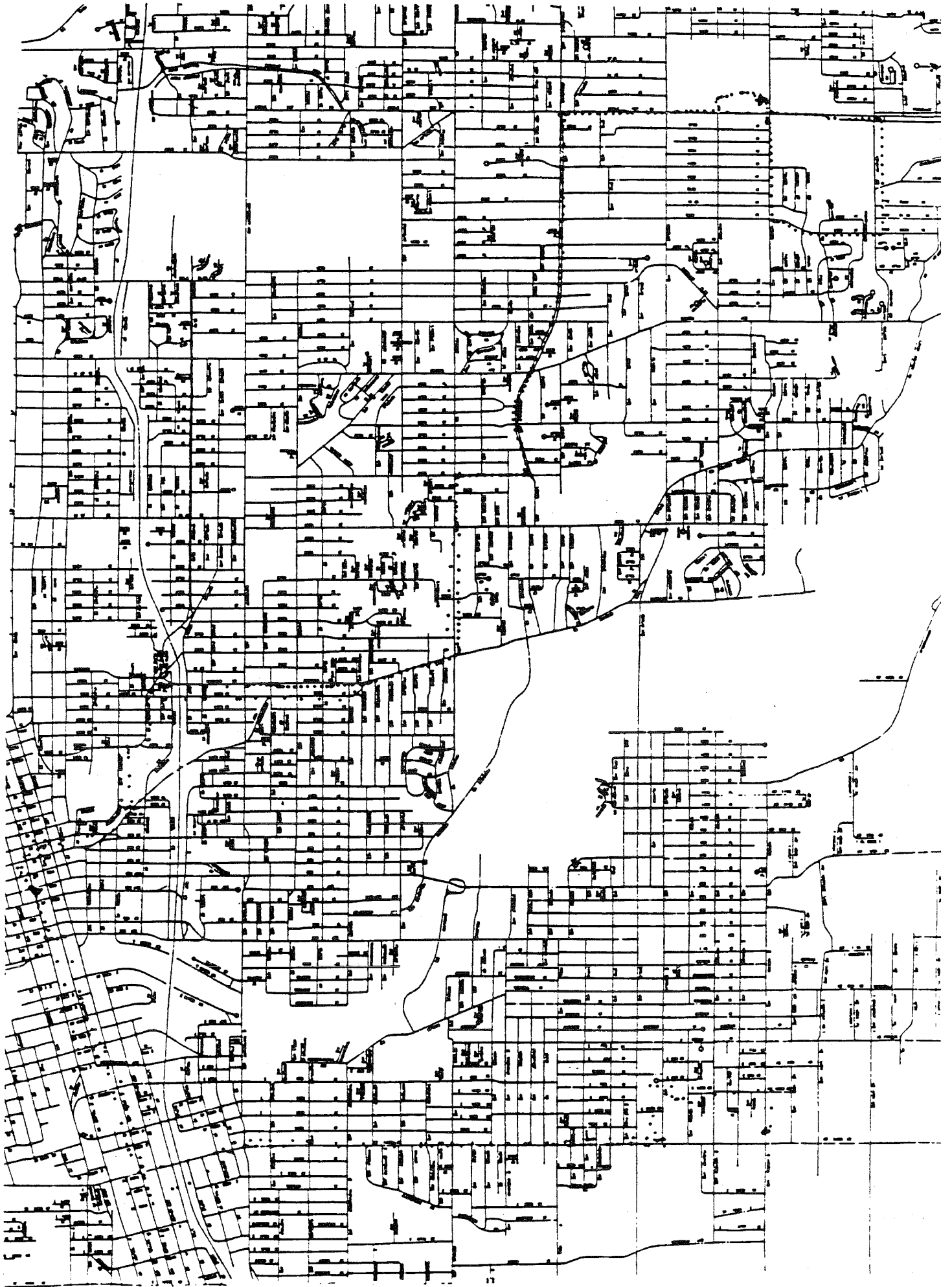
dispatcher in assigning specific pick-ups or drop-offs to individual vehicles. Subscriber's regular trips could be processed in advance of scheduling to assist in quick selection of routes. Such a concept would respond to the needs for accuracy and detail associated with paratransit, but not overburden the overall map with detail down to the level of individual addresses.

The concept of using nodes as reference points for dispatch is already being used by taxi companies and is at the heart of dynamic scheduling programs which are being more widely tested in paratransit operations.

Assessment of GIS Software for the Display

As indicated above, GIS software would need to have several key features in order to be useful in transit applications: flexibility, ability to import maps, and plot bus routes with GPS accuracy. ability to refresh the screen quickly, and zoom features.

Tests of a number of different applications were run using GDS, which is a software initially obtained from McDonald Douglas. (GDS is now owned and maintained by GDS, Inc., of St. Louis, Missouri.) It proved to be responsive to the needs of this project. It could import available maps, had the required zoom feature, permitted recording GPS tracks in coordinates, and imported files in the Oracle relational database. Problems experienced with the CAD package were primarily attributed to the size of the network system in operation at the University (Project Vincent). The GPS protocols are written for a stand-alone rather than a network environment. A smaller Micro GDS version was tested also because the typical transit operation would be using a stand-alone microcomputer. However, Micro GDS had some difficulty in relating to a relational database management system.

Other software packages were also evaluated. MapGraphix is user-friendly and provided a crisp map and quick screen refreshing. However, the Macintosh version which the team reviewed did not have the required zoom feature.

InFoCAD proved to be flexible and user friendly. It includes easy-to-read graphics and a "virtual pan" or zoom feature. InfoCAD also permits importing maps from available sources and can respond to a relational database. The most recent Beta version of InFoCAD, Pro (version 2.0), for the Windows NT operating system, was tested. This version responds to communications software relaying GPS-derived fixes. This allowed the study team to write software to compare GPS-computed locations with scheduled locations and highlight the exceptions on the display screen.

InFoCAD also will allow the development of a networking program which can be used by a paratransit dispatcher. Network analysis requires more advanced tools with spatial buffer and scanning functions than are currently used in basic GIS AVL applications. In addition to InFoCAD, Intergraph and ArcInfo offer network analysis tools on the UNIX platform. They all have open architecture and will permit access and manipulation of data for analysis.

EQUIPMENT ASSESSMENT

The foregoing covered general criteria for a GPS tracking system for a transit company like the Des Moines Metro. Before making any decision to purchase, however, two critical elements must be weighed against the overriding interest in finding a low cost solution.

(1) GPS tracking systems are still far from turnkey installations. The software needed to interface the various pieces of equipment and to insure that the real-time location of a vehicle will ultimately appear as a point on a display, is obscured by a discussion focused primarily upon hardware and display maps.

(2) The viability of incremental systems development depends on investment in equipment with specifications that are easily recognized and accommodated by a number of vendors and integrators. It would be unwise to invest in equipment for a portion of the fleet and then find that it is very difficult for a subsequent vendor to deal with and interrelate with the equipment purchased in an earlier phase. National standards that will assure basic compatibility are being developed. J1708, is an example of a basic standard being adopted by the International Association of Electrical Engineers for electrical circuits used in AVL equipment. Until such standards are widely accepted and used by all manufacturers, it is important for small transit companies to select well-known and proven equipment that can be used by subsequent system integrators.

The following discussion focuses on (1) the major components of the on-board system (GPS receivers, the logic board or computers, and radios) and (2) the major components of the base station.

GPS Receivers

To fit the original parameters of this project, GPS receivers need to provide accurate tracking at reasonable cost.

The study team used a Rockwell Navcore V receiver because it was made available by the Iowa Department of Transportation and Rockwell International. This relatively low cost device, about $500, performed well. Rockwell guaranteed +/- 100 meter accuracy without differential but the receiver actually provided +/- 15 meter accuracy on most of the city's bus routes. Rockwell has subsequently updated the receiver and offers increased levels of accuracy.

The only location where accurate location fixes are difficult is a two block urban canyon which coincides with the transit mall where buses make a mandatory stop and accept transfer passengers. Once buses depart the transit mall, they can again be tracked easily. The added accuracy provided by differential GPS is not needed when headways are typically 15 minutes to one half hour and the routes do not intersect frequently.

Specification sheets of other receivers were also reviewed in summer 1994, but the equipment was not available for testing.

(1) *Magnavox* has a six-channel GPS Engine which allows continuous tracking with or without a differential base station. The price is under $500. Data is received in ASCII format at 9,600 bps, but the receiver is easily adjustable to different band rates. Data is only output in latitude and longitude. Accuracy is +/- 100 meters without differential and +/- 2-5 meters with differential.

(2) *Trimble Navigation's Navtrak* costs about $900. It receives data in ASCII format at 9,600 bps. Data can be output in x, y State Plane Coordinates as well as latitude-longitude. As with most GPS receivers, accuracy is guaranteed to +100 meters without differential and +/- 2-5 meters with differential.

(3) *Motorola* also has a six-channel receiver. It has fast acquisition times and has the option of responding to differential. The price is approximately $1,200. Data is output only in binary format in latitude-longitude. It is transmitted at 9,600 Band and at the same level of accuracy +100 meters without differential and +/- 2-5 meters with differential.

(4) *Navistar Navigation System* offers a six-and a twelve-channel receiver. The six-channel model costs approximately $2,995 while the twelve-channel model costs about $5,495. Both receivers could work with transit applications. The output is binary format latitude-longitude. Unlike the Rockwell product which uses the Lambert projection of the North American Datum of 1983 (NAD83), the Navistar system uses the Universal Transverse Macerator (UTM) projection system. The company maintains their receiver is very accurate in urban canyons. It was tested in England with considerable success.

An evaluation of current comparable equipment and prices would be essential before proceeding with any equipment purchase. The mid-sized transit property should request evidence of tests conducted in similar settings.

The Logic Board

The logic board is a key component in the communication link. The following functions are performed by the logic board:

- Data integration: Integrates data from different sources
- Data manipulation: Reduces or compresses data to save memory and radio time
- Data preparation: Prepares data packets for transmission

Some GPS units have built-in logic boards and cost about $5,000-$6,000 per vehicle. This is more expensive than purchasing the elements individually (about $500 for the GPS core receiver and antenna + $500 to $800 for a solid logic board controller that could withstand the regular jostling of a bus). However, the built-in boards are more rugged and designed to withstand the g-forces present on a bouncing bus. So if components are acquired separately it would be essential to house them in a solid

case with a power source. Rugged construction is required to withstand the rigors of mobile operation as well as routine bus and system maintenance. Malfunctioning units must be plug-in/plug-out replaceable so buses are not detained. GPS repairs could then be made at the garage or other electronic maintenance facility.

The study team built a rugged logic board and developed software to relay locational data from the bus to the base station. The board was programmed for tracking and has space available to add on other AVL elements such as passenger counters. Low cost must be weighed in relation to qualities essential for a fully operable GPS system that will not only satisfy basic GPS but enable expansion to include more features as funds permit. It is important to avoid investing in a system with closed architecture that cannot be expanded later to add features such as silent alarms, on-board voice location announcements, public information systems, and passenger counters.

When the laboratory prototype logic board is translated to the operational bus environment, the team recommended encasing the board and associated power supply in a solid card cage. The full equipment list is included in Table 3.

Radios

The project leased radios from Motorola, which also provided maps of radio coverage of the Des Moines area. Similar radios are available from GE, Philips, Ericson, and others.

Ever cost-conscious, the study team began its series of radio tests with a 400-Mhz simplex radio ($600) which would send a stream of data to the base station. An on-board switch could interrupt that stream and intersperse a data stream from a second vehicle. This simple process would work successfully for a few vehicles, but would be cumbersome for a fleet of 100 vehicles. Simplex radio is restricted to a uni-directional flow of data from, say, buses to base station and precludes a reverse flow of information or base station-initiated polling commands. Thus, simplex radio would satisfy only the simplest version of the "smart central" concept.

With increasing awareness of the complexities involved in the continuous relay of locational data from an entire fleet to the base station, the team began to explore ways to reduce the amount of data to be transmitted. The team focused on how and where to complete schedule verification. Comparing GPS-derived fixes of all buses with their respective scheduled positions at the base station would require considerable computer capacity, heavy dispatcher involvement, and extensive use of communications. By performing the comparison on each bus, scarce radio resources would be saved. In addition, discrepancies could be displayed immediately to the driver who could make independent intelligent choices and adjustments to rectify a discrepancy on-site before it required external intervention by a dispatcher.

This concept appeared to have considerable merit. It led to a discussion about how to provide the daily schedule to each bus in a system where vehicles and drivers are assigned different runs every day. Issuing the schedule for each bus on a floppy disk was briefly explored, but dropped in view of the potential for errors that might be

TABLE 3

SMART BUS COMMUNICATIONS SYSTEM EQUIPMENT

1)   **Vehicle Logic Unit**
        Integrator: Kinetic Computer Corp.
        includes:
        • Rugged On-Board Computer
                manufacturer: Kinetic
                model; OBC-32-286
                unit cost: $2,988
        • 750 KB SRAM
                unit cost: $120
        • GPS Receiver/antenna
                manufacturer: Rockwell Collins
                unit cost: @$500
        • integration of GPS receiver with CPU, and antenna connector
                unit cost: $285

2)   **Communications Radios**
        (includes 1 at base station & 1 on board each bus)
                manufacturer: Ericsson GE*
                model: Orion
                unit cost: $1,222 plus radio antenas @ about $75
        (1 for base station & 1 onboard each bus)
                digtial modem: Data Radio Company
                unit cost: $6,200

3)   **Computer, Monitor, and Software**
        company: Data General, and Digital Matrix Services, Inc.
                model: 92508-A (includes InFoCAD Pro)
                cost: $12,995

4)   **Computer, Monitor, and Software**
        company: Data General, and Digital Matrix Services, Inc.
                model: 92507-A (includes InFoCAD Desktop)
                cost: $10,995

5)   **Computer, Monitor, and Software**
        company: Apex, and Digital Matrix Sevices, Inc.
                model: 486 DX2/66 Mhz; Baby AT Case w/200 W Power Supply; 128 KB Cache;
                        4 MB RAM; 250 MB Hard drive; 1.44 MB 3.5" Floppy Drive; FK 6000
                        Keyboard; IDESPG (Ports); Paradise 1 MB Video Card; 14" Monochrome
                        VGA Monitor; Navigator; DOS Windows 3.1; Mouse
                cost: $1,302 (+Navigator cost)

<u>Miscellaneous Costs</u>
• **Cables**

* The Motorola Spectra is a viable option for higher cost

induced by jostling a disk drive. Relaying the appropriate schedule to each bus every day by radio would be efficient, but would require communication from the base station to the buses. Thus, the study team turned to half-duplex radio. This allows transmission of schedules from the base station to the respective buses. The preponderance of transmissions would still be from bus to base station. There would be no need for full-duplex radio unless the buses needed to communicate their positions to each other under some other scenario.

A decision was made to proceed with separate radios to communicate the digital fixes and not to integrate voice and digital on a single transceiver. A review of the literature and discussions with venders and integrators convinced the team that attempting to relay digital information over the existing analog radios would be difficult. Regular polling of vehicles for location would probably interfere with voice communications and vice versa. Some transit companies have circumvented the problem by encoding the most common voice messages (like police codes). The driver speaks the code numbers, thereby reducing the daily air time needed by each bus. The team may explore this further.

Radios designed to communicate digital information were difficult to acquire and costly. The team decided to use analog radio and a modem to translate digital fix data to analog at the bus and the reverse at the base station. Radios with a built-in modem were preferable in the bus environment because they are more compact and rugged.

Despite the acknowledged merits of 800-Mhz radio (less interference, less signal deterioration, longer range), the team opted for a 400-Mhz radio because it was readily available and cost half as much. The decision to use 400-Mhz radio requires more attention to signal coverage and where to locate repeaters and the base station. The problem is exacerbated by the location of the MTA offices and dispatcher at a low point near the river. The options considered were:

- Base radio located at a high elevation, e.g., atop a water tower or the Principal Building (tallest building in the city). The fixes could be relayed to a base station at MTA via telephone, but this might exceed the telephone link maximum band rate.

- Base radio located at MTA Headquarters and linked to buses via a repeater station located at a high elevation. This appears to be more practicable, but might be more costly.

For communication between MTA and the rural buses network, a series of repeater stations will be necessary with 400-Mhz radios. A more comprehensive study is needed to determine the cost/benefits of investing in 400-Mhz radios and repeater stations vs. 800-Mhz radios with fewer repeaters.

On-board Computers

The decision for on-board schedule verification affected plans for an on-board computer. A simple Zenith lap top 386 computer to receive and verify data from the

GPS receiver proved to be fully capable of the task. However, if the GPS equipment were actually installed in a bus, a more compact computer with similar or greater power would be needed. A small single-board computer was developed by the project team and a program to compress and relay GPS signals was written and installed. The device performed well as a controller. A team member also wrote a software program which allowed transmissions from individual buses to be acknowledged by the base station.

Base Station (Dispatcher)

The base station radio and its polling modem would obviously need to be compatible with radios on the buses. Given the need to poll and receive data from about 100 buses, the base station would need a full-duplex radio plus a controller (computer). One option is to add repeater stations, each with a duplex radio and a controller (computer). This would provide a clear signal and enable expanded use of a 400-Mhz frequency. A 400-Mhz repeater can cover a radius of about 35 miles. In some areas it is possible to subscribe to an existing radio net and pay monthly communication charges. The cost for 400-Mhz repeater stations is about $4,000, compared with $10,000 for an 800-Mhz radio. One vender proposed a relatively low cost simplex base station for $1,200 or $1,600 for duplex, both at 400-Mhz. The cost of a polling modem is about $2,000. An 800 Mhz duplex radio costs $2,300. A differential base GPS requires a more sophisticated and costly duplex radio set-up.

At current prices it is possible to outfit a base station with three mini-computers based on Intel's 486 and oversized map display monitors for about $25,000. A work station environment would add speed, capacity, and cost. This would not be needed for most of the basic AVL functions performed by a mid-sized transit operation.

Software licenses would add to the cost of the base-station computers. A key parameter is the storage required for a GIS map plus a relational database. Storage capacity might be reduced via a local area network linking two computers for fixed-routes; one with a relational database including all schedules and driver information and the other with a display map. An equivalent system could serve paratransit with one computer for a map display and another computer with a relational database including characteristics of the subscriber riders as well as their travel schedules.

Display

Initial map display testing utilized UNIX workstations with an Oracle relational database and a GIS software package called GDS. But an alternative GIS package (InFoCAD) was also tested because it had networking features which could enhance paratransit scheduling. The latest version of InFoCAD runs in the Windows NT environment that requires a stand alone PC with extended memory. A package is available that includes the hardware necessary to run InFoCAD and the appropriate site license. The issues are cost and compatibility with other computers the transit operation might be using.

The needs of the paratransit dispatcher and the fixed-route dispatcher are sufficiently diverse as to require different computer displays. Each would have the capability of bringing in the whole city map to show relationships. In fact, a third computer display could show all vehicles in operation at any one time and be able to zoom in to a sector with a problem.

The paratransit dispatcher needs the capability to zoom to an even higher level of detail when scheduling or inserting trips. This allows the dispatcher to determine the position of available paratransit vehicles relative to a caller's location. A modal concept (see page 23) would provide a way to preplan trip times and distances when using the networking feature. To transfer a passenger to an accessible fixed-route bus stop, the dispatcher needs to view similar map displays of fixed-route and paratransit vehicles. This is not a major challenge since both dispatchers could access basically the same display(s) with different layers and different sections of the city in focus.

Finally, the paratransit display also needs to relate to the operations' scheduling program. This allows a dispatcher to relate characteristics of a caller, especially an ADA-eligible caller, with the geographic location of the pick-up. Although several vendors have developed geo-based software to display paratransit schedules, none has completed the next step (i.e., associating that information with the location of vehicles available to retrieve the passenger).

The fixed-route dispatcher needs to see only the bus routes with buses proceeding along them. By suppressing the detailed street map and only showing the bus routes, the display screen can be read easily. When the dispatcher is notified by exception reporting that a vehicle is operating outside established operating parameters, the dispatcher can zoom in to the area where that vehicle is located. The detailed street map would then be accessed to establish precise location. This allows ease in observing the whole system and provides sufficient detail whenever needed.

Composite "Smart Bus" Communications System

Table 3 lists the equipment components recommended for a mid-sized transit operation. Prices quoted in summer 1994 will vary with time and individual vendors.

The selected elements are not always the least expensive. The team created a prototype design using lower cost elements patched together by specially tailored connectors and software. (For example, the team used an $895 multi-port single board computer as the rugged on-board computer.) Such a prototype design can yield useful tracking data but would require the regular availability of a maintenance staff sufficiently familiar with the system to diagnose problems and make repairs/modifications. Additions or upgrades would require the intervention of a team that understood the circuitry sufficiently to redesign it. The point is that initial savings in equipment costs might easily be absorbed by larger maintenance expenses and costly delays associated with a system with excessive downtime. "Help" lines and warranties available for standard equipment would not be available on modified equipment.

Therefore, the team opted for proposing an easily-replicated configuration that cost more initially but used standard equipment to permit incremental additions to the tracked fleet . Each item listed is readily available and system compatible. They interconnect to provide vehicle tracking and optional features useful to modern transit systems.

The item listed as "vehicle logic unit" includes everything needed on each bus in addition to the radio. This integrated unit includes a rugged on-board computer, CPU (central processing unit) card, a GPS receiver card, GPS antenna, and appropriate connectors. All components meet NEMA standards to withstand the bus environment. The base station would include the computers listed in items 3 through 6 plus a compatible radio.

The Orion radio is listed as the communications radio since it has a built-in modem. The equivalent but more expensive Motorola product is the Spectra. Most other radios need a separate modem. Having fewer pieces of equipment on each bus assures compatible modems and reduces inventory problems. Nevertheless, a number of transit companies are working with separate radios and modems carefully linked together. The team explored using an MDX Ericson-GE radio, for example. The list price is $1,225, although a discount might be available for a public entity. An external modem is extra.

The computers listed as items 3 through 6 in Table 3 are high quality workstations with InFoCAD software already installed. The more expensive one, number 3, is for para-transit and number 4 is for the fixed-route system. The more elaborate paratransit computer permits networking plus on-call scheduling and tracking on a map display with sufficient detail to locate the block of the requested origin and destination. Both use Window NT operating systems and are capable of displaying the whole system. A detailed zoom area can be displayed using the virtual pan function. The workstations also support other monitors if needed. Less expensive computers and mapping programs can provide a background display. However, the team selected display systems that provide for an accurate GIS system into which bus tracks could be integrated—a map display of GPS recoded positions with the same accuracy as received.

Miscellaneous costs include a printer, cables, GPS receiver manual, DOS Development Environment to facilitate programming, and a radio frequency license. The cost of software development can be very high but it is essential if the various pieces of equipment are to interrelate and function as a system. The study team developed key pieces of prototypical software but were not able to complete the software needed for this system because the specified equipment was not made available. A mid-sized transit company should plan to spend at least $20,000 for software development and fine tuning the system. Installation and maintenance would entail additional charges.

The costs involved in setting up an AVL system are considerable. Base station costs are the same whether the company intends to track one or 100 buses. When the cost of the base station equipment in this configuration is distributed over ten buses the cost per bus is $8,000. However, when distributed over 100 buses the cost per bus

drops to about $5,500. The cost per bus for a 100 bus fleet could be further reduced if on-board components are procured in bulk. If the company planned to add additional buses to the tracking program over time, it would be essential to purchase the base station first, complete the necessary software programming, and then acquire on-board units as affordable. Costs would be increased if differential GPS were required.

To test the viability of the proposed configuration, the study team conducted an operational test which integrated the pieces of equipment listed in Table 3. The only variation was in the radios and modems used—Johnson radios and Dataradio modems made available by AutoTrac (a system integrator discussed in the next section of this paper).

Software Innovations has developed new proprietary software which links the radio directly to the display computer. This short cut was possible because of the multiple function features of the Window NT environment and the versatility of the InFoCAD Pro GIS program and companion InFoTran bridge program. The study team was joined by a computer engineer from Software Innovations and a computer program in C++ was written by a member of the study team to retrieve the signals received and input them into the InFoCAD program. In the operational environment it might be important to retain a record of bus locations in data form. If so, a communications data retrieval computer will be needed.

A test was performed in Ames using the study team's laboratory as a central base station and a car as a surrogate paratransit vehicle. Locational data was successfully received and transmitted to the GPS base station. Fixes were displayed on an Ames Map. Subsequent tests involved tracking Ames Cy-Ride buses along fixed routes and displaying that data on the Ames map. Although not performed in Des Moines, the operational test demonstrated 1) the viability of the proposed equipment configuration, 2) the potential of the InFoCAD GIS software, and 3) underscored the importance of the radio/modem compatibility. It also highlighted the significance of the software which enables GPS signals to be relayed to a base station and conveys it to a display map. The potential for combining other information with the GPS-derived fix data is tied to the level of flexibility built into this software. The software developed by Software Innovations left the door open to adding on a variety of other location-specific data such as passenger counts and fare box tallies.

SYSTEM INTEGRATORS

Table 3 lists the equipment which the study team identified as appropriate for a GPS tracking system for the Des Moines MTA. The team also began developing software which would enable communication and provide for a display of vehicle tracking at the base station. DM-MTA had determined to proceed with a pilot AVL system. But going from a prototype developed by a university study team to actually installing and maintaining it for a bus company is a major step.

Given the complexities involved in developing a GPS system for transit, a number of transit companies have elected to contract with systems integrators (SI) who are responsible for custom designing a system for a specific client. A good SI is entitled to professional scale fees and the transit company becomes dependent upon the SI for advice, training, non-routine maintenance, and system upgrades; especially for the "black box" core receiver package and accompanying proprietary computer programs.

A small transit company might not be able to engage a full time systems integrator. Companies like Westinghouse and Harris are in the field. Others, like Trimble and Motorola, which supply the full GPS package, are expanding into systems integration. Westinghouse currently is serving as integrator for Denver and Milwaukee. Harris is developing part of a GPS system for Dallas. The chart in Table 4 lists the equipment used in Milwaukee. Another operational test of similar equipment is Travlink, part of the integrated Guidestar Project in the Twin Cities. This project involves 80 buses and focuses on the I-394 corridor. Cost estimates for the 80 bus demonstration exceed $2.5 million. Outfitting the full 900 bus fleet is estimated to cost over $6 million. The project uses the Westinghouse Smart Rock system and Motorola radios. All of those projects are partially supported by demonstration funds from the Federal Transit Administration.

There is a middle ground which this project team has explored. Having worked through the various aspects of both hardware and software needed for a basic AVL system that will track both fixed-route and paratransit vehicles, the study team began looking for an integrator that met several criteria:

- competent and experienced— interested in installing a basic AVL system for a small transit company
- capable of overseeing initial maintenance and debugging of the system
- dedicated to low-cost-with-quality objective and interested in long term financing
- dedicated to open system and software architecture—allowing a small transit company to expand the system incrementally in fleet size and features.

A small SI was recommended by COLTS (County of Lackawanna Transit System) in Scranton, PA. Auto-Trac. was contacted and assisted the study team in conducting a field test of the components of an AVL tracking system. This provided an opportunity to work with an SI and to observe the benefits of using their

TABLE 4

MILWAUKEE'S AVL SYSTEM EQUIPMENT

1) **Central Controller** (makes system smart)
   manufacturer: Motorola
   model number: T5272

2) **Control Station Computers** (qty= 2)
   manufacturer: Hewlett Packard
   model number: 9000-827

   Software: Westinghouse "Smart Track"

3) **GPS Receiver**
   manufacturer: Trimble
   model name: Tiger
   model number: 16634-10

   GPS Differential: model number 16900-76

4) **Control Station Radio**
   manufacturer: Motorola
   model name: Spectra C7
   model number: D35KGA5JC7AK
   spec. info: 800 MHz, 15W

5) **Bus Radio**
   manufacturer: Motorola
   model name: Spectra C7
   model number: D45ZXA5JC7AK
   spec. info: 800 MHz, 35W

6) **Radio Modem**
   manufacturer: Motorola
   model name: UDS
   model number: V3225

7) **Radio Antenna**
   manufacturer: Yeagy
   model number: TDF6311A

- system cost = $7,880,000

- based on 582 buses
  currently installed on 300 buses
  goal: to be installed on 626 to 630 vehicles

Information supplied by Ron Rutkouski at Milwaukee Transit

experience in interfacing GPS receivers and communication equipment. The team also noted the benefits of working closely with technicians familiar with fine tuning the system components. Those services are invaluable to a small or mid-sized transit company which does not have an in-house staff for developing computer programs needed to interconnect and debug the system. These benefits must be weighed against preferences for features not found in equipment used in the Auto-Trac solution.

Auto-Trac, Inc., was founded in 1990 in Dallas, Texas. Its business concept is to provide fleet tracking and management systems utilizing the NAVISTAR Global Positioning System as a navigational aid. In May, 1994, it became a wholly owned subsidiary of E-Systems Corporation, a company known primarily for development of flight controls for commercial airlines, shipborne radios, and military command and control systems. The Auto-Trac Fleet Service AVL System is a fleet tracking and management system developed for commercial fleets. It features in-vehicle tracking and a control center that consists of PC compatible computers on which locations of vehicles are displayed at a customer's dispatch or communications center. Data obtained from the GPS satellites are received in the VTU (vehicle tracking unit) in the vehicles and transmitted to the control center using radios or cellular telephones. The Scranton operation is unique in that it includes an annunciation system which announces key bus stops in keeping with the ADA requirements. In addition to the COLTS installation in Scranton, Auto-Trac also has installed a functioning tracking system for KFOR-TV of Oklahoma City, Oklahoma.

The working system which Auto-Trac supplied for use as a demonstration by the study team included:

- the Auto-Trac designed VTU which incorporated a ten-channel receiver from Magellan Systems Corporation of San Dimas, California
- a GPS receiver
- Johnson half-duplex analog radios
- Data-Radio modems
- radio antennas
- a 12-volt power supply from Radio Shack
- a variety of connector cables

Auto-Trac also loaned the study team its own tracking software.

This set of equipment was not necessarily the same as would be installed in an operating bus system because each company has the opportunity, within limits, to request use of specific pieces of equipment. For example, COLTS specified SPECTRA radios. Those added to the cost but had the built-in modems discussed earlier. The Magellan GPS receiver is a low cost solution and is generally used by Auto-Trac. However, it is an OEM board and could not be easily integrated into the equipment which the study team had independently selected.

The study team had proposed the more rugged Kinetic STD-32 card-based GPS receiver based on the Navcore V chip set. The study team continued to use the computers it had proposed for the base station and developed its own software for

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displaying data received from the communication system on its own GIS display map. Typically, Auto-Trac uses its own Fleetservice Mapping Controller which includes an Intel 486 computer with 8 MB internal memory.

By using the Auto-Trac system, the study team was successful in tracking a moving vehicle in real-time and reporting its location at a base station. The study team then developed its own C program for displaying the reported data points in relation to a display map. The next step required the study team to show the path of the vehicle on a map using the InFoCAD GIS software. Having completed post-mission processing, the team moved ahead to develop software which would relay the position of a vehicle and show its progress on a computer display made by using InFoCAD GIS software.

Although Auto-Trac typically uses software from MapInfo in Troy, New York, for its geo-graphic display, the study team continued with the InFoCAD Pro software. MapInfo provides an adequate geographic display but does not permit actually incorporating the location points into the map and assuring the accuracy of reporting that comes from use of a true GIS system. With MapInfo, the city map acts as a background over which the bus track is displayed. As indicated in the section of this report on displays, the virtual pan feature of InFoCAD makes it possible to view the entire city and then zoom into a specific subsection of town. Since the bus location points are integrated into the map, they will remain accurate no matter what projection level of the map is shown. This allows following a bus over its entire route or zooming in to a particular transfer point without having to refresh the screen to show different background maps as the bus moves through the city. This can be particularly important in tracking vehicles enroute to an emergency. InFoCAD will also enable a transit company to use the same display for networking, thereby enhancing the effort of the paratransit dispatcher.

Specifically, the efforts of the study team were as follows: The GPS signals, which were received by the GPS receiver on the moving vehicle, were conveyed via radio to the base station where they were received by a matching radio unit (antenna, radio, and modem) and conveyed to a host computer (486 DOS PC) via RS232C port. The data was collected every twenty seconds and stored in a flat file with an HST extension. The twenty second interval was used in this experiment to permit use of the same radio to verify location by voice communication. The interval could be reduced to three seconds in operational mode.

Plans called for data transfer from the computer receiving the digital fixes to the computer with the display map via an assembly language program written by a member of the study team. The assembly language program was written to access the input port and put the data into a buffer where it could be used for further manipulations. The stored data is a set of records, each 89 characters long, corresponding to a point in the route of the moving vehicle. The latitude and longitude of those points could then be extracted from each record by using a routine written in C language. The latitude and longitude of the points are converted into their respective x, y coordinates by using another routine. The final step is to plot the x, y coordinates on the computer-based display map using InfoTran, an InFoCAD sub-program. Hence the movement of the vehicle would be seen as a

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series of points on the map along the actual route reported by the vehicle. Problems were encountered in transferring the data received in the Intel 468 computer to the display map computer which was using a Windows NT environment. More work would be needed to adjust the output protocols of the AutoTrac software to enable a full interface with a GIS display using a Windows NT environment.

By building upon the experience of this integrator, who shared the interest of the study team in keeping costs low, providing for incremental additions to the fleet, and longer term financing, the study team was able to complete the initial field tests proposed for this project. Decisions on a pilot project to be mounted on Des Moines MTA vehicles must be made in light of the options presented. Engaging a systems integrator to install and monitor an AVL system will be less risky. It will probably be less expensive in the long term to buy a complete system package which has been integrated and proven in the real world than attempt to modify one piecemeal by variously substituting prototype hardware or software.

APPLICATION TO A RURAL AREA

Having considered the application of AVL to both fixed-route and paratransit operations, the team turned its attention to the rural area surrounding Des Moines.

The Des Moines metropolitan area includes about 200,000 people living in Des Moines and a number of satellite communities in central Polk County, Iowa. Recent population growth has seen suburbs develop in nearby Warren and Dallas Counties as well. Yet Des Moines is still wedged into the rural setting so typical of Iowa. Corn fields surround the city on all sides. None of the surrounding suburbs has a population over 50,000, the threshold for urban designation by the U.S. Census. Public transportation in the surrounding counties and in much of Polk County is provided by rural transit services, all of whom receive public transit funding (Section 18). Each county has its own transit service and the nine counties surrounding Des Moines are coordinated by the Heart of Iowa Regional Transit.

There are no scheduled transfers between or among these rural systems and the Des Moines MTA. Individual intercounty transfers are arranged by telephone and two-way radio. The county systems operate on an advanced call/subscription basis and trips are planned by the dispatcher the night before. Last minute calls are inserted when possible but are difficult to arrange given the size of the area served and the fact that most of the operating time is absorbed by regular many-to-one trips to nutrition sites and developmental workshops.

In many ways these rural demand-responsive systems are very similar to others in Iowa and other states as well. Table 5 shows they are small (average < 10 vehicles). Although their services are available to the general public, they are generally designed for senior or disabled citizens. A review of these systems affords an opportunity to consider the broader relevance of AVL to small rural systems.

As with fixed-route systems, it is essential that a rural demand-responsive system identify problems and needs and determine whether a technology could address those needs. The ultimate question is whether the investment is feasible and wise. The problems listed in Table 6 were compiled during telephone interviews conducted by the study team and show commonalty on some key issues. In general, the concerns of rural paratransit operators can be grouped as follows:
- the need to increase vehicle operating efficiency
  - by increasing vehicle performance
  - by regularizing maintenance schedules
  - by anticipating problems requiring vehicle down time
- the need to increase operational effectiveness
  - by responding to the needs of "will call" patrons
  - by permitting real-time trip insertions
  - by reducing response time
  - by assuring driver schedule adherence
  - by responding to the challenges of the ADA
  - by permitting interline transfers
  - by enabling schedule adjustments.

TABLE 5

DEMAND RESPONSIVE RURAL PARATRANSIT PROVIDERS
HIRTA AREA

County	Transit Provider	Service Description	Fleet Size
Boone	Boone County Transportation	5 days/wk, 24 hr advance notice county-wide service for senior citizens and the general public; 6 days/wk, 24 hr advance notice service within Boone	6 buses 5 vans
Dallas	Home Care Services Inc.	24 hr advance notice service throughout the county and adjacent areas	2 buses 6 vans
Jasper	Progress Industries	5 days/wk, 24 hr advance notice service for senior citizens and the general public; 7 days/wk, 24 hr advance notice service within Newton	7 buses 4 vans
Madison	Madison County Service for the Elderly	5 days/wk, 24 hr advance notice county-wide service for senior citizens and the general public	1 bus 4 vans 1 minivan
Marion	Marion Community Action Center	5 days/wk, 24 hr advance notice county-wide service for senior citizens and the general public	4 vans
	Christian Opportunity Center	7 days/wk service for general public and disabled; 7 days/wk 24 hr advance notice service within Pella	3 buses 4 vans
Story	Heartland Senior Services Inc.	5 days/wk, 24 hr advance notice county-wide service for senior citizens and the general public	7 buses 5 vans 1 station wagon
Warren	Red Rock Area Community Action	5 days/wk, 24 hr advance notice county-wide service for senior citizens and the general public	3 buses 5 vans

TABLE 6

PROBLEMS/NEEDS IDENTIFIED BY PARATRANSIT PROVIDERS

1) Difficulty reaching drivers while drivers are away from their vehicles
(Wichita Transit Authority, Wichita, KS)

2) Occasional difficulty in reaching drivers by radio due to "dead spots"
(Wichita Transit Authority, Wichita, KS)

3) Tracking vehicle maintenance
(Boone County Transportation, Boone, IA; Heartland Senior Services, Ames, IA; Madison county Services for the elderly, Winterset, IA)

4) Assistance with dispatching for demand response calls
(Heartland Senior Services, Ames, IA; Wichita Transit Authority, Wichita, KS)

5) Assistance with billing and reports
(Wichita Transit Authority, Wichita, KS)

6) "Street" supervision of drivers
(Heartland Senior Services, Ames, IA; Wichita Transit Authority, Wichita, KS)

7) Increase ridership
(Mayflower Contract Services, Rancho Cucemonga, CA)

note: Wichita Transit Authority has acquired PtMS computer assisted routing/scheduling/dispatching software by Automated Business Solutions, which has helped with their dispatching, billing, and reporting problems.

Most of these needs can be addressed either directly or indirectly by AVL but that is certainly not the only solution. For example, drivers could be reached by a two-way radio, cellular phone, or a pager. There are less costly alternatives to AVL that might well address the primary concerns of individual rural operators.

Before selecting an alternative solution there are a number of key considerations that must be addressed including:

- size of the transit system
- extent of the service area
- complexity of operation
- capability of maintenance staff
- data collection requirements
- funding level available

Since the installation of a computer base station is required for any AVL system and the cost per vehicle is incremental, it is not economically feasible for a very small system to invest in an AVL system. One base station can easily manage 100 vehicles but a similar base station would still be required to manage a fleet of six vehicles. As indicated above, if the cost of a base station were distributed among ten vehicles along with the cost of the on-board equipment on each of the ten buses, the cost per bus would be over $8,000, while the cost would drop to about $5,500 per bus for a fleet of 100 buses. For a rural bus base station, savings could be achieved primarily by eliminating one computer and monitor. Table 3 includes separate computers for fixed route and paratransit. Here only one of these would be required.

The size of the service area is also critical since lower cost radios are often lower power or lack sophisticated design features and require more repeater stations if signals are to be received with the signal-to-noise quality required by AVL. Repeater stations consist of antenna, computer, and duplex radio and boost the overall cost. A skilled electronic technician is necessary to troubleshoot AVL communications systems.

AVL can generate a large number of reports. The number and nature of reporting requirements are best reviewed before a system adds AVL. It is possible for a small system to be inundated with data. Funding estimates must be made and sources identified. AVL systems require considerable continued investment. An assessment of the length of pay back time is critical before a small rural operation should proceed with AVL. If the operation involves largely a subscription list of travelers who travel within a defined area requiring a limited number of transfers, it may not be necessary to know the precise location of all vehicles at all times.

Lower cost alternatives that address some of the needs of rural operations include:

- a fleet manager program
- a dynamic scheduling program

Fleet Management

Fleet management systems are widely used in the trucking industry. They provide accurate, dependable information on driver performance, route and stop analysis and vehicle performance information. Data is logged during the trip and downloaded when the vehicle returns to base. Although this does not provide real-time tracking, the reports contain sufficient information to schedule preventive maintenance, to plan routes, and assess driver performance. Fuel analysis reports monitor fuel consumption. Other reports provide information on vehicle and driver history and reminders on preventive maintenance. The reports are easy to read and can be collected over time to show trends and long-term performance summaries.

The same kinds of information can be valuable for small rural demand-responsive operations which are managed without an in-house maintenance staff. Data is gathered by on-board sensors and downloaded to a computer at the base station. It is then analyzed by off-the-shelf software programs and presented in easy-to-read graphics. It could assist a rural system in anticipating maintenance problems and help reduce breakdowns in remote areas.

Fleet management systems can be linked with AVL systems by regularly relaying vehicle performance data in conjunction with GPS-generated vehicle location information over a radio communication system. For a small rural operation, however, a full scale AVL system may not be economically viable. An independent fleet management system might be all that is needed to address the most critical problems of monitoring vehicle performance. Without the requirements of GPS installation and digital radio communication, the cost would be far more reasonable and could be operated with fewer personnel than are required to operate and maintain an AVL system.

Dynamic Scheduling

Dynamic scheduling is time-specific rather than location-specific like AVL. It differs from a typical scheduling system in that it provides for real-time insertions into the pre-established schedule. It is a program increasingly used by taxi cab companies to assign trips to cabs located closest to the caller to increase efficiency and reduce the "scooping" of fares by aggressive drivers.

For paratransit, it can build off a subscription list and include passenger-specific characteristics affecting travel time. Although such a program does not provide real-time tracking on individual paratransit vehicles, it derives location based on typical travel times between points. Map displays show vehicle location within zones and can be updated using confirmation calls from drivers after completing pick-ups. Trips can be inserted permitting "real-time" schedule modification. Data collection reflects "real-time" updates and can be stored and used to improve future scheduling. When the Santa Clara, California, paratransit operation installed such a system, the scheduling process improved from hours to minutes and efficiency increased proportionally. Santa Clara is a broker operation for a number of smaller paratransit operations. Dynamic scheduling has permitted efficient interrelating of the participating paratransit operations. Santa Clara plans to add an AVL component

to this system. Given the size of combined operations this will probably prove viable.

For small rural systems, a dynamic scheduling program might prove valuable for inserting trips and entering regular updates on vehicle location. Pre-established trip times between and within towns could be fed into the system to provide a type of zonal networking. Vehicles could report to base with standard message codes following each pick-up, giving the dispatcher a clearer idea of actual vehicle location and loading. Dynamically updated schedules could increase operational efficiency while reducing passenger anxiety with "close to real-time" pick-up information. The cost of dynamic scheduling programs vary but the chart in Figure 12 indicates the range of possibilities.

Dynamic scheduling does not replace AVL because it cannot report actual vehicle locations. A small paratransit operation in Oakland, California, is working on a pilot project using dynamic scheduling in association with AVL. Although that operation has only eight vehicles at this time, an expansion to provide the complementary paratransit service needed for the city of Oakland is planned. Such expansion would justify the expense involved in a full real-time operation. For a typical small rural operation, however, dynamic scheduling alone could improve its ability to insert trips. The additional benefits gained from real-time vehicle tracking would need to be weighed against the considerable costs involved in acquiring an AVL system.

Coordinated Operations

An alternative approach, using AVL, would be to assemble the critical mass of about 35 vehicles by linking several county operations which would share a common base station. Real-time location information could be received for all vehicles in the various fleets at the common base station and relayed to cooperating dispatchers on an exception reporting basis. Identifiers would be used to insure that each subscriber only had access to locational information regarding its own fleet. A joint effort by a number of companies to build a combined fleet large enough to warrant an investment in an AVL is worth exploring for the counties ringing a metropolitan area.

A privately-operated system, TELETRAC, uses a ground-based triangulation method to track the vehicles of subscriber operations in Riverside County, California. Subscribers install a vehicle locator unit in each vehicle and a PC computer with a proprietary GIS mapping program at their individual base stations. For a charge of about $1.50 per day per vehicle, it is possible to track an entire fleet to +/- 150 feet accuracy. A computer key stroke at the base station of any subscriber is sufficient to bring up the location of an individual bus or a fleet of buses within seconds. The system does not track the forward progress of all vehicles, but allows for insertion of trips and regular observation by the dispatchers. Built-in passwords insure that subscriber files are maintained in confidence. The system provides a panic button on each vehicle which is most helpful for systems operating in remote rural areas. PAC-TEL TELETRAC operates in California and several urban areas outside the state.

An Iowa company (Omnistar) is exploring the idea of developing a commercial satellite system to relay location information to subscribers. They propose to operate and maintain the base station and subscribers would receive precise information about the location of vehicles by querying the common base station. The Omnistar system would provide far greater precision than the tracking system which the commercial tracking service, Qualcom, currently operates nationally for commercial vehicles.

It is already possible for rural transit companies in Iowa to lease radio equipment and the use of an established communications network. Fairchild Communications provides subscription communications services over a large portion of Iowa. It could save small operations big headaches to lease existing radio communications networks to relay GPS/AVL signals.

The subsequent project being pursued by this study team, *Linking Real-time and Location in Scheduling Demand-Responsive Transit*, will address the issue of funding for rural transit more completely. The need for regular and precise information on the locations of buses in rural paratransit operations may provide the impetus for furthering intersystem coordination and achieving the economy of scale that allows upgrading to smart high accuracy location systems.

Having considered the possible application of AVL to both fixed-route and paratransit operations in Des Moines, the study team turned its attention to the potential application to the rural area surrounding Des Moines.

CONCLUSIONS

A project like the one presented in this report probably raises more questions than it answers. An important underlying theme was the need of each transit operation for precise locational information. AVL, specifically GPS, can help insure on-time transfers between fixed route vehicles and complementary paratransit vehicles—one of the initial points of inquiry. It can also increase schedule accuracy and improve reliability of service. Historic data generated from GPS can be used to monitor vehicle and operator performance and also to modify schedules. It can pinpoint vehicles in emergency status, thereby improving driver and passenger safety. For paratransit operations, it can facilitate inserting last minute call-in trips.

Operators must decide what purposes are most critical to them and weigh the level of costs involved. This project set out to determine whether it was possible to develop a low cost system that a mid-sized city could afford. We attempted a careful analysis of each piece of equipment needed for a GPS/AVL system. We explored the potential for saving money at each step of the process. The findings were somewhat inconclusive. It was possible to build a laboratory prototype that would receive GPS signals for about $2,000 per vehicle. The cost of radios and modems added to this figure. Costs of computers for the base station also would be distributed over the fleet. And costs for prototypes can mask "real world" operationally-durable system costs related to logistic support, reliable communications, etc. The size and quality of displays can heavily impact budgets. Installing a very low cost system could simply postpone these very real costs that over time make the system more expensive than one that was higher in quality and price. If the transit company lacks an in-house computer-competent maintenance staff, the need for a systems integrator becomes more imperative.

Consequently, the project also explored the potential for hiring a cost-conscious systems integrator and found that it was feasible albeit with some potential tradeoffs in the flexibility for adding other data gathering, reporting, and analysis functions at a later date.

Ultimately, the Des Moines MTA did elect to proceed with hiring a cost-conscious systems integrator to develop a pilot application including ten vehicles, four fixed route and six paratransit. Plans called for incremental additions of GPS to the rest of the fleet. An RFP developed by the MTA attracted four venders who offered a variety of technologies, ranging from dead reckoning with GPS verification to full GPS. Bids ranged from $139,578 to $182,836. The primary differences in cost were in the set up of the base station which ranged from $32,000 to $70,000 reflecting the preferences for PC or workstation solutions. Costs for proposed on-bus equipment ranged from $2,350 to $4,360 per bus, not including costs for installation and, most important, not including the cost of radios. The comparable costs as estimated by the study team were in the same range $3,893 for on-board equipment without the radio and $32,497 for the base station. In July, 1995, a contract for the 10 bus pilot was awarded to AutoTrac.

Can a small or medium-sized city acquire a low cost GPS system for its transit system? The answer is a qualified yes, it is possible. However, the key is whether the GPS system they can afford would: 1) address their needs, 2) be maintainable, and 3) be expandable at a later date. They also need to consider how they will complete the installation and train staff.

Investigations of variations in requirements of rural public transit were begun in this project. More thorough cost analyses await the conclusion of the follow-up project on smart linkage. The issues include:

- clarifying objectives to be served in the application: fleet management, real time scheduling, or location verification

- assembling a viable unit for purchase of an AVL by coordinating several small agencies

- developing a subscription service for location monitoring or radio networking

Further examination of cost/effective models for these alternatives is the focus of the smart linkage project being pursued by the same study team.

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