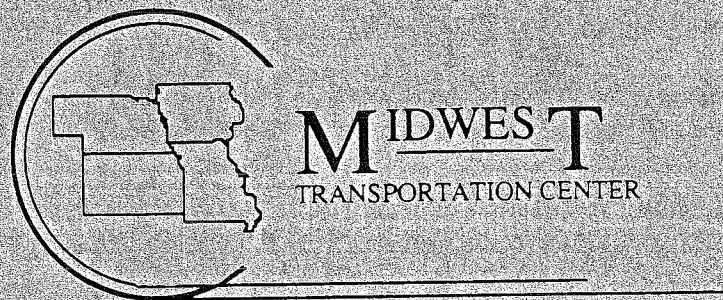


IMPROVING INTERBUS TRANSFER WITH
AUTOMATIC VEHICLE LOCATION
YEAR ONE REPORT



AUGUST, 1993

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**SUBMITTED BY
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AUGUST, 1993

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FORWARD

This paper is intended as a first year progress report on a two year project addressing the parameters of the issues involved with interbus transfer using AVL. Since completing this paper in August, 1993, the study team has focused extensively on the equipment issues discussed herein. An updated report will be available by August, 1994.

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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 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 a 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 affect 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. Cities where full turnkey

operations are now being developed are relying on heavy federal subsidies. For smaller transit companies to explore the potential of using AVL will require gradual implementation as funding becomes available. A critical issue is insuring that they will have a workable system at the various stages of development and that they do not invest in one part of an operation that will become a "white elephant" by being unable to be later incorporated into a wider AVL system.

The current study is intended to contribute to this investigation in two important areas:

- first, focusing on the potential for using AVL to affect transfers between fixed route and paratransit vehicles and
- second, focusing on the application of AVL to a smaller transit operation.

Year two of this project will focus on the linkage between the urban fixed route transit system and the demand-responsive systems operated by social service agencies in the rural areas surrounding a mid-sized city.

The test site is Des Moines, Iowa, where the Metropolitan Transit Authority operates a fleet of about one-hundred vehicles along twelve fixed routes and a fleet of seventeen paratransit vehicles which offer complementary door-to door demand-responsive service.

Automatic Vehicle Locators

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. Further evaluation of installations supported by the US DOT are currently underway. They will be conducted by the Volpe Transportation Assistance Center of the US DOT. (Trimble Navigation ,1992).

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 as described in a recent publication by the Ontario Ministry of Transport "Automatic Vehicle Location and Control Systems for Small Ontario Properties," Sept. 1991 are:

- * to improve the safety and security of drivers and passengers
- * to provide more reliable service to the public
- * to allow for more efficient transit resource management
- * to 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. With AVL installed that concept is being successfully tested in London, England, which is notorious for its traffic jams. AVL also enables on-going collection and storage of historical route travel time information and refining schedules so as to more closely 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 efficiency, increased reliability, greater service to special populations while objectives might include system monitoring, schedule monitoring and/or route assessment. Goals should be prioritized, but it is essential that a focus on a short term priority not preclude a longer term objective.

One objective that is often cited is data collection and verification. Yet it is essential to determine what data are needed and for what purpose. AVL can interface with other smart devices such as passenger counters and fare collection systems and has the potential of generating reams of data regarding, for example, schedule performance, driver efficiency, vehicle engine performance, passenger counts and passenger characteristics, all in relation to real time and location. What data are to be collected and how often, and what is to be analyzed and what data are to be retained and for how long are significant decisions. Properties which already have AVL often are inundated with data.

For paratransit, objectives and data requirements are significantly different from fixed route. For example, individual passenger related data is more important to paratransit, but not even an issue with fixed route systems. What is important for an integrated fixed route-paratransit system is that the objectives remain complementary--allowing 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 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 manifest in the fundamental differences between the two different types of systems. The fixed route service is characterized by regular schedules, preestablished 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 services.

Fixed Route

For the fixed route service, problems associated with schedule reliability are the results of: 1) the operating environment, 2) driver performance, or 3) vehicle malfunction. The operating environment including 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 establish back-up plans. 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 passengers until help arrives.

Automatic Vehicle Location 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 conveyed to the driver who can take appropriate action. Any unauthorized route deviation can be quickly noted. Knowing the precise location of equipment failure or an on-board emergency can direct the quick response of appropriate assistance. The schedules themselves can also 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. The service 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 preestablished and urge twenty-four hour 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 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 preplan 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, a paratransit system with 17 service vehicles has 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 even so the system only accommodates about one thousand persons a day while a number of the time-blocks are underutilized.

If a paratransit dispatcher were provided with a computer display with icons noting the real time locations of the various paratransit vehicles, he/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, integrated complementary service. To date, however, as many as eighty percent of the paratransit trips performed are for "subscription" or regular riders generally to the same regular locations.

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 has 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 read a vehicle's geographic position fix. The signpost emits a low power beacon which can be detected by any vehicle fitted with a proper receiver. Each signpost has its own ID and the vehicle's receiver relays each signpost's ID to the control center (dispatcher). The dispatcher can then plot the exact location of the vehicle in relation to the signpost. Since the vehicle's position is only accurately known within 300 to 360 meters of a sign post, the 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 the central site. (Ontario Ministry of Transport, 1991)

Problems with the signposts 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 must be made by using a "cherry picker," equipment which the transit authority must borrow from the electric company." More concerns relate to the maintenance of the devices mounted on the vehicles themselves. These can be easily dislodged during regular maintenance or even during vehicle washing. They, therefore, need to be regularly tested and replaced. Vandalism is a concern in other cities. Weather proof cabinets are needed for sign posts in the colder climates in Canada. Other concerns rest with the limited flexibility of the system. It can only be used effectively to monitor fixed route buses and they are generally locked into a particular route. Signposts in themselves are not effective for demand-responsive paratransit. When used in conjunction with odometer reading they act as a "point in time locator" rather than as a continuous reporter of real time data.

Nevertheless, the lower costs involved as well as established consultant experience in using this type of system encourage new cities to elect this approach. For example, Tampa, Florida, is currently installing 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 figure 1 provides more detail on cities and the type of AVL which they are currently using.

Loran-C

Land-based radio navigation location systems such as Loran-C uses low frequency radio waves to provide signal coverage on land for up to 1500 kilometers. Loran-C signal coverage is provided using sets or chains of 3 to 5 Loran stations. Each 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 the knowing amount of time during which they were delayed from a reference system. Location determination is accomplished by the reception of each transmission and its associated timing. With this information the receiver can under normal conditions provide an absolute position accuracy within 500 meters, which is quite adequate for tracking buses in all but the most congested cities (Ontario Ministry of Transport 1991).

Figure 1. North American AVL Systems

City, State/Province	Vehicles	\$M	Status (as of 3/31/92)	Principal Contractor	Location	Freq.	Poll
Ann Arbor, MI	0/67	0.3	System to be Replaced	General Railway Signal	DR (+ 4S)		13-14
Baltimore, MD	900/900	11	Soon to Release RFP for Full Implementation	Westinghouse	LC or GPS		20
Champaign-Urbana, IL	69/69		In Regular Use	II Morrow	LC		
Chicago, IL	1900/1900		RFP to be issued			8	
Dallas, TX	844/844		Final Testing	ElectroCom Automation	GPS	9/2	180 *
Denver, CO	833/833	10.4	Currently Under Installation	Westinghouse	GPS	7/2	*
Fort Lauderdale, FL	192/192	2.3	Currently Under Installation	Motorola	SO	2/1	*
Halifax, Nova Scotia	170/170	1.0	In Regular Use	(Agency)	SO		30-40
Hamilton, Ontario	275/275	6.0	In Regular Use	RMS Industrial Controls	DR	3/1	30
Houston, TX	1000/1000		Designing/Building System	(Agency)	GPS		
Hull, Quebec	162/162		Testing	(various)	SO		
Lacksville, FL	180/180		RFP Issued in 10/91				
Kansas City, MO	275/275	2.1	In Regular Use	F & M Global	SO	1/1	15-30
Miami, FL	520/520		Evaluating Proposals		GPS		
Milwaukee, WI	550/550		To Begin Installation Soon	Westinghouse	GPS	2	*
New Jersey Transit	1800/1800	30.7	Currently Under Installation	Motorola	SO		*
Notfolk, VA	160/160	2.0	In Regular Use	F & M Global	SO		40
Ottawa, Ontario	40/800		Initial Testing of Alternatives	Amtech	SO		
Palm Beach, FL	74/74	1.2	Currently Under Installation	Motorola	SO / LC	3/1	60
San Antonio, TX	537/537	3.7	In Regular Use / Examining Potential Upgrades	General Railway Signal	SO (GPS?)		60
San Mateo, CA	320/320		Final Testing	Motorola	SO	3/1	
Seattle, WA	1341/1341	17	Installing Equipment	Harris Corporation	SO	2	
Shelbyville, WI	20/33	0.1	In Regular Use	II Morrow	LC	3	10-20
Tampa, FL	172/172	1.6	Installing Equipment	Motorola	SO	3/1	180 *
Toronto, Ontario	2300/2300	38	In Regular Use	Bell Radio	SO	11/31	6

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.

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.

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.

Baltimore has 50 buses being tracked by the Loran-C system. When Baltimore installed its system about three years ago 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.

Few other cities have experimented with the Loran-C approach since until recently adequate signal coverage was not available to communities in the southern part of the United States or for cities in the interior. One other city which is using the Loran system is Champaign-Urbana, Illinois. 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 1000 meters. There are also blank spots in the reporting in urban areas which high rise buildings block signals. One other transit related problem is that the florescent lights on buses interfere with the ground based-radio signals. Ultimately, however, other cities have lost interest in Loran-C since reception with long radio waves is much slower than with the newer Global Positioning System(GPS) technology.

GPS

Recently, considerably more interest is being shown in using the Global Positioning System (GPS) as a vehicle tracking system. Although no North American city is currently employing GPS in full operation, a number of cities are committed to testing it and several have begun installing it in pilot tests. Denver has a functioning demonstration with several fixed route buses already being tracked. Milwaukee plans to have a pilot project operational within the next few months. Dallas is moving ahead with its plans for an operational test in the near future. The Chicago CTA has just let bids for a major demonstration of an AVL system involving 165 buses on 5 routes initially with plans to install the system wide if it is successful. Minneapolis and Tulsa are beginning initial studies which would lead in the direction of installing GPS. Baltimore plans to use GPS when it expands its AVL system to include an additional 900 vehicles. Even Tampa which has just installed signposts plans to switch over to GPS within the next ten years.

GPS refers to a US military positioning and navigational system now available for civilian use. A full complement of twenty-one satellites are now 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 veritually anywhere in the world. However, the US 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 the confirm the location. That location is then communicated to a base station where the vehicle location is confirmed in relation to a display map. Location data is then graphed and updated using CAD software. According to the US Defense Department accuracy of moving vehicles can be assured to within 60 feet by using this system. Tests in individual cities, have, however, established much closer accuracy. Tests in Dallas, for example, established accuracy within 14 feet.

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 in reporting vehicle locations and in terms of potential for displaying information in graphic form for the riding public. It permits maximum flexibility and seems to minimize the complexity involved in maintaining a field-based system like signposts.

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 with the Des Moines Metropolitan Transit system serving as a test case.

The Des Moines MTA

The Des Moines MTA was selected as the test site for the project for several key reasons.

- * The 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. In addition, 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.

- *Proximity to the research team.

The expectation is that many of the findings of the project will also be valuable to other mid-sized bus operations which, like Des Moines, are operating with limited funding for a stable ridership .

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 one hundred cars and had nine hundred 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 and since the new freeway did not have electric trolley lines, the new company converted to diesel motor coaches causing severe financial problems and 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 (metro) and took over all assets of the IRTC. With government subsidies it was possible for Metro to replace the aging bus fleet , acquire a new facility and increase the productivity and efficiency of the system. (Baumhover, 1993)

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 associated with static information including the preestablished bus schedule.

Other components could include:

- * passenger counters
- * engine component monitoring/mechanical alarms
- * signal preference/HOV lane access equipment
- * security alarm
- * connections to passenger information systems

In an effort to develop a system that will be as low cost as possible, the current study will focus exclusively on the first three elements with the determination not to foreclose any of the other options as additional resources become available. Nevertheless, 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 costs available.

Level of accuracy

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

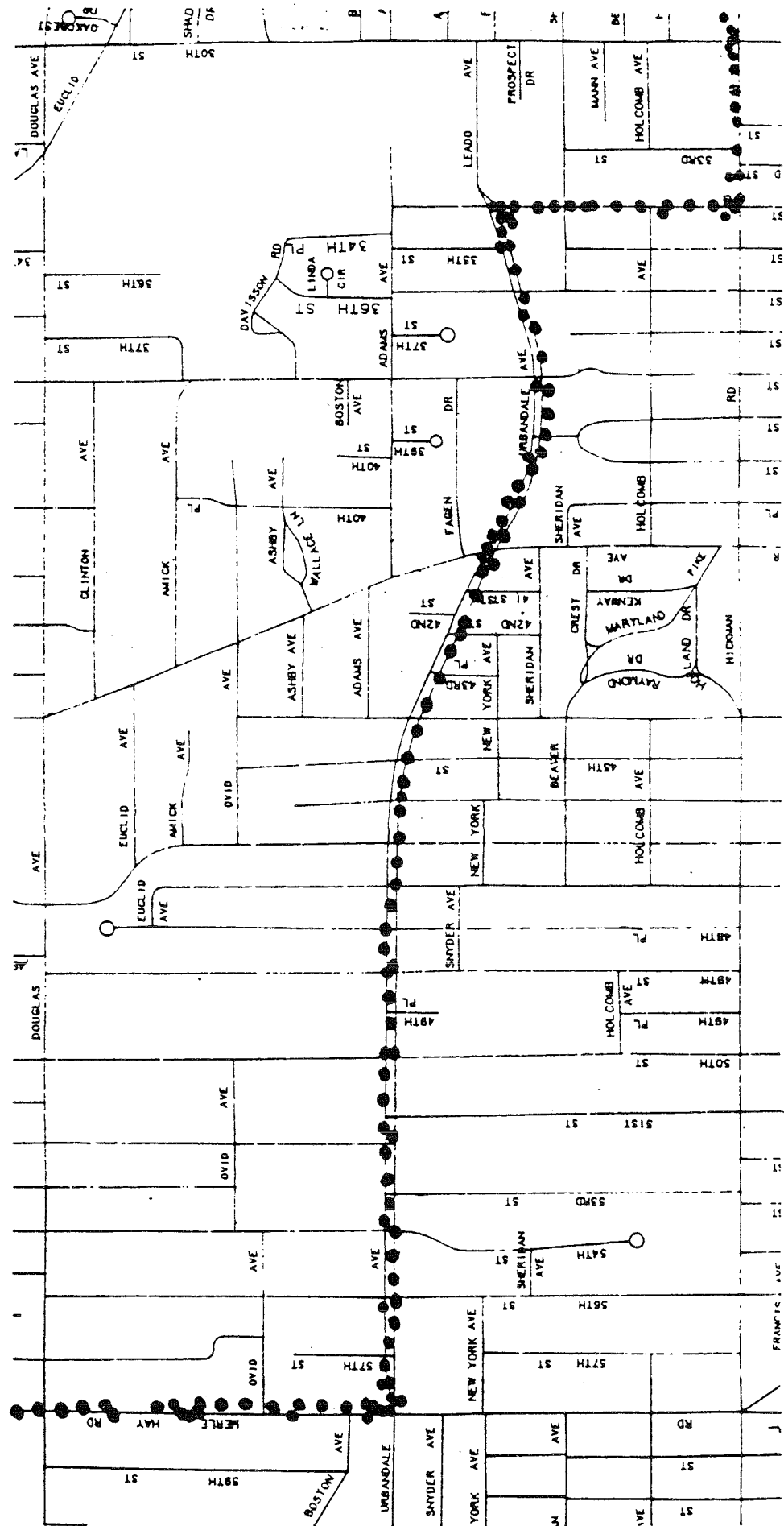
It is generally possible to track a bus within one-hundred meters of accuracy by using basic GPS. This may be adequate for a city with half-hour headways and no concern about vehicle bunching. To be assured of greater precision would require use of a differential base station. Now that the military is employing selected availability (SA) on a more regular basis the use of a differential base station has, however, become more attractive. A differential system provides a constant correction factor for 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. There is, of course, a cost involved in purchasing and maintaining the differential base station and the on-board equipment would need greater sophistication than that required for receiving the signals directly. Further analysis of the relative merits of a differential base station for a mid-sized transit operation is still needed.

For all systems there are operational requirements that distinguish tracking procedures for fixed route and for paratransit operations. Initially, the level of precision required for tracking demand-responsive paratransit vehicles is generally not as critical as for a fixed route system with a precise schedule. With paratransit, the issue is the relative position of a vehicle vis-à-vis an on-call pick up, or another paratransit vehicle. Typically 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. Hence for basic tracking of paratransit vehicles a differential base station would not be required at this time.

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 fifteen 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 a GPS tracking test was applied to fixed route buses without using differential adjustments, the location was accurately reported well within one hundred meters. In fact, the buses were tracked to within fifteen meters of actual location in all areas except in about a two block area downtown. See figure 2 for plot of GPS Tracking of Buses in Des Moines. This approach proved to be very satisfactory for vehicles operating on half-hour headways. Real-time tests and tests using differential GPS are planned for the future. The addition of differential could insure greater accuracy, but for a fixed route system with scattered routes on one-half hour headways the relative benefits would have to be closely weighed in light of costs.

The process involved in tracking Des Moines MTA paratransit vehicles would be similar to that involved in tracking the fixed route buses. Given a fairly small fleet of vehicles there would be little reason to track the trip of paratransit vehicles with any greater precision than

Figure 2. Accurate Tracking; of Yellow Fixed Route



that required for the fixed route buses. Currently the paratransit system operates with two preplanned pickups within an hour. Even if more on-call stops were to be added, tracking would generally be for relative position rather than for precise location. Hence accuracy within one-hundred meters 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 block access to GPS signals or more suburban areas with heavy foliage which also tends to block reception of satellite signals. In these areas the answer generally is to rely on dead reckoning to supplement GPS.

The recent increase in the application of selective availability (SA) to satellite reception has led to revisiting the issue of a need for a back-up system for GPS in urban areas. By using Selective Availability (SA) the US Defense Department which owns the satellites causes a conscious degradation of the code signals from the satellites. This leads to 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 for a receiver to track the same configuration of satellites consistently. These factors associated with the urban canyon frequently lead to what is known as Position Dilution of Precision (PDOP), an error factor that needs to be taken into consideration in tracking. The combination of PDOP and the signal degradation caused by the SA 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 pp. 32,34)

Dead reckoning uses odometers and compasses and assumes the forward progress of the vehicle. These systems range from a simple odometer/compass arrangement to costly gyroscope and accelerator systems. They all require an onboard data systems to calculate and maintain the relative position of a vehicle. All dead reckoning systems accumulate tracking errors which either appear as drifting or as inaccurate reporting of position. For example, dead reckoning assumes that the rotation of a vehicle's tires indicates constant forward progress. 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 dead reckoning even when corrected with occasional signposts to be very inaccurate.

Hence, dead reckoning cannot be used alone and requires either a signpost or radio-based location system to reinitialize the system. When used by fixed route buses as a supplement for GPS dead reckoning can be useful in urban canyons, however. In the Paris example indicated above, dead reckoning was to interface with GPS so that dead reckoning would fill in the gaps in the urban canyon for the GPS system and GPS would in turn help to recalibrate the dead reckoning system. That would seem to provide the ideal system. The problem is in switching back to GPS from dead reckoning which causes position jumps. One idea suggested by Fantou is to use dead reckoning as the primary positioning method with periodic use of GPS position fixes to smoothly resynchronize the system (Fantou, p. 38).

The relative value of the adding a dead reckoning system as a back up for GPS is dependent upon the distance within the urban area when the vehicle cannot receive consistent GPS signals as indicated by a high PDOP value. In some cities like Dallas, for example, the GPS signals are only blocked by tall towers for about a block at a time and the expectation is that the vehicle would report its position both on entering and departing that section of the route. Some systems only request the position of their vehicles every two or more minutes. That time is often sufficient for a vehicle to enter and emerge from an urban canyon created by an individual large office tower and then lock on to the satellites again. The key issue is --whether it will lock on to the same satellites and if not whether that will create a jump or a spike in the track. Such an issue would need to be resolved in each individual urban setting.

The benefit of dead reckoning for a paratransit demand-responsive vehicle is less apparent. Paratransit does not travel down any specific route and may weave around different streets to avoid congested areas. In general, the issue in tracking paratransit, as indicated above, is relative distance from other vehicles or specific pick up or drop off points. For either fixed route or paratransit systems the relative benefit to be gained from adding the additional system would need to be weighed against the additional cost in installing it.

In the case of Des Moines, a city with a limited number of taller buildings, it was possible to access four satellites at almost all times when following a fixed route bus route through the heart of the city. Since only three satellites are required to complete a triangulation and determine position, this was most reassuring. In fact, the fourth satellite does not improve position accuracy, but it did offer a better choice of satellites and lower the PDOP level. (Fancou, p.34). The only location where spiking or drifting in signal reception occurred was a two block area in downtown where there are several tall buildings. See Figure three for plot of GPS reporting in this two block area. That situation may, in fact, have been associated with the equipment used, rather than an indication of a real loss of accuracy in signal reception. A review of the equipment at the manufacturer is now proceeding. At the present time, however, it does not appear that the relative refinement in position recording would justify the additional cost of adding a dead reckoning back up system in the Des Moines setting.

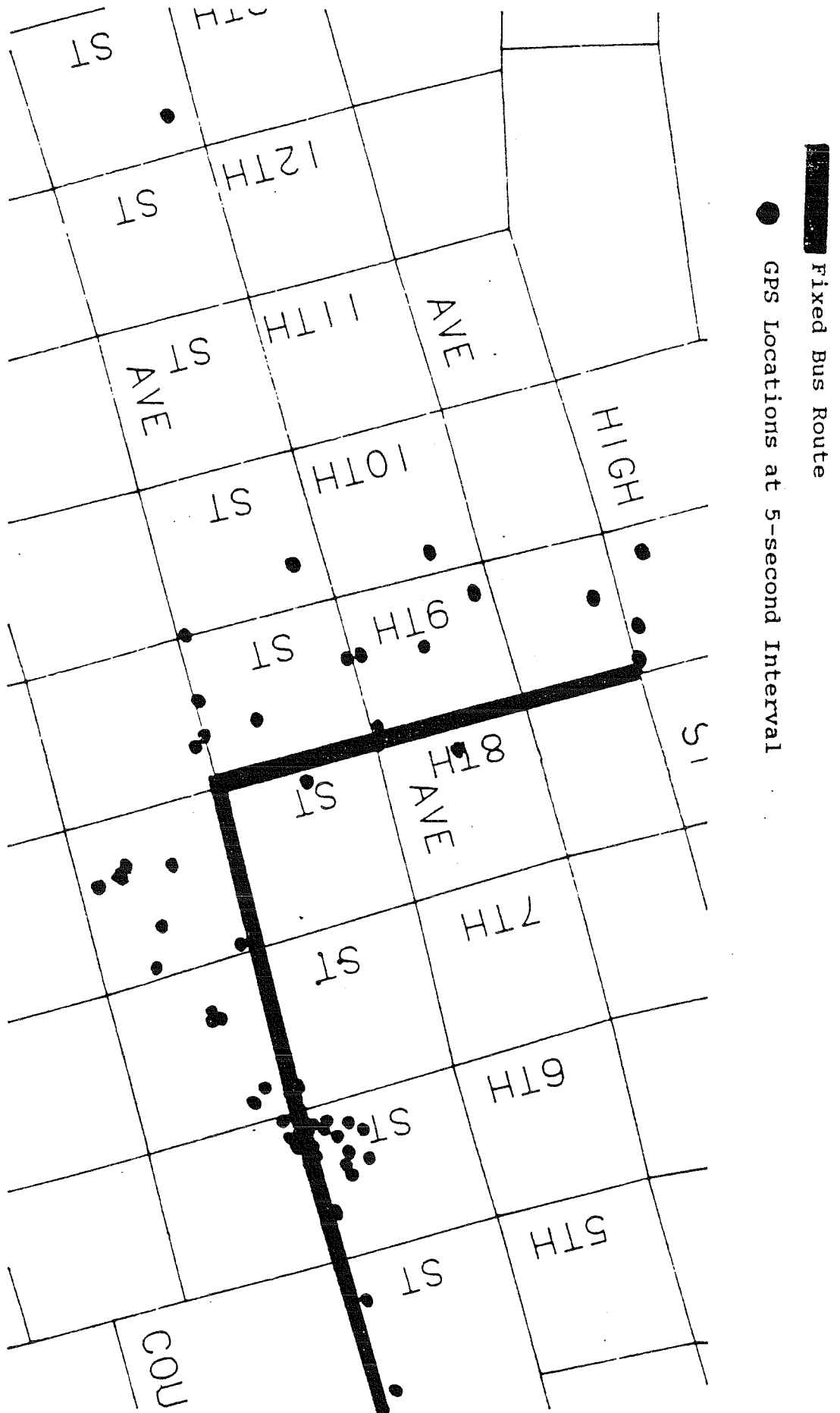
Frequency of Polling Required

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

1. Polling permits receiving of data in a legible format at the base station. Each bus generates a "packet" of data. The packets from the various buses need to be communicated **sequentially** so that the records are written into a relational data base management system (RDBMS) at the base station in a layered manner. An identifier is associated with each data packet and is used to isolate data packets for individual buses. It is illogical to attempt to receive data from the buses **simultaneously**.

2. 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 database at the base station with far more data than is required. This would slow up all related operations as all data would be filtered and processed.

Figure 3. Tracking at Downtown Des Moines



3. It permits user focus in case of emergency. Let us assume that buses are being polled every three minutes. In the case of an emergency only the buses requiring attention can be tracked frequently (every second if required) and the remaining ones can be tracked at longer intervals.

Polling is made possible with the use of 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 (radios atop buses) in a regular sequence. For example bus 1 bus 2 bus 3.....bus 100 and again bus 1 bus 2 bus 3. See figure four for concept drawing.

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 most frequently imposed by the number of radio frequencies available to the transit company.

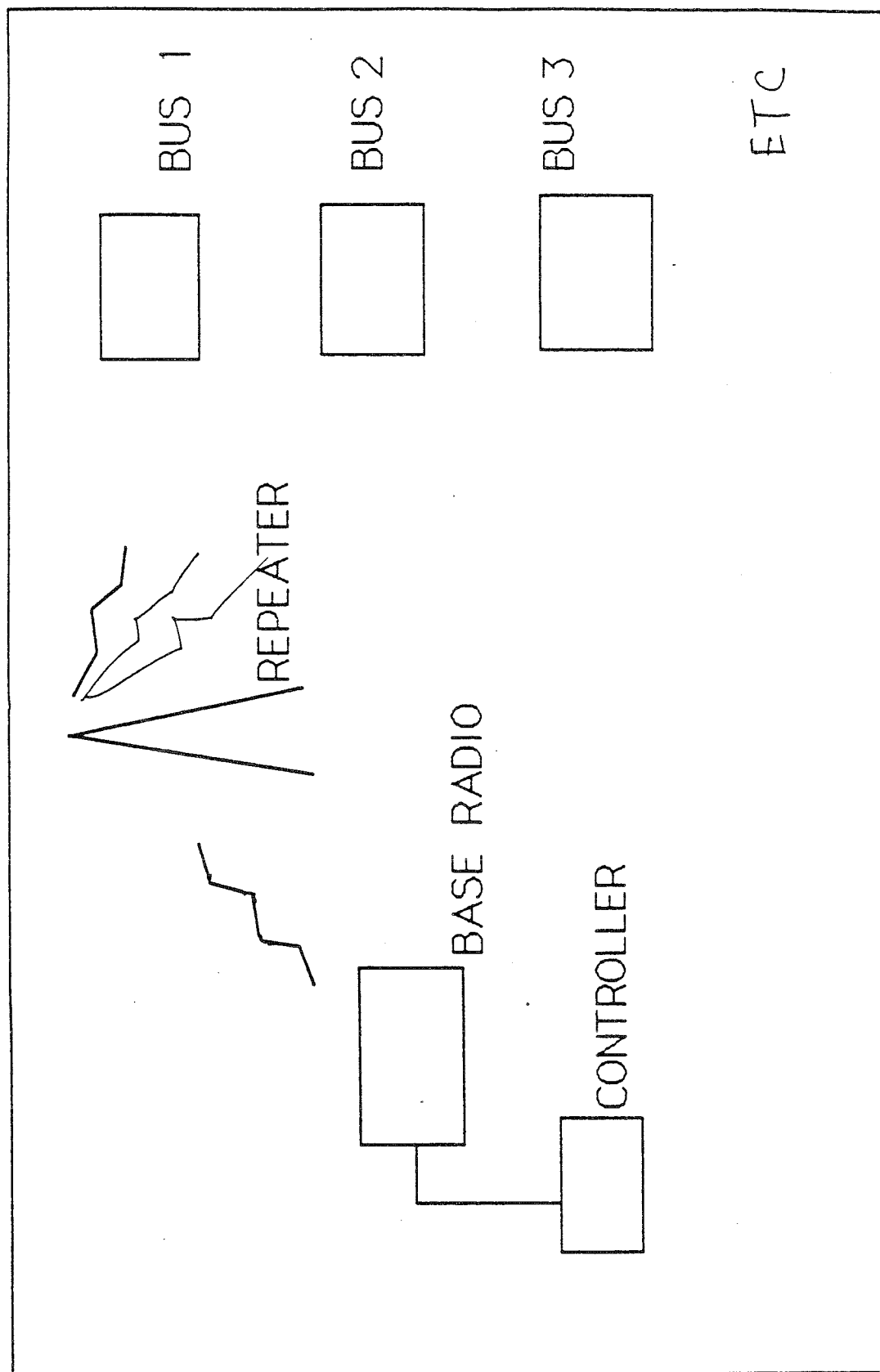
In reality, the frequency of polling needed on a fixed route system depends on the headways of the buses, the interlocking of routes, and the extent of transfers required. Some fixed route bus companies poll vehicles only every fifteen minutes. Typically, polling every two minutes would be sufficient for buses with half-hour headways operating at 10 pmh 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 which is operating outside a given set of parameters (too early, too late or experiencing mechanical or security-related problems) could be flagged and shown 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, however, turning to exception reporting because of the shortage of available radio frequencies. In addition to saving on radio frequency exception reporting avoids an overly cluttered display screen and directs full attention to a vehicle with a concern. Paratransit vehicles should also have the capability of being polled every two minutes, but their progress through city streets would only become important if an extra stop were required. Hence, they would only need to be polled on command or by exception if they missed or were late for a prearranged stop.

In the Des Moines case the location of a test vehicle was reported every second. Yet the frequency of reporting will very likely change as real time operation is initiated. The position of the Des Moines paratransit vehicles, will not usually be reported as frequently as fixed route buses; but it will be necessary to poll frequently when zooming in on a vehicle targeted for an extra pickup or trying to affect a transfer with a fixed route bus.

A Communication Device

With a GPS receiver or transponder receiving satellite signals at the requisite level of accuracy and consistency, the focus of the study turns to the process of communicating the vehicle's 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 frequency, radio type (simplex vs duplex) and baud rate. Again an over-riding factor is cost.

Figure 4. Polling Concept Drawing



Frequency

An issue of increasing importance is the availability of radio frequencies for licenses and the length the time required to process a request for a license. Most transit operations have several 400 band radios available for voice communication with drivers. Such communication is periodic with a variety of different drivers and hence is not seriously impacted by the clutter and background noise that is associated with a fairly congested type of frequency. Transmission of GPS positions, on the other hand, must be in digital form and be fairly constant across the whole fleet (depending on the agreed polling frequency). Noise would interfere. In addition the 400 band does not carry far enough to extend over the city without repeater stations. Although some transit companies try to transmit both voice and digital information over the same 400 band radio frequency, by allowing a voice override, this is not very successful especially with a large fleet. When voice overrides the digital signals it interrupts the regular reporting of position. The very brief time required to transfer the data does not interrupt voice communication with small fleets. It does become more problematic for larger fleets.

The use of 800 band radios is the move of the future, despite the increase in cost for the radios. The problem comes with the limited number of 800 frequency licenses available and the lengthy review process required to acquire one. Some cities have applied for and received 800 trunk lines which are 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. This issue of available frequencies has, in fact, determined the frequency of polling of vehicles and has prompted a number of transit operators to opt for exception polling. This assumes that most vehicles are operating within an acceptable range of schedule accuracy and those which are operating outside a preestablished set of parameters of schedule or route are identified and only those are polled frequently. With more transit companies adapting GPS the issue of available 800 frequency bands will become increasingly important.

Baud Rate

The second set of issues associated with the radio are technical. GPS receivers typically transmit data at 9600 Baud (bits per second). Lower cost radios typically transmit at lower levels --4800 Baud or lower. This leads to requirements for data reduction or data compression. One factor that may prove to be significant is that the higher the baud rate used, the lower the range of reception. Hence a baud rate of 1200 has a broad range of reception.

Basic GPS, reporting only the x and y coordinates of the buses in association with time or schedule, can be transmitted with only 1200 Baud. Transmitting the other data indicated in the expanded GPS system --passenger counting, engine monitoring, and data to passenger information systems may require a radio with a faster broadcast rate. This leads to somewhat of a trade off between cost for a more expensive radio system vs. the amount of data which is to be collected. One aspect that will be essential to tie in with GPS is a security system with a silent alarm system. This can pin-point the location of a vehicle in difficulty and emergency vehicles can be directed to it immediately. This would, however, require an interruption in regular sequential polling and may involve more sophisticated radios. The Denver GPS test has discovered the complexity of this issue.

Radio Type (Simplex vs Duplex)

Again a major issue is cost. Simplex radios are less expensive. The question is whether they can ultimately do the job. Polling is possible using simplex radios. The situations which would require duplex are:

1. Where the buses would communicate among themselves
2. Where two-way simultaneous communication is needed.

For most aspects of the Des Moines test site the use of simplex radios would seem to be sufficient. The mobiles are not expected to communicate with each other. The mobiles talk to the base station only. Any communication from base to the buses could be by the existing voice radios. In addition, data is not needed more frequently than every 5 seconds. This would allow sufficient time for simplex radios to receive the data. The only need for a duplex radio would be in conveying the expected schedule to each bus. For this purpose a half-duplex will meet the need for two way transmission of data to and from the base station

The study team experimented with a 1200 Baud radio using the 400 MHz band available to the MTA. Complexities were encountered in trying to communicate data received at 9600 Baud from the a Navcore V Rockwell GPS receiver. The team opted for data reduction using a single board microcomputer which served as a compressor. This was sufficient for transmitting X-Y positions, but questions remain as to whether it will have to be expanded to perform full data transmission. See Figure 5 for configuration considered by the study team during the first year of the project. Alternative configurations were examined in year two.

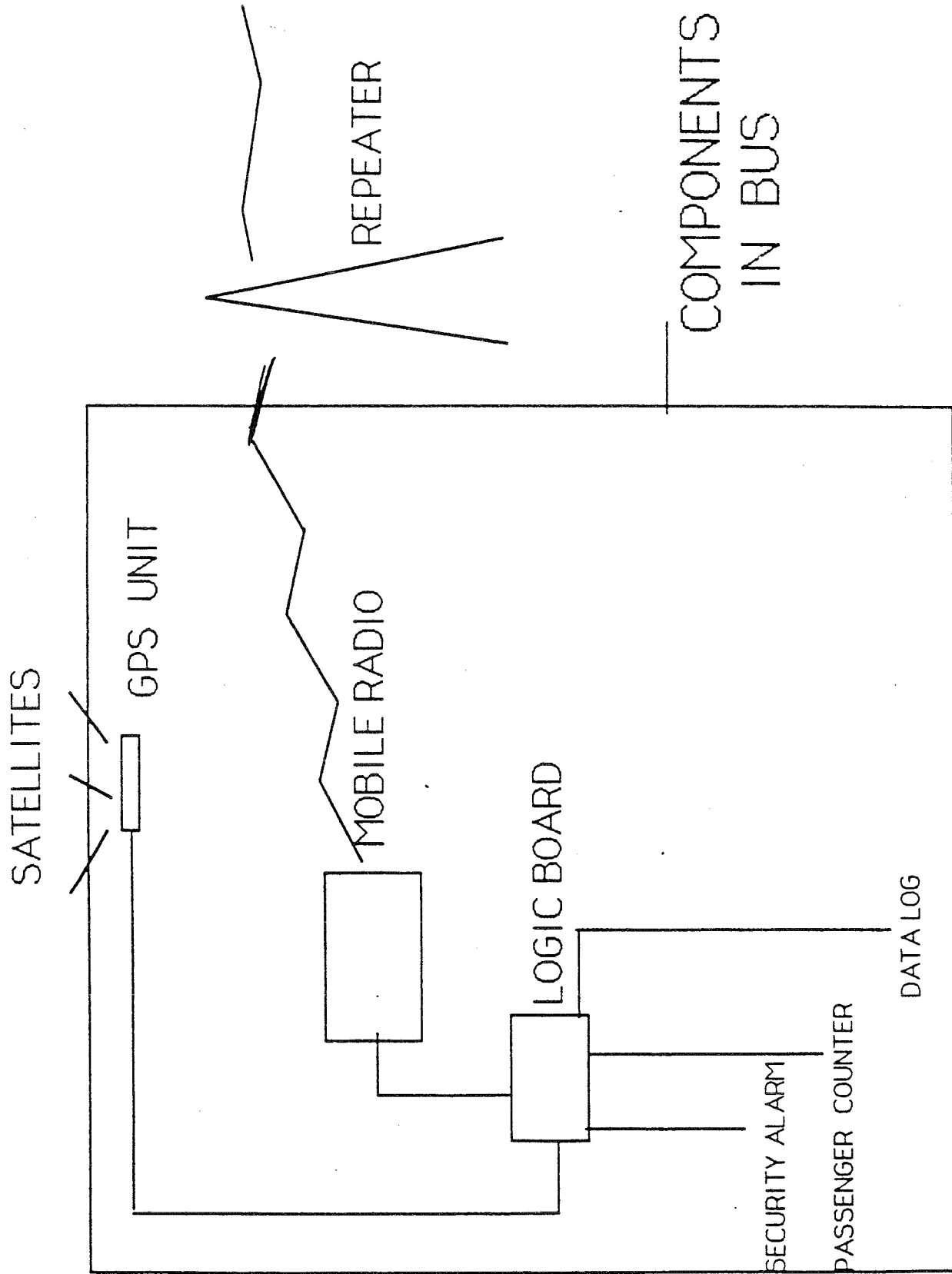
Central processor capable of storing and using transmitted information

The decisions on what data are to be collected and how often and what are to be analyzed, what are to be retained and for how long are all significant and need to be made before the central processing system is selected. Properties which already have AVL are often inundated with data which far exceeds the capacity of analysis. For example, one property has the capacity to collect data in real time on eighteen aspects of bus performance as associated with bus location. In reality however, only the oil pressure and fuel gauge are monitored because there is no staff to review all the rest of the data on a regular basis. This information is more generally downloaded once a day when the buses return to the garage.

The level and type of computer to be used for data processing and storage is largely a factor of the extent of the system, the number of components associated with the GPS system, data requirements and the type of display desired. Hence it is logical to reach agreement on these aspects 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 data bases associated with fare collection, maintenance, scheduling, and tracking. There are many transit companies which 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. UNIX allows 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. On the other hand more off the shelf software for scheduling is available for PC's. but networking software which allows for displatching is largely UNIX

Figure 5. Communicating with Buses through a Network of Repeaters Stations



based. The unix environment is also more open to the use of relational data base programs and hence is more open to adding on additional components for the system. The price difference between a PC and a UNIX-based workstation is dropping rapidly.

For paratransit, objectives and data requirements are significantly different from fixed route systems. For paratransit passenger origin and destination and personal attributes of passengers 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 temptation has been to develop objectives and make decisions independently for the fixed route service and then attempt to add on paratransit. What are needed are mutually determined objectives guiding decisions relative to vehicle tracking and the type of data to be collected, analyzed, and stored.

Display systems.

Related to the requirements for the central processor are the needs associated with a display system. 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 there are a number of transit companies which operate AVL without using map displays, the systems which are in the process of installing the new GPS systems all include map displays. Real time displays showing icons which represent bus locations provide updates on schedule adherence, vehicle malfunction, the location of vehicles with security problems at a glance. The displays can also make real time additions to paratransit scheduling a feasible concept. In fact, since display maps are very visual, they are symbolic of the new tracking systems. The decision to use a display map, however, introduces a number of issues which impact the selection of a central processor and additional issues related to computer software.

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 work stations, 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 realtime location of the buses in operation. Tests are being conducted on several of these in connection with the Des Moines project.

A critical issue, especially for the paratransit dispatcher will be to insure that it is possible 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 potentially 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. It is essential to be able to scroll through the large maps associated with a metropolitan area so as to zoom in on a specific location.

Overall 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. On the other hand, for paratransit detail is more important. It is key to be able to pan the area requested for origin and destination and to consider alternative travel routes. To interrelate displays associated with

fixed route and paratransit and to facilitate transfer would require either two adjacent display screens or potentially a window inserted into the paratransit display to show a map of the closest accessible fixed route. Both maps would need to be in the same coordinate system and be approximately equally accurate.

When dispatching is included, the specific street names would be essential so that the dispatcher can zoom in to one area of town and identify the street location of the caller requesting a ride. For a display to be useful in planning networking, it would also need to reflect topology as well as indications of major intrusions into a traffic pattern--i.e. one way streets, construction zones, prohibitions on left hand turns. Without such information it is difficult to gauge the shortest 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.

While any map could serve as base for the fixed route bus display, a paratransit display would require a far more complete map, such as the US Census 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 GPS monuments so as to insure an accurate record of GPS vehicle tracking on the display.

For the Des Moines project, two maps were made available locally--a very detailed map constructed by the Central Iowa Area Mapping (CIAM) group which includes county and metropolitan agencies and an Intergraph map developed by the Iowa Department of Transportation. (See figures six and seven for sample maps.) For purposes of this study both maps were used. The CIAM map, which was developed initially in conjunction with the GPS monuments, proved to be more accurate. However since the CIAM map, was developed to serve the needs of the utility companies, public works departments, the police and other city agencies, it included far more detail than was needed for a display of either the fixed route or paratransit services. For example, it had curb lines rather than a center line for each street. This became an issue since the map was so large and complex that it required considerable work station storage space and time to refresh the screen. When displays are drawn in real time the screen must refresh rapidly in order to be useful. Ultimately, the project made use of both maps.

Neither map available to the study team included topology. Hence no attempt was made in this first year to develop a display which could assist in networking. One lower cost option available to the team would be to institute a nodal approach to the demand-responsive trip assignment. This would involve identifying trip nodes across the city. These nodes would be distributed across the service area and associated with major trip generators or points of origin for a number of regular riders. The travel time between these nodes (or links) would be carefully calculated and used as standardized trip references. These links would then be posted in a look-up trip table and be cross referenced by street and attractor to be used by dispatchers for quick selection of "routes" for paratransit. This type of approach is currently being used by taxi companies. Paratransit vehicles would be expected to travel between nodes on preestablished streets or routes so as to maintain the times associated with each trip in the trip table. More detailed maps would be prepared and keyed in with the nodes to assist the dispatcher in allocating particular pick ups or drop offs to individual vehicles. Subscribers regular trips would be processed in advance of scheduling to assist in quick selection of routes. This system would respond to the needs for accuracy and detail associated with paratransit, but still allow the display screen to refresh rapidly. The quick

Figure 6. CIAM Base Map

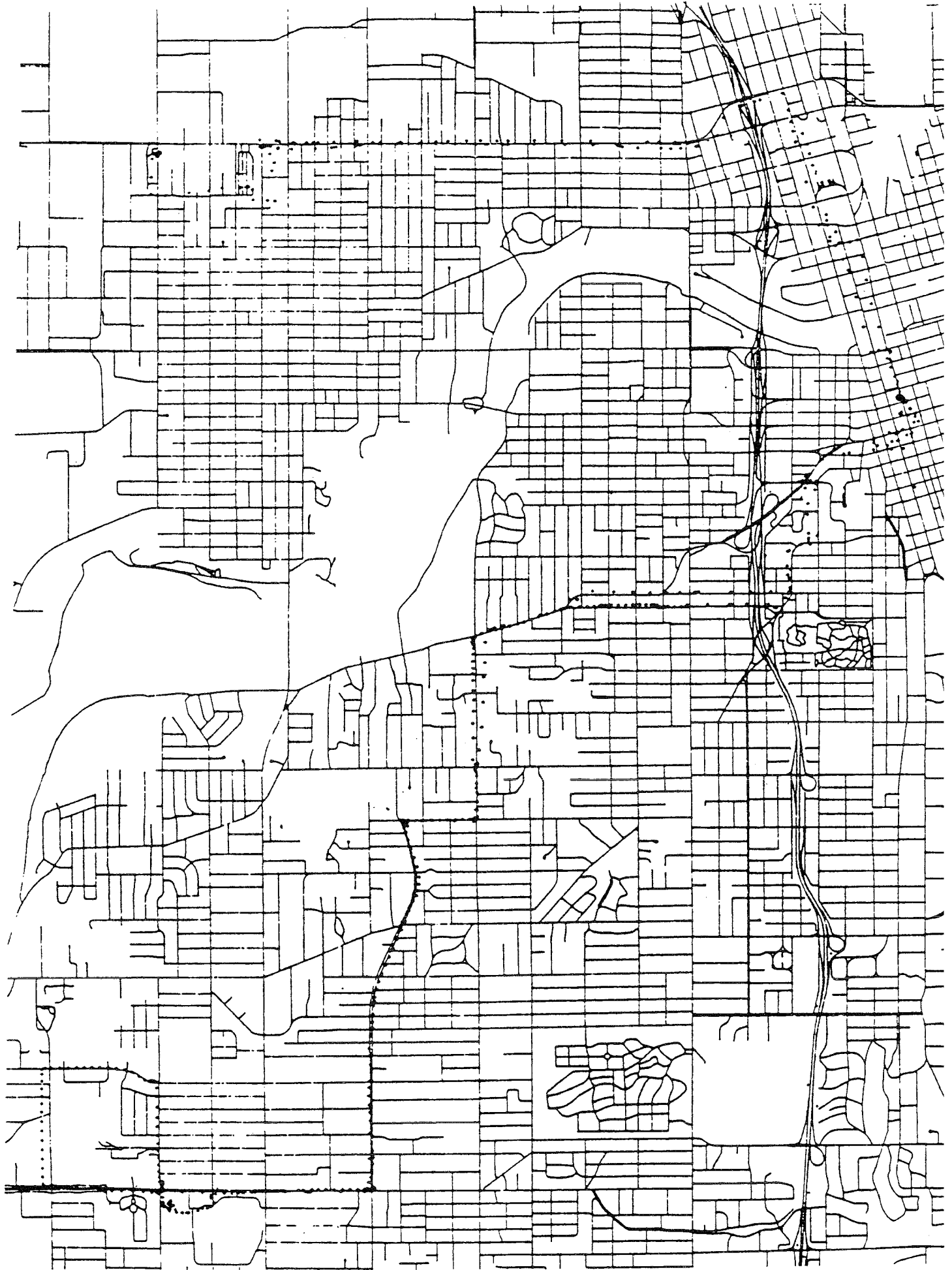
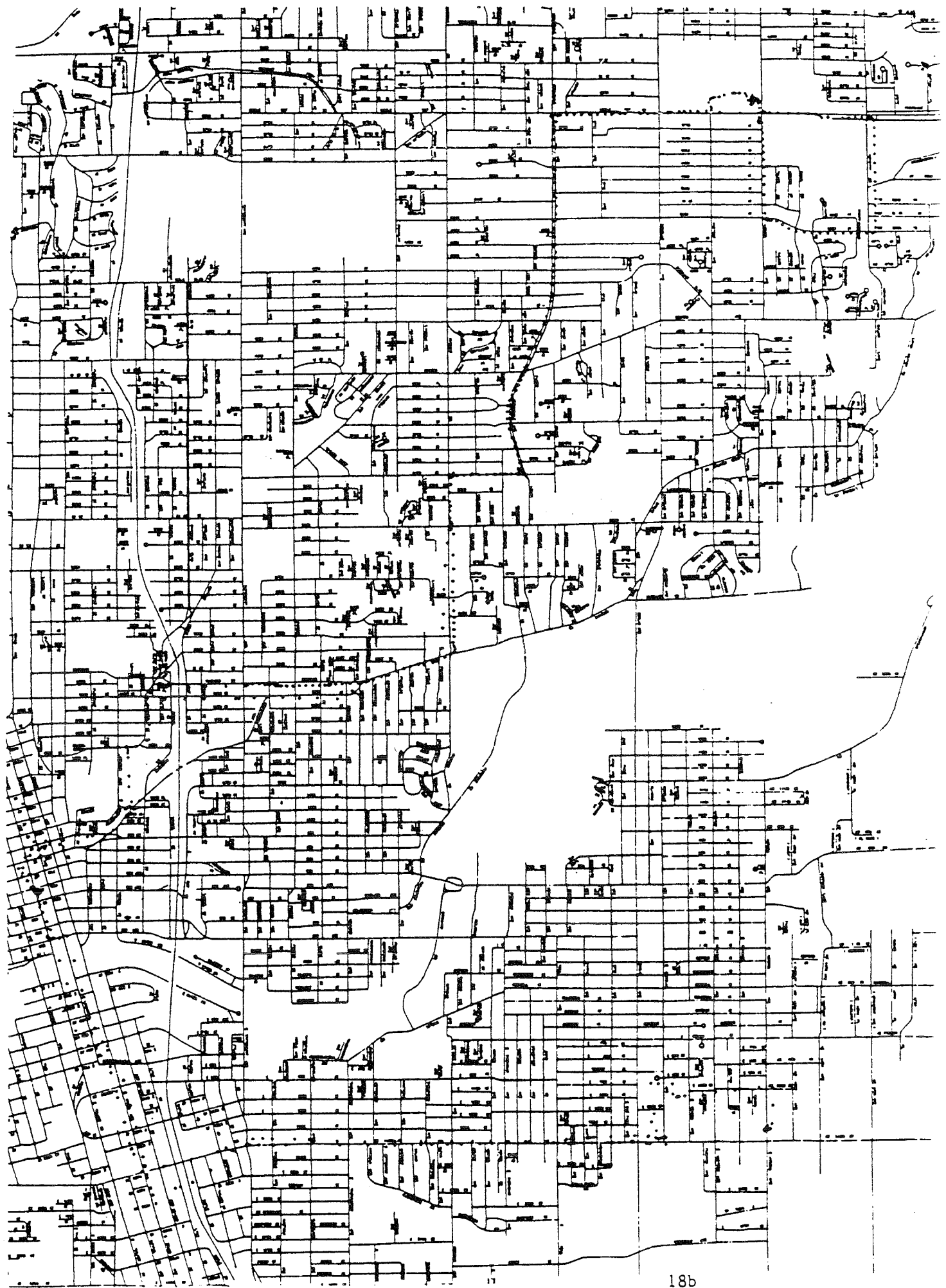


Figure 7. Iowa DOT Base Map



response enabled by this type of look up table would also enable the dispatcher to respond more readily to the needs of "will call" and other inserted rides. This approach would seem most appropriate for rural paratransit operations that operate as "line haul" vehicles between various small towns where they typically perform several stops.

System Components

Software

The software required for an AVL tracking program includes programs that provide for:

tracking
dispatching and
scheduling
(See figure eight for concept diagram.)

1. Tracking:

The first concern is tracking the buses. Tracking can be achieved by any CAD or GIS software that is open enough to receive constant incoming data from external sources. The only other requirement is to have an accurate base map as discussed earlier. While some GPS units offer positional data in many different projection systems the Navcore V provides data in latitude and longitude using WGS 84 coordinates. It is important that the base map share identical map parameters with the GPS unit.

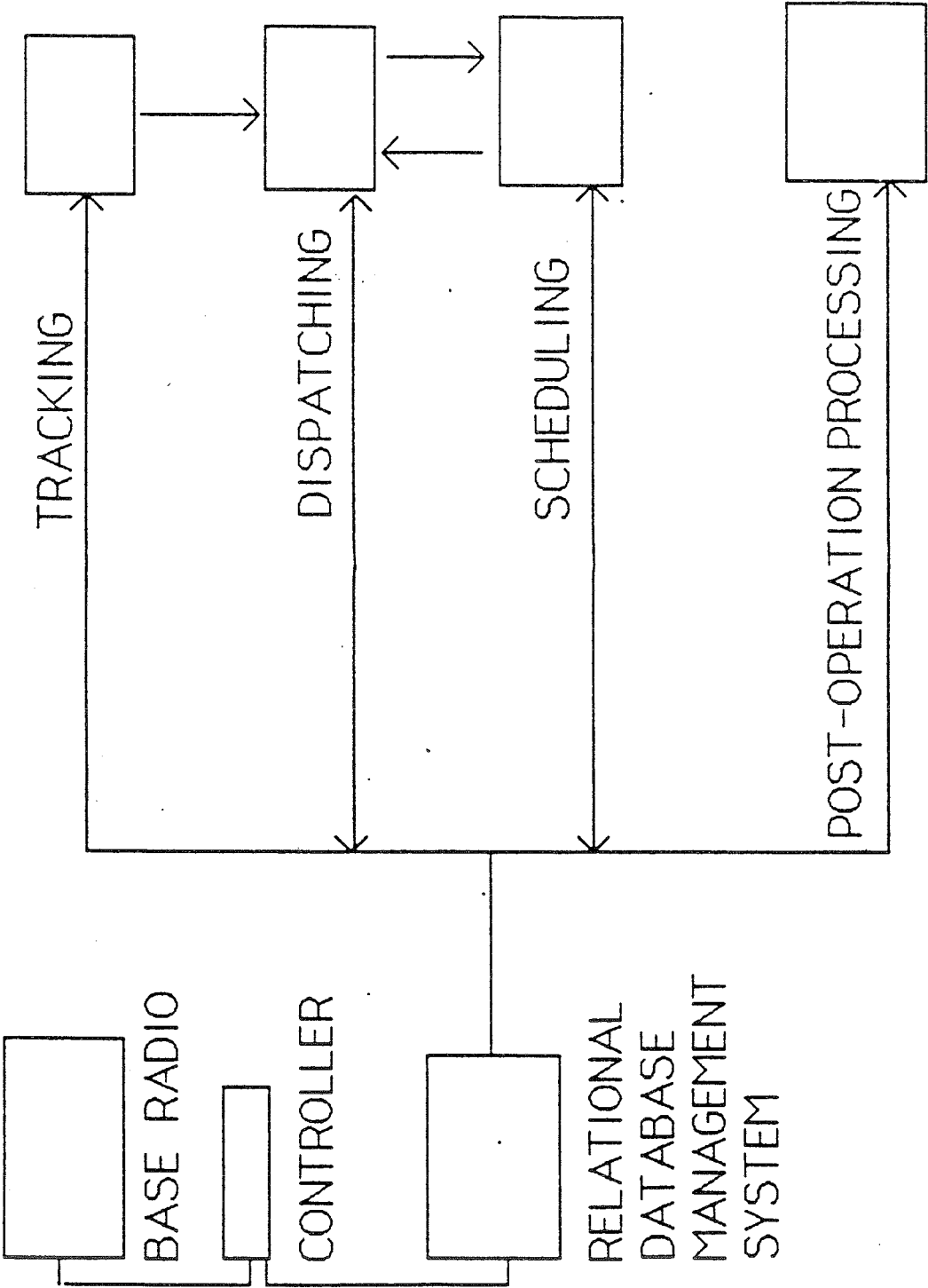
2. Dispatching

This is where a GIS is needed. Dispatching requires networking or network analysis tools, over and above basic GIS analytical tools of spatial buffer and scanning functions. On UNIX platforms, currently, InfoCad, Intergraph, and ArcInfo offer network analysis tools. The UNIX based software listed above all have open architectures, will permit access and manipulation of data for analysis.

Typically a networking software has nodes and chains. The streets can be visualized as chains and street intersections as nodes. The address of a Des Moines resident can be treated as a node also. The following information pertaining to the streets of Des Moines needs to be stored in a database for dispatching analysis.

1. Speed limit on any particular street segment.
2. Number of stop signs in-between two major intersections.
3. Direction of traffic, whether it is a one-way street.
4. Volume of traffic, indicating how busy a street is.
4. Other obstacles such as roads closed due to repair.

Figure 8. System Components: Software Required for AVL Tracking Program



With all this information stored, using network analysis, a dispatcher could pose a question, "What is the shortest / quickest path from point A to B to C to D?" There are readily available maps for network analysis offered by some private vendors, although none are currently available for Des Moines.

One solution is to trade off some detail for greater speed by allocating a major node to a neighborhood, thereby reducing the total number of nodes (intersections) and chains (streets) in our network analysis. This will permit rapid dispatching.

3. Scheduling

Scheduling can be of two types:

1. Next days. A request is made for a call for a trip the next day. The request is processed and the next day's schedule prepared.

2. Peak time. The request is accommodated into the first available trip. The scheduling software has a link with dispatching. Questions are posed such as how much time does it take to travel from A to B -- 8 minutes. Therefore, the trip can be accommodated. For another request--the time from C to D is 15 minutes and cannot be accommodated.

GIS Software

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 with GPS accuracy and present bus tracks, ability to refresh the screen quickly, zoom features, ability to respond to a relational data base.

Initial tests were run using GDS which is a software initially obtained from McDonald Douglas but now is owned and maintained by GDS, Inc. of St. Louis, Mo. The software was available to the team and tested in a number of different applications. It proved to be responsive to the needs of this project in that it permitted importing available maps, allowed the required zoom feature, permitted recording of GPS tracks in X Y coordinates and permitted importing of Oracle files. Complexities associated with the CAD package were primarily a product of the large network system in operation at the university (Project Vincent). The GDS protocols are written for stand-alone work stations and had to be modified to work in the "Project Vincent" environment. Given the number of users on the system the time involved in refreshing the screen was also too slow for real world applications. Plans to test the Micro GDS in the coming year will enable a review of this GIS program in an environment similar to a transit operation.

Other software packages which were available to the team were also reviewed. Although MapGraphix is user friendly and provided a crisp map and quick screen refreshing on Macintosh the version which the team reviewed did not have the required zoom feature. InfoCAD proved to be flexible, to be user friendly, to have easy to read graphics and to have a zoom feature. It permits importing maps from available sources and can respond to a relational data base. It can relate origins and destinations on a trip-by-trip basis, but was not able to display multiple vehicles with different destinations (many to many) at one time. The potential for accommodating this need by drawing each trip in rapid sequence is being explored. (This issue was to be resolved by the vendor during year two of this project.)

A Relational Data Base Management System

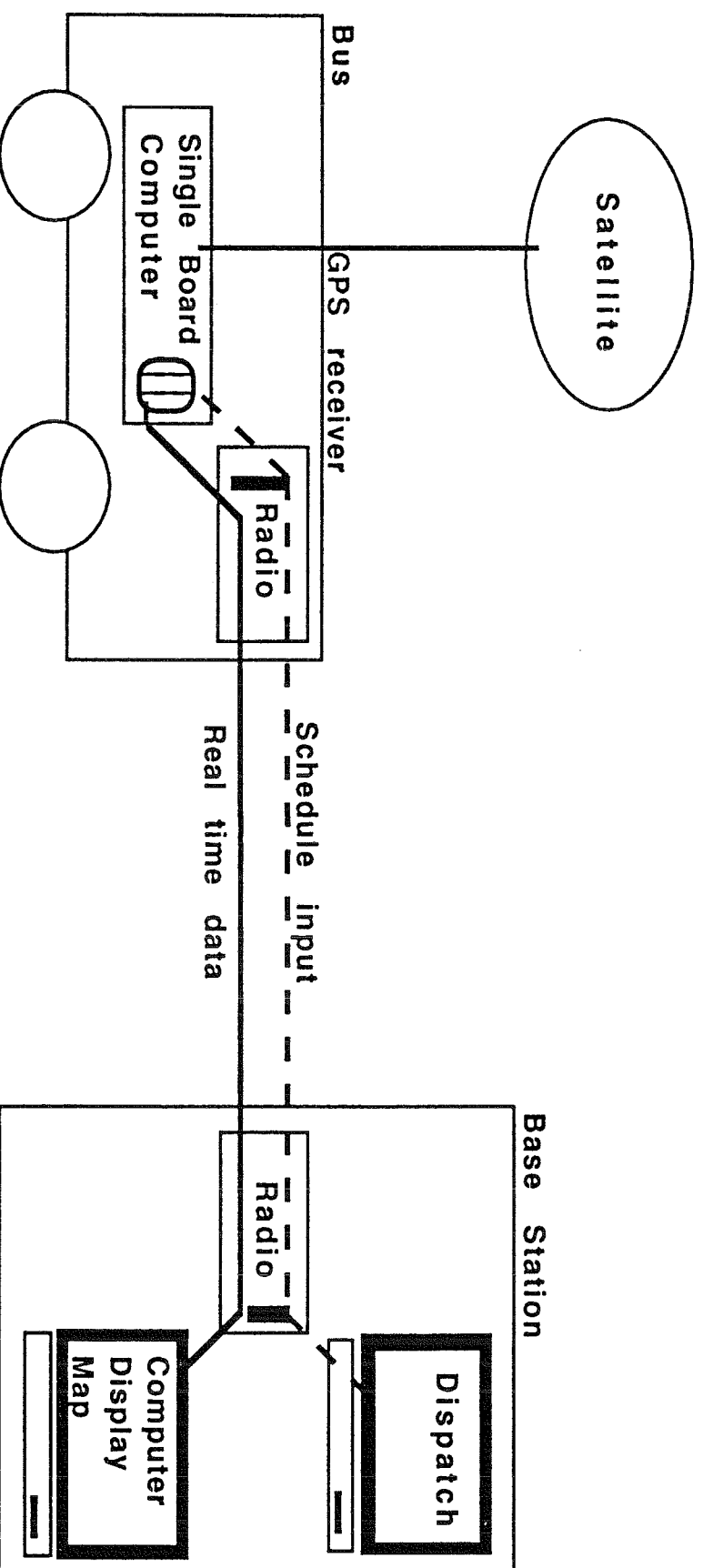
In selecting a relational data base management system the study team was again directed by the particular software available. Oracle is a computer-based data storage and management facility from Oracle, Inc. which is widely used by transit operations that was also available to the study team.

Oracle provides programs called "tools" to store, manipulate, and maintain the stored data.-i.e. to manage the database. Oracle is a SQL-based (Structured Query Language) relational data base management system (RDBMS). SQL is used to ask questions of or to "query" the databases (stored data) and obtain information as to a specific subset of data. This language is usually hidden inside the tools so as to simplify the use of the RDBMS.

The project team was able to use Oracle to write a program that determines the expected arrival time of a bus at a certain location (bus stop) based on its departure time from the previous bus stop. As the project progresses Oracle will be used to extract data from the real time information sent through the radios and display such data on the map. This will enable the dispatcher to see the actual location of the bus at a given time based on the real-time data stored in Oracle as compared with the scheduled time of the bus which would also be stored in Oracle. This would allow the dispatcher to determine whether the bus is on time, ahead of schedule, or behind schedule, information that is most important to managing the operation of the bus system.

For data acquisition at the base station (Relational Data Base Management System) the use of a data transfer protocol becomes necessary. This issue will become a major area of emphasis in year 2.

GPS : Tracking Model



Equipment Assessment

GPS Receivers

To be useful for the project the GPS receivers needed to meet the following set of criteria: low cost, accurate tracking.

The study team used a Rockwell Navcore V receiver since it was made available by the Iowa Department of Transportation and Rockwell International. The relatively low cost device, about \$300, proved to be capable of performing the task as needed. Although the company only guarantees accuracy at the level of 100 meters without differential, the receiver was actually able to track vehicles accurately within 15 meters on most of the city's bus routes. The only exception was in a two block area downtown. That may have been the result of the urban canyon phenomenon described above, but a Rockwell representative indicated that this may have been an equipment related problem related to switching from 2D to 3D reception and that their next generation model would correct for this flaw.

Other receivers were also reviewed but were not available for testing on site.

Magnavox has a 6 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 9600 Baud, but the receiver is easily adjustable to different Baud rates. Data is only received in latitude and longitude. Accuracy is within 100 meters without differential and 2-5 meters with differential.

Trimble Navigation's Navtrak costs about \$900. It receives data in ASCII format at 9600 Baud. Data can be received in X-Y State Plane Coordinates as well as latitude-longitude. As with most GPS receivers, accuracy is guaranteed up to 100 meters without differential and within 2-5 meters with differential.

Motorola also has a 6 channel receiver. It has fast acquisition times and comes with the option of responding to differential. The price is \$1200. Data is only received in binary format in latitude-longitude. It is transmitted at 9600 Baud and at the same level of accuracy--within 100 meters without differential and 2-5 meters with differential.

Navstar Navigation System offers both a 6 and a 12 channel receiver. The 6 channel model costs \$2995 while the 12 channel model costs \$5495. Both receivers could work with transit applications. Data is received in binary format in latitude-longitude. Unlike the Rockwell product which uses the Lambert projection of the North American Datum of 1983 (NAD83), the Navstar system uses the Universal Transverse Mercator (UTM) projection system. The company maintains that their receiver is very accurate in urban canyons. It was tested in England with considerable success.

In designing a communication system the most important consideration is the nature and volume of data that is to be communicated. Only the Rockwell Navcore V was available for direct testing in the project.

This equipment assessment will continue in year two of the project.

The Logic Board

The logic board is a key component in the communication link. The following functions can be achieved by the logic board:

1. Data integration: Integrate data from different sources.
2. Data manipulation: Reduce or compress data for transmission.
3. Data preparation: There are integrated GPS units which have built-in logic boards and radios. Costs are in the range of about \$5000 per vehicle. This is far more expensive than purchasing the elements individually at about \$425 for the GPS core receiver and radio antenna + \$300 for the logic board(or controller) + \$600 for the radio. These integrated units are also more rigid. They would not be flexible enough to allow the organization to integrate other data and manipulate it as the needs of an organization changed.

Radios

The project used a series of Motorola radios which were made available through a leasing arrangement. Motorola regional representatives also provided maps of radio coverage of the Des Moines area and additional consultation on new product lines. Similar radios are available from GE, Philips and Ericson, to name a few.

In an effort to respond to the low cost objective of the project, the study team tested a series of radios, beginning with the 400 MHz digital simplex radio. An initial decision was made to proceed with digital radios rather than attempting to integrate voice and digital on the same instrument. A review of the literature as well as discussions with venders and integrators convinced the project team that attempting to incorporate digital with existing analog radios would not work successfully for a fleet of 100 vehicles. The constant regular polling of the vehicles for location would potentially interfere with voice communications and visa versa. Furthermore radios sold expressly as digital are more sensitive to communicating that type of signal. Some transit companies have attempted to integrate digital and analog by encoding the most common voice messages and having the driver simply report the code thereby increasing the efficiency of communication. This may be an approach worth investigating further but would require full cooperation of the drivers.

A low cost simplex radio (about \$600) proved to be successful on board in relaying the signals received by the GPS receiver. A stream of locational data was sent to the base station from a single vehicle. A type of on-board switching device permitted interrupting that stream and interspersing it with a similar stream from a second vehicle. Such a process becomes cumbersome for a fleet of over 100 vehicles and this type of radio would not permit acknowledgment of receipt of signal from the base station. Requests for data on position are requested from a common base station, hence the simplex radio are appropriate. The table in Figure ten shows the differences in cost between simplex and duplex radios. This issue will become a major focus in year 2 of this project. It goes to the heart of the basic issue of whether a system should operate a smart bus with information on schedule correction on board or a smart central system which receives information from the buses and relays schedule correction back to the buses.

Figure 10. Radios Costs Schedule

<u>Radio</u>	<u>Mhz</u>	<u>Baud</u>	<u>Dollars</u>	<u>Repeaters (\$)</u>
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	

In terms of communication within the Des Moines urban area the following options are available:

a) First, the base radio could be located at a high elevation e.g. atop the Principal building (the tallest building in the city) or atop a water tower and the data could be communicated to a base station at the MTA headquarters via telephone link. Second, the base radio could be located at MTA and communicate with mobile radios on the buses via a repeater station located at an high elevation.

b) More powerful radios could be used. Currently there are two possibilities. While the 800 band radios offer greater range of reception the entire communication system will be more expensive. Tests conducted in the Des Moines area seem to indicate that the use of 400 band radios will insure adequate communication. However, the 400 band width also has more users and may cause deterioration of signals.

For communication of MTA with rural buses a network of repeater stations will be necessary. A comparative study will be conducted regarding the cost benefit ratio of number of 400 repeater stations and 400 radios against 800 repeater stations and radios. Figure five indicates a possible option.

The study team is still exploring a digital radio that will enable the full communication and interface well with the logic board which serves as controller on board the bus. Here the parameter of low cost must be weighed in relation to qualities essential for a fully operable GPS system that will not only satisfy basic GPS needs but at the same time enable expansion to include more features as funds permit. It is important not to make an investment in a system with closed architecture that cannot be expanded to add on other features such as silent alarms, on board voice location announcements, public information systems and passenger counters.

On-board computers

The project team initially used a simple Zenith lap top 386 computer with 85K memory to receive and verify data from the GPS receiver. It proved to be fully capable of the task. However, if the GPS equipment were actually installed in a bus, a smaller computer would be needed. Hence a small single board computer was developed by the project team and a program that would compress and relay GPS signals was written and burned onto it. The device which would as a controller performed well and would be inexpensive. With some rewriting a team member was also able to write a software program which allowed the signals from individual buses to be acknowledged by the base station. Polling is built into this concept. More work is needed to complete the interface between the single board computer and a radio with polling.

Dispatch or Base Station

The radio and associated polling modem required at the base station needs to be compatible with the mobiles. Given the need to poll and receive data from about 100 buses this radio needs to be a full duplex radio complete with a controller (computer). One option is to add repeater stations, each with a duplex radio and a controller (computer). This provides a clear signal and enables use of a 400 band frequency. With 400 MHz each repeater can cover a radius of about 35 miles. The cost for repeater stations is about \$4000 for 400

frequency as compared to \$10,000 for an 800 MHz radio. One vender has suggested a relatively low cost base station set up for about \$1200 for a simplex radio at 400 MHz or \$1600 for a duplex radio at the same frequency. The cost of a polling modem is about \$2000. The cost is about \$2300 for a duplex radio with 800 MHz. Other perspectives will also be sought. If differential GPS is installed, that factor would require a far more sophisticated duplex radio.

With the current market in mini-computers (based on Intel's 486) it is possible to outfit the base station with three computers and oversized monitors needed for the display maps for less than \$15,000. A primary issue is the storage capacity for the GIS map and the relational data base. One possible way of reducing the storage requirements is to develop a local area network linking two computers for fixed route-- one with the relational data base including all schedules and driver information and the other with the display map. A parallel system can work for paratransit with one computer for a map display and a local area network linking that to another computer with a relational data base including characteristics of the subscriber riders as well as the schedules.

Display

Given the number of functions which this project envisions bringing together, the project will require using several computers at the base station as well as base radio with a modem. The tasks involved require speed similar to that of an IBM compatible 486 computer. The study team has worked with UNIX work stations which allows use of the Oracle relational data base and GDS. Experiments are proceeding to determine whether the programs will work in the PC environment. Venders have provided that reassurance. The issues here are cost and compatibility with the other computers available to the transit operation.

The needs of the paratransit dispatcher and the fixed route dispatcher are sufficiently different to require two different computer displays. Each would have the capability of bringing in the whole city map to show relationships. In fact, a third computer display might well be regularly set to show all vehicles in operation at any one time with the ability to zoom in to a specific sector if problems developed there.

The paratransit dispatcher needs the capability to zoom to a much higher level of detail especially when scheduling trips or inserting trips. The nodal concept presented above would provide a way of preplanning trip times and distances once networking began. In the interim the ability to zoom to an area and see the relative position of paratransit vehicles to a caller's location is sufficient. Having a high level of detail on the full display not only challenges the system but also confuses the dispatcher. If the paratransit vehicle needs to transfer a passenger to an accessible fixed route bus stop, the dispatcher needs to be able to see the real time display map with fixed route as well as paratransit vehicles displayed in real time. This does not present a major challenge since both dispatchers are viewing basically the same real-time display but with different layers and with different sections of the city in focus.

Ultimately, 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 venders have developed geobased software to associate with paratransit schedules, none has completed the next step in associating that information with the real time location of vehicles available to retrieve the passenger.

The fixed route dispatcher needs to see only the bus routes with buses proceeding along the. By developing a display screen with the detailed map of the city suppressed and only a layer with the bus routes showing, the screen can refresh quickly and the dispatcher can be notified by exception reporting to zoom to a particular vehicle. At that time, the street map detail would be visible. This type of display allows ease in observing the whole system, quick screen refreshing and sufficient detail when needed.

System Integrators

Given the complexities involved in developing a GPS system for transit, a number of transit companies have elected to contract with systems integrators who would be responsible for custom designing a system for a particular setting. Costs are considerable for such an integrator's services and then the transit company becomes dependent upon that company for maintenance and upgrades specially for the maintenance of the "black box" core receiver package and accompanying proprietary computer programs. It is unlikely that a small transit company would be able to engage a full systems integrator. Companies like Westinghouse and Harris are in the field. Others, like Trimble and Motorola which supply of the full GPS package, are expanding into the realm of systems integrator. Westinghouse currently is serving as integrator for Denver and Milwaukee. Harris is developing part of a GPS system for Dallas. All of those projects are partially supported by demonstration funds from the Federal Transit Administration. A the key concept would be to require an open architecture which would allow the small transit company to expand its system incrementally.

Year Two Outlook

Year two of this project will refine a number of the issues developed in this paper and move ahead to a real time test of GPS as it relates to affecting a transfer between fixed route and paratransit operations in the Des Moines test site. It will furthermore refine the map display system and test it in a single work station environment. A more complete assessment of the requirements for interfacing tracking, dispatching and scheduling will also be completed.

At the same time the project will proceed to an assessment of the applicability of a GPS tracking system to rural demand responsive systems. A multi county map display will be developed to enable tracking of vehicles for a rural regional system. The same issues regarding the interface between tracking and dispatch and scheduling will be critical in this context.

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