

**FINAL REPORT**

**PENINSULA TRANSPORTATION DISTRICT COMMISSION  
ROUTE DEVIATION FEASIBILITY STUDY**

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Transportation Research Council  
(A Cooperative Organization Sponsored Jointly by the  
Virginia Department of Transportation and  
the University of Virginia)

In Cooperation with the U.S. Department of Transportation  
Federal Highway Administration and the  
Peninsula Transportation District Commission

Charlottesville, Virginia

November 1998  
VTRC 99-R11

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**INTRODUCTION**

Many urban transit providers are faced with the problem of declining ridership on traditional fixed route services in low density suburban areas. As a result, most fixed route services in such areas are not economically viable for the transit provider. Ridership levels on such routes could be increased by adding more flexibility to the fixed route structure by replacing the fixed route with a route deviation service. The higher level of service offered by route deviation has the potential to attract non-traditional transit riders.

Another reason why transit providers are turning to route deviation is the passage of the Americans with Disabilities Act (ADA) in 1990, which has brought forth new and greater responsibilities for transit agencies. With the law mandating that certain disabled persons must be provided complementary paratransit service at a nominal cost, public transportation providers were suddenly faced with the challenge of providing traditional fixed-route transit service while also serving individuals with disabilities. There are three categories of paratransit-eligible riders under the ADA:

1. Those who cannot independently board, ride, disembark from accessible vehicles
2. Those who can independently board and ride an accessible bus but an accessible vehicle is not available for the route and time desired
3. Those who have a specific impairment that prevent them from boarding or riding a bus.

ADA requires that only the first of the three categories be provided service, and only if they want to travel within 3/4 mile of an existing fixed route. To accomplish this, around 550 fixed route systems across the nation have increased or added the availability of paratransit

services (Balog, 1997). Consequently, there has been a notable and steady increase in the demand for paratransit by disabled people in the post-ADA era. Since the cost of providing accessible paratransit is definitely higher than the cost of accessible fixed route, the increased demand for paratransit is burdening transit agencies (Balog, 1997). Also, some individuals with disabilities currently using paratransit services could effectively use accessible fixed route services at a lower cost to the transit provider. This has led a number of transit providers to look for new options to encourage paratransit riders to use fixed route services. Most of these options are centered on improving the level of service of fixed route operations and making them more accessible to individuals with disabilities (Balog, 1997).

One such option that has been tried by a few transit agencies in rural and suburban areas, with much success, is route deviation service. Route deviation has the potential to meet the challenges faced by urban public transportation providers in a more efficient manner than the current two service practice. Route deviation transit has been used effectively in a limited number of rural and small urban areas of the United States (Rosenbloom, 1996) and some suburban areas. However, it has not been proven to be effective in a large urban area.

Currently, the Peninsula Transportation District Commission (Pentran) operates a fixed-route bus system with 13 routes in a service area composed of the cities of Hampton, Newport News and York County. Additionally, Pentran provides paratransit services for the disabled under the mandates of the 1990 Americans with Disabilities Act (ADA).

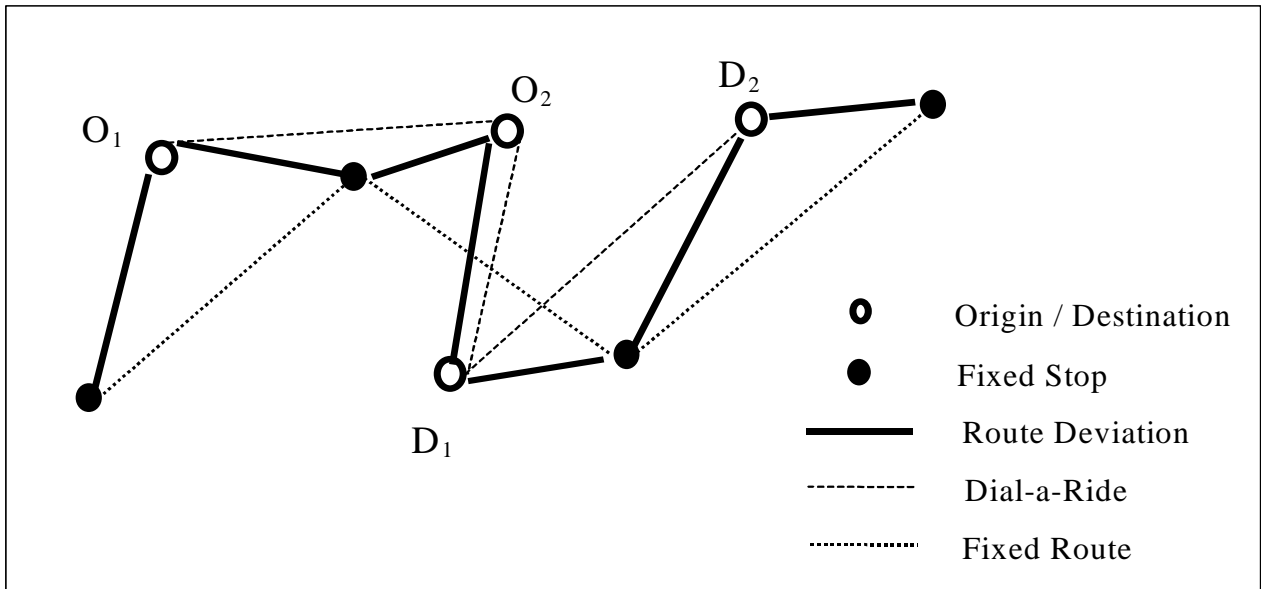
### **Route Deviation Service**

In a route deviation system, service is provided at fixed times and locations, while also providing an on-demand service to customers off the standard route (see Figure 1). Real-time scheduling and dispatching can pose a significant challenge due to high demand at fixed-stops, the large volume of requests for deviations, and the dynamics of bus schedule adherence. This challenge poses a need for a route deviation decision support system, which can process information in a real-time manner.

In order to implement route deviation services in a real time urban environment, certain system components are necessary (Round and Cervero, 1996). First, there must be an automatic vehicle location system so that the dispatcher can have instantaneous information about the location of the vehicles in the system. Secondly, a geographic information systems (GIS) database is required to locate vehicles en route on a map of the service area, store system specific information and also view the street networks. Thirdly, there must be a communication system that can send the information between the vehicles and the transit control center. Finally, a decision support system (DSS) specifically designed for route deviation is needed that processes the inputs from the subsystems along with customer request information. It would be advantageous if such a decision support system was within an existing GIS.

In the past, technology has been a major impediment in providing route deviation transit service in urban areas. However, with the recent improvements in automatic vehicle location

(AVL) technology and desktop geographic information systems (GIS), the tools now exist to effectively support such a transit service.



## PURPOSE AND SCOPE

The purpose of this study was to demonstrate the technical feasibility of operating a route deviation bus service. The Peninsula Transportation District Commission (Pentran) provided a case study setting. To accomplish its objective, the study has developed a decision support tool using “off-the-shelf” GIS software products, to support the provision of route deviation service in a large urban area. The premise of this effort is that the powerful spatial analysis capabilities provided by GIS can be used to support the operations of a route deviation service. In addition, many transit agencies are already using GIS for planning purposes. Therefore, much of the data and GIS experience exist to support the introduction of an operational application of transit GIS.

The study also had two additional objectives: 1) demonstrate the use of GIS as a tool to develop applications for transit operations, and 2) investigate route deviation design alternatives using the decision support tool.

## METHODS

The following tasks were undertaken to accomplish the objectives of this research:

1. *Review of the Literature.* A literature review was undertaken to ascertain pertinent information regarding route deviation strategies and any impediments to implementing such a system. Transit systems, both domestic and international, that have or were considering using route deviation were identified and information about their respective programs was

reviewed. Additionally, literature was reviewed relating to the requirements set forth by the 1990 Americans with Disabilities Act and how this affected the need for new paratransit services.

2. *Route Selection and Modifications.* In consultation with Pentran management, two of thirteen bus routes were identified and selected for study. Once the routes were identified, they were modified to facilitate the operation of route deviation service. These modifications included the removal of low-volume fixed stops and the increase of headways.
3. *Development of Route Deviation Software.* Based on the literature and the needs of Pentran, the route deviation software was designed using Avenue, the object-oriented scripting-language with ArcView. In addition, the internal and external interfaces were developed using the Dialog Designer extension within ArcView.
4. *Analysis of Route Deviation Service.* The route deviation service design parameters were evaluated to gain an insight of the potential effectiveness of operating a route deviation system and to identify the critical design parameters that affect route deviation service.
5. *Identification of Implementation Issues.* Critical issues to deploying route deviation are raised and discussed.

## RESULTS

### Background and Literature Review

Although, the concept of route deviation as an innovative transit service has been around since the late seventies, its implementation has not been widespread. Until very recently implementation of route deviation service by transit agencies was limited to rural and small urban areas due to the complexity of scheduling such a service in densely populated urban and suburban areas. However, with the advent of new information technologies the tools now exist to implement route deviation in urban and suburban areas. This section summarizes the past and current experience of transit agencies with route deviation in the United States and Europe, followed by a brief description of the available demand responsive scheduling software.

#### *Experience with Route Deviation*

A report by the Federal Transit Administration (Rosenbloom, 1996) summarized the operating experiences of several transit operators across the United States and Canada from mid-1994 to early 1995 that implemented three major types of non-traditional transit options: 1) route deviation services, 2) service routes or community buses, and 3) general public demand responsive systems. Of the forty different transit systems surveyed in depth, fifteen operated route deviation services. All route deviation service areas were either in rural, suburban or small urban areas. It may be easier to operate route deviation service in such areas since the demand levels are low and the routes deviate over small distances. None of the systems surveyed was

using a routing and/or scheduling software nor vehicle location technology. Prospective riders must call from one day to one hour before they make a trip so that the buses leave the transit center with the knowledge of the pick-ups and deliveries along the routes. The study concluded that such services have not been widely implemented in urban and densely populated areas due to the complexity involved in the dynamic routing and scheduling of customer requests between fixed stops.

### *Madison, Wisconsin*

Madison Metro, the transit agency for the City of Madison, Wisconsin, currently operates a service route system with eight routes that are "fixed," with published routes and schedules. The eight routes run on 60-minute headways. The system provides deviation service to ADA-eligible customers that are within 3/4 mile of the fixed route. Currently, about 2.5 passengers per hour are being served by deviations. A request for deviation must be made by 4:30 p.m. the day before the intended trip. In restructuring their system for the service route concept, most "flagstops" were eliminated; i.e., signs for stops were removed. A few fixed stops were kept as time checks. In performing a deviation, a bus must return to the fixed route at or before the next time check. According to Madison Metro, their service is in "flux." They intend to provide "real-time" deviation service (requests to be considered up to one hour ahead of service) with future upgrades to their current scheduling software, which is developed by Trapeze, Inc.

### *Potomac and Rappahannock Transportation Commission (PRTC), Virginia*

The Potomac and Rappahannock Transportation Commission (PRTC) in Prince William County, Virginia, Dallas Area Rapid Transit (DART) in Texas, and the Montgomery County Department of Transportation in Maryland are currently conducting operational tests for providing "flexible route" or route deviation services under the Federal Transit Administration's Advanced Public Transportation Systems (APTS) program (FTA, 1996). Of these, PRTC was the first to fully implement its route deviation service in its low-density service areas as a cost-effective alternative to providing both fixed-route and paratransit services. The system called Smart Flexroute Real-time Enhancement System (SaFIRES) was formally deployed in October 1997 using intelligent transportation systems (ITS) technologies such as automatic vehicle location (AVL) systems, computer aided dispatch (CAD) software, Mobile Data Terminals and a proprietary routing and scheduling software developed by Trapeze, Inc. PRTC claims that it has saved "roughly 50 percent from the cost of operating both fixed route and paratransit services, or an estimated \$560,000 in annual operating savings" (ITS America News, 1997).

### *SAMPO*

In 1995 a demonstration project called System for Advanced Management of Public Transport Operations (SAMPO) was initiated in Europe under the Transport Telematics Program of the European Union (Engels, 1997). The primary objective of SAMPO was to provide demand responsive transport services (DRTS) using "telematic technologies." Specifically, the

goals of SAMPO were to improve, (a) mobility for people in rural and urban areas, (b) participation of elderly and disabled within their community, (c) business and viability of public transport operations, and (d) rural and urban community environments, using the "added potential and the effectiveness of telematics technology." The test sites for this project are located in five European countries: Finland, Belgium, Ireland, Italy and Sweden.

The objective of DRTS under SAMPO is to provide "on demand" services to passengers by integrating all the different modes such as, buses, taxis, minibuses, and rail services. The DRTS system can be accessed by a passenger by calling a Travel Dispatch Center (TDC). A TDC will have advanced booking and reservation systems that have the ability to dynamically assign passengers to vehicles and optimize the routes and schedules.

At the Finnish site under the SAMPO project, there were essentially four generic concepts of DRTS services with increasing levels of flexibility (Engels, 1997). The four concepts are: (i) Predefined Timetable and Route- this is similar to the traditional fixed route service, (ii) Partially Predefined Timetable and Route with Deviations to Predefined Stops - this is similar to route deviation service, (iii) Stops in a Region - this service is similar to a paratransit service, i.e., on-demand shared ride, (iv) Points in a Region - this service is similar to a taxi service, i.e., on-demand exclusive ride. All the above services follow some common guidelines. One such guideline is that customers have to make a trip reservation at least one hour in advance. Another type of DRTS service implemented was the concept of using DRTS as a feeder service to a major rail line.

Preliminary results from a market survey of the SAMPO demonstration indicate that the public's perception of the fixed route service has improved remarkably. About 74% of the passengers interviewed rated the new system as either "good" or "excellent."

#### *Other Systems in the Planning Stage*

DART and the Montgomery County Department of Transportation are in the preliminary stages of implementing route deviation service. The two agencies also plan to use ITS technologies and hope to provide real-time route deviation service (FTA, 1996).

#### *Existing Demand Responsive Software*

There are a number of vendors in the market that provide demand responsive scheduling software, especially for paratransit, with a variety of functional requirements. A comprehensive listing of the vendors, contact names and their software can be obtained in the Transit Cooperative Research Program (TCRP) report by Lave et al. (1996). Among the existing vendors, Trapeze Software Group Inc., is the primary one that presently has their proprietary "flex-route" software in the market that allows for real-time scheduling of a route-deviation service. Their software named Trapeze4 has the capabilities of scheduling fixed route, paratransit and route deviation services using a single graphical user interface (Trapeze, 1998). The bulk of the data for all the three different systems are stored within a relational database.

This database interfaces with proprietary mapping software to enable the user to geocode addresses and visualize the system on a map. Since the software is fairly new, there has been no formal evaluation of its performance.

Under the SAMPO project a system called “Ring” was developed based on an “extensive set of software modules.” This software includes all the necessary applications required to efficiently operate a demand responsive transit service (Engels, 1997). Primarily, its strength lies in the integration of demand responsive services with all other public transportation services. It has modules for handling trip reservation, trip cancellations, modifications, information on other public transit services (e.g., fixed route, rail), on-line processing of data, and for linking the radio-communications and AVL system. The “Ring” software can also allow real-time connections between different public transit services.

### **Fixed Route Structure and Schedule Modifications**

Once the decision to provide route deviation service has been made, the next critical step is selecting the service area. This can be an existing fixed-route and/or paratransit service area or a completely new area. In the case where an existing fixed route is being converted to a route deviation service, as is the case with this study, several modifications have to be made to the fixed route structure to enable the provision of route deviation service. This is required because the routing and scheduling structures for a fixed-route and route deviation service differ in many ways. For instance, the primary objective of designing a fixed route service is to locate the fixed stops within a 1/4-mile walking distance of the surrounding population (Gray and Hoel, 1992). Whereas a route deviation service must be designed with the objectives of (1) serving high-activity fixed stops and (2) providing the necessary slack time in the schedule to allow deviation service.

Although there is no literature directly dealing with how these modifications are to be made, there is one study that addresses a similar situation (Welch et al., 1991). The methodology used in that study with a similar goal was adapted to this case. The ensuing sections describe in detail how the service area was selected and the route and schedule modifications made for the Pentran service area.

#### *Selection of Test Routes and Removal of Existing Fixed Stops*

Of the 13 routes operated by Pentran, two were selected in consultation with the Pentran management for route deviation: Routes 10 and 11. These routes were chosen due to low ridership at majority of the stops coupled with low population density along the routes. The next step was to modify the selected routes to facilitate the operation of route deviation service. The following factors were evaluated to consider potential changes in route structure to provide route deviation service:

- Ridership data for each stop on the route
- Population and population density along the route
- Socioeconomic data (e.g., household income) along the route



- Methodology for Evaluating Out-of-Direction Bus Route Segments
- Travel time to be saved
- Transfer points in affected areas
- Qualitative factors (trip generators impacted, political considerations, etc.)

Since route deviation is viable with a smaller number of scheduled stops, the next step after selecting the test routes was removing existing low ridership fixed stops along these routes. Table 1 shows the number of fixed time stops under the current and modified systems for each route. Along with high ridership at the fixed stops another criteria used to retain a stop was its proximity to other fixed time stops and whether it was an important landmark such as, a hospital, a mall, a community college, etc. Coincidentally, fixed stops that were landmarks also had a high ridership, thus precluding the need for their removal.

**Table 1. Comparison Between Current and Modified Schedules for Routes 10 and 11**

<i>Route direction</i>	<i>Current schedule</i>	<i>Modified-Alternative 1</i>	<i>Modified-Alternative 2</i>
Route 10 inbound	45 min, 6 stops	55 min, 5 stops	55 min, 5 stops
Route 10 outbound	50 min, 6 stops	55 min, 5 stops	55 min, 5 stops
Route 11 inbound	55 min, 6 stops	60 min, 5 stops	55 min, 4 stops
Route 11 outbound	55 min, 6 stops	55 min, 6 stops	60 min, 5 stops

### *Route and Schedule Modifications*

Some modifications were made to the existing route structure in order to streamline it and achieve travel timesavings between the retained fixed time stops. The methodology outlined by Welch et al. (1991) and used by the transit agency in San Diego, California, to remove out-of-direction (OOD) segments was used for this purpose. An OOD segment can be defined as the portion of the route that deviates from the main line of a fixed route service. The OOD segments for the two routes, Routes 10 and 11, were identified and removed so that travel times between the retained fixed stops would be reduced and additional slack time could be introduced for route deviation. Using this methodology, an OOD impact index is calculated for each OOD segment. Based on the value of this OOD index a decision on whether to retain or remove an OOD segment is made. The OOD impact index is defined as *the weighted measure of travel time as a function of through riders, OOD riders (greater than 1/4 mile off mainline) and travel time difference between OOD and mainline*. In short, it essentially measures the penalty to through riders imposed by OOD riders. The impact index can be calculated as:

$$\text{Impact Index} = (\text{Through riders per day} \times \text{Travel time increase due to OOD segment}) / \text{OOD riders per day}$$

Next, the following criteria were used to make a decision on retaining or removing an OOD segment (Welch et al., 1991):

1. If Impact Index < 5 - then retain OOD segment.
2. If Impact Index between 5 and 15 - then decide based on resource needs, operating cost, effectiveness, and qualitative factors.

3. If Impact Index > 15 - then eliminate OOD segment.

For this research potential OOD segments were considered, using ridership data provided by Pentran and travel time information from our data collection, schedules, and maps. The OOD segments identified for each route in each direction are shown in Table 2.

**Table 2. The OOD Segments Identified for Routes 10 and 11**

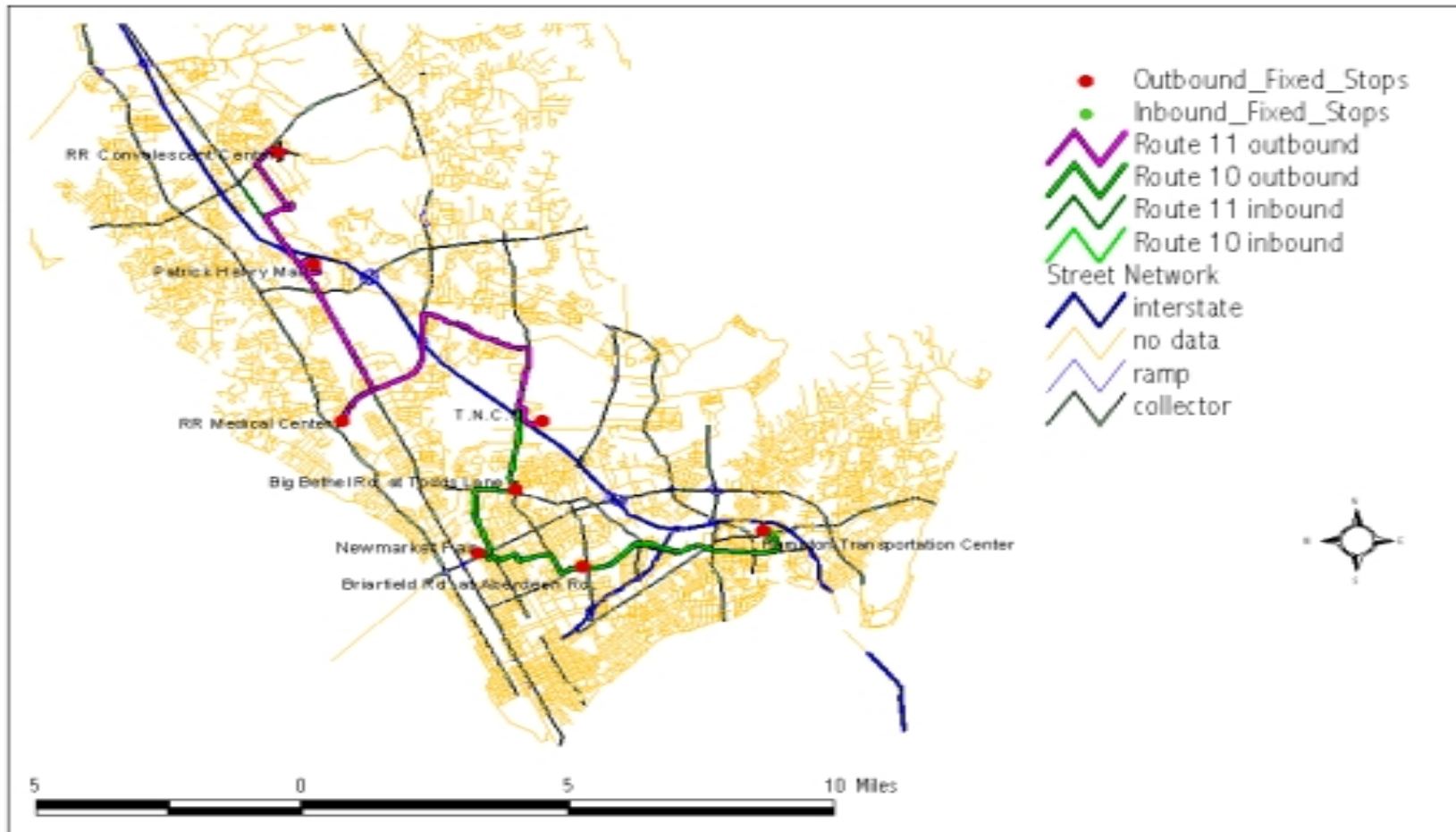
<i>Alternative (Direction)</i>	<i>Through riders</i>	<i>Travel Time Savings (Minutes)</i>	<i>OOD riders</i>	<i>Impact Index</i>	<i>Decision</i>
<b>Route 10</b>					
A (out)	120	3.0	46	7.8	Retain
A (in)	133	2.75	47	7.8	Retain
B (out)	80	5.0	13	30.7	Remove
B (in)	80	3.0	9	26.7	Remove
<b>Route 11</b>					
A (out)	52	4.25	43	5.2	Remove
A (in)	63	4.25	29	9.2	Remove
B (out)	74	3.25	23	10.4	Retain
B (in)	86	3.25	33	8.5	Retain
C (out)	63	2.0	13	9.7	Retain
C (in)	80	2.5	20	10.0	Retain
D (out)	No ridership data	1.5	No ridership data	-	Retain
D (in)	No ridership data	1.0	No ridership data	-	Retain
E (in)	No ridership data	2.0	No ridership data	-	Remove

In addition to the OOD impact indices, several other qualitative factors such as transfer points and potential transit ridership were also considered. Finally, upon examination of the impact indices, transfer points, potential travel time savings, and other qualitative factors, the decision to retain or remove an OOD segment was made (See Table 2). Finally, the new travel times between the retained fixed stops for the modified routes were computed and the new schedules including the slack time were prepared. Two alternative route schedules were developed (See Table 1). Among the two proposed alternatives, alternative 2 was finally adopted for implementation. Figure 2 shows the modified Routes 10 and 11 along with the major fixed stops that were retained.

## Route Deviation Software Design

### *System Architecture*

The route deviation decision support software is just one of the many components of a bigger architecture for a comprehensive route deviation system. The architecture for the GIS based software application is described in this section. Figure 3 is a graphical sketch of the overall system architecture showing the various sub-systems. The route deviation data flow diagram shown in Figure 4, Figure 5, and Figure 6 illustrates the design of the route deviation software developed for this study and depicts the relationship between the different processes of



**Figure 2.** The Fixed Stops on Routes 10 and 11

the application. (Appendix A provides a detailed description of each process within the decision support system as graphically represented in Figures 4, 5, and 6.) All processes of the software, except for the AVL/GPS process, are within the GIS. The internal and external interfaces have been developed using the Dialog Designer extension within ArcView, and *Avenue*, the object-oriented scripting language within ArcView. Within ArcView the spatial and attribute data are organized into what are called *views* and *themes*, in a *project*. A *project* can have many *views*, and *views* can have many *themes*. The attribute data are stored in *tables*, which are relational dBase tables related to the corresponding spatial feature. Themes have the capability to display spatial and attribute data stored in any data format such as, an ArcView shapefile, an Arc/INFO Coverage or a CAD drawing. A shapefile is a simple spatial data format for storing the geometric location and attribute information of geographic features in ArcView. The shapefile format stores spatial data in three basic files with specific extensions that should be stored in the same workspace or directory. They are:

1. File with a **.SHP** extension - this stores the feature geometry,
2. File with a **.SHX** extension - this stores the index of the feature geometry, and
3. File with a **.DBF** extension - this stores all the attribute data associated with the features.

For example, the *streets.shp* file will contain the geometry of the street features, the *streets.shx* will contains the spatial index of the feature geometry and the *streets.dbf* file will have all the attribute information related to the streets such as, length of street segment, name of the street, address ranges, zip codes, speeds, etc. Shapefiles support the following feature type:

- **Points** - Point features represent geographic features such as bus stops, activity centers, cities etc.
- **Lines** - Line features represent geographic features such as streets, rivers, bus routes, etc.
- **Polygons** - Polygon features represent geographic features such as census tracts or blocks, service areas, states, counties, etc.

A theme or a shapefile can contain any of the above feature types. However they can only contain one feature type. For instance, point features can only be added to themes based on point shapefiles. The system level design, such as the contents and organization of the spatial and attribute data in ArcView and the functioning of the external and internal interfaces, is discussed in this section.

### *Problem Framework*

The characteristics of the route deviation service for which the decision support system is being developed are described in this section. The terms, definitions and assumptions used to formulate the problem are outlined below.

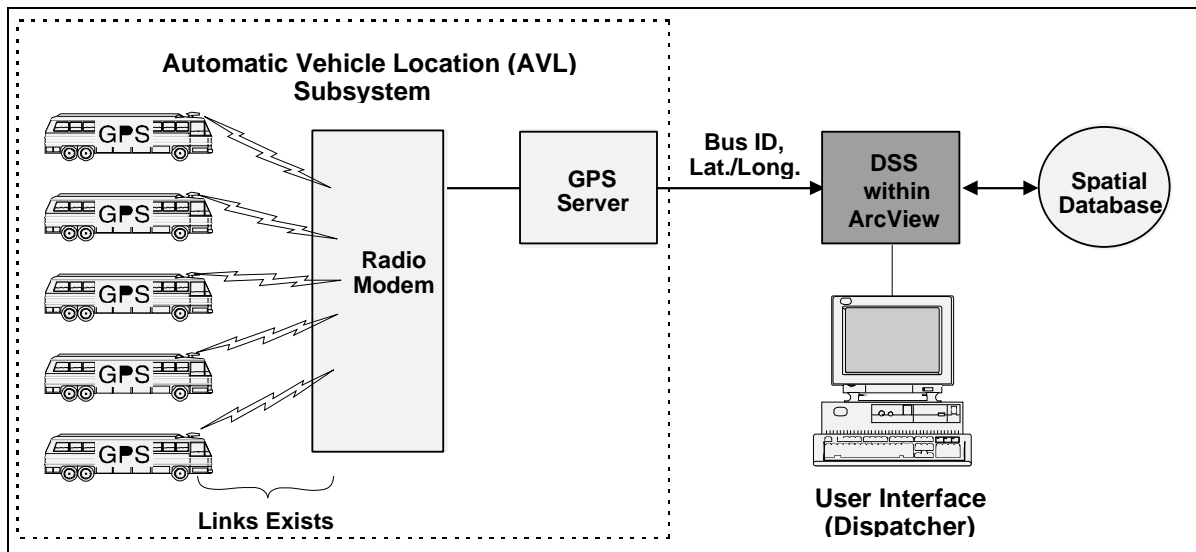


Figure 3. Overall System Architecture

- A “segment” or “service zone” has been defined as the region between a pair of two consecutive fixed stops on a route. Each zone is then given a unique identification number that is based on the route it is on and the fixed stops it falls between. For example, (1, 2) is the ID of the zone between the stops 1 and 2. This definition will be used to track the position of the vehicle with respect to the fixed stops in a real time manner.
- The bus will make mandatory stops at the retained fixed stops and will adhere to the constraint of arriving on schedule at these stops.
- Two directions of travel have been used between the end points of the routes: *inbound* and *outbound*. These directions are global and the definitions hold for all routes. The bus is said to be traveling in the inbound direction if it is traveling in a general direction that is going *towards* the downtown area of the city and the reverse is true for the outbound direction.
- The total time needed to travel from one end of the route to the other end will be *one hour*; i.e., the headways at each stop in each direction of a route will be one hour. This time will include the slack time for deviation. A “schedule block” is defined as the time period between two fixed stops or time check points.
- A *run* or a *pass* of a bus will be defined as continuous travel of the bus from one end of the route to the other in one direction. Thus in a time span of one hour, the bus on a route would have made *one pass* in *one direction*. This is an important definition specific to this problem and will serve as a method to generate a list of customer pickups and drop-offs for a given time period.

### Why a Geographic Information Systems (GIS)-Based System?

A geographic information system (GIS) allows users to store, manage, display, manipulate and analyze spatial and attribute data. The power of GIS lies in its analytical

capability to tie spatial and descriptive attribute information together. Although GIS has and is being used widely for transportation planning and inventory analyses, the employment of GIS-based application for real-time transit operations is a relatively new concept.

As discussed in the background and literature review section, it is evident that many systems are using GIS as part of the overall system architecture. This is being done by interfacing a stand alone scheduling and dispatching system with a electronic mapping system with minimal spatial analysis capabilities, such as address geocoding. As such, most paratransit scheduling software comes with an interface between the scheduling component of the software and their own proprietary “GIS.” In this context, the definition of what constitutes a GIS is becoming increasingly blurred and includes any software that can perform routine spatial analysis such as address geocoding. However, specialized GIS software that are wholly designed for complex relational database management and spatial and attribute analysis provide the user with more capabilities, control and flexibility. Such software (e.g., Arc/INFO and ArcView) are currently being used by most agencies for the purposes of planning, data storage, etc. Our premise is that, rather than purchasing proprietary scheduling software it would be more efficient to “embed” a decision support using existing “off-the-shelf” GIS software. This is further justified with the availability of desktop GIS software that can perform relatively complex spatial and network analysis.

The GIS software package selected for this project, ArcView 3.0a, operates on a personal computer platform and has many tools for developing a customized application. ArcView 3.0a, developed by Environmental Systems Research Institute (ESRI), was selected for this project because it contains the following elements:

- *Avenue*, an object-oriented programming language within ArcView, which allows the user to directly access all of the “building blocks” within ArcView and to customize ArcView for specific applications
- *Network Analyst*, an extension that can assist in solving shortest-path and other transportation-related problems
- *Dialog Designer*, an extension that allows application developers to create specialized input and output forms, thus providing a convenient graphic user interface for applications
- Support of geocoding, the process of identifying the coordinates of a location and displaying it on a map, given its address.

The necessary spatial and attribute data were acquired for the study area, and a database was built within ArcView. The spatial data identify locations of features of interest (such as bus stops and routes) and attribute data describe the features (ridership volumes, presence of benches and shelters, etc.). An augmented version of the U. S. Census Bureau’s “TIGER” files provides detailed street centerline coverage with address ranges. The bus routes and stops were collected by the study team using the global positioning system (GPS). All of this digital data were then imported into ArcView to create a *project* for manipulation and analysis. The end product is an ArcView application customized for the processing of route deviation requests in Pentran’s service area.

## Future Design Options

### Intermediate Check Points

Intermediate checkpoints, not fixed time stops, can be incorporated into the separate point themes for each direction, route, and segment by just adding them as points to the theme. The shortest path will have to pass through these points while solving the network optimization problem. Unlike fixed stops, these checkpoints will not have a scheduled time of arrival associated with them, i.e., they constitute only a spatial constraint, not a temporal one.

### Storing Request Data for Two Weeks

This will be necessary in a system where customers can call up to two weeks in advance to book a request. Table 3 below shows the number of files and the amount of disk space that would be required to store point themes for one week and for two weeks on a transit system with 12 routes. The total disk space required for all the point themes has been calculated by multiplying the disk space required for a point theme of six points, which is 3 kilobytes. To calculate the number of files required, it has been assumed that on an average the number of segments on each route would be four.

**Table 3. Data Requirements for Storing Customer Requests for One and Two Weeks**

<i>Time Period</i>	<i>Required Number of Shape Files for a 12 Route System</i>	<i>Required Disk Space on the Hard Drive (MB)</i>
<b>Option 1</b>		
1-Week	11,424	33.4
2-Weeks	22,848	66.9
<b>Option 2</b>		
1-Week	1,428	4.1
2-Weeks	2,856	8.4

### Polygons for Fixed Route Service Only

A polygon for a service area where only fixed route service can be provided can be distinguished within the theme. A field called 'FIXED' can be added to the polygon theme that will take a Boolean value (YES or NO). A polygon in which only fixed route services can be provided will have a value 'YES' for the FIXED field. When a customer calls for service and his/her origin/destination falls under this polygon, then a message box can be created informing the dispatcher that part or all of the trip request falls under a polygon for fixed route service. This field will be added to the themes, SERVICE\_ZONES\_IN and SERVICE\_ZONES\_OUT.

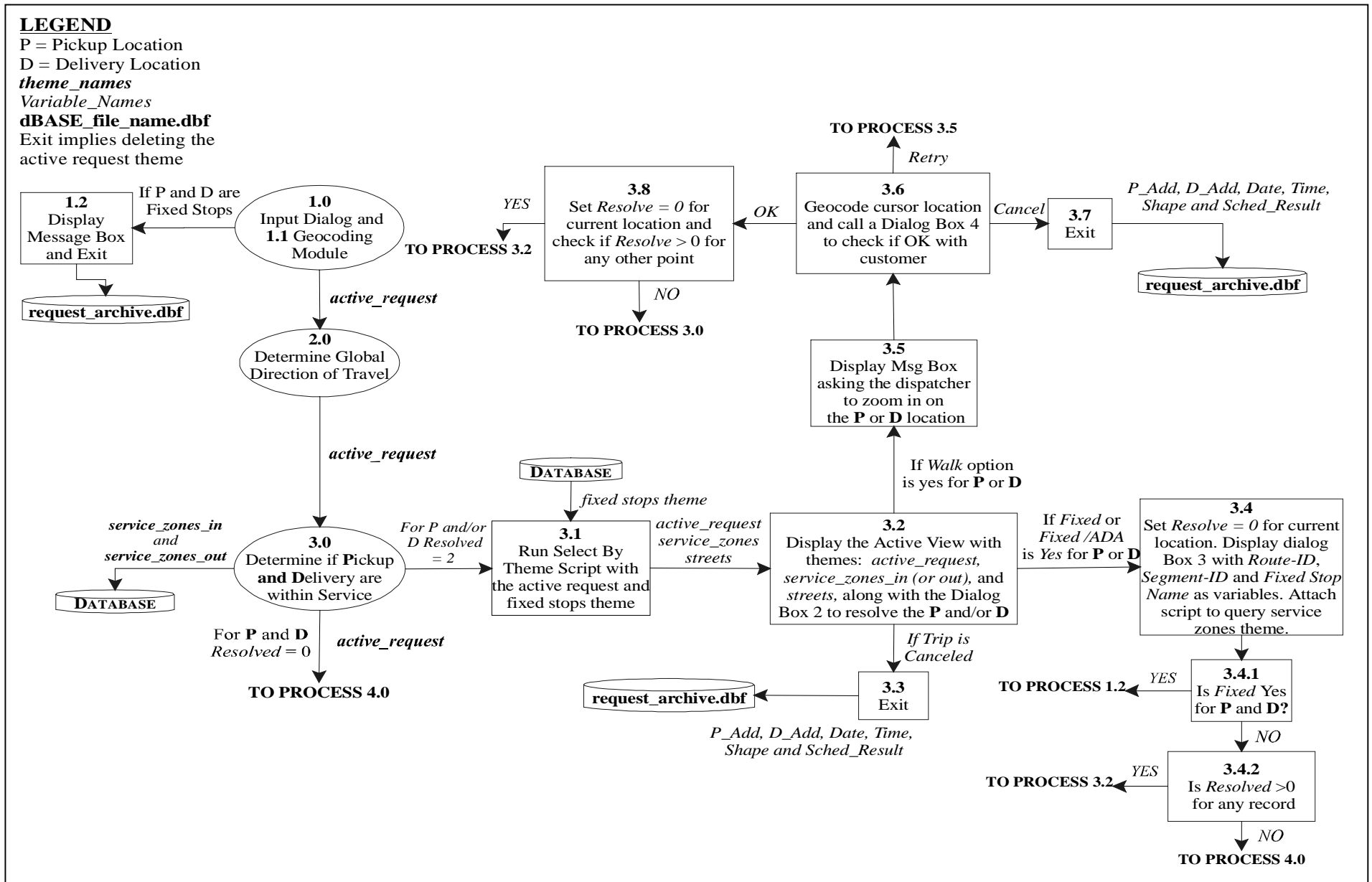
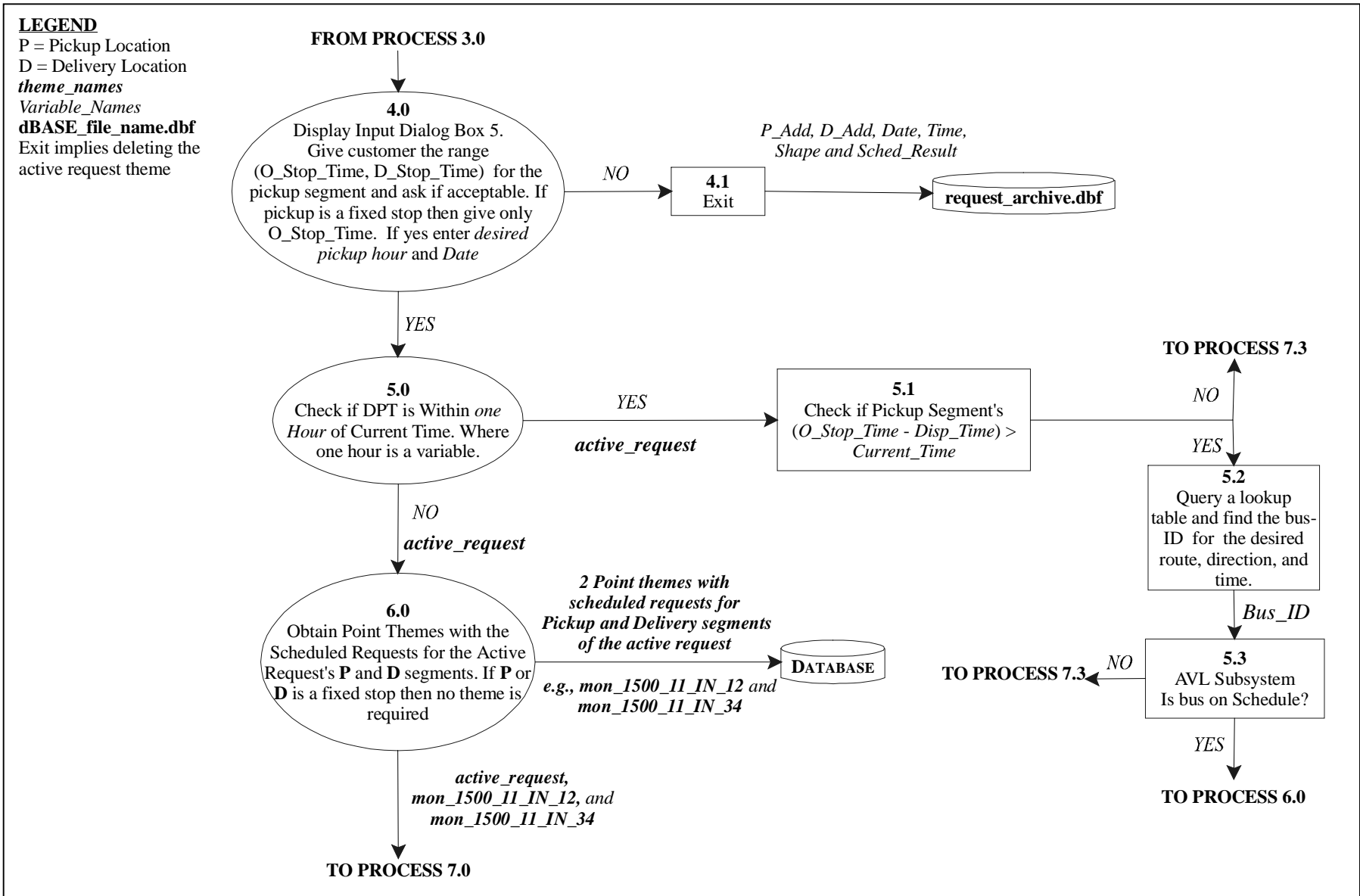
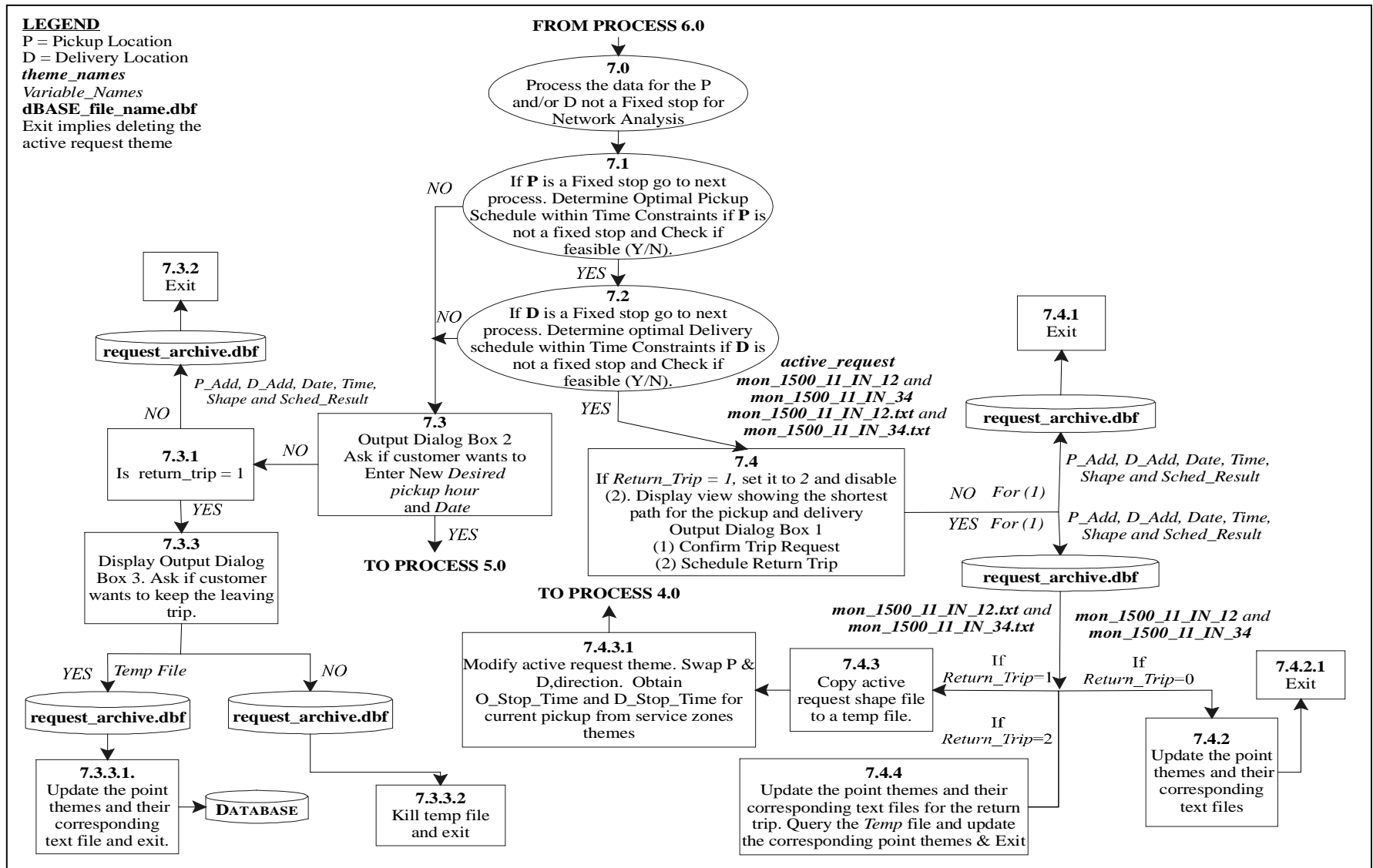


Figure 4. Route Deviation Software Data Flow Diagram: Check for Spatial Constraints





**Figure 5.** Route Deviation Software Data Flow Diagram: Check for Temporal Constraints



**Figure 6.** Route Deviation Software Data Flow Diagram: Network Optimization and Output Modules

## Analysis of Route Deviation Design Parameters

This section summarizes the results obtained by statistically analyzing the affects of various route deviation design parameters on the performance measures of the system. The objective of this evaluation was first, to gain an insight on the potential effectiveness of operating a route deviation service to meet the existing paratransit demand; and secondly, to identify the design parameters affecting a route deviation service and conduct a sensitivity analysis using appropriate performance measures. The data used for the analysis were actual paratransit ridership data in the form of origin and destination (O-Ds) addresses, obtained from Pentran’s Handi Ride operations.

### *Summary of Handi Ride Ridership Data*

A total of three days (08/19/97, 03/07/98, 03/11/98) worth of Handi Ride data were used for the analysis. Table 4 summarizes the statistics of the data, which were organized in the form of origin and destination address for each person certified eligible under the Americans with Disabilities Act (ADA). Apart from the origin and destination addresses, the data also included the name of the passenger, time of pickup, type of disability, vehicle number and certificate number.

**Table 4. Summary Statistics of Handi Ride Paratransit Ridership Data**

<i>Data</i>	<i>Number</i>	<i>Percent of Total</i>
Total Trips	519	-
Total Trips within 1200 & 800 m of all routes	423	<b>81.50</b>
Number within 1200 m of Routes 10 &11	167	<b>32.18</b>

### *Effect of the Buffer Distance on Paratransit Trips*

One of the objectives of providing route deviation service is to divert some of the riders currently using paratransit services under the ADA to fixed route. Therefore, it is important to know how many of the paratransit riders are within the route deviation service area of existing fixed routes. In order to determine this, the line themes of Pentran’s 12 fixed routes were buffered at distances of 1/4, 1/2, and 3/4 mile (400, 800, and 1200 m respectively) and were overlaid over the point theme with the Handi Ride data. The buffer distances were varied to see if there was a substantial increase in the number of paratransit riders with an increase in the buffer distance.

Table 5 shows the origin and destination (O-Ds) points within the different service areas (based on varying buffer distances) of Pentran’s 12 fixed routes. The data clearly indicate that the number of potential paratransit riders increases as the buffer distance increases.

**Table 5. Number of Paratransit Origins and Destinations within the Fixed Route Service Area**

<i>Pentran Fixed Routes</i>	<i>Buffer Distances</i>		
	<i>400 m (1/4 mile)</i>	<i>800 m (1/2 mile)</i>	<i>1200 m (3/4 mile)</i>
<b>1</b>	59	103	132
<b>2</b>	35	47	61
<b>3</b>	30	52	66
<b>4</b>	26	47	53
<b>5</b>	42	66	79
<b>6</b>	34	55	65
<b>7</b>	39	60	69
<b>8</b>	43	74	90
<b>9</b>	26	31	37
<b>10</b>	22	38	58
<b>11</b>	27	34	42
<b>12</b>	28	44	59

An analysis of variance (ANOVA) was conducted on the data shown in Table 5 to see if the increase was statistically significant. The ANOVA results indicated that overall there was a statistically significant increase in the number of O-Ds with the increase in the buffer distance, at 95% confidence level. Within the three buffer distances, although the increase in O-Ds is significant from 400 to 800 m and from 400 to 1200 m, the increase is not statistically significant when the distance is increased from 800 to 1200 m. This implies that Pentran would not be substantially increasing the potential paratransit riders by increasing the service corridor from 800 to 1200 m on either side of the fixed route. This information could help in planning future route deviation service areas.

### *Dwell Time Estimation*

#### *Dwell Time at Fixed Stops*

Total dwell time, in seconds, at a fixed stop can be obtained by the relation between dwell time and the number of boarding and alighting passengers developed by Levinson (1983).

$$DT = 5 + 2.75A \text{ (seconds)}$$

DT = Estimated total dwell time in seconds

A = Number of boarding and alighting passengers

Based on the above relationship, the total dwell time at each fixed stop along Routes 10 and 11 was estimated. The value of A in the equation was computed by taking the average

number of boarding and alighting passengers per hour at each for each fixed stop. These numbers were obtained from a recently completed operational analysis conducted by Associates Consultants for Pentran and are shown in Table 6.

**Table 6. The Dwell Times at each Fixed Stop**

<i>No.</i>	<i>Fixed Stop Name</i>	<i>Values of A (Average Hourly Ridership)</i>	<i>Total Dwell Time in Seconds</i>
1	Riverside Regional Convalescent Center	6	22
2	Patrick Henry Mall	5	19
3	Riverside Regional Medical Center	15	46
4	Thomas Nelson Community College (TNCC) on Route 11	10	33
5	Thomas Nelson Community College (TNCC) on Route 10	15	46
6	Big Bethel Rd and Todds Lane	4	16
7	Newmarket Fair	15	46
8	Briarfield at Aberdeen Rd	4	16
9	Hampton Transportation Center (HTC)	12	38

*Dwell Time at Deviated Stops*

Levine and Torng (1994) conducted several trials in order to estimate the average boarding times for the wheelchair bound passengers using conventional buses. They found that on average it takes a total of 185 seconds (3 min. 5 sec.) for a wheelchair bound passenger for boarding and alighting. Table 7 shows the breakdown of the boarding and alighting times that were obtained in this study.

The dwell time for disabled or elderly riders who are not wheelchair bound was assumed to be one minute (60 seconds). This assumption was based on the information provided by JAUNT, Inc., which provides demand responsive services for the disabled and elderly in Charlottesville, VA, and surrounding counties.

Having found the dwell times at fixed stops and at deviated stops, the next step was to calculate the proportion of wheel chair and non-wheelchair bound ADA riders from the sample size. Among the ADA riders whose origin and/or destination fell within a 1200 m (3/4 mile) distance along Routes 10 and 11, there were 23 (24%) wheelchair bound riders and 72 (76%) non-wheelchair bound or slow moving riders. The composite dwell time at any deviated

**Table 7. Average Wheelchair Passenger Boarding Times in Seconds (Source: Levine and Torng, 1994)**

<i>Component of wheelchair passenger boarding and alighting time</i>	<i>Conventional Buses</i>
<b>(a) Boarding Process</b>	
1. Door open to wheelchair on board	36
2. On board to in position	10
3. In position to secured	52
4. Secured to bus ready to move	16
<i>Total Time</i>	<i>114 sec (1 min.54 s)</i>
<b>(b) Alighting Process</b>	
5. Door open to start releasing	15
6. Start releasing to finish releasing	15
7. Finish releasing to wheelchair on sidewalk	18
8. Wheelchair on sidewalk to bus ready to move	24
<i>Total Time</i>	<i>72 sec (1 min.12 s)</i>
<b>Average Time to Board or Alight</b>	<b>93 sec (1 min. 33 s)</b>

stop, based on the proportion of wheelchair and non-wheelchair bound (or slow moving) riders, was calculated using the equation below:

$$DT = \frac{(N_{WC} \times DT_{WC}) + (N_{SM} \times DT_{SM})}{(N_{WC} + N_{SM})} = \frac{(23 \times 93) + (72 \times 60)}{(23 + 72)} = 68 \text{ seconds}$$

where,

$N_{WC}$  = No. of riders with wheelchairs

$N_{SM}$  = No. of riders without wheelchairs or slow moving riders

$DT_{WC}$  = Dwell time for a rider with wheelchair to board or alight (see Table 7)

$DT_{SM}$  = Dwell time for a rider without wheelchair or slow moving rider

Therefore, 68 seconds (which is about 14% of the average slack time of 8 minutes) was used as the dwell time at *each* deviated stop for the network analysis.

#### *Methodology for Sensitivity Analysis of Design Parameters*

During the course of this study, two design parameters that are critical for providing route deviation service were identified. They are, the *area of the service zone* and the *slack time for*

*each service zone.* A service zone has been defined as the region between two consecutive fixed stops. In all, there are four service zones for Route 10 and three service zones for Route 11 (see Table 8 and Figure 7 for details). The two design parameters outlined above were found to be critical as they determine the level of service that a route deviation service can achieve. A sensitivity analysis was conducted to evaluate the effect of the design parameters on measures of effectiveness. The two measures (of the three in Table 9) that were chosen for evaluating the performance of route deviation service are: (1) *maximum number of feasible deviations* and (2) *additional dwell time or excess slack time remaining at the fixed stops*. Table 9 shows in detail the sensitivity analysis scenarios and the performance measures used to evaluate each scenario.

**Table 8. Definition of the Service Zones**

<i>Zone-ID</i>	<i>Fixed Route-ID</i>	<i>Fixed Stops at the end of the Zones</i>	
Service Zone 1	Route 11	Riverside Convalescent Center	Patrick Henry Mall
Service Zone 2	Route 11	Patrick Henry Mall	Riverside Regional Medical Center
Service Zone 3	Route 11	Riverside Regional Medical Center	Thomas Nelson Community College (TNCC)
Service Zone 4	Route 10	TNCC	Big Bethel Rd at Todd's Lane
Service Zone 5	Route 10	Big Bethel Road at Todd's Lane	Newmarket Fair
Service Zone 6	Route 10	New Market Fair	Briarfield Rd. at Aberdeen Rd.
Service Zone 7	Route 10	Briarfield Rd. at Aberdeen Rd.	Hampton Transportation Center

**Table 9. Sensitivity Analysis Scenarios and Performance Measures**

<i>Design Parameter</i>	<i>Scenarios</i>	<i>Performance Measures</i>
<b>Area of the Service Zone (Distance from the route in meters)</b>	1. 400 m (1/4 mile)	<i>Maximum number of Feasible Deviations</i>
	2. 800 m (1/2 mile)	<i>Additional Dwell Time at Fixed stops</i>
	3. 1200 m (3/4 mile)	
<b>Slack Time (ST) distribution</b>	1. ST distributed by weighted average of running time between stops (SDWR)  2. ST distributed by weighted average of number of ADA riders (SDNP)	<i>Maximum Feasible Deviations</i> <i>Additional Dwell Time at Fixed stops</i>

The buffer distance has been used as a surrogate for defining the area of the service zone in order to increase the size uniformly. The scenarios were created by buffering the two routes with a buffer distance of 400 (1/4 mile), 800 (1/2 mile) and 1200 m (3/4 mile), respectively (See Figure 7). These distances were chosen as they are representative of what is currently being used by transit agencies to provide route deviation service (Farwell and Marx, 1996; FTA, 1996).

Most agencies are using a 3/4-mile service corridor on either side of a fixed route mandated by the ADA, as a benchmark to define the service area for route deviation. However, under some situations it could be more appropriate to reduce the service area to 1/2 or even 1/4 mile from the fixed route, in order to accommodate more deviations. Hence, one of the objectives of this evaluation was to assess the effect of the buffer distance on the performance measures. The other important design parameter is the slack time that should be allocated to each service zone. After the route structure and schedule modifications for the chosen routes have been made, the following parameters are known:

- the total nonstop travel time or running time between two consecutive fixed stops (F)
- the total running time of the entire route in minutes (T, which for this study is 60 minutes)

Given these, the total slack time for a route can be computed from the relation:  $S = (T - F)$ . Instead of distributing this slack time between each service zone arbitrarily, two methods are recommended and tested under this evaluation. They are:

1. Slack time distribution as a weighted average of the nonstop travel time between the two fixed stops of a zone (SDWR)
2. Slack time distribution as a weighted average of the total number of origins and destinations of ADA certified trips (SDNP).

The analysis was conducted using the prototype system developed in ArcView to determine the maximum number of feasible deviations that could be accepted given the schedule constraints at the fixed stops and the time window constraints at each of the deviated stops. The network analysis used the dwell time values at fixed and deviated stops that were previously computed. For each service zone, a random number generator was used to randomize the order in which persons were served. Requests for deviations for each zone were picked from a list of paratransit addresses that were within that particular service zone. After randomizing the order, the requests were added one after the other from the list to the system, each time checking whether the additional request was feasible within the time constraints. If the addition of a point was not feasible then it was dropped from the list of feasible points. Thus, several iterations were performed to include all the different orders of requests. The next step was to compute the *average* number of allowable deviations and the *average* additional dwell time over all iterations, for each service zone under each scenario (shown in Table 9).

### *Results of the Sensitivity Analysis*

A summary of results of the sensitivity analysis is presented in this section. The values of the two design parameters were varied and the effect of this variation on the performance measures was determined. Specifically, the analysis was aimed at gaining more insight on the relationship between the design parameters and the performance measures. This information will help in designing an efficient route deviation service.



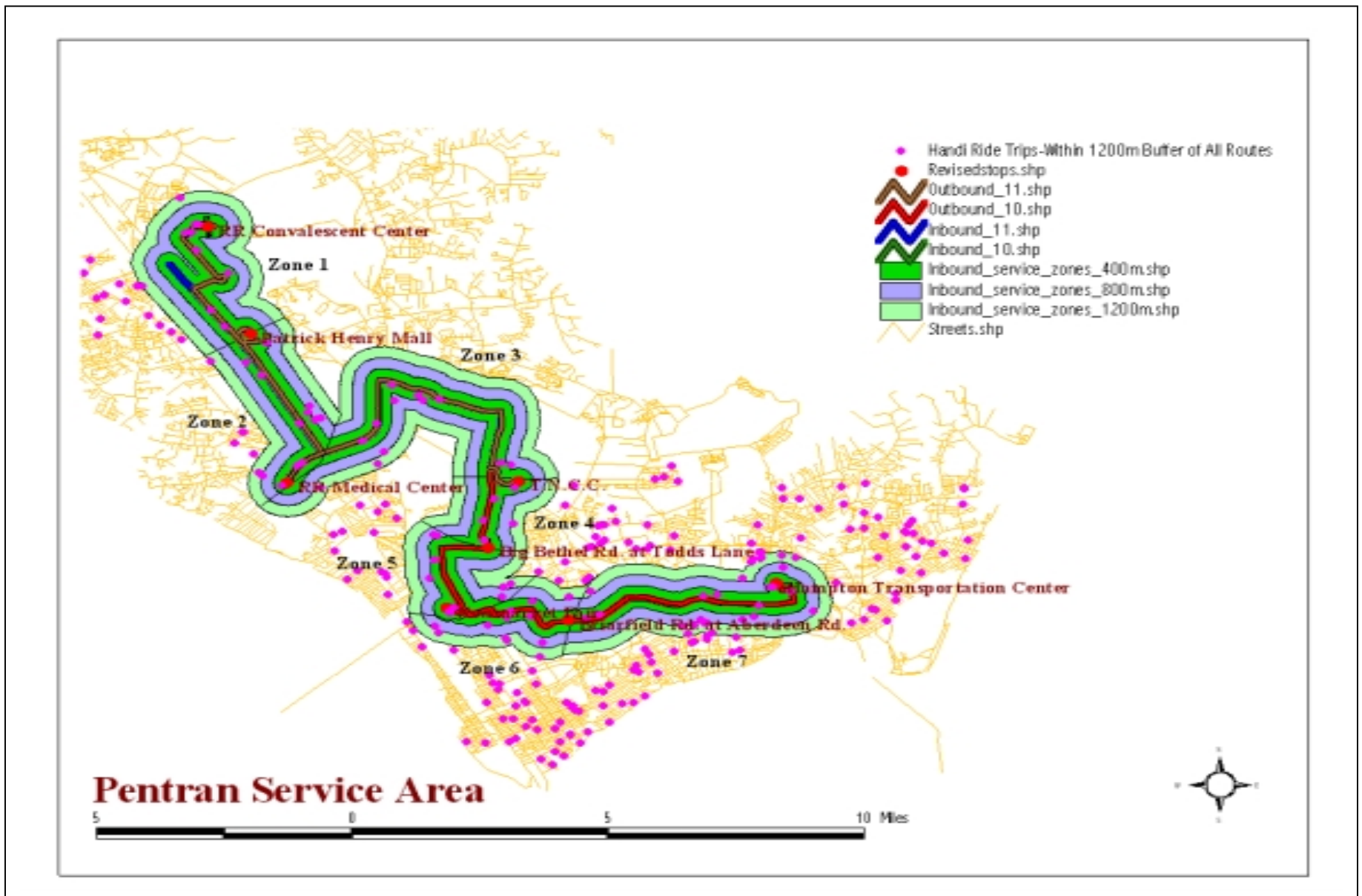


Figure 7. Service Zone sizes and the Paratransit Trips

*Effect of Service Zone Size (Varying Buffer Distances)*

The average number of feasible deviations and the average additional dwell time was computed for each zone, for different buffer distances using the analysis methodology outlined earlier. Table 10 shows the average (over all iterations) maximum feasible deviations that can be accommodated for each service zone under different buffer distances. The number in parentheses represents the total potential deviations for that zone and is also the number of iterations performed. The slack time was distributed as a weighted average of the non-stop running times between the fixed stops. Under this method of distribution, the slack time allotted to a service zone remains unchanged over the different buffer sizes. Hence the results of this scenario are used to compare the effect of varying service zone size on the maximum feasible deviations that can be accommodated while keeping the slack time constant.

**Table 10. Average Maximum Feasible Deviations per Hour (Number of interactions) for All Service Zones**

	Buffer Distance			Avg. Daily Peak Hour Paratransit Trips <sup>1</sup>
	400 m	800 m	1200 m	
<b>Zone1</b>	<b>6.00 (8)</b>	<b>6.00 (8)</b>	<b>5.50 (10)</b>	1
<b>Zone2</b>	2.91 (11)	2.50 (14)	2.38 (16)	1
<b>Zone3</b>	<b>5.57 (7)</b>	<b>5.80 (10)</b>	<b>5.83 (12)</b>	0.667
<b>Zone4</b>	1.50 (4)	1.50 (4)	1.40 (5)	0.667
<b>Zone5</b>	<b>3.80 (5)</b>	<b>3.38 (8)</b>	<b>3.50 (10)</b>	0.667
<b>Zone6</b>	2.00 (4)	1.50 (8)	1.42 (12)	1
<b>Zone7</b>	<b>9.00 (9)</b>	<b>6.06 (17)</b>	<b>5.40 (30)</b>	2

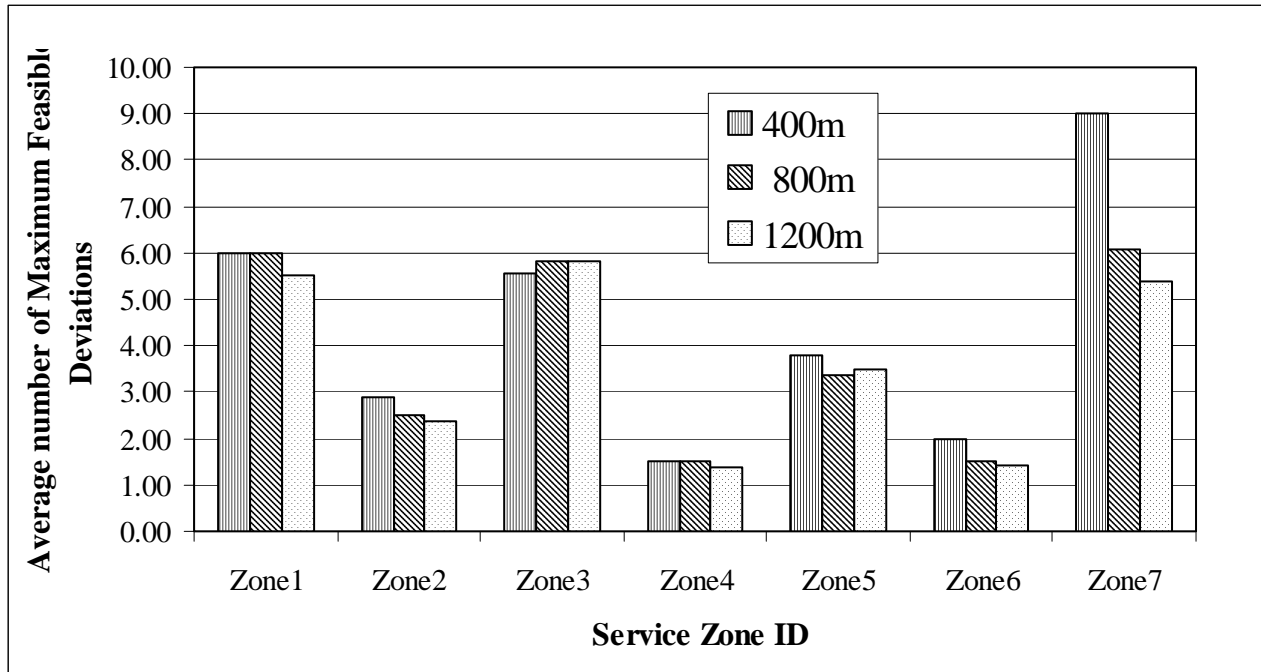
1. Averaged over three days

The numbers in the first three columns are encouraging, as they reveal that a reasonable number of deviations can be accommodated within each zone. The last two columns of Table 10 show the actual hourly distribution of trips for each zone obtained from the Handi Ride data. This could be interpreted as the peak or average hourly “demand” for deviations. A comparison of the numbers in bold in the first three columns with the actual hourly trip distribution indicates that for most zones the maximum feasible deviations are much higher than the peak hour paratransit trips. This means that there is room to serve more deviations if the hourly demand for the trips increases. However, for three of the zones the maximum feasible deviations are barely equal to the peak hour and average hourly demand.

Another finding of interest is that the number of feasible deviations increases with a decrease in the buffer distance for all zones with an exception of zone 3. This effect seen visually in Figure 8. can be attributed to the fact that as the area of the service zone shrinks the average time taken for each deviation also reduces considerably as the deviated stops are spread over a smaller area. Consequently, this gives the bus enough time to accommodate more deviations. However, the downside of shrinking the service zone size is that the busses may have to spend more time idling at the fixed stop in the end of the zone possibly adversely affecting the rider attitude (see

Table 11 and Figure 9). For almost all zones (with an exception of zone 6) there is an increase in the additional dwell time when the buffer distance is reduced from 1200 to 400 m.

Ideally, the service zones for route deviation should be designed such that the number of feasible deviations is high and the additional dwell time at the fixed stop is low. The results presented in this section indicate that it is hard to achieve both objectives simultaneously. One solution is to prioritize the objectives based on the needs and perceptions of the service provider. Pentran will have to decide as to which objective gets priority over the other. Another approach



**Figure 8. Effect of Buffer Distance on Maximum Feasible Deviations (Slack Time Distributed as a weighted average of the Running Time)**

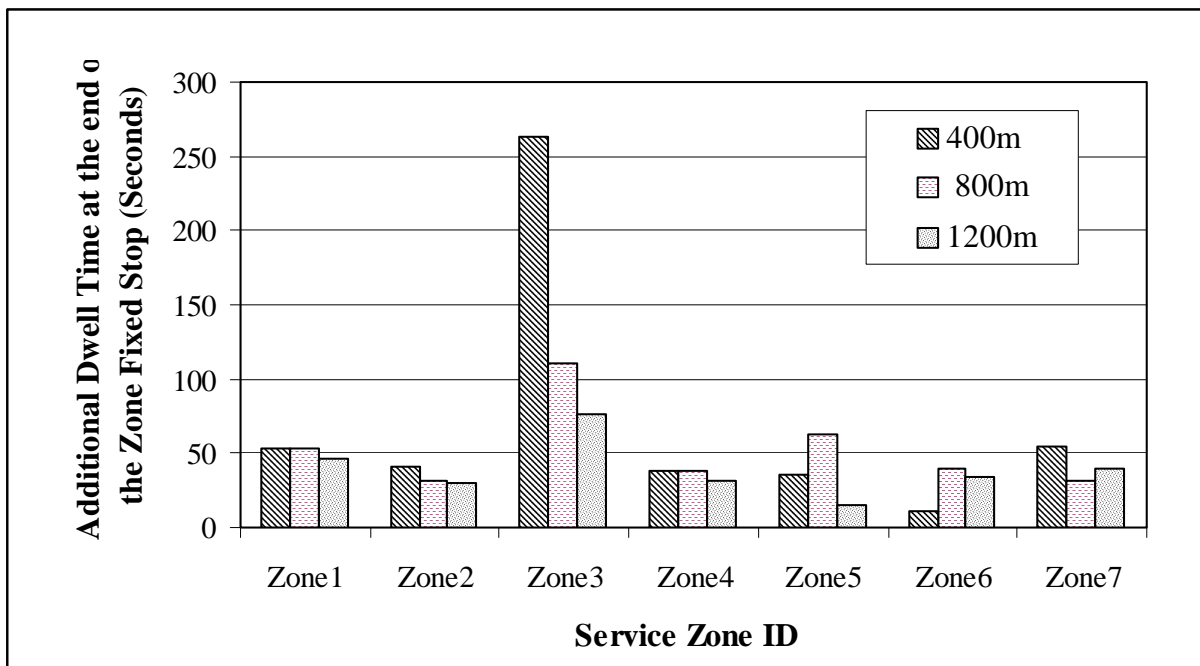
could be to pick the buffer size for each zone individually based on the best values for the performance measures. This could lead to a situation where each zone would not have the same length of service corridor. For instance, service zone 1 would be 800 m wide on either side of the fixed route whereas service zone 2 would be 1200 m wide.

### *Effect of Slack Time Distribution Methods*

As previously discussed, the slack time allocation between the service zones is an important issue to consider when designing a route deviation service. A methodology for such a delineation could not be found in the literature. In this section the effects of distributing the slack time using the two methods, henceforth referred to as SDWR and SDNP, on the

**Table 11. Effect of Buffer Distance on Additional Dwell Time at Fixed Stop**

	Buffer Distance		
	400 m	800 m	1200 m
<b>Zone1</b>	52.96 (8)	52.96 (8)	46.11 (10)
<b>Zone2</b>	41.43 (11)	31.38 (14)	30.21 (16)
<b>Zone3</b>	263.49 (7)	110.64 (10)	76.56 (12)
<b>Zone4</b>	38.78 (4)	38.78 (4)	31.02 (5)
<b>Zone5</b>	35.93 (5)	63.16 (8)	15.28 (10)
<b>Zone6</b>	11.05 (4)	39.52 (8)	33.66 (12)
<b>Zone7</b>	54.11 (9)	30.69 (17)	39.14 (30)



**Figure 9. Effect of Buffer Distance on Additional Dwell Time at the Fixed Stop**

performance measures are presented and discussed. Table 12 and Table 13 summarize the effects of slack time distribution methods on the performance measures for each zone. Our initial hypothesis in testing the two methods was that the slack time distribution method based on the weighted average of the number of potential deviation points (SDNP) within each zone would be more effective in increasing the number of feasible deviations that can be accommodated and also reducing the additional dwell time or excess slack time. The results in Table 12 and Table 13 indicate that the total number of deviations for both the routes is higher and the total dwell time is lower under the SDNP method than the SDWR method, when the overall totals are compared for the system as a whole under varying buffer sizes.

**Table 12. Effect of Slack Time Distribution Methodology on the Number of Feasible Deviations**

	1200 m Buffer Area		800 m Buffer Area		400 m Buffer Area	
	<i>SDWR</i> <sup>1</sup>	<i>SDNP</i> <sup>2</sup>	<i>SDWR</i>	<i>SDNP</i>	<i>SDWR</i>	<i>SDNP</i>
<b>Zone1</b>	5.50	5.30	6.00	5.88	6.00	6.88
<b>Zone2</b>	2.38	5.38	2.50	5.71	2.91	6.36
<b>Zone3</b>	5.83	4.50	5.80	5.00	5.57	3.86
<b>Zone4</b>	1.40	1.00	1.50	1.00	1.50	2.00
<b>Zone5</b>	3.50	2.90	1.50	2.38	2.00	2.00
<b>Zone6</b>	1.42	1.83	3.38	3.38	3.80	3.80
<b>Zone7</b>	5.40	6.80	6.06	6.06	9.00	8.00
Totals	<b>25.43</b>	<b>27.71</b>	<b>26.73</b>	<b>29.40</b>	<b>30.78</b>	<b>32.90</b>

1. Slack time distributed among zones as a weighted average of the running time

2. Slack time distributed among zones as a weighted average of the number of potential deviated points

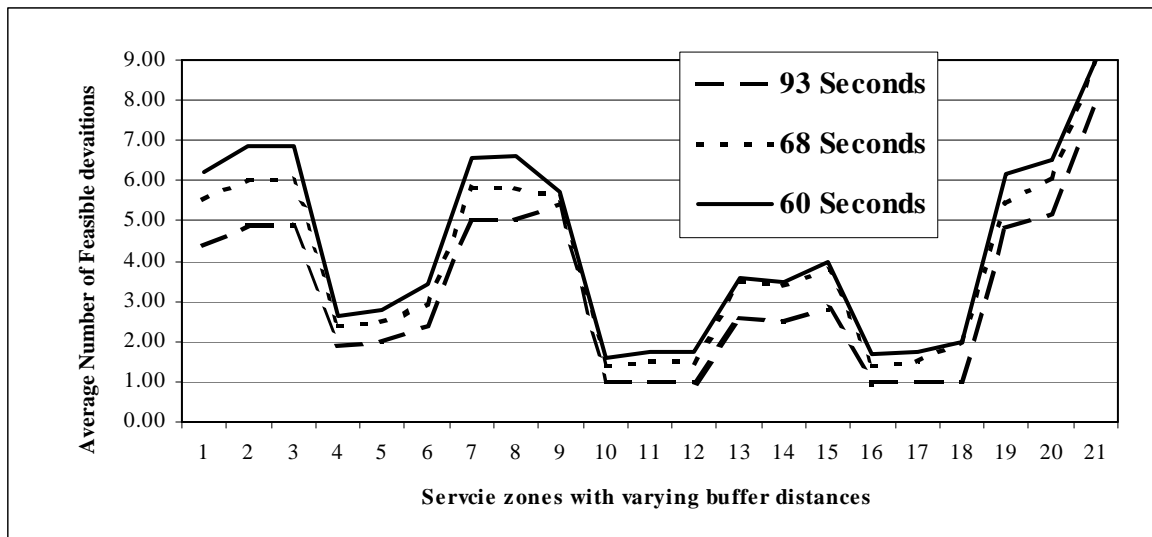
**Table 13. Effect Of Slack Time Distribution Methods On Additional Dwell Time At The Fixed Stops**

	1200 m Buffer Area		800 m Buffer Area		400 m Buffer Area	
	<i>SDWR</i>	<i>SDNP</i>	<i>SDWR</i>	<i>SDNP</i>	<i>SDWR</i>	<i>SDNP</i>
<b>Zone1</b>	46.11	5.39	52.96	1.46	52.96	53.46
<b>Zone2</b>	30.21	54.92	31.38	55.78	41.43	27.27
<b>Zone3</b>	76.56	40.35	110.64	39.79	263.49	54.87
<b>Zone4</b>	31.02	20.89	38.78	20.89	38.78	59.42
<b>Zone5</b>	15.28	25.40	63.16	63.16	35.93	35.93
<b>Zone6</b>	33.66	41.06	39.52	57.02	11.05	71.05
<b>Zone7</b>	39.14	29.18	30.69	30.69	54.11	150.11
Totals	<b>271.98</b>	<b>217.20</b>	<b>367.14</b>	<b>268.79</b>	<b>497.75</b>	<b>452.11</b>

However, a similar trend is not seen when the individual zones are compared to each other. This can be attributed to the fact that there are other factors causing variability between the service zones such as, the spatial distribution of the points within a zone, which impact the performance measures and were not considered in the analysis. For the same reason, the change in the values of the performance measures was *not* found to be statistically significant between the two methods; thus no categorical statements can be made on the efficiency of the two methods. Conducting further tests on additional data could possibly lead to statistically significant results. However as a general guideline, the first method (SDWR) should be used before the system is implemented, especially if there is no data on the potential deviation points.

*Effect of Dwell Time at Deviated Stops on Number of Feasible Deviations*

The results of the sensitivity analysis presented above used a composite dwell time of 68 seconds. Similar analysis was conducted using a dwell time at deviated stops of 93s (which assumes all riders at the deviations are wheelchair bound) and 60 seconds (which assumes all riders at the deviations are not wheelchair bound), to see the impact of dwell time at deviated stops on the maximum number of feasible deviations. Figure 10 shows the average number of feasible deviations measured under three different dwell time values, 93, 68, and 60 seconds for the seven zones with three different buffer distances adding up to a total of 21 zones. The intent was to measure the effect of increase in dwell time at deviated stops on the average number of feasible deviations, irrespective of the buffer distance for each zone. Hence, the zone-IDs and buffer sizes are not mentioned in Figure 10.



**Figure 10. Effect of Dwell Time at Deviated Stops on the Number of Feasible Deviations**

The results clearly indicate that even a slight change in the dwell time of 8 seconds has a substantial effect on the number of deviations that can be accommodated, irrespective of the service zone size. As the dwell time is increased from 60 to 93 seconds, there is a significant drop in the number of deviations that can be accommodated. The difference was also found to be statistically significant at the 95% confidence level.

## CONCLUSIONS

The results of this study are promising and demonstrate the technical feasibility of providing route deviation service under certain conditions. The prototype decision support system developed in this study can be used as the foundation for developing a full-fledged route deviation scheduling software that public transportation agencies can use to implement such a service. Some final conclusions are presented in this section.

### Route Deviation Design Parameters

So far, there is little or no literature available that deals with specific guidelines to be followed in designing and implementing a route deviation service. In a recent article evaluating the Potomac and Rappahannock Transportation Commission's (PRTC) route deviation service, Farwell (1998) acknowledges this fact. PRTC designed its route deviation system primarily based on what it "felt" was right. The results of the analysis conducted in this research identified and shed some light on the key design parameters for route deviation: service area and slack time distribution. Specifically, the results indicate that as the area of the service zone is increased the number of feasible deviations that can be accommodated decreases. However, the additional dwell time, or the excess slack time left over, increases with the reduction in service area. Thus the objectives of increasing the number of feasible deviations and simultaneously reducing the excess slack time are conflicting. Therefore, an agency providing route deviation service will have to prioritize one objective over the other in order to make a decision.

Also, based on the results obtained, the second methodology to distribute slack time is most effective, i.e., distributing the slack time by weighted average of the number of potential deviated points within a zone (SDNP), if the potential demand is known. In the situation where the information on the potential deviation points is unknown, for example if paratransit ridership data are not available for an area, then, it is recommended that the first method of slack time distribution, i.e., SDWR be used.

Although the second method (SDNP) was found to be more effective in improving the overall values of the performance measures, the difference between the two methods was not found to be statistically significant due to an insufficient sample size. Therefore, the two methodologies should be further tested with more data in order to draw more categorical conclusions.

Finally, another important parameter is the dwell time at the deviated stops. As the results indicate, large dwell times at the deviated stops could lower the efficiency of the route deviation service. Specific measures must be taken in order to reduce bus dwell times at deviated stops. For instance, studies have shown that the use of low-floor busses significantly reduces the overall boarding and alighting time of passengers with disabilities (Levine and Torng, 1994). Another important step is to train the fixed route drivers in assisting disabled passengers.

## GIS Software

One of the key findings of this study was that “off-the-shelf” geographic information systems (GIS) software can be used to develop a customized decision support system for transit operations. This means that GIS software can now be successfully used for the purposes of traditional planning as well as operations. The findings also demonstrate the robustness of the software used in this research, ArcView 3.0, in handling complex spatial and network analysis. With desktop GIS software becoming more and more powerful and easy to use, there are many advantages to storing and managing all of the a public transportation agency’s spatial and attribute data within a GIS database. Such a system could be used to support transit operations and conventional planning simultaneously, thus eliminating the need to invest in a separate proprietary scheduling software. Also, having both the scheduling and planning systems in once place, any updates to the database need only be made in one place. Another factor to be considered is that maintaining a proprietary GIS is more expensive than obtaining an “off-the-shelf” GIS software and using shared data.

## Route Deviation Service Viability

Based on the promising results of this research effort, it is likely that a route-deviation transit system could provide effective service in urban and suburban areas similar to that of the Hampton Roads region of Virginia. A preliminary examination of the implementation issues, as identified in Appendix C, revealed that an operational test would require investment in equipment, training, and possibly additional personnel. Furthermore, the prototype software developed for this research effort would need to be further developed to prepare it for “live” operations.

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**APPENDIX A**  
**SYSTEM BEHAVIORAL DESIGN**

## System Behavioral Design

The behavior and functioning of the various modules of the system in relation to each other is described in this section. All the components of the software, except for the GPS server (this device will pass the latitude/longitude from the receiver to the DSS), will be embedded within ArcView. Therefore, it is paramount to comprehend the organization of spatial and attribute data within ArcView. Additionally, the processing of the inputs and outputs, along with the external and internal interfaces of the system must be understood. All of these are described below in detail. Please note that all the tables referred to in this section are in the Appendix B.

### Process 1.0 - Input Dialog 1

This process consists of the Input Dialog Box 1 and the geocoding module. At the end of the process, a point theme called **active\_request** will be created. This theme will contain the spatial features and fields created from the variables of the Input Dialog box in addition to other fields describing the characteristics of the request. The variables or fields of the input dialog box 1 are shown in Table 14 in the Appendix B.

### Process 1.1 - Geocoding Module

The pickup address and the delivery address will be geocoded to create a point theme. The name of this theme will be **active\_request**. The variables described in Table 14 of the Appendix B will be added to the active request's attribute table (dBASE file), **active\_request.dbf**, as fields. Other fields, e.g., **direction** (the values for which will be added in the subsequent processes), will also be created in the attribute table of the point theme. Under this process the (x, y) coordinates of the pickup and delivery points will be added to the table **active\_request.dbf** as fields. Table 25 in the Theme Meta Data section of Appendix B shows *all* the fields contained within the dBASE file, **active\_request.dbf**. This dBASE file will have only *two* records, one for the origin point and other for the destination point.

### Process 1.2 – Display Message Box and Exit

This point in the process is reached if both the pickup and delivery points, given by the customer and entered by the dispatcher in input dialog box 1, are fixed stops. The following message will be displayed by the box- “Both the pickup and delivery points are fixed stops. Please ask the customer to use fixed route service instead of route deviation.” Next the process will terminate and exit out of the system after copying the result to the dBASE file, **request\_archive.dbf**.

### Process 2.0 - Determine the Global Direction of Travel

In order to assign the customer to a particular bus, the direction of travel for the request must be determined. In this process the global direction of travel will be determined based on the coordinates of the pickup and delivery points. This is done by defining a fixed reference axis for the entire network. The reference axis will be arbitrarily defined such that the axis will pass

through the downtown area and a point farther away from the study area. The angles  $\theta$  and  $\phi$  are defined as follows:

$\theta$  - the angle between the reference axis and the line joining the pickup point and the origin of the axis

$\phi$  - the angle between the reference axis and the line joining the delivery point and the origin of the axis

Figure 11 clearly illustrates how the angles for the origin and destination will be determined. The customer's global direction of travel can be determined from the following relation:

$$Direction = \begin{cases} Inbound, & \text{if } \theta \geq \phi \\ Outbound, & \text{if } \theta < \phi \end{cases}$$

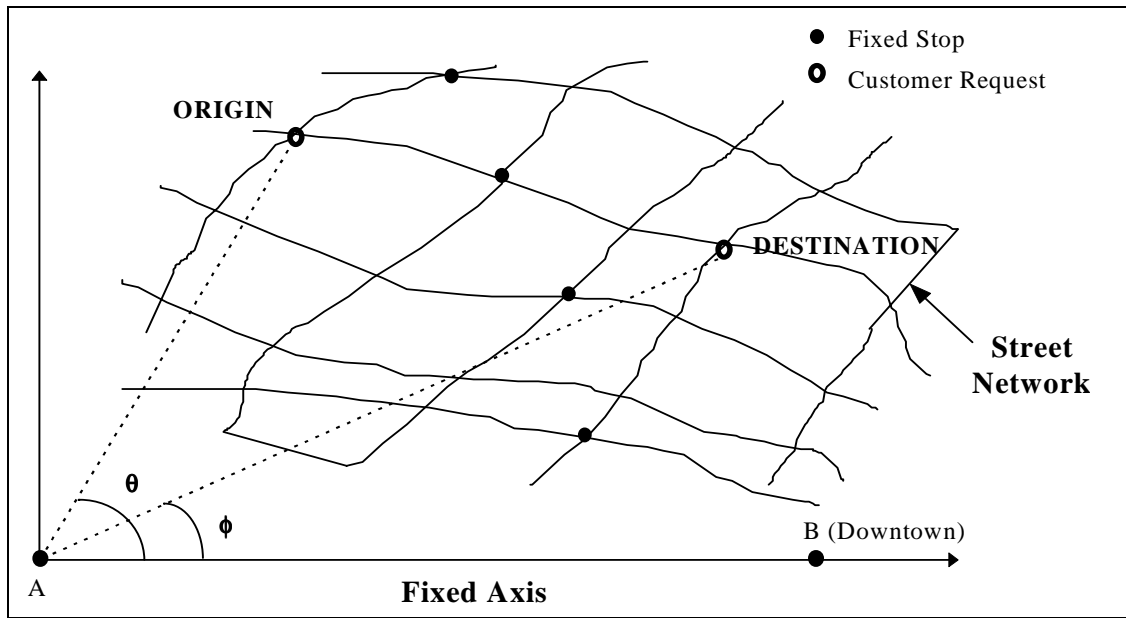


Figure 11. Finding the Global Direction of Travel

In order to determine the angles it is necessary to know the coordinates of the origin ( $x_o$ ,  $y_o$ ) and the destination ( $x_d$ ,  $y_d$ ) points. The latitude/longitude coordinates of points within a GIS provide a convenient preexisting system for determining the angles  $\phi$  and  $\theta$ . The reference axis will be defined as a line passing between an arbitrary point A and the downtown area (designated B). The point A will be assigned such that  $Y_A = Y_B$  and  $X_A \neq X_B$ . The value of the angles can then be calculated by:

$$\theta = \tan^{-1} \left( \frac{y_o - y_A}{x_o - x_A} \right) \text{ and } \phi = \tan^{-1} \left( \frac{y_d - y_A}{x_d - x_A} \right)$$

This relation can be used in all cases except for when the *inbound* and *outbound* directions are parallel to each other on a route. This exception will occur in cases where a route is highly convoluted in its structure. However, such an occurrence is very rare and does not arise for the Pentran routes. The reference axis can be created and the angles can be computed using the tools in ArcView. Once the direction (inbound or outbound) is calculated in this manner the value for the field, *direction*, is entered in the table *active\_request.dbf*.

### Process 3.0 - Determine If Pickup And Delivery Are Within Service Zones

In this process the preexisting field **resolve** in the **active\_request.dbf** file will be populated. The following is a list of values that the field **resolve** can take and the status indicated by the value.

- Resolve = 0**; Implies that the point has satisfied all the requisite spatial constraints
- Resolve = 1**; Implies that the point is within ¼ mile of a fixed stop
- Resolve = 2**; Implies that the point is outside the service zone and not near a fixed stop.

The theme **active\_request** is passed on to a script that will determine if the pickup and delivery points fall within the service zones or not. Based on the direction of travel obtained in process **2.0**, this script will execute a “Select by Theme” on the **service\_zones\_in** or **service\_zones\_out** theme, which could result in two possible scenarios. The two scenarios and the specific action(s) taken under each are described below.

- I. *The pickup and delivery locations fall within the service zones.* The segment ID, route ID and other information, such as the origin and destination stop of the segment, will be obtained from the attribute table of the **service\_zones\_in** or **service\_zones\_out** theme. The information for the following fields will then be added to the attribute table **active\_request.dbf**:

- route\_ID**
- segment\_ID**
- o\_stop**
- d\_stop**
- o\_stop\_time**
- d\_stop\_time**

After this step the algorithm will directly go to process **4.0**. At this point, a value to the field, **resolve**, will be added. If this scenario is true then **Resolve** will be set to **0** for both the pickup and delivery points.

- II. *The pickup and/or delivery locations fall outside the service zones.* Under this scenario the value for the field **resolve** will be set to **2**, for pickup and/or delivery location. Again, in this case two possibilities exist for the pickup and delivery location:
  1. The pickup and/or delivery location is within 1/4<sup>th</sup> mile of a fixed stop, or
  2. The pickup and/or delivery location is outside the service zone, but not near a fixed stop.In order to determine which of the above two cases is true for the pickup and delivery locations, the immediate process executed after **3.0** is process **3.1**.

### Process 3.1 - Run Select By Theme Script with the Active Request and Fixed Stops Theme

In this process the fixed stops theme is accessed from the database based on the ROUTE-ID of the pickup and delivery location. A “Select by Theme” script will be executed to select the pickup and/or delivery locations if they fall within 1/4<sup>th</sup> mile of a fixed stop, in the fixed stops

theme. In the event that either of the points is selected the value for the corresponding record of the field **RESOLVE**, in the *active\_request.dbf* file, will be set to **1**. Therefore, at the end of this process it will be known as to whether the pickup and/or delivery locations are near a fixed stop or outside the service zones.

### Process 3.2 - Display Active View and the Input Dialog Box 2

Under this process the active view along with the input dialog box 2 will be displayed on the screen. The active view will comprise of the following themes: *active\_request*, *service\_zones\_(in or out)* and *streets*, respectively. This will enable the dispatcher to determine where the pickup and delivery locations are with respect to the service zones.

A description of the field associated with the input dialog box 2 is given in 15 in the database schema section of this document. They are:

*fixed*  
*fixed and ADA*  
*walk*  
*cancel*

However, all fields will not be automatically activated in the dialog box. The fields will be enabled based on the value of the field *resolve* for each point, i.e., pickup and delivery. The following conditions lead to particular fields to be enabled or disabled.

1. If *resolve* = 0 for pickup or delivery, disable all fields
2. If *resolve* = 1 for pickup and/or delivery and the field *wheelchair* in the *active\_request.dbf* is = 1, then disable *walk* and ask customer if he/she is eligible under ADA. If yes, then the dispatcher will check the field *fixed and ADA*. Otherwise give the customer the options of getting to a fixed stop or canceling the request.
3. If *resolve* = 1 for pickup and/or delivery and the field *wheelchair* in the *active\_request.dbf* is =0, then disable *walk* and *fixed and ADA*.
4. If *resolve* = 2 for pickup and/or delivery then disable *fixed* and *fixed and ADA*.

Based on which field is checked for the pickup or delivery location in this dialog box the respective process will be activated. This information can be obtained from the diagram of the processes.

### Process 3.3- Exit

This process is activated if the *cancel* is checked in the input dialog box of process **3.2**. In such an event the scheduling process will be terminated and the result written to the request archive dBase file.

### Process 3.4- Resolve Current Location and Display Dialog Box 3

This process will be activated if the dispatcher checks one of the fields *fixed* or *fixed and ADA* in the input dialog box of process 3.2. This will imply that the customer has either agreed to walk to a fixed stop or is eligible for route deviation even though the pickup or delivery location is near a fixed stop. The following fields will be displayed in this input dialog box:

*segment\_ID*  
*route\_ID*  
*fixed\_stop\_ID*

If the field checked in process 3.2 is *fixed and ADA* then only the fields *segment-ID* and *route-ID* will be enabled. On the other hand, if the field *fixed* is checked then only the field *fixed\_stop\_ID* is enabled. Now, if in this process, the fields *segment-ID* and *route\_ID* are filled in, then a script will be activated to query the service zones theme. The service zones theme will be queried based on the *direction* field in the active request dBase file, to get the *o\_stop\_time* and *d\_stop\_time* for the given segment and route ID. All this information will be written to the corresponding fields in the active request dBase file. If the field *fixed\_stop\_ID* is filled in then this information will be written to the active request's dBase file and the field *fixed* will be set to *yes*. After this step, the respective pickup or delivery location for which the information was added will be deemed resolved by changing the value of the *resolve* field to *0*.

### Process 3.5- The Dispatcher will zoom in on the Pickup or Delivery Location

This process will be activated if the field *walk* is checked for the pickup or delivery location in process 3.2. In this process the dispatcher will zoom in to the relevant point on the map and find an intersection that is within the service zone. This location will be close to the customer's pickup or delivery point, whichever lies outside the service zone. The next subprocess after this is 3.6.

### Process 3.6 - Geocode Cursor Location and Call the Dialog Box 4

After process 3.5, 3.6 will be activate a script that will ask the dispatcher to click on the desired location on the map. The XY coordinates of the cursor location will be obtained and stored. Next the XY coordinates of the point will be reverse geocoded to get the address of the location. The XY coordinates and the address of the location will be displayed in the input dialog box 4. This dialog box will have the following fields:

*X coordinate or Longitude*  
*Y coordinate or Latitude*  
*Location Address*  
*OK*  
*Retry*  
*Cancel*

The moment this dialog is displayed the dispatcher can tell the customer the address of the location to walk to. The customer can either accept it, in which case the dispatcher will click the **OK** button otherwise the trip can be canceled by clicking the **Cancel** button. At this point the dispatcher also has the option of retrying another location by clicking on the **Retry** button if the current address is not a feasible location to walk to. If the dispatcher clicks the **Cancel** button, then the process will be terminated and the result written to the **request\_archive.dbf** file. If the **OK** button is clicked then the next step is process **3.8**. If the **Retry** button is clicked is then it goes back to process **3.5**.

#### Process 3.7 - Exit

Clicking the **Cancel** button in **3.6** activates this process. At this point the scheduling process is terminated and the results written to the **request\_archive.dbf** file.

#### Process 3.8 - Resolve Current Location and Check if $Resolve > 0$ for any Other Point

Clicking the **OK** button in **3.6** activates this process. Under this process the current location being processed, i.e., the pickup or delivery point, will be resolved by changing the value of the **Resolve** field in the **active\_request.dbf** to **0**. Next, it will be checked for all the records in the **active\_request.dbf**, if the **Resolve** field has a value greater than **0**. If the answer to this query is **Yes** then the next process will be **3.2**, otherwise the next process is **3.0**.

#### Process 4.0 – Display Input Dialog Box 5

At this point in the entire scheduling process, all the spatial constraints would have been satisfied for the pickup and delivery points. In this process the input dialog box 5 will be displayed. This dialog box will have the following fields:

**O\_stop\_time** (for the pickup segment)

**D\_stop\_time** (for the pickup segment; this will be disabled if the pickup location is a fixed stop, i.e., the field **fixed** is **yes**)

**Desired\_pickup\_hour** (a drop down menu of the various hours will be displayed)

**OK**

**Cancel**

Clicking on the **OK** button will go automatically to process **5.0**, whereas clicking on **Cancel** will terminate the process and copy the results to the **request\_archive.dbf** file. If the given range of time is **OK** for the customer then the dispatcher will have to ask for a desired pickup hour and choose the appropriate hour from the drop down menu, and click the **OK** button.

#### Process 5.0 - Check if DPT is Within One Hour of Current Time

Under this process, it will be checked if the desired pickup time (DPT) given by the customer is within one hour of the current time or not. If the answer to that is **YES** then the next step will be **Process 5.1** otherwise the next step will be **Process 6.0**.



Process 5.1 – Check if Pickup Segment’s (O Stop Time – Disp Time) is Greater than Current Time

From **Process 3.0** the customer’s pickup segment, its origin stop and the origin stop’s scheduled time (given by the field *O\_STOP\_TIME* in the themes *service\_zones\_in* and *service\_zones\_out*) is known. Using this information and the value for a global variable *disp\_time* representing the dispatch time requirement, e.g., five minutes, the following check will be made under this process:

Is  $(O\_STOP\_TIME - disp\_time) > current\_time$  ?

If the answer to that is YES then the algorithm will proceed to process **5.2** otherwise it will go to **Process 7.3**, which will exit out of the system.

Process 5.2- Query a Lookup Table to Find the Bus ID for the Desired Route, Direction, and Hour

In this process the Bus\_ID is determined for the bus scheduled to be on the route and direction that the pickup is on, for the desired hour. This can be achieved by querying the timetable for the buses. This table will have the Bus\_ID’s for each route, direction, and hour. The Bus\_ID can then be used to query the AVL subsystem to check if presently the bus is on schedule or not. Hence the next logical process after this is **5.3**.

Process 5.3 – Query AVL Subsystem to check if the Bus is on Schedule

This process will constitute of the AVL subsystem. In this step, the real-time location information pertaining to a particular bus will be obtained and displayed on the map. This information can be corroborated with the lookup table to determine if the bus is behind schedule or not. There will be two possibilities under this scenario: either the bus is behind schedule or not. If the bus is on schedule then the next subprocess is **6.0**. Otherwise, it will automatically move on to process **7.3**.

Process 6.0 - Obtain Point Themes for Scheduled Requests

In this process the point themes containing the scheduled requests for the active request’s pickup and delivery segments will be obtained. If the pickup or delivery happens to be a fixed stop then no themes will be obtained for that location and also no network analysis would need to be done for that point.

Point themes will be created and stored within the database for each *segment, direction, route, pass* and *day* of the week. The total number of these point themes will be approximately 1284. This number was calculated by adding the following numbers:

Route 10 Out: (4) segments x (16) hours x (6) days = 384

Route 10 In: (4) segments x (15) hours x (6) days = 360

Route 11 Out: (3) segments x (15) hours x (6) days = 270

Route 11 In: (3) segments x (15) hours x (6) days = 270

One option to reduce the number of point themes would be to have a point theme for each *direction, route, pass* and *day* of the week. The total number of themes required under this option would be fewer. Under the first option there would be no querying required whereas under the second option each theme would have to be queried for a particular segment. The nomenclature used to name each of these point themes will be the following:

<Day>\_<Time>\_<Route>\_<Direction>\_<Segment-ID> under the first option, or  
<Day>\_<Time>\_<Route>\_<Direction> under the second option.

For example, the point theme with the name *mon\_1500\_11\_in\_12* will contain the scheduled requests for the most recent **Monday**, for the **3 PM** pass on **Route 11** in the **Inbound** direction on segment **12**. The attribute fields in the dBASE file are shown in Table 23. Two such point themes will be obtained from the database for the active request's pickup and delivery *segments*. The attribute tables for the two themes will have the fields shown in Table 23. The above point themes along with *active\_request* theme will be passed on to process **5.0**.

#### Process 7.0 – Process the Data for the P and/or D not a Fixed Stop for Network Analysis

ArcView's Network Analyst extension will be used in this process to find the shortest path starting at the origin stop, passing through the scheduled and current pickup/delivery locations, and ending at the destination stop, for the pickup and delivery segments of the active request. In order to find a path through a set of points, a point theme containing the points must be passed to the Network Analyst. In finding the shortest path as explained above, the origin and destination points of a segment will remain constant, while the intermediate points can be rearranged to find an optimal order. As this cannot be directly achieved within Network Analyst, the process will be broken down into a number of steps. The two point themes containing the scheduled requests for the active request's pickup and delivery segments and the *active\_request* theme will be passed to the Network Analyst. At this stage, three point lists will be created from the point themes, for the pickup and delivery segments of the active request. These point lists are:

- **origin** - this list will contain the origin stop for the pickup or delivery segments
- **intermediate** - this list will contain the pre-scheduled requests for the pickup or delivery segments along with the active request's pickup or delivery point
- **destination** - this list will contain the destination stop for the pickup or delivery segment.

#### Process 7.1- Determine Optimal Pickup Schedule within Time Constraints

Under this process, it will be checked if the pickup is a fixed stop or not. If the pickup is a fixed stop, then the algorithm will automatically move on to the next process, which is **7.2**. Otherwise the optimal pickup schedule will be determined in this process. The shortest path is calculated by finding the best order to visit each of the points in the intermediate list using the Network Analyst extension. The Network Analyst extension within ArcView has the capability

of computing the shortest path between a start and an end point by finding the best order to visit the intermediate points.

The final result will be the shortest possible travel time from the origin stop to the destination stop, through a set of intermediate points, for the pickup segment of the active request. Also, for each run, it will be checked to see if the time windows are violated for the prescheduled requests within that segment. Finally, the total travel time will be compared to the difference of the scheduled times at the origin and destination stops of the two segments to determine if a pickup and/or delivery is feasible. If the pickup is feasible then the next process will be **7.2** otherwise the next process will be **7.3**. Under this process it can be determined if the active request involves a transfer or not. Checking if the *ROUTE\_IDS* for the pickup and delivery locations, obtained in process **3.0**, are the same, can do this. If they are the same then no transfer is required, otherwise the transfer point is the Thomas Nelson Community College stop.

#### Process 7.2 - Determine Optimal Delivery Schedule within Time Constraints

This process is reached under two possibilities: either the pickup is a fixed stop or the pickup schedule was feasible. First, it is checked to see if the delivery point is a fixed stop or not. If it is a fixed stop then the process moves on to **7.4**, otherwise the optimal delivery schedule is determined in the same manner as described in **7.1**. If the delivery is feasible, then the next process is **7.4**, else it is **7.3**.

#### Process 7.3 - Output Dialog Box 2

Upon determination in processes **7.0-7.2** that the requested trip is infeasible, this dialog box will be displayed. A message that the requested trip is infeasible due to time constraints will be shown, and the dispatcher will notify the customer accordingly. If the customer decides not to attempt to schedule the trip again, the dispatcher canceling the active request will invoke process **7.3.1**. If the customer would like to try to schedule the trip at another time, the dispatcher will enter new values for the desired hour (**DPH**) (to be concatenated with **O\_STOP\_TIME** into a new value for **DPT**) and the date of the trip (**DATE**), and process **5.0** will be invoked.

#### Process 7.3.1 - Return Trip Check

In this process, the status of the field **RETURN\_TRIP** in *active\_request* will be checked. If the value is zero, then the active request is not a return trip, the active request will be submitted to *request\_archive* and process **7.3.2** will be invoked. If the value is one, then the current request is a return trip, and process **7.3.3** will be invoked.

#### Process 7.3.2 – Exit

This process is a simple exit process in which *active\_request* will be deleted and the system returned to rest.

### Process 7.3.3 - Output Dialog Box 3

In this process an output dialog box will appear, prompting the dispatcher will ask the customer if the previously scheduled leaving trip is to be kept. If so, the dispatcher will indicate accordingly, the temporary file containing the leaving trip and *active\_request* will be sent to *request\_archive* and process **7.3.3.1** will be invoked. If not, then the dispatcher will indicate accordingly, *active\_request* will be sent to *request\_archive* and process **7.3.3.2** will be invoked.

#### Process 7.3.3.1 - Update Schedule Themes and Exit

In this process, the point themes corresponding to the segments affected by the active request, and the associated text files, will be updated, *active\_request* will be deleted, and the system returned to rest.

#### Process 7.3.3.2 – Exit

In this process, the temporary file containing the leaving trip and *active\_request* will be deleted, and the system returned to rest.

### Process 7.4 - Output Dialog Box 1

Upon determination that the requested trip is feasible, this dialog box will be displayed. The value of **RETURN\_TRIP** will be checked. If **RETURN\_TRIP** is equal to zero, then the check box regarding whether or not a return trip should be scheduled will be enabled. If **RETURN\_TRIP** is equal to one, then it shall be set equal to two. The dispatcher will ask the customer if (1) the feasible trip is acceptable to the customer, and (2) whether or not a return trip should be scheduled. If the trip is not acceptable, the dispatcher will cancel the active request, it will be submitted to *request\_archive*, and process **7.4.1** will be invoked. If the feasible trip is acceptable to the customer, it will be submitted to *request\_archive*, and if a return trip is to be scheduled (the check box will be checked and **RETURN\_TRIP** set equal to one), process **7.4.3** will be called; if **RETURN\_TRIP** is equal to two, process **7.4.4** will be activated. If the no return trip is desired (**RETURN\_TRIP** will be equal to zero), process **7.4.2** will be invoked.

#### Process 7.4.1 – Exit

This process is a simple exit process in which *active\_request* will be deleted and the system returned to rest.

#### Process 7.4.2 - Update Point Themes and Exit

In this process, the point themes corresponding to the segments affected by the active request, and the associated text files, will be updated, *active\_request* will be deleted, and the system returned to rest.

#### Process 7.4.2.1 – Exit

This process is a simple exit process in which *active\_request* will be deleted and the system returned to rest.

#### Process 7.4.3 - Creation of Temporary File

In this process, a temporary file will be created (as a duplicate of *active\_request*) to store the information pertaining to the leaving trip. Process **7.4.3.1** will then be invoked.

#### Process 7.4.3.1 - Development of Return Trip Characteristics

In this process, *active\_request* will be modified such that the spatial component of the scheduling of the return trip is complete. The relevant fields in *active\_request* will be switched between the entry for the pickup and the entry for the delivery, the value of the direction field will be switched (e.g. inbound to outbound) and the appropriate service zones theme will be called in order to extract the appropriate values for **O\_STOP\_TIME** and **D\_STOP\_TIME**. Process **4.0** will then be invoked to begin the temporal check.

#### Process 7.4.4 - Update Point Themes and Exit

In this process, the point themes corresponding to the segments affected by the active request (comprising the return trip) and by the temporary file (comprising the leaving trip), and the associated text files, will be updated, *active\_request* will be deleted, and the system returned to rest.

### **Database Schema**

The database schema for the prototype system, presented in the Appendix B of this report, describes the database design in detail. Specifically, it delineates the nomenclature used in naming the themes, the fields in each attribute tables, and the local and global variables in developing the entire system.



**APPENDIX B**  
**DATABASE SCHEMA**

## DATABASE SCHEMA

### Input and Output Dialog Boxes

**Table 14. Local Variables/Fields for Input Dialog Box 1**

<i>Variable-Id</i>	<i>Variable Description</i>	<i>Variable Name</i>	<i>Format</i>
1.	Name of the customer	<b>NAME</b>	<String>
2.	Pickup or Origin Address	<b>P_ADD</b>	<String>
3.	Delivery or Destination Address	<b>D_ADD</b>	<String>
4.	Type of Disability	<b>DISABILITY</b>	<Integer> (0 = No disability 1 = disabled)
5.	Is wheelchair used	<b>W_CHAIR</b>	<Boolean> (Yes - with wheelchair   No - without wheelchair)

**Table 15. Local Variables for Input Dialog Box 2**

<i>Variable-Id</i>	<i>Variable Description</i>	<i>Variable Name</i>	<i>Format</i>
1.	This variable is activated if the P or D lie near a fixed stop and the customer is not on a wheelchair	<b>FIXED</b>	<Boolean> (True – Resolve the P or D and activate input dialog box 3   False – Do not resolve the P or D)
2.	This variable is activated if the P or D lies near a fixed stop and the customer is on a wheelchair	<b>FIXED/ADA</b>	<Boolean> (True – Resolve the P or D as route deviation service and activate input dialog box 3   False – Do not Resolve the P or D )
3.	This variable is activated if the P or D lies outside the service zones and not near a fixed stop	<b>WALK</b>	<Boolean> (True – activate process 3.5   False – Do not activate process 3.5)
4.	This variable is activated under all scenarios and gives the dispatcher an option to cancel the request if the customer does not want to make the trip	<b>CANCEL</b>	<Boolean> (True – cancel the trip, copy the result to the request archive dBase file and exit the system   False – do not terminate the process)



**Table 16. Local Variables for Input Dialog Box 3**

<i>Variable-Id</i>	<i>Variable Description</i>	<i>Variable Name</i>	<i>Format</i>
1.	The bus route number for the pickup and delivery points. A drop down menu of the different route IDs will be provided for this variable. This will be activated if the Fixed and Fixed/ADA variables are YES in process 3.2.	<b>ROUTE-ID</b>	<Integer> (10 or 11)
2.	Segment ID for the pickup and delivery points. A drop down menu of the different segment IDs will be provided for this variable. This will be activated if the Fixed/ADA variable is YES in process 3.2	<b>SEGMENT_ID</b>	<Integer> (12, 23 etc.)
3.	This variable denotes the fixed stop for the pickup and delivery points. This variable will be activated if the variable Fixed is Yes in process 3.2	<b>FIXED_STOP_ID</b>	<Integer> (1, 2, 3 etc.)

**Table 17. Local Variables for Input Dialog Box 4**

<i>Variable-Id</i>	<i>Variable Description</i>	<i>Variable Name</i>	<i>Format</i>
1.	Address of the cursor location that has been reverse geocoded in process 3.6.	<b>LOCATION_ADD</b>	<String> (obtained from the P_ADD and D_ADD variables in process 1.0 or from LOCATION_ADD from process 3.6 if OK)
2.	If this variable is YES then process 3.8 is activated to resolve P or D.	<b>OK</b>	<Boolean> (True – Go to process 3.8   False – don’t go to 3.8)
3.	This variable allows the dispatcher to zoom into a different location in case the previous location was not suitable to the customer	<b>RETRY</b>	<Boolean> (True – go to process 3.5   False – Don’t go to process 3.5)
4.	This variable allows the dispatcher to exit out of the system if the customer does not want to confirm the trip request or if a suitable location is not available after several trials	<b>CANCEL</b>	<Boolean> (True – cancel the trip, copy the result to the request archive dBase file and exit the system   False – do not terminate the process)

**Table 18. Local Variables for Input Dialog Box 5**

<i>Variable-Id</i>	<i>Variable Description</i>	<i>Variable Name</i>	<i>Format</i>
1	The scheduled time at the origin stop of the pickup segment	<b>O_STOP_TIME</b>	<hh.mm> (h = hour, m = minutes)
2	The scheduled time at the destination stop of the pickup segment	<b>D_STOP_TIME</b>	<hh.mm> (h = hour, m = minutes)
3.	Desired Pickup Hour	<b>DPH</b>	<hh.mm> (h = hour, m = minutes)
4.	The date for which service is desired	<b>REQUEST_DATE</b>	mm/dd/yy (m = month, d = day, y = year)
5.	This variable allows the dispatcher to exit out of the system if the customer does not like the time window of service.	<b>CANCEL</b>	<Boolean> (True – cancel the trip, copy the result to the request archive dBase file and exit the system (process 4.1)  False – Go to process 5.0)

**Table 19. Local Variables for Output Dialog Box 1**

<i>Variable-Id</i>	<i>Variable Description</i>	<i>Variable Name</i>	<i>Format</i>
1.	This variable will confirm the trip request.	<b>OK</b>	<Boolean> (True – Confirm trip and go to 7.4.2 or 7.4.3   False – exit and go to 7.4.1)
2.	This variable will let the dispatcher terminate the process and exit the system if the customer does not confirm the trip	<b>CANCEL</b>	<Boolean> (True   False)
3.	This variable will flag the trip as a return trip if the	<b>RETURN_TRIP</b>	<Integer> (0 = it is a leaving trip; 1 = it is a return trip; 2 = return trip is feasible)

**Table 20. Local Variables for Output Dialog Box 2**

<i>Variable-Id</i>	<i>Variable Description</i>	<i>Variable Name</i>	<i>Format</i>
1.	Desired Pickup Hour	<b>DPH</b>	<hh.mm> (h = hour, m = minutes)
2.	The date for which service is desired	<b>REQUEST_DATE</b>	Mm/dd/yy (m = month, d = day, y = year)
3.	This variable will confirm the trip request	<b>OK</b>	<Boolean> (True – Confirm trip and go to 5.0   False – exit and go to 7.3.1)
4.	This variable will let the dispatcher terminate the process and exit the system if the customer does not want to enter a new date and hour	<b>CANCEL</b>	<Boolean> (True   False)

**Table 21. Local Variables in Output Dialog Box 3**

<i>Variable-Id</i>	<i>Variable Description</i>	<i>Variable Name</i>	<i>Format</i>
1.	This variable will confirm the trip request	<b>OK</b>	<Boolean> (True – Confirm leaving trip and go to 7.3.3.1  False – exit and go to 7.3.3.2)
2.	This variable will let the dispatcher terminate the process and exit the system if the customer does not want to enter a new date and hour	<b>CANCEL</b>	<Boolean> (True   False) (results are a reverse of the OK variable)

**Table 22. List of all Fields in the ACTIVE\_REQUEST.DBF**

<b>Field-ID</b>	<b>Description of the Field</b>	<b>Field Name</b>	<b>Format</b>
1.*	Default field for a theme	<b>SHAPE</b>	<String> (Point)
2.	Default field for a theme	<b>ACTIVE_REQUEST_ID</b>	<Integer>
3.	Name of the customer	<b>NAME</b>	<String>
4.	Type of point, i.e., pickup or delivery point	<b>TYPE</b>	<Integer> (1 = Pickup point and 2 = Delivery point)
5.	X coordinate or longitude of the point	<b>X_COORD</b>	<Floating Number>
6.	Y coordinate or latitude of the point	<b>Y_COORD</b>	<Floating Number>
7.	The address of the pickup and delivery points	<b>ADDRESS</b>	<String>
8.*	Type of Disability	<b>DISABILITY</b>	<Integer> (0 = No disability 1 = disabled)
9.*	Does the customer use wheelchair	<b>W_CHAIR</b>	<Boolean> (Yes   No)
10.	This variable shows the desired service time at each point. Here, the value of the desired pickup time ( <b>DPT</b> ) from the Input Dialog Box will have to be entered for the Pickup point, and the value of the desired delivery time ( <b>DDT</b> ) will be entered for the Delivery point.	<b>D_SERVICE_TIME</b>	<hh.mm> (h = hour, m = minutes)
11.*	The date for which service is desired.	<b>REQUEST_DATE</b>	mm/dd/yy (m = month, d = day, y = year)
12.*	This field shows whether a customer can walk to a closer pickup point and/or walk from a closer delivery point.	<b>ACCESS</b>	<Boolean> (Yes   No)
13.*	Time at which the request is placed, i.e., current time.	<b>C_TIME</b>	<hh.mm> (h = hour, m = minutes)
14.*	Direction for pickup and delivery points	<b>DIRECTION</b>	<String> (Inbound or Outbound)
15.	The bus route number for the pickup and delivery points	<b>ROUTE_ID</b>	<Integer> (10 or 11)
16.	Segment ID for the pickup and delivery points	<b>SEGMENT_ID</b>	<Integer> (12, 23 etc.)
17.	The origin stop for the pickup and delivery segments	<b>O_STOP</b>	<Integer>
18.	The destination stop for the pickup and delivery segments	<b>D_STOP</b>	<Integer>
19.	The scheduled time at the origin stop of the pickup and delivery segments	<b>O_STOP_TIME</b>	<hh.mm> (h = hour, m = minutes)
20.	The scheduled time at the destination stop of the pickup and	<b>D_STOP_TIME</b>	<hh.mm> (h = hour, m = minutes)

<b>Field-ID</b>	<b>Description of the Field</b>	<b>Field Name</b>	<b>Format</b>
	delivery segments		
21.	X coordinate for the origin stop	<b>O_STOP_X_COORD</b>	<Floating Number>
22.	Y coordinate for the destination stop	<b>O_STOP_Y_COORD</b>	<Floating Number>
23.	X coordinate for the origin stop	<b>D_STOP_X_COORD</b>	<Floating Number>
24.	Y coordinate for the destination stop	<b>D_STOP_Y_COORD</b>	<Floating Number>
25.	This field denotes whether the pickup or delivery is a fixed stop or not.	<b>FIXED</b>	<Boolean> (YES   NO)
26.	This field helps denote whether the trip being processed for feasibility is a leaving trip or a return trip.	<b>RETURN_TRIP</b>	<Integer> (0 = it is a leaving trip; 1 = it is a return trip; 2 = return trip is feasible)
27.	This field denotes whether the pickup and/or delivery locations are spatially feasible or not i.e. met all the spatial restrictions	<b>RESOLVE</b>	<Integer> (0 = Resolved i.e. feasible; 1 = outside the service zones and near a fixed stop; 2= outside the service zone)
28.	Estimated service time at each point. This is the Estimated Pickup Time ( <b>EPT</b> ) and the Estimated Delivery Time ( <b>EDT</b> ), at the pickup and delivery points, respectively.	<b>E_SERVICE_TIME</b>	<hh.mm> (h = hour, m = minutes)

\* For these fields, the values for the two records will be the same.

**Table 23. Fields in the dBASE file for the point themes, e.g., MON\_1500\_11\_IN\_12.DBF**

<i>Field-ID</i>	<i>Field Description</i>	<i>Field Name</i>	<i>Format</i>
1.	Default field for a theme	<b>SHAPE</b>	<String> (Point)
2.	Name of the Rider	<b>NAME</b>	<String>
3.	Type of point, i.e., pickup or delivery point	<b>TYPE</b>	<Integer> (1 = Pickup point or 2 = Delivery point)
4.	The day on which the pickup and delivery is needed.	<b>DATE</b>	<mm/dd/yy>
5.	Type of Disability	<b>DISABILITY</b>	<Integer> (0 = No disability 1 = disabled)
6.	Does the customer use wheelchair	<b>W_CHAIR</b>	<Boolean> (Yes   No)
7.	This variable shows the desired service time at each point. Here, the value of the desired pickup time ( <b>DPT</b> ) from the Input Dialog Box will have to be entered for the Pickup point, and the value of the desired delivery time ( <b>DDT</b> ) will be entered for the Delivery point.	<b>D_SERVICE_TIME</b>	<hh.mm> (h = hour, m = minutes)
8.	Estimated service time at each point. This is the Estimated Pickup Time ( <b>EPT</b> ) and the Estimated Delivery Time ( <b>EDT</b> ), at the pickup and delivery points, respectively.	<b>E_SERVICE_TIME</b>	<hh.mm> (h = hour, m = minutes)
9.	The bus ID to which the pickup and delivery were assigned	<b>BUS_ID</b>	<Integer>

**Table 24. Fields in the dBASE file REQUEST\_ARCHIVE.DBF**

<i>Field-ID</i>	<i>Field Description</i>	<i>Field Name</i>	<i>Format</i>
1.	Pickup or Origin Address	<b>P_ADD</b>	<String>
2.	Delivery or Destination Address	<b>D_ADD</b>	<String>
3.	Result of a trip request, i.e., whether the trip was completed successfully, could not be filled, or was refused despite being feasible.	<b>SCHED_RESULT</b>	<Integer> (0 = Could not be Filled; 1 = Could be filled successfully; 2 = refused)
5.	The day on which the pickup and delivery is needed.	<b>DATE</b>	<mm/dd/yy>
4.	Time at which the request is placed, i.e., current time.	<b>C_TIME</b>	<hh.mm> (h = hour, m = minutes)

**THEME META DATA**

**1. Point Theme Containing All The Information Of The Active Request**

**THEME NAME:** *ACTIVE\_REQUEST*

**DBASE FILE NAME:** *ACTIVE\_REQUEST.DBF*

**DESCRIPTION:** Contains the spatial and attribute information of the pickup and delivery points of an active request. If the request is feasible all the spatial and attribute information of the request will be written to a table, *SCHEDULED\_REQUESTS.DBF*.

**Table 25. List of Fields for ACTIVE\_REQUEST.DBF**

<i>Field-ID</i>	<i>Description of the Field</i>	<i>Field Name</i>	<i>Format</i>
1.	Default field for a theme	<b>SHAPE</b>	<String> (Point)
2.	Default field for a theme	<b>ACTIVE_REQUEST_ID</b>	<Integer>
3.*	Name of the customer	<b>NAME</b>	<String>
4.	Type of point, i.e., pickup or delivery point	<b>TYPE</b>	<Integer> (1 = Pickup point and 2 = Delivery point)
5.	X coordinate of the point	<b>X_COORD</b>	<Floating Number>
6.	Y coordinate of the point	<b>Y_COORD</b>	<Floating Number>
7.*	Type of Disability	<b>DISABILITY</b>	<Integer> (0 = No disability 1 = disabled)
8.*	Does the customer use wheelchair	<b>W_CHAIR</b>	<Boolean> (Yes (= 1)   No (= 0))
9.	This variable shows the desired service time at each point. Here, the value of the desired pickup time ( <b>DPT</b> ) from the Input Dialog Box will have to be entered for the Pickup point, and no value of the desired delivery time will be entered for the Delivery point.	<b>D_SERVICE_TIME</b>	<hh.mm> (h = hour, m = minutes)
10.*	The date for which service is desired.	<b>REQUEST_DATE</b>	mm/dd/yy (m = month, d = day, y = year)
11.*	This field shows whether a customer can walk to a closer pickup point and/or walk from a closer delivery point.	<b>ACCESS</b>	<Boolean> (Yes   No)
13.*	Time at which the request is placed, i.e., current time.	<b>C_TIME</b>	<hh.mm> (h = hour, m = minutes)
14.*	Direction for pickup and delivery points	<b>DIRECTION</b>	<String> (Inbound or Outbound)
15.	The bus route number for the pickup and delivery points	<b>ROUTE_ID</b>	<Integer> (10 or 11)
16.	Segment ID for the pickup and delivery points	<b>SEGMENT_ID</b>	<Integer> (12, 23 etc.)



<b>Field-ID</b>	<b>Description of the Field</b>	<b>Field Name</b>	<b>Format</b>
17.	The origin stop for the pickup and delivery segments	<b>O_STOP</b>	<Integer>
18.	The destination stops for the pickup and delivery segments	<b>D_STOP</b>	<Integer>
19.	The scheduled time at the origin stop of the pickup and delivery segments	<b>O_STOP_TIME</b>	<hh.mm> (h = hour, m = minutes)
20.	The scheduled time at the destination stop of the pickup and delivery segments	<b>D_STOP_TIME</b>	<hh.mm> (h = hour, m = minutes)
21.	X coordinate for the origin stop	<b>O_STOP_X_COORD</b>	<Floating Number>
22.	Y coordinate for the destination stop	<b>O_STOP_Y_COORD</b>	<Floating Number>
23.	X coordinate for the origin stop	<b>D_STOP_X_COORD</b>	<Floating Number>
24.	Y coordinate for the destination stop	<b>D_STOP_Y_COORD</b>	<Floating Number>
25.	Estimated service time at each point. This is the Estimated Pickup Time ( <b>EPT</b> ) and the Estimated Delivery Time ( <b>EDT</b> ), at the pickup and delivery points respectively.	<b>E_SERVICE_TIME</b>	<hh.mm> (h = hour, m = minutes)

\* For these fields, the values for the two records will be the same. For the other fields the values may or may not be the same.

## 2. Polygon Themes With The Inbound And Outbound Service Zones

**THEME NAMES:** *SERVICE\_ZONES\_IN* and *SERVICE\_ZONES\_OUT*

**DBASE FILE NAME:** *SERVICE\_ZONES\_IN.DBF* and *SERVICE\_ZONES\_OUT.DBF*

**DESCRIPTION:** This theme contains the spatial and attribute information on the service zones for the inbound and outbound directions of the two routes, Routes 10 and Route 11, respectively. Each polygon represents the service area between a pair of consecutive bus stops.

**Table 26. List of Fields for SERVICE\_ZONES\_IN.DBF and SERVICE\_ZONES\_OUT.DBF**

<i>Field-ID</i>	<i>Description of the Field</i>	<i>Field Name</i>	<i>Format</i>
1.	Default field for a theme	<b>SHAPE</b>	<String> (Polygon)
2.	Default field for a theme	<b>SERVICE_ZONES_IN_ID</b> or <b>SERVICE_ZONES_OUT_ID</b>	<Integer>
3.	This field identifies the segment associated with each polygon of the theme	<b>SEGMENT_ID</b>	<Integer> (e.g., 12, 34 etc.)
4.	This field identifies the bus route on which the polygon (service zone) lies	<b>ROUTE_ID</b>	<Integer>
5.	This field stores the origin stop of the segment for the polygon	<b>O_STOP</b>	<Integer>
6.	This field stores the destination stop of the segment for the polygon	<b>D_STOP</b>	<Integer>
7.	This field stores the scheduled time at the origin stop of the segment	<b>O_STOP_TIME</b>	<hh.mm> (h = hour, m = minutes)
8.	This field stores the scheduled time at the destination stop of the segment	<b>D_STOP_TIME</b>	<hh.mm> (h = hour, m = minutes)
9.	X coordinate for the origin stop	<b>O_STOP_X_COORD</b>	<Floating Number>
10.	Y coordinate for the destination stop	<b>O_STOP_Y_COORD</b>	<Floating Number>
11.	X coordinate for the origin stop	<b>D_STOP_X_COORD</b>	<Floating Number>
12.	Y coordinate for the destination stop	<b>D_STOP_Y_COORD</b>	<Floating Number>

### 3. Point Themes Containing The Intermediate Points For Network Analyst

**THEME NAMES:** *PICKUP\_SEGMENT\_SCHED*

and *DELIVERY\_SEGMENT\_SCHED*

**DBASE FILE NAME:** *PICKUP\_SEGMENT\_SCHED.DBF*

and *DELIVERY\_SEGMENT\_SCHED.DBF*

**DESCRIPTION:** These point themes show the scheduled requests within the pickup and delivery segments of the active request.

### 4. Point Themes for the Fixed Stops on the Routes in Two Directions

**THEME NAMES:** *INBOUND\_STOPS* and *OUTBOUND\_STOPS*

**DBASE FILE NAMES:** *INBOUND\_STOPS.DBF* and *OUTBOUND\_STOPS.DBF*

**DESCRIPTION:** These themes contain the spatial and attribute information about the fixed stops on Routes 10 and 11 in the inbound and outbound directions, respectively.

**Table 27. List of Fields in INBOUND\_STOPS.DBF and OUTBOUND\_STOPS.DBF**

<i>Field-ID</i>	<i>Description of the Field</i>	<i>Field Name</i>	<i>Format</i>
1.	Default field name	<b>SHAPE</b>	<String> (Point)
2.	Default field name	<b>INBOUND_STOPS_ID</b> or <b>OUTBOUND_STOPS_ID</b>	<Integer>
3.	Name of the stop	<b>STOP_NAME</b>	<String>
4.	Scheduled time	<b>TIME</b>	<hh.mm> (h = hour, m = minute)
5.	Is it a transfer	<b>TRANSFER</b>	<Boolean> (YES   NO)

**APPENDIX C**  
**IMPLEMENTATION ISSUES**

## **Implementation Issues**

Although the results summarized in the previous section indicate a potential for route deviation service to serve a sizeable number of paratransit passengers, there are a number of implementation issues that need to be considered. This section discusses some of the critical issues that must be resolved before a full-scale implementation of a route deviation service can be achieved.

### **Fare Structure**

The fare of a transit service is often a critical determinant of its productivity and sustenance. Therefore determining the fare structure for route deviation service such that it is economically viable and also is in compliance with the mandates of ADA, is an important issue. Under the ADA the cost of complementary paratransit service to persons with disabilities should not exceed twice the base fare on a fixed route system. The same fare structure could be used for the route deviation service or reduced to account for the change in the level of service. A study conducted by Rosenbloom (1996) reported, that in the long run, most systems could achieve substantial savings by implementing one or more route deviation services, under the assumption that the fare for route deviation is equal to the paratransit service. Among the 15 cases of route deviation services reviewed, the fare for route deviation service ranged from being free to \$1.50. Some systems have fares as low as 25 cents for the elderly and disabled without any additional charge for a deviation request. The average fare for the 15 systems reviewed by Rosenbloom (1996) was one dollar.

In case of the non-ADA passengers or the general public accessing route deviation services the fare could be considerably increased over the normal fixed route fare, due to the higher level of service provided by route deviation. This increase in fare could help Pentran in recovering a portion of the cost of operating route deviation.

### **Communication Systems**

Traditionally, dispatchers have communicated with bus drivers using analog, or voice, radio. In this era of wireless communications, traditional voice based communication systems have given way to digital communication systems. A radio frequency (RF) modem is used to communicate the data. These modems offer a more efficient usage of limited-capacity channel radio channels. Faster and cheaper RF modems are increasingly becoming available. Presently a 4,800 baud rate RF modem can be purchased for several hundred dollars (Lave et al., 1996). However, the cost of a modem is reduced considerably when it is bought with a mobile data terminal.

The other issue with installing a communication system has to do with obtaining a dedicated communication channel, which leads to increased costs. Typically, communication links used by transit agencies between the dispatch center and the vehicle do not require a dedicated channel (FTA, 1998). They can “piggy back” on transmissions by conventional commercial FM radio stations and other such transmitters, as usually the spectrum allocated to these stations exceeds their actual requirements.

Another alternative to a dedicated channel is for the transit agency to participate as a partner in a shared communication system (FTA, 1998). In a shared system a state-of-the-art trunk system can be used by local agencies such as the local police, who share the costs of developing and operating the system. Trunking is a concept under which the available spectrum can be partitioned into a number of channels and each channel can then be used by a participating agency. At any time, signals are automatically routed through an available channel and thus increasing the efficiency. Transit agencies can also use a communication channel by obtaining a permission from the Federal Communications Commissions (FCC) to operate as a secondary user. This requires that the agency operate without interfering with the primary user that holds the spectrum allocation (FTA, 1998). Table 14 describes some of the alternative communication approaches.

**Table 28. Alternative Communication Approaches (Source: FTA, State-of-the-Art Update,1998)**

<i>Approach</i>	<i>Description</i>
Analog/digital Cellular	Conventional Cellular services cover most metropolitan areas but are nearing saturation levels; digital cellular will expand availability
FM subcarrier RDS	information transmitted on side bands of commercial FM radio stations
Personal communication services	still in developmental stages but will allow communications anywhere
Low-earth orbit satellite services	satellite communication services under development, IRIDIUM System
Spread spectrum systems	transmit a low power signal distributed over a band of frequencies; need not be licensed by the FCC
Wireless data services	Utilization of wireless data services such as Cellular Digital Packet Data, ARDIS

### **Driver Interface**

An important component of the overall architecture is the interface between the dispatcher at the transit management center and the driver in the vehicle en-route the origin, destination or fixed stop. This component becomes even more vital in a system operated in real-time. This can be achieved by using an in-vehicle computer that receives the digital data being sent through an RF modem. Most transit providers are using relatively powerful and inexpensive in-vehicle display and processing units called mobile data terminals (MDTs) or mobile computers. There is a slight difference in power and capabilities between MDTs and mobile computers. A brief description of MDTs and mobile computers given in (Lave et al., 1996) is presented here.

MDTs are becoming widely available to transportation agencies and increasingly powerful with improvements in display, storage and processing capabilities. A typical MDT for a paratransit system and has the following capabilities:

- Receiving, storing and subsequently displaying multiple dispatch messages, such as passenger pickup and drop-off addresses and any special instructions
- Recording and temporarily storing information relating to passenger boarding and alighting, e.g., passenger counts

- Interacting with other on-board electronic devices such as location devices and card readers.

In addition to having all the capabilities MDTs, mobile computers have a relatively powerful microprocessor with memory and storage capability, a keypad with varying numbers, a display terminal, and possibly a built-in or attached printer. They also have a digital communication link to the central computer, which can be either an on-line link for real-time operations, or off-line for end-of-the-day processing.

Although the costs of MDTs and mobile computers has dropped significantly over the past years, they remain relatively expensive. A typical MDT costs \$1,150 to \$1,700, which includes an RF modem, automatic odometer and installation (Lave et al., 1996).

### Automatic Vehicle Location (AVL) Systems

Automatic vehicle location (AVL) technology is a key component of the overall architecture (Figure 3) for operating a real-time route deviation system. An increasing number of transit agencies are equipping their vehicles with some type of location technology, as the accuracy offered by these systems is increasing for a cheaper cost. The vehicle location technologies widely available and used some transit agencies are described in Table 29.

**Table 29. Types of Location Technology (Source: State of the Art Update '98, FTA, 1998)**

<i>Technology</i>	<i>Description</i>	<i>Advantages</i>	<i>Disadvantages</i>
<b>Dead-reckoning</b>	Most autonomous form; Given the starting location of the vehicle finds the subsequent location using odometer and compass readings.	Not dependent on any other technologies or physical systems.	Has to be reset constantly. Is always used as a supplement system to another location technology. Never used alone.
<b>Ground-Based Radio Systems</b>	Offered by some private vendors; finds the location by triangulation using transmitting and receiving towers the vendor is able to locate the position of a vehicle within 150 feet	Very inexpensive if the usage per month is low	Has problems with signal reception in urban canyons; can be very expensive when used for real-time location
<b>Global Positioning Systems (GPS) Technology</b>	Uses signals transmitted from a network of 24 satellites in orbit to determine position through triangulation	Satellite signals can be interrupted by the presence of tall buildings	With differential GPS the accuracy is within 2 meters. It is easy to install and cheaper in the long run.

Many transit agencies throughout the US have already installed or are in the process of installing AVL systems. Among the different technologies available, GPS is widely used and maybe the most promising. The two main reasons for choosing GPS receivers as the AVL technology are: (1) the use of the satellite signals is free, and (2) the cost of GPS receivers has declined significantly over the past four to five years. A GPS receiver costs several hundred dollars while an antenna costs an additional \$100 (Lave et al., 1996). Moreover, circuit board GPS units are available that have all the components of a GPS receiver and can be integrated or interfaced with an in-vehicle device such as a mobile data terminal. The total installation cost of such a unit including the antenna is between \$200 to \$500. Such developments are making GPS based AVL systems more affordable.

More recently, the vendors of ArcView 3.0, Environmental Systems Research Institute (ESRI), developed a new extension for ArcView, the Tracking Analyst, which directly reads and updates the location data from a GPS receiver and displays it on a map. This extension is also capable of complex spatial analysis with the real-time GPS data. If Pentran were to decide to install an AVL system, it could use the Tracking Analyst extension and obtain a “seamless” integration between the GPS and GIS in ArcView to automatically update the location of the vehicles in a real-time manner.

### **Personnel Training**

If route deviation were to be implemented in order to divert some of the ADA riders from the existing paratransit service, there is a need to adequately train fixed route bus drivers in how to appropriately interact with disabled individuals. The increased responsibilities of bus drivers would include assisting mobility impaired individuals in boarding and alighting, communicate with them courteously and offer services that will enable them to use public transit. Such training is often referred to as “sensitivity” or “empathy” training. A recent study supported by the Transit Research Cooperative Program (TCRP) titled “Guidebook for Attracting Paratransit Patrons to Fixed-Route Services”, discusses in detail how such driver training should be imparted (Balog, 1997).

### **Bus Size**

An obvious question that comes to mind with regard to the implementation of route deviation is the feasibility of maneuvering a 40 ft. bus on narrow residential roads. This begs the need to investigate the option of reducing the bus size to 20 or 25 ft. to facilitate maneuvering in residential streets. Some transit systems providing route deviation services have made the transition from a 40 ft. to a 20 ft. bus. The cost of such a transition is an important issue that must be resolved. For instance, although the bigger busses are more expensive to acquire, they prove to be economical in the long run due to their extended life. The same is not true of the smaller buses. A thorough benefit-cost analysis must be done to see if the benefits of acquiring the smaller buses outweigh the costs incurred due to their shorter life span and capacity constraints.

### **Public Policy**

There are several policy issues that must be resolved before implementing a route deviation service. As discussed earlier, the fixed route structure needs to be modified considerably before route deviation can be implemented in place of it. There could be strong public opposition to the removal of existing fixed stops. With this regard before changing an existing route structure public opinion from the surrounding areas may need to be garnered. The other issue is the reaction of residents to buses deviating into residential neighborhoods in order to pick-up and drop-off passengers. This problem could be mitigated to a certain extent by selecting routes that do not penetrate deeply into residential areas and using smaller and quieter vehicles. Another issue that warrants attention is determining who should use route deviation service. For instance, non-ADA people living within a 1/4 mile radius of a fixed stop could



easily walk to it to access the service. Similar restrictions, if any, on accessing the service should be well publicized before live operations begin so that people aren't taken by surprise when service is denied.

### **An Accurate GIS Database**

The importance of having an up-to-date and accurate GIS database cannot be emphasized enough. For the purposes of developing the prototype system a fairly detailed street centerline layer of the Peninsula area with address ranges and zip code attributes was obtained. However, it was not complete as some existing streets were missing from this map. Particularly, the entire street network within the Fort Eustis Military Reservation and the Langley Air Force Base area were missing. These areas are important paratransit trip generators, as observed from the data obtained from Handi Ride. Although in most cases this is not a major impediment in the functioning of the software, it will, however, fail to geocode the points if a passenger origin or destination falls in that area. Hence, it is recommended that such inconsistencies within the street network be rectified before any live operations begin. This can be done by either acquiring a fully up-to-date street centerline map in a GIS format from a private vendor or digitizing the missing streets using an up-to-date street atlas such as the ADC street map.

### **System Integration**

Finally, the most important element necessary for the smooth and uninterrupted functioning of a real-time route deviation system is the seamless integration between the different component technologies of the overall architecture. There is always some amount of "integration risk" associated with different technologies by different vendors (Lave et al., 1996). Many of these systems and technologies may work well in isolation but fail when integrated with two or more technologies. For example, the scheduling and dispatching software may not be easily integrated with the software that comes with the mobile data terminal (MDT). Such problems can be minimized and eliminated to an extent, by judiciously selecting a vendor that perfectly understands how the different components work together (Lave, et al., 1996). Also, it is important to know the specific objectives and needs of the system that would be in place before selecting the vendor. It is recommended that after delineating the system needs, Pentran consult with a system integration expert to tie the pieces together.