U.S. Department of Transportation
Federal Transit Administration

Federal Transit Administration

Feasibility Study on the Use of Personal GPS Devices in Paratransit

May 2009

http://www.fta.dot.gov/research

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
May 18, 2009

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Feasibility Study on the Use of Personal GPS Devices in Paratransit

5. FUNDING NUMBERS

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Federal Transit Administration
U.S. Department of Transportation
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Task Order Manager: Ms. Charlene Wilder
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400 7th Street, S.W. Room 9402
Washington, DC 20590

12a. DISTRIBUTION/AVAILABILITY STATEMENT
In addition to FTA's method of distribution, document will be made available though the Lehman Center for Transportation Research's (LCTR) website: lctr.eng.fiu.edu

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
The use of personal mobile GPS devices offers a potentially powerful use for paratransit. The conventional pickup procedure requires reservations via telephone or through the Internet for the paratransit driver to meet passengers. In this case, the potential problem is that a missed pickup may occur due to the ambiguity of the address information or the inability to find a specific location. However, with the availability of existing mobile GPS devices, passengers and vehicles can be located instantly, thereby facilitating the pickup process. This research project explores the feasibility of using personal mobile GPS devices to help develop more efficient paratransit services. Four different GPS-tracking devices were examined, and a prototype was developed. Using the prototype, the vehicle operator and passengers are able to know each other's location through the help of an agency dispatcher. With this additional information, it is expected that the number of missed pickups will be reduced. Surveys were also distributed to collect opinions and concerns from different agencies. Results indicated that a majority of transit agencies showed interest in adopting GPS devices to improve paratransit services.

14. SUBJECT TERMS
Global Positioning Systems, Application of Personal GPS Devices, Paratransit, Feasibility Study, Transit Operations Management

15. NUMBER OF PAGES
67

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500
Prescribed by ANSI Std. 239-18298-102
Standard Form 298 (Rev. 2-89)

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Foreword

The Federal Transit Administration (FTA) sponsored this research to determine the feasibility of using new technologies to aid and improve the paratransit pickup procedure. The research evaluated personal mobile GPS devices and analyzed their ability to function within a computer application. A prototype application was developed and tested with two of the GPS devices. While feasibility of the prototype program is high, a pilot program is needed to assess the net benefits of such an application.

Preface

The information developed and presented in this document was prepared for the Federal Transit Administration (FTA) by researchers from the Lehman Center for Transportation Research at Florida International University. The project team included Dr. Fabian Cevallos, Quan Yuan, Xiaobo Wang, Jon Skinner, and Dr. Albert Gan. The project was contracted through December 31, 2008.

The project was managed through the FTA Office of Mobility Innovation. Overall guidance was provided by the FTA project manager, Charlene Wilder. These contributions were important to the direction and quality of this research study.

The project team would also like to thank the employees of various transit agencies who willingly replied to the project's paratransit survey instrument. This information was valuable in assessing the interest in and need for GPS devices in paratransit.

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Abstract

As transit agencies continue to improve service efficiency, the availability of new technologies offer innovative solutions. One innovation is the use of personal mobile Global Positioning System (GPS) devices in paratransit. The conventional pickup procedure requires reservations via telephone or through the Internet for the paratransit driver to meet passengers at designated locations. In this case, the potential problem is that a missed pickup may occur due to the ambiguity of the address information or the inability to find a specific location. However, with the availability of existing mobile GPS devices, passengers and vehicles can be located instantly; thereby, facilitating the pickup process.

This research project explores the feasibility of using personal mobile GPS devices to help with the development of a more efficient paratransit service. Four different GPS-tracking devices were examined, and a prototype was developed. Using the prototype, the vehicle operators and passengers are able to know each other's location, and the agency dispatcher can see both the operator and the passenger. With this additional information, it is expected that the number of missed pickups will be reduced. Surveys were also distributed to collect opinions and concerns from different agencies. Results indicated that a majority of transit agencies showed interest in adopting GPS devices to improve paratransit services. The methodologies, as well as data flows, are described, and suggestions for further research are presented.

EXECUTIVE SUMMARY

The objective of this research was to determine the feasibility of applying GPS tracking technology to the paratransit pickup procedure. Study efforts consisted of assessing the need for personal GPS, comparing suitable GPS devices, and developing a prototype application.

Paratransit Pickup Procedure and the Potential Use of GPS Technology

Paratransit service has experienced a rapid rate of growth since the ADA was passed in 1990. Although paratransit only serves a small group of people, the average operating costs are much higher than most other public transit services. Presently, the operating expenses of paratransit in the U.S. are largely paid by government subsidies. Therefore, ensuring that monetary support is used efficiently and not squandered is a top priority for transportation providers and policy makers.

Compared with other public transit modes, the appointed pickup locations and schedules are flexible in paratransit service. Occasionally, missed trips occur because the vehicle operator has difficulty finding passengers at a previously indicated pickup location – an event termed as a missed pickup in this paper. For instance, at a large mall, hospital, or residential facility having multiple entrances, distinguishing the appropriate waiting area can be confusing for paratransit passengers. In this situation, a missed pickup is likely to occur if the vehicle operator and passengers are waiting for each other at different exits of the building.

However, this situation can be avoided if the passenger's exact location is instantaneously known by either the vehicle operator or the transit agency's dispatch personnel. If either of these paratransit employees is aware of the waiting passenger's location, the situation can be corrected immediately and a missed pickup may be avoided. Exact location information can aid in promoting a punctual, accurate, and efficient transportation service. These efforts would help promote a more efficient alternative to the current pickup procedure.

Although customary cell phone devices may seem like a feasible solution, paratransit riders' varying abilities make this option impractical. Significant numbers of paratransit riders have sensory, cognitive, neurological, or motor disabilities that make using a cellular phone difficult or impossible; GPS technology is necessary to create an instrument which can be used universally. With a mobile GPS tracking device that informs the paratransit service provider where passengers are waiting, the odds of a missed pickup can be minimized. Compared with the conventional method of looking for passengers in a defined area, a mobile GPS device provides a more reliable approach; the GPS instructions will lead the driver to the exact location of the passenger.

Study Objectives

The principle objectives of this research focused on examining the feasibility of using GPS devices to improve the paratransit pickup procedure. Several tasks were completed in order to properly assess the main objective. Transit agency interest levels in GPS were assessed through a survey instrument. Surveys were completed by a total of 36 U.S. transit agencies of varying size and geographic location. To best understand the complexities of developing a GPS system, a review of current GPS fundamentals was performed. Since GPS technology has improved and expanded significantly during the past few years, an up-to-date synopsis is included within the report.

The next significant objective focused on determining the most suitable GPS devices for assisting with paratransit. Four devices were examined for their accuracy, portability, reliability, durability, and user friendliness. After selecting the two preferred GPS devices, a prototype application was developed by the research team to test the coordination of the pickup procedure. To further assess the devices and prototype application, testing simulations were carried out under different scenarios. For this purpose, each simulation incorporated the use of three fictitious parties: the passenger, the vehicle operator, and the agency dispatcher.

Interest Levels in Using GPS to Aid the Pickup Procedure

Survey responses overwhelmingly indicated that most agencies are very interested in applying new technologies to paratransit operations. From the valid 36 responses, 26 transit agencies were strongly or somewhat interested in incorporating new GPS technology to help improve their services. Five agencies were indifferent to making changes in their current modes of operation. A total of five agencies were unenthusiastic about utilizing new GPS technologies.

In attempts to determine which agencies were more interested in using new GPS technologies, interest levels were compared and analyzed against virtually all other data obtained from the survey. Surprisingly, there were no associations found between interests in using the new technologies, and number of missed trips, missed connections, percentage of trip purposes, etc. Although there was no association with agency size, all of the larger agencies, those that had above 200,000 paratransit trips per year, were interested in experimenting with new GPS technologies.

Location Based Service Technology and Assisted GPS

Utilizing personal GPS devices for paratransit is essentially dependant on locating technologies. Location Based Service (LBS) technology enables the instant identification of an exact position from a mobile device. There are four measuring approaches, all of which offer opportunities to ameliorate the current paratransit passenger pickup: cell identification, angle of arrival, time of arrival, and enhanced observed time difference. Cell identification is one of the most common approaches and greatly ties into Assisted GPS (A-GPS)

Unlike regular GPS, which requires a complete download of data from satellites and may take up to several minutes, A-GPS relays information already obtained by the cell phone network and processes location data in a much faster and reliable manner, minimizing the impacts whenever the GPS signal is poor. Assisted GPS is important since large buildings and dense tree coverage can often impede or delay receiving satellite signals. In this project, since passenger location needs to be known instantly, any lapse in information could cause delay and frustration for drivers and passengers.

In real practice, the accuracy obtained with a Global System for Mobile communication (GSM) network ranges up to several hundred meters and is not sufficient to precisely describe a pickup location. However, accuracy can be improved by retrieving GPS signals from satellites regarding existing GSM network information. Without a GSM network, a mobile GPS device requires more information from the satellites, and more calculations are involved. Under the existing GSM network, because the mobile phone is already approximated in a certain zone, the final location will be obtained much faster, even if partial GPS information is not obtainable.

Comparison Testing of Devices

Four mobile GPS devices were purchased for comparison analyses: the Motorola i415, the Gemtek tracking device, the HP iPAQ hw6945, and the Garmin Forerunner 305. The following criteria were considered as a way to compare the four units among several important factors:

- Portability - a smaller sized device without the need for a power outlet is preferred, so that it can be easily transported.
- Reliability – GPS signals should be successfully acquired and free from other disturbance factors, such as those occurring at different times, in various places, or under inconsistent weather conditions.
- User friendliness - users should be able to easily operate the device.
- Durability - the product should have a relatively long usable life, and a sustainable battery.
- Compatibility – the device needs to be adaptable, with room for future hardware upgrades and functionality expansions.
- Accuracy - the passenger's exact location must be calculated precisely so that the vehicle will arrive directly in front of the passenger with little effort.

Upon device testing and comparison, the Motorola i415 and the HP iPAQ hw6945 were deemed to be best suited for the development of a GPS prototype. These devices both had acceptable costs and accuracy comparisons. Furthermore, these two devices supported programming capabilities.

Prototype Development

Next, a GPS prototype was developed to explore the feasibility of developing a complete working system. The best possible solution involved use of both the GPS enabled Motorola i415 cell phone and the HP iPAQ hw6945 Personal Digital Assistant (PDA). This prototype connects the passenger, vehicle operator, and the agency dispatcher together via a central computer. To synchronize these devices, separate programs, written by the research team, were created for each device.

Once the devices are turned on, the programs automatically initiate and send positional information continuously acquired from satellites to a server. The server translates the position coordinate numbers to point marks on Microsoft and Google maps, so that the agency dispatcher can track both the passengers and vehicles by view. On the driver's PDA screen, the vehicle operator is able to see driving directions and the passenger's location on a digital map. The passenger is able to receive the waiting time and vehicle distance. At the same time, a service log of all activities is recorded into the system database. Aspects of the prototype were determined to show significant promise for improving the punctuality and predictability of the pickup process.

Future Applications and Enhancements

The project team was able to successfully develop a working prototype, but it has yet to be tested at a paratransit program. Although initial software installation and program familiarization might require additional time and energy, there is evidence that this prototype system can be replicated at any paratransit agency. A pilot program is the next logical step for evaluating feasibility. By testing the prototype on an actual paratransit system, cost and benefit evaluations may eventually be conducted, answering important feasibility questions.

In the long term, other advancements will improve the proposed prototype. The pickup process can potentially be combined with service vehicle assignments. If a change is requested from a passenger, the system will immediately determine the most economical way to rearrange the service schedule. Potential benefits include less time needed for reservations and more adaptable services. Technology upgrades to GPS-enabled cellular phones, and other newly developed GPS devices may further improve the existing prototype. Future options for alarm notification, voice capabilities, and message services will also enhance the attractiveness of a GPS tracking system for paratransit.

1.0 INTRODUCTION

1.1 Expansion of Paratransit Services

Paratransit within the U.S. offers on-demand transportation services for qualified senior citizens and people with disabilities. Under the Americans with Disabilities Act (ADA), paratransit has become the well known demand-responsive service system embedded within the regular public transit network. Paratransit service is a transportation alternative that provides a high degree of accessibility for individuals with almost no mobility.

Although paratransit only serves a small group of people, the average operating costs are much higher than most other public transit services. Presently, the operating expenses of paratransit in the U.S. are largely paid by government subsidies. Since these subsidies often come under intense scrutiny during budget shortfalls, ensuring that monetary support is used efficiently is a priority for transportation providers and policy makers.

Historically, paratransit service has experienced rapid growth since the ADA was passed in 1990. ADA requires that public transit providers also provide complementary paratransit service to origins and destinations within corridors having a width of three fourths (¾) of a mile on each side of each fixed route *(1)*. In addition, many agencies offer paratransit services beyond those required by ADA. Sometimes called Dial-a-Ride, these services are especially popular in small cities or rural areas where no fixed route services are available.

In 1986, there were about 6,300 private paratransit companies in the United States. Together, these agencies operated more than 200,000 vehicles, representing more than 350,000 drivers and other staff. In September 1998, twelve years later, an estimated 22,884 private paratransit companies operated more than 370,000 vehicles. During the same year, some 500+ transit agencies made 8.86 billion passenger trips, of which 68 million or 0.77% of total trips were demand-responsive trips. Reports from the Federal Transit Administration (FTA) National Transit Database indicate that in 2006 the number of passenger trips had stretched to 9.40 billion, of which 88 million or 0.94% of total trips were demand responsive trips.

The database clearly shows that there has been tremendous growth in paratransit use. However, this is not the complete picture since the data do not include growth aspects attributed to increased transportation spending for Medicaid transportation, airport shuttle operations, or human services, all of which are paid for through other non-FTA grant programs (2).

1.2 Missed Trips Issue

Because paratransit has undergone rapid expansion and requires significant subsidies, agencies are continually under pressure to efficiently utilize budgets and reduce waste. A missed trip is one example of a wasted resource; since a missed trip, occasionally referred to as a missed pickup, is a scheduled trip that did not complete. This missed pickup may happen for a variety of reasons; including things such as operator absence, a vehicle failure, a dispatch error, traffic congestion, or failure of the driver to find the passenger. It may also occur if a passenger simply does not show up on time for the paratransit ride. In this case, the event is typically referred to as a no-show.

Drivers also have difficulties picking up a passenger if there are location ambiguities. These problems can occur when passengers submit inaccurate address information or are unsure of their exact location. Pickup requests in residential alleys also can create locational ambiguities. More commonly, at very large facilities, like hospitals, retirement homes, and mall complexes, multiple exits exist and the passenger may be more likely to miss a pickup due to the ambiguity of which door is the appropriate waiting location.

Although there is no specific industry terminology for this specific type of missed trip, in this document we will use the term *connection failure*. For the remainder of the report, a connection failure will refer to occasions where the paratransit driver and waiting passenger are unable to find each other.

Because of connection failures, or even a delay in making the connection with the passenger, both driver and passenger end up wasting time, leading to deterioration in the level of service. When the driver cannot find the passengers within a designated amount of time (a connection failure), the scheduled request has to be canceled, leaving the passenger stranded. On many occasions, the vehicle operator and passenger may be very close to one another, but are simply unable to physically see each other. Whatever the cause, missed trips result in significant financial consequences for both the passenger and service provider.

One consequence of a connection failure is that the passenger may have to spend money on a last minute taxicab. If the destination is far away, it could easily cost in excess of $20.00, whereas the price of paratransit is usually between $2.00 and $4.00. Alternatively, the passenger may be forced to stay home, and perhaps be charged for missing a doctor's appointment, or miss out on money earned from working at their job.

The costs suffered by the service provider include additional labor, gas, and associated vehicle maintenance costs that agencies must pay while vehicles are driven around searching for passengers. The extra financial burdens eventually fall onto the shoulders of passengers, agencies, and taxpayers. These costs can be easily quantified when the connection failure results in a missed trip. Costs are likely to vary depending on agency size. Results from a 1997 survey of 28 paratransit providers determined that the average cost of a missed trip was $10.90 for small-urban systems, $14.33 for mid-sized systems, and $26.03 for large agencies (*3*). It is important to note that according to the U.S. Energy Information Administration, the average cost of gasoline in 1997 was $1.24. With gasoline prices that went over $4.00 per gallon in July of 2008, the costs for missed trips can be significant. As late as 2004, the Utah Transit Authority (UTA), a medium to large sized agency, calculated that each missed trip cost $24.18 *(4)*.

1.3 Tracking Technology to Minimize Missed Trips

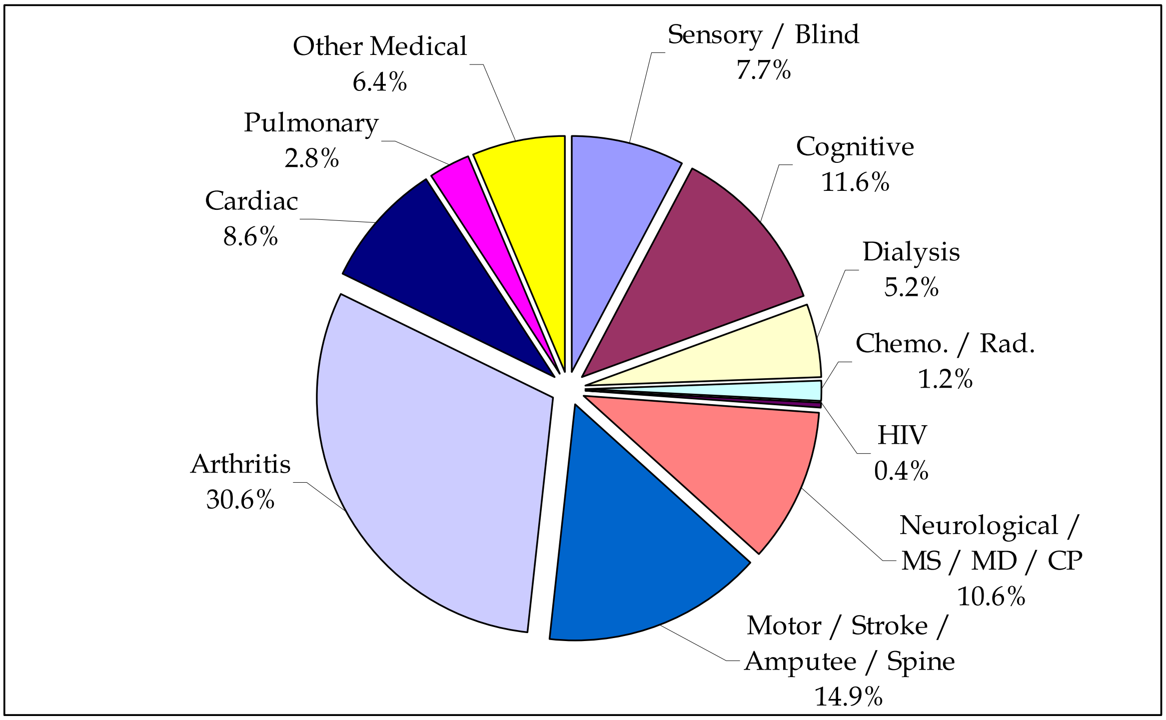
If service providers have a way to accurately identify a passenger's location in real time, the frequency of connection failures can be reduced. With the ever growing popularity of the Global Positioning System (GPS) market in civilian applications, incorporating new technologies, such as ITS, GPS, and computerized systems, will become more realistic for agencies with a limited amount of funds. These technologies can help prevent connection failures, thereby saving time and resources.

The varying degree of riders' disabilities may exclude the normal use of regular cellular phones as a solution for locating riders. Significant numbers of paratransit riders have sensory, cognitive, neurological, or motor disabilities that make using a cellular phone difficult or impossible. For instance, individuals who are mute, deaf, or blind may be unable to answer a phone, listen to the instructions, or describe their surroundings to the paratransit driver. Individuals with cognitive problems may forget to answer a phone, or how to answer, and become confused by a conversation with the driver or dispatcher. Furthermore, the actual answering and handling of a cellular phone may be impossible for someone with neurological problems or a person who has suffered a stroke.

While some paratransit riders may be able to communicate effectively with a regular cellular phone, such a device could not be used as a uniform method for improving connection failures. Based upon the classification of disabilities at Miami-Dade Transit (MDT), it is estimated that roughly half of all paratransit riders may have difficulty using a cellular phone (**Figure 1**). Paratransit users with sensory, cognitive, neurological, or motor disabilities comprise 45% of all persons authorized for travel (*5*). Furthermore, it is debatable whether paratransit riders in other categories could use a cellular phone. As a result, GPS devices, which eliminate the need for additional communication, are likely to be better suited for determining locational information. While the use of GPS devices may at first glance seem to be difficult, these devices can be pre-programmed to be user friendly (e.g., pushing the on button can start sending the location information at one minute intervals).

Without having to call or contact waiting riders, GPS technology may allow paratransit drivers to find their passengers more quickly, thereby saving time and resources. GPS also eliminates the need for a rider to explain directions over the phone – a request that could potentially lead to erroneous instructions for the driver, especially when asked to riders with a cognitive disability. The passenger may be further comforted knowing that with GPS, the driver will be able to locate him or her, no matter the circumstances. With some GPS-enabled devices, the waiting rider can even track the driver's location on a local map and judge the remaining wait time. This may provide reassurance to the passenger, and potentially reduce the number of calls to the agency about late drivers.

Figure 1 MDT Profile of Paratransit Riders by Disability Type, April 2008



To test the feasibility of this new concept, four mobile GPS devices were purchased to examine their capabilities. They are: a GPS enabled cell phone Motorola i415, a Gemtek tracking device, a Garmin Forerunner 305, and an HP iPAQ hw6945. All instruments were selected based on six major criteria: portability, reliability, user friendliness, durability, compatibilities, and accuracy. Both the advantages and disadvantages of each device are presented for comparison and contrast.

In this research, a prototype was developed to demonstrate the use of these devices in paratransit operations. The mobile GPS devices, combined with a computerized system, would eliminate the possibility of the actual pickup location being inconsistent with the one that had been previously scheduled, thus minimizing potential human errors.

Instead of finding passengers based entirely on information received during the reservation step, which heavily depends on manual operations, a mobile GPS device will be carried by each passenger, so that his or her real-time current location can be instantly tracked. The passenger's and paratransit vehicle's location is processed by a computer to generate a digital map showing where the passenger and driver are located. This allows vehicle operators to efficiently reach passengers by following precise instructions from the dispatch center.

The prototype brings with it a series of significant operational changes. For agencies, it introduces a systematic operational flow that uses fewer manual procedures, allowing for lower labor costs and fewer human-made errors. More importantly, improvements in service quality can be achieved. For passengers, the location system guarantees a more predictable pickup. As long as the device is working, regardless of whether a passenger knows his or her exact location or whether any previous mistakes were made in the reservation process, the passenger will benefit from a shorter waiting time.

Although advanced technologies usually lead to innovations, improved services inevitably will have minor initial flaws. These deficiencies must be modified before further improvements can be made toward customer satisfaction in the long run. In the future, transit agencies will have an opportunity to hear feedback from customers, and so improvements can be always made. However, agencies will have to address several new issues. Problems such as the durability of the devices, insurance, and legal tracking activity will be carefully evaluated in order to maintain efficient operations and a good rapport with customers.

2.0 AGENCY SUPPORT

A survey was conducted to understand more about transit agency interests and feasibility of using GPS technology to assist paratransit services. A fifteen question, online survey was developed inquiring about typical paratransit service characteristics and the agency's willingness to utilize new technology. A link to the online survey was emailed to 65 transit agencies of various sizes around the country. Follow up emails were then sent out to encourage response.

A total of 36 agencies responded, for a survey response rate of 55.4%. Responding agencies ranged in size and geographic area representing 16 states. Survey respondents had annual paratransit passenger trips ranging from 746 to 1,584,382 (**Table 1**).

Table 1 Size of Agencies Responding to Survey, by Total Yearly Paratransit Trips

Paratransit Passenger Trips per Year	Number of Agencies Responding to Survey
0 - 20,000	8
20,001 - 40,000	6
40,001 - 100,000	7
100,001 - 300,000	8
300,001 - 800,000	3
800,001 – 1,600,000	4

Survey responses overwhelmingly indicated that most agencies are very interested in applying new technologies to paratransit operations. From the valid 36 responses, 26 transit agencies were strongly or somewhat interested in incorporating new GPS technology to help improve their services (**Figure 2**). Five agencies were indifferent to making changes in their current modes of operation. A total of five agencies were unenthusiastic about utilizing new GPS technologies.

In attempts to determine which agencies were more interested in using new GPS technologies, interest levels were compared and analyzed against virtually all other data obtained from the survey. Surprisingly, there were no associations found between interests in using the new technologies, and number of missed trips, missed connections, percentage of trip purposes, etc. Although there was no association with agency size, all of the larger agencies, those that had above 200,000 paratransit trips per year, were interested in experimenting with new GPS technologies.

Figure 3 displays this information graphically. The numeric interest levels correspond to the following survey answers about how interested agencies are in applying GPS technologies: 5 = strongly interested, 4 = somewhat interested, 3 = neutral, 2 = not very interested, 1 = strongly not interested. Eight agencies had more than 200,000 paratransit trips per year, and each was either 'strongly interested' or 'somewhat interested'.

Figure 2 Agency Interest in Applying GPS in Paratransit Services

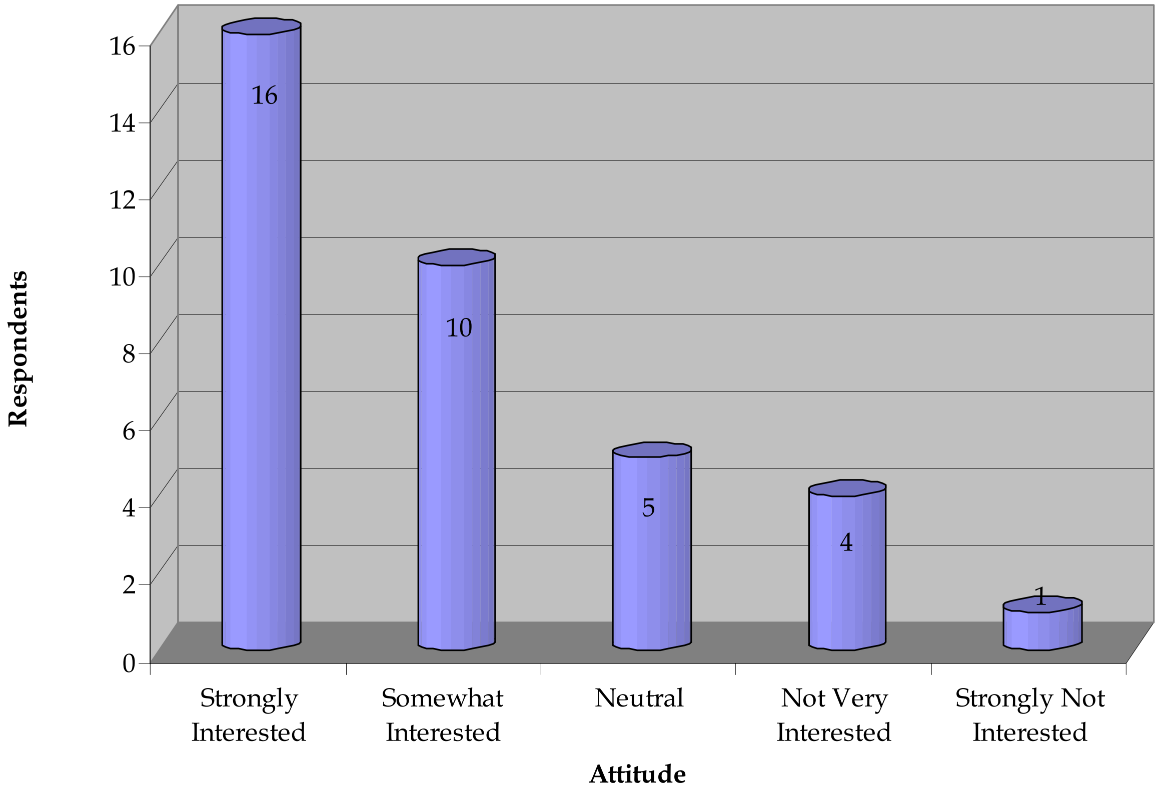
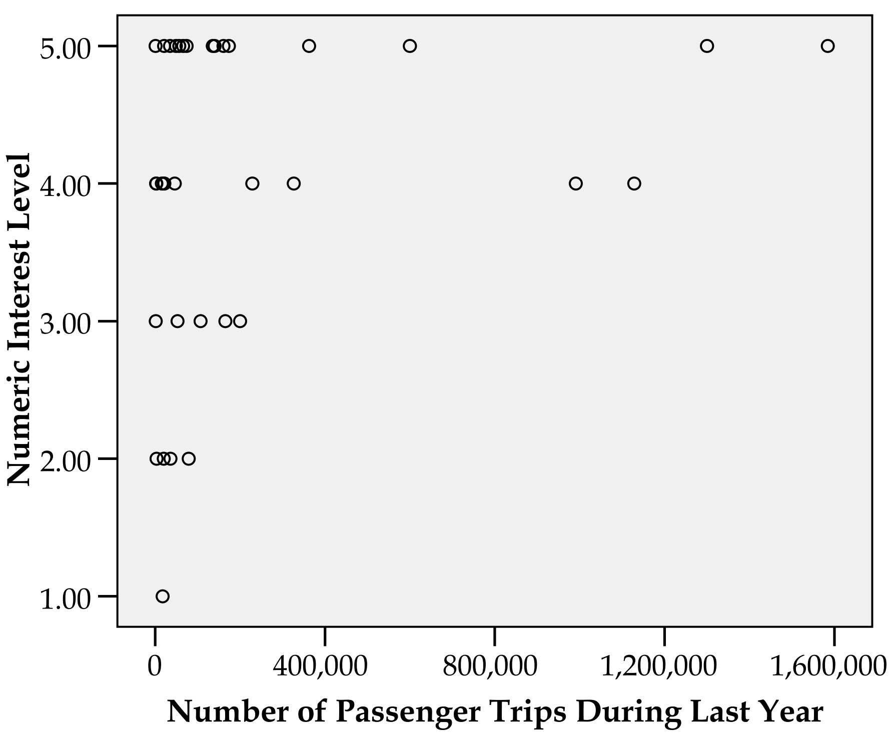


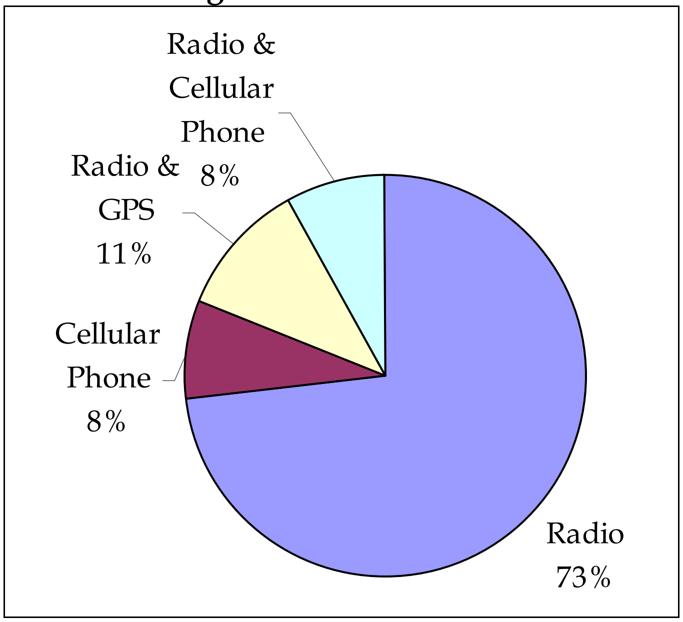
Figure 3 Agency Interest Levels in GPS Technology vs. Paratransit Passengers



Responding agencies currently use a variety of technologies to communicate between the dispatch center and the vehicle operator (**Figure 4**). Of the 36 agencies responding to this question, 73% exclusively use radio for communication. About 19% of responding agencies utilize radios and another device – either GPS or Cellular Phones. Eight percent of agencies only use Cellular Phone. Agencies showed high interest in using new technologies, even those already using GPS technologies.

Current communication methods reflect how easily a new system could be incorporated into the existing ones. A compatible system is always more realistic due to its low investment cost for upgrading. Though **Figure 4** groups technologies into 4 discrete categories, data showed that many agencies use a mix of systems to coordinate with field vehicles including walkie-talkie, mobile data terminal, cell phone, automatic vehicle locator, GPS, telemetry, and special dispatch software. Consequently, using a GPS enabled cell phone to aid the operation procedure is not completely new. More extensive use of GPS devices may not be far away.

Figure 4 Current Technologies in Use for Paratransit Service Operations

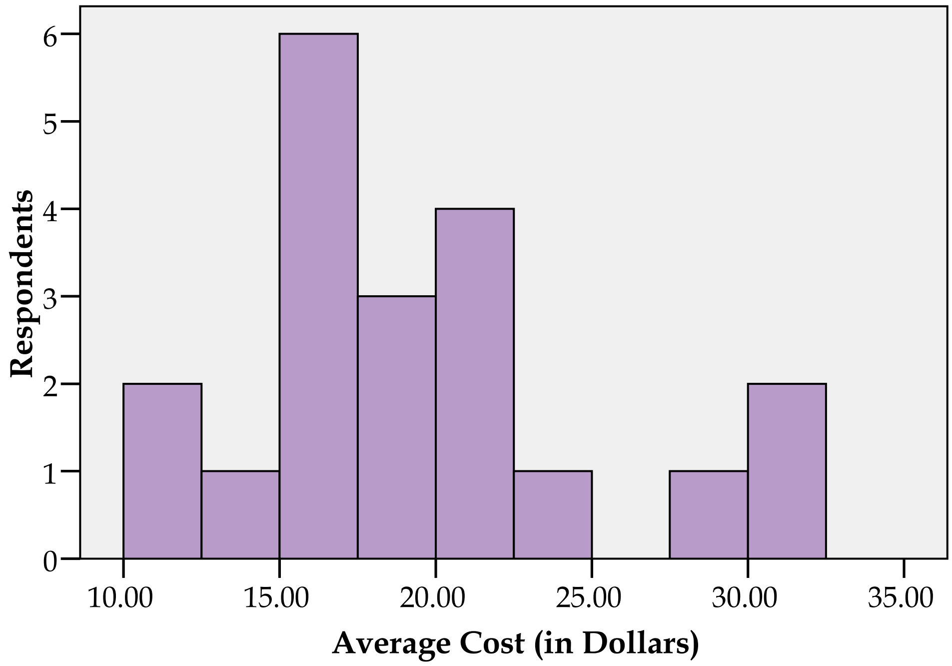


Another key purpose of the survey was to help quantify financial losses resulting from no-show trips. With this information in hand, a more accurate estimation about the benefits of using GPS tracking devices can be made. Survey results showed that losses from no-show trips are substantial and implementing personal GPS location technology would be cost effective.

The annual financial loss due to no-shows ranged from $60 at a small agency in Puerto Rico up to over $700,000 at a large agency on the west coast. Of the 20 agencies responding to this question, the mean value of losses per year was close to $89,000.

Looking at all agencies, the average cost for each no-show ranged from roughly $10.00 to $32.50. However, most agencies lost between $15.00 and $22.00 per no-show trip (**Figure 5**). On average the financial cost of each no-show trip was $18.21.

Figure 5 Average Cost of Each No-Show Trip

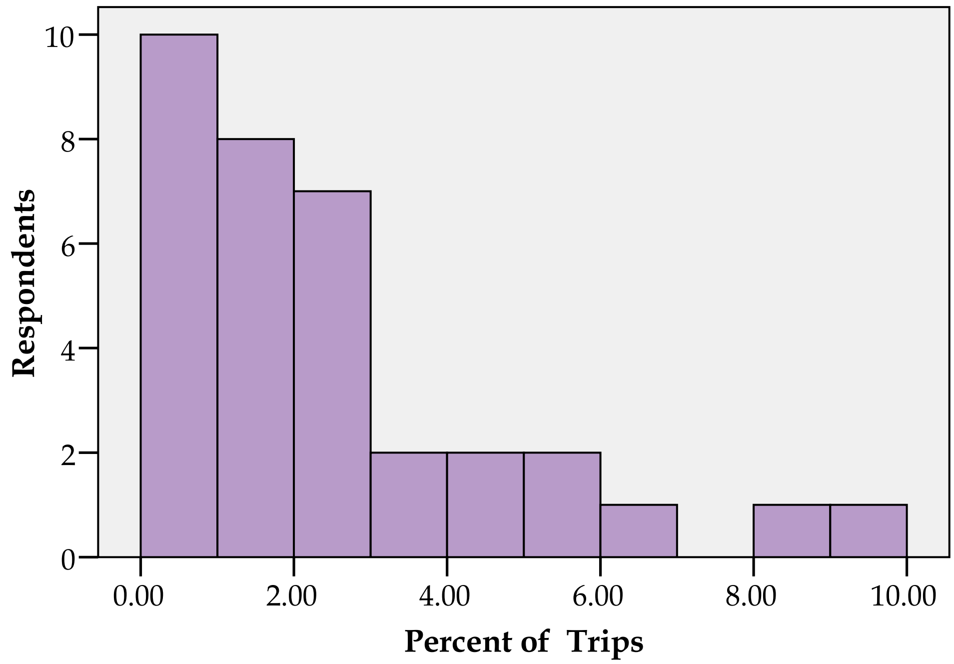


Thirty-five of the survey respondents provided information on their total number of no-shows each year and the total number of paratransit trips provided. Using this information, the percentage of no-show trips to total passenger trips was calculated. Most agencies had fewer than 3% of total trips due to no-shows. However, two agencies had a no-show rate of over 8% (**Figure 6**).

It is important to note that some of these percentages may also include late cancellations. Late cancellations are defined differently based on each agency's own internal policies and regulations and may have overlapped our no-show definition. To that extent, these cancellations may or may not impact our no-show data collected in our survey.

To specifically investigate the connection failure phenomenon, agencies were asked to estimate the percentage of no-show trips that occurred due to the passenger and driver being unable to find each other. Of the 25 agencies responding to this inquiry, 20 stated that connection failures constituted less than 8% of all no-shows. Five agencies indicated that connection failures constitute greater than 20% of all no-shows and of those, two agencies reported 75% and 80%.

Figure 6 Percent of No-Show Trips to Total Passenger Trips



While most agencies only have a small number of connection failures, five agencies indicated real difficulties locating passengers within an allotted amount of time. These five agencies were medium to small in size, and according to estimates, had total connection failures ranging between 2 and 1,225. These results indicate that significant benefit could be derived from implementing new technology targeted at improving the performance of the paratransit service.

For additional survey data and analysis, please refer to Appendix A

3.0 BACKGROUND

3.1 GPS Fundamental Synopsis

The Global Positioning System uses 24 navigation satellites in orbit around the Earth – six groups of four evenly spaced satellites per orbit. All satellites constantly emit square waves, or enciphered codes in different patterns. For accurate geolocation performance, the ground based GPS devices must receive these codes from at least three satellites simultaneously and decipher them to compute spatial positions. However, the precision of GPS signals depends upon many factors, which can accumulate to generate large errors that have an impact on locational accuracy. Multiple sources of error and deviation are listed in **Table 2** (*6, 7, 8, 9, 10*). Usually, error range of GPS measurements are less than 15 meters, depending on the ultimate offsets of all impacts.

Table 2 Error Sources Impacting the Precision of GPS Signals

Source	Error Range	Explanation
Ionospheric Effects	± 5 meter	The ultraviolet rays from the sun ionize a portion of gas molecules to release free electrons in the atmosphere, distorting the propagation of GPS broadcasts.
Ephemeris Errors	± 2.5 meter	This is a difference between the expected and actual orbital position of a GPS satellite.
Satellite Clock Errors	± 2 meter	The small inconsistency of time deviation, in different satellite entities.
Multipath Distortion	± 1 meter	This distortion varies depending on the environment within which the receiver is located, satellite elevation angle, receiver signal processing, antenna gain pattern, and signal characteristics.
Tropospheric Effects	± 0.5 meter	Delay of the GPS signal waves with respect to free space propagation due to the effect of troposphere properties, including temperature, pressure, and humidity.
Numerical Errors	< ± 1 meter	Based on the theory of relativity, the wave speed generates a different frame from the Earth reference frame.
Cumulative Errors	> ±13 meter	The total theoretical errors listed above, excluding the receiver device bias.

Sources: (6, 7, 8, 9, 10)

The GPS locating method heavily depends on satellite visibility, so the failure rates vary under many different circumstances. Sometimes the electromagnetic wave signal is reflected and, though the signal is still ultimately redirected to the satellite, minor distortion occurs. Most GPS devices do not lose their signals completely if there is only minor shielding, because the sensitivity of antennas and receivers has been continuously improved. For instance, if the passenger is waiting next to a tall building or under the eaves, the reading fluctuations may create some problems for the driver in determining the actual location of the passenger.

Assisted GPS is an enhancement to a mobile phone's locating ability. The development of A-GPS was accelerated by the U.S. FCC's E911 mandate requiring the position of a cell phone to be available to emergency call dispatchers *(11, 12)*. A-GPS uses both GPS and a terrestrial cellular network to obtain geographic position. Assisted GPS plays an important role in most contemporary mobile GPS devices.

Unlike regular GPS, which requires a complete download of data from satellites, which may take up to several minutes, A-GPS relays information already obtained by the cell phone network and processes location data in a much faster and reliable manner, minimizing the impacts whenever the GPS signal is poor. Without a Global System for Mobile communications (GSM), a mobile GPS device requires more information from satellites, as well as further calculations, so the locating time is much longer. However, under the existing GSM network, the cell phone signal tower offers a rough locational estimation in a range from 100 meters to 300 meters. Therefore, within this limited area, location information is readily obtainable even if only partial GPS data can be downloaded from the satellites.

A higher spatial accuracy level is obtainable using the Wide Area Augmentation System (WAAS). By referring to ground control stations, WAAS corrects any detected discrepancies in the GPS results. The achievable accuracy limitation is within 7.6 meters in the worst case scenario. With ongoing technology improvements, future mobile devices may have the potential to apply WAAS to obtain higher accuracy levels (*13, 14*).

3.2 Extensive GPS Applications

Because GPS can almost instantly locate a ground target, many aspects of our civilian life have been recently improved. For example, the functioning of industrial production organizations, including agriculture, ecology, commerce, politics, etc., are all now influenced significantly by GPS.

The agricultural industry in the State of Kansas employed GPS technology in beef production management in order to control the spread of Bovine Spongiform Encephalopathy (BCE). All cattle are tracked by GPS and, thus, their movements are recorded. With the aid of a Geographic Information System (GIS), a quarantine map showing potential disease threatened areas can be plotted. Tracking the animals' positions provides effective immunization management and improves the security of food supplies. Additionally, the tagging of the cattle from birth to death makes conventional farm administration more systematic (*15*).

In commercial businesses, applications extend much further. For instance, car rental companies now have reliable methods for locating their vehicles at any instant for safety and security reasons. By installing Automatic Vehicle Locating technology (AVL), rental companies have prevented improper usage, reduced insurance costs, and deterred theft. In fact, most major car rental companies have already implemented GPS navigation service as an optional accessory for their clientele. Cargo tracking technology allows businesses to oversee cargo's movement by attaching a GPS tracker to containers and trucks. This also enhances the security of transportation.

Environmental scientists employ GPS in many research projects. Many species have been extinguished because of encroachment and the consequent necessity to adapt to new habitats. In Africa, researchers from wildlife protection organizations use GPS trackers to collect data on elephant activity (*16*). With the database showing the living boundaries of these animals, land use patterns can be modified to minimize the impact of human activities. GPS also serves as a valid tool for vegetation management. In Scotland, researchers relied on GPS data to analyze and monitor herbivores' grazing locations. Researchers determined with relative GPS, modules affixed to roving animals had a mean accuracy of 10 m and precision was < 10 m 95% of the time (*17*).

3.3 Location Based Service (LBS)

According to the definition provided by the SENSEable City Lab at the Massachusetts Institute of Technology (MIT), Location Based Service is the technology that allows instant identification of a mobile device's exact position (*18*). There are generally four measures involved in achieving this goal: cell identification, angle of arrival, time of arrival, and enhanced observed time difference (*19*).

- Cell identification determines the location based on the wireless network. Usually, a mobile phone communicates with the nearest signal tower, and its location falls into the cell that the tower serves. Due to the difference in shape or size of each cell, the accuracy ranges from 100 meters to 600 meters.

- The angle of arrival calculation depends on the signal receiving direction. At minimum, two base stations are required to monitor the signal path and calculate the sender's location using trigonometry principles. The obtainable accuracy limits range from 50 meters to 150 meters, varying due to signal travel path deflections.

- The time of arrival approach emits signals in all directions from three base stations. The signals leave each station simultaneously and are reflected back. Once they reach the device, distances to the three stations are all known for positioning.

- The observed enhanced time difference approach is relatively complicated. A mobile device is preinstalled with locating software that computes its own position, and later the position is generated by nearby base stations.

4.0 LOCATING METHODOLOGY

4.1 Location Interpretation

Only a limited amount of spatial distance deviation may be allowed to avoid missing a passenger who might be waiting on the other side of a building or merely a block away from a specified pickup location. The most popular way to express a geographic position is using longitude/latitude coordinates. These coordinate numbers can be converted to actual distances using a scale factor. By converting sets of coordinates to linear distance, users will have a better sense of whether the distance errors are acceptable.

The conversion from coordinates to actual distances becomes more complicated as accuracy requirements become more demanding. There are ways to depict distance on the Earth's surface to a very exact degree if sufficient investment and equipment support are provided. In fact, the equipotential surface, also referred as mean sea level, is an irregular surface relative to an ideal ellipsoid surface, so there is no universal mathematical formula to perform the algorithms to a very high degree of accuracy. Yet, an acceptable approximation method can be found on the Internet to complete the interpretation. The Internet resource MaNIS/HerpNet/ORNIS Georeferencing Guidelines (*20*) provides a simplified conversion factor table, as shown in **Table 3**.

Table 3 Uncertainty Based on Coordinate Precision Using WGS84 Ref. Ellipsoid

Precision	0 degrees Latitude	30 degrees Latitude	60 degrees Latitude	85 degrees Latitude
(all values in meters)				
1.0 degrees	156,904	146,962	124,605	112,109
0.1 degrees	15,691	14,697	12,461	11,211
0.01 degrees	1,570	1,470	1,247	1,122
0.001 degrees	157	147	125	113
0.0001 degrees	16	15	13	12
1.0 minutes	2,615	2,450	2,077	1,869
0.1 minutes	262	245	208	187
0.01 minutes	27	25	21	19
0.001 minutes	3	3	3	2
1.0 seconds	44	41	35	32
0.1 seconds	5	5	4	4
0.01 seconds	1	1	1	1

From the above table, it can be seen that the same degree of longitude/latitude differences equate to different real distances at different latitudes. Because all our experiments were performed in Miami, Florida, where latitude is around North 25 degrees, the second column data are employed because they are the closest conversion factors. Here, 1 minute is approximately equal to 2450 meters; likewise, 1 second is equal to 41 meters.

4.2 Criteria for Selecting GPS Devices

To select the most appropriate mobile GPS devices for our paratransit pickup system, the following criteria were considered: portability, reliability, user friendliness, durability, compatibility, and accuracy.

- Portability is one of the most basic requirements, reflecting the necessary convenience since the device must be carried by users. Generally speaking, to satisfy this requirement, a smaller sized device without the need for a power outlet is preferred, so that it can be easily transported.

- Reliability ensures that GPS signals are acquired successfully, free from other disturbance factors, as GPS readings can vary due to time differences, geographic location, and weather conditions. This criterion has no absolute quantitative measurements. Therefore, comparisons are performed among the different candidates to determine a relatively better choice after actual testing for a period of time.

- User friendliness is determined by how easily users can manipulate the device. It would not be beneficial to spend large amounts of time on tutoring paratransit passengers how to use it. In addition, a nice-looking device is a plus.

- Durability concerns the usable life of the product, including maintenance and future reoccurring costs. It includes a study of the sustainability of the battery, the fragility of the device, and comparisons of administrative costs after the new system is implemented. Note that using a single device for one year without problems is not enough evidence to declare a device durable.

- Compatibility requires that the newly developed operating platform has good adaptability and, thus, provides savings on overall expenditures and equipment. Furthermore, there should be a large enough margin for future hardware upgrades and functionality expansions.

- Accuracy is really the core criterion of employing GPS devices. It ensures that the passenger's exact location is known so that the vehicle will arrive directly in front of the passenger with little effort. Each GPS device was tested a total of 40 times to retrieve position information at a control point for longitude and latitude readings.

All tests were conducted within the course of two hours during a single day. These data were then statistically examined and quantitatively compared. With the aforementioned criteria in mind, four mobile GPS devices were purchased for comparison analyses: the Motorola i415, the Gemtek tracking device, the HP iPAQ hw6945, and the Garmin Forerunner 305. Each device is discussed in the following sections. Selection procedures provide typical examples of how the candidacy of a new device was evaluated. It is unlikely that all criteria will be simultaneously embodied in one device. Consequently, positives and negatives had to be considered when determining device eligibility. Among all criteria, accuracy was the only parameter where the four devices could be compared quantitatively. As a result, further accuracy tests were conducted to draw a dependable conclusion.

4.3 Motorola i415

4.3.1 Overview

The Motorola i415 (**Figure 7**) is a GPS enabled mobile phone. Basic features include the regular Bluetooth cell phone, walkie-talkie, and GPS navigator. The GPS locating service in this test is offered by Boost Mobile Company, and an approximately $30 monthly service fee was charged at the time of this research for unlimited data transfers. This does not include voice communication. A service fee is necessary because Internet access is required to send location information. Additionally, the cell phone supports Java coding, allowing for the implementation of potential applications to extend its adaptability and compatibility.

Figure 7 Motorola i415

The voice communication offers another way to re-coordinate the pickup and can be used as an aid whenever the GPS fails. For instance, there may be cases when passengers experience technical problems and need to communicate with the service provider.

4.3.2 Criteria Judgment

- **Portability**: As a regular mobile phone with dimensions 140 × 48 × 22 mm, the Motorola i415 is convenient to carry. A carrying case is generally available as an accessory option.

- **Reliability**: There are still some reliability improvements that the manufactures can make. There have been no breakdowns since testing; however, at low battery levels, the GPS location readings are far beyond an acceptable range, with deviations up to 500 meters. As a consequence, it is important to make sure that the device is always operated at a sufficient battery level. According to a similar phone's support center, the unreliability is due to several factors. For instance, a low battery cannot provide sufficient wireless signal strength, or surrounding radio noises may be so strong as to cause interference. When the GPS signal is weak or satellite visibility is low, the locating method falls back to the GSM network (*21*). There is no significant evidence showing that cloudy weather had a significant impact on the readings. Another deficiency is that text messages were occasionally difficult to send due to a failure to connect with the server. It is expected that in the future, GPS enabled cell phones will perform better.

- **User Friendliness**: The Motorola i415 generally follows the typical cell phone panel arrangement; hence, people with experience using cell phones should become easily acquainted. Tracking functions were able to be performed automatically with few manual operations once the research team designed and implemented a Java program code.

- **Durability**: There was not sufficient time, nor a sufficient sample size, to draw conclusions as to the durability of this type of phone. However, the cell phone has a hard plastic texture and was still in good condition after one year's usage. The power consumption is relatively short; it only lasts about 8 hours in GPS active mode. Yet, this is still sufficient for a normal, one-day service span.

- **Compatibility**: The Java programmability of the Motorola i415 provides excellent compatibility, and codes can be implemented into the device for user-defined tracking activities. The project team created a program to simplify the tracking procedure so that only one press of the button is needed and rest of the task will be automatically completed.

- **Accuracy**: Results from the 40 longitude/latitude readings were converted to real distance deviations in meters. The results, summarized in **Figure 8** and **Figure 9**, represent readings obtained during the two hour period of testing. Outliers resulting from low battery levels are excluded in the following analysis.

Figure 8 Frequency Histogram for the Motorola i415

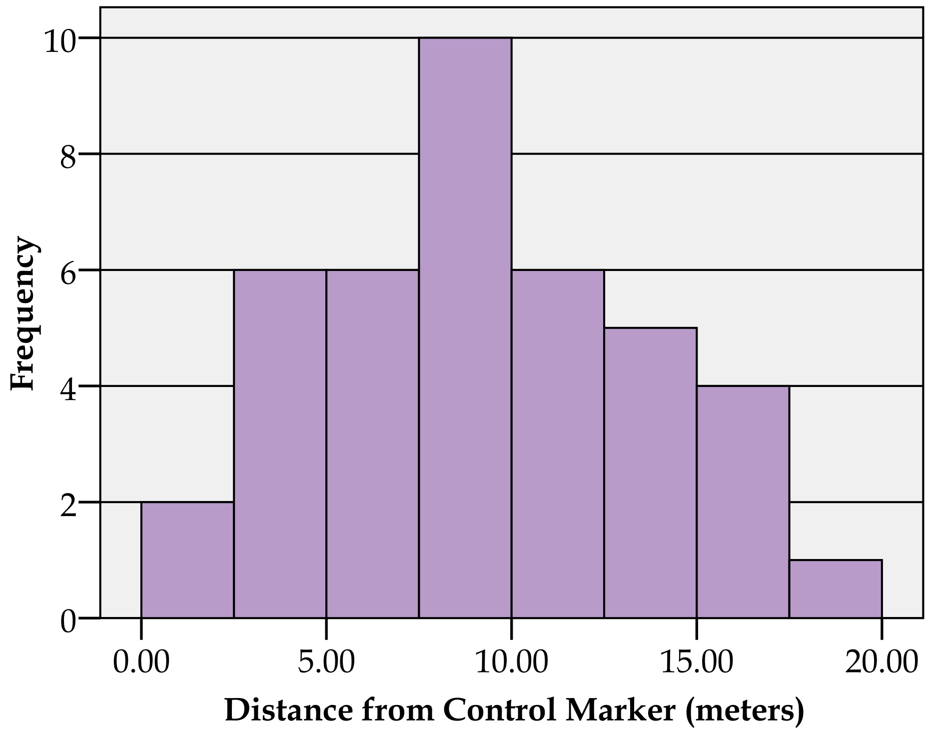
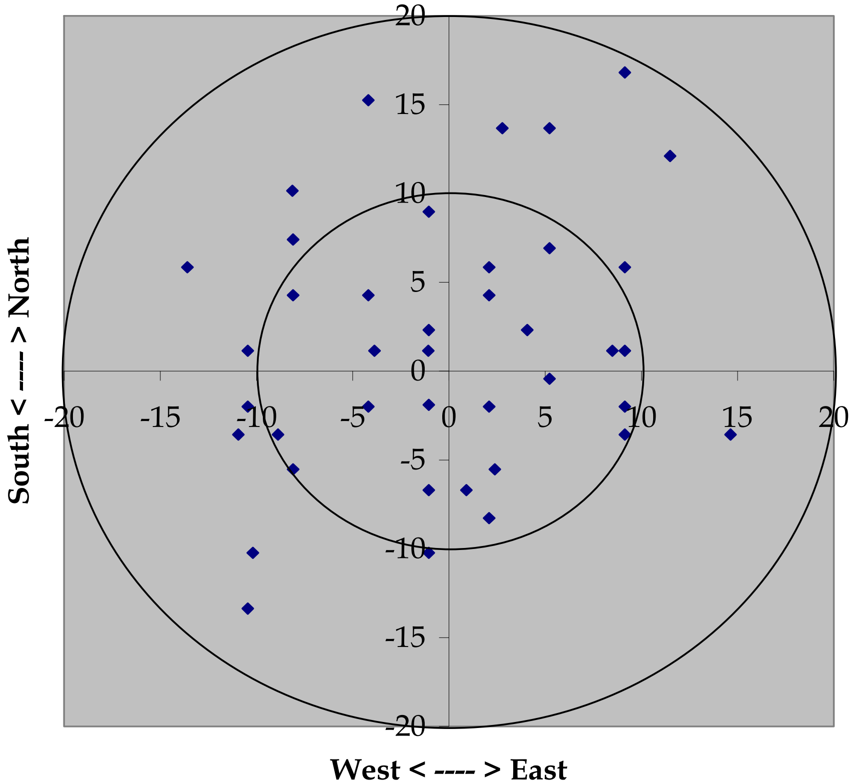


Figure 9 Real Distance Deviation for the Motorola i415 (distance in meters)



The histogram shows that the majority of measurements had a deviation of less than 10 meters. All of the results were within a distance of 20 meters from the center of the control point (survey marker). These observations seem accurate enough to provide a vehicle operator with confidence that his or her passenger is very near.

4.4 Gemtek Tracking Device

4.4.1 Overview

The Gemtek tracking device (

Figure 10) allows for instant location queries as well as traveling path log recording. Besides the wireless GPS communication channel, a voice communication channel is also included. A customer service phone number plus two user-defined phone numbers are preset. The voice communication is enabled by pressing the corresponding speed dialing keys. In case passengers cannot find the vehicle operator, they can this function to contact the service provider. Except for the two phone number limitation, this device functions the same as a regular cell phone.

Figure 10 Gemtek Tracking Device

Two other features worth mentioning are the SOS alarm and geofencing. When the SOS alarm button is pressed, location information will be sent immediately to the pre-stored phone numbers for emergency assistance. Another optional feature, geofencing mode, can be used to alert the designated contacts if the carrier goes beyond a predefined geographic zone.

This device uses three colored indicator lights to show operating status. The blue flash starts when the device is turned on. If the flash changes to green, it indicates that it is under GSM coverage. If there is sufficient clearance, the flash finally turns to red, meaning the GPS satellite signal is being received. The signal light provides an advantage since the user knows to move around for better satellite visibility. The development of the Gemtek device was aimed at tracking seniors, primarily for their own safety; therefore, many special functions are incorporated into the design.

4.4.2 Criteria Judgment

- **Portability**: The Gemtek's size is approximately 90 × 45 × 20 mm. It comes with a leather bag in the package and is readily attachable to the wrist or belt.

- **Reliability**: In both cool and warm starting modes, it normally takes about one minute for the GPS satellite signal to be acquired in an open environment. As long as the red flashing light is on, which indicates the device is in GPS coverage area, the position information was instantly available upon a query entry.

- **User Friendliness**: Because there are only seven buttons on the panel, users are neither required to memorize phone numbers nor spend time familiarizing themselves with usage. Appropriate phone numbers would be pre-programmed into the Gemtek device by transit agency staff.

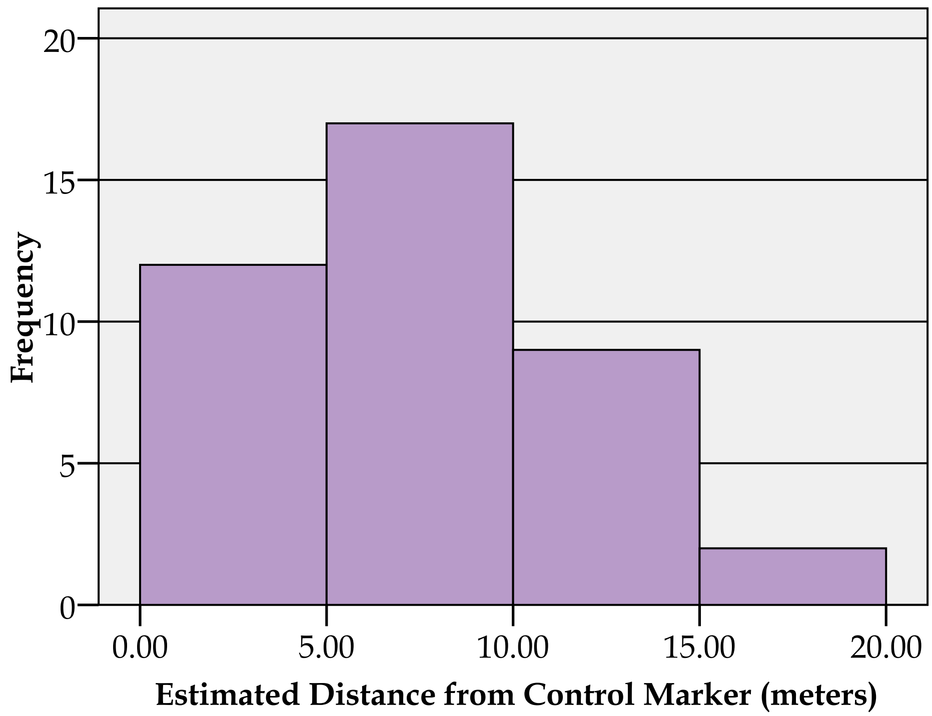
- **Durability**: During testing, the device worked properly. The battery lasted more than 20 hours if no voice calls were made and it supported up to four hours of talk time on a full battery charge.

- **Compatibility**: Because the Gemtek device is provided as a packaged end product, including the service plan, changes cannot be made internally. As a result, it is impossible to create customized applications, since there is no way to load or implement programs.

- **Accuracy**: The accuracy description of the Gemtek tracking device is different from the others. Unlike the conventional longitude/latitude coordinates that define a point in a numerical manner, the web application only provides a digital map or, at most, an aerial image for some urban areas. With no obtainable numerical location information, there was no way to quantify the degree of accuracy. As a result, a rough estimation was performed. Using high-resolution aerial images, an estimate of 5 meters was chosen as the minimum distance interval, and the data were grouped into four categories.

Note in **Figure 11** that none of the 40 test results fall outside of a 20-meter range, and 38 out of 40 trials are concentrated within a radius of 15 meters. Only 2 out of 40, or 5% of the trials, were located between a 15 and 20-meter interval. Therefore, the accuracy is likely to be satisfactory in real field applications of the paratransit pickup system.

Figure 11 Gemtek Frequency Histogram and Estimated Distance Deviation



4.5 Garmin Forerunner 305

4.5.1 Overview

The Garmin Forerunner 305 (**Figure 12**) is a multiple function electronic watch with GPS tracking capability. This device was designed to monitor the user's physical exercise conditions and thereby offer training guidance. Some basic features include a stop watch, palpitation measurement, calorie consumption, and route distance calculation. Users are able to preset their exercise schedules into the watch, including running distance, heart rate, and calorie consumption. An alarm reminds the user whenever a certain goal is achieved. Besides the watch component, there is a band that can be worn on the user's chest for measuring the heart rate. This communicates with the watch wirelessly via Bluetooth.

The watch records the longitude/latitude position continuously, and all of the data can be later downloaded to computer by a USB cable. From these data logs, users can compare their exercise activities on a daily basis. The Garmin Forerunner 305 has the best accuracy because it is World Wide Augmentation System (WAAS) supported. Additionally, the high sensitivity SiRFstar III antenna gives it extraordinary dependability. Yet, a lack of wireless communication channels excludes it from the candidate pool; essentially, no position information can be transmitted instantly via wireless. Because there is no wireless communication channel, there is no way to instantly send back location information to an agency. Hence, it is not feasible to use the Garmin Forerunner 305 in this project.

Figure 12 Garmin Forerunner 305

4.5.2 Criteria Judgment

- **Portability**: The Garmin Forerunner 305 easily satisfies the portability requirement because it is a wristwatch size and unlikely to inconvenience users.

- **Reliability**: One of the shining points of this product is the integration of a high sensitivity SiRFstar III GPS antenna. The extraordinary signal detectability is superior to the other three devices and takes significantly less time to retrieve position coordinates.

- **User Friendliness**: With more user functions available, the device requires extra learning time for users to familiarize themselves.

- **Durability**: A disadvantage is that the battery life only lasts about 4 hours. This is much shorter than a typical service day or even the service span of a round trip. If a passenger has to stay somewhere for more than 4 hours, it would be necessary to turn off the device to reserve sufficient battery power for the return trip.

- **Compatibility**: Lack of compatibility is the major flaw of the Garmin Forerunner 305 for this project. The current cost of implanting a wireless communication chip into a small watch is not yet popular for civilian use, but may become more realistic in the future. More importantly, this watch is non-programmable, and no alternations can be made to accommodate a custom application for this device.

- **Accuracy**: Accuracy is perhaps the most outstanding feature of this product because of its integration with Wide Area Augmentation System (WAAS) technology. The majority of GPS measurements fall within six meters of the control point, regardless of the battery level or sky conditions. The maximum distance deviation was only eleven meters (**Figure 13**). Combined with its high reliability, the Forerunner 305 proves WAAS has a better locating accuracy than ordinary GPS technology.

Coincidentally, all points are aligned perfectly in both vertical and horizontal directions; this is because the reading digits can only reach the third decimal in seconds. Several points overlap and thus appear as fewer dots on the distance deviation chart (**Figure 14**). In terms of actual distance, there is a systematic error approximately larger than 1.3 meters because of the number of decimals. The interspaces between points are always multiples of 1.3 meters.

Figure 13 Frequency Histogram for the Garmin Forerunner 305

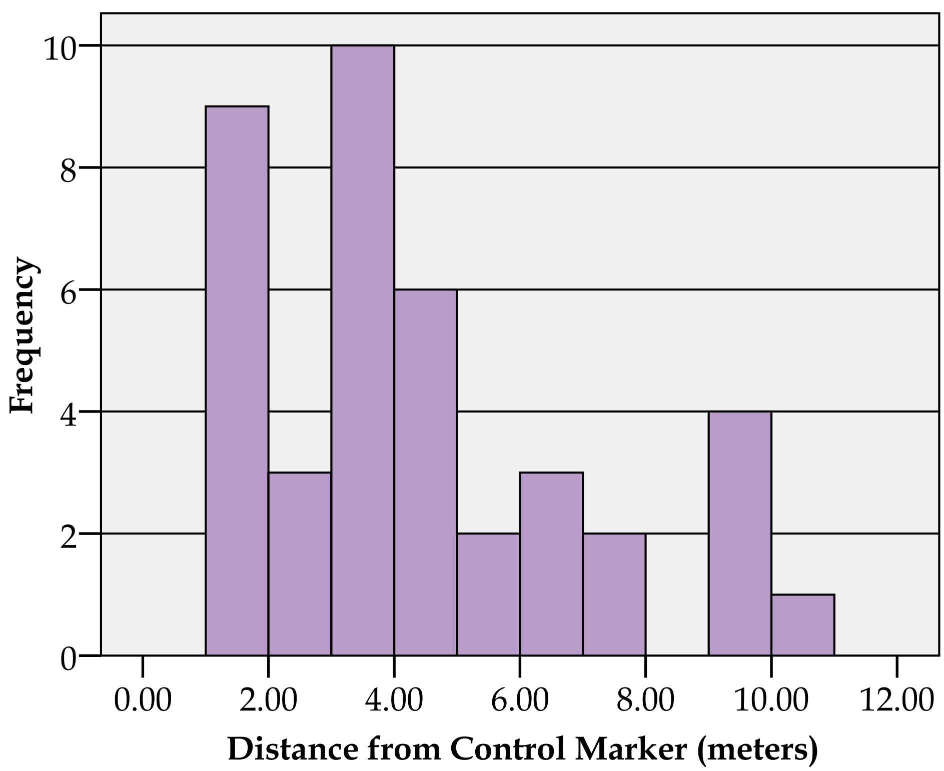
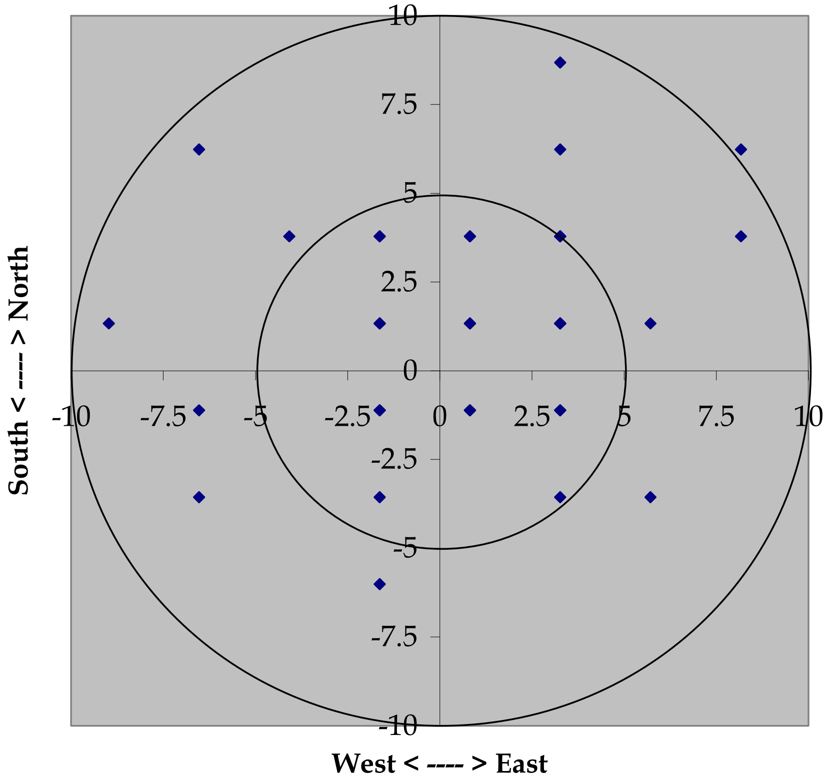


Figure 14 Garmin Forerunner 305 Real Distance Deviation (distance in meters)



4.6 HP iPAQ hw6945

4.6.1 Overview

The HP iPAQ hw6945 (Figure 15) is a powerful Personal Digital Assistant (PDA) that uses the Windows Mobile 5 operating platform. Its volume is slightly larger than a regular cell phone; however, its powerful capabilities by far exceed those of the other handheld devices reviewed here. Many advanced technologies are integrated into the device, making it a versatile choice, but also an expensive one.

Examining the feasibility of the iPAQ is quite different from examining the other devices because its capabilities can assist beyond the role as a pickup connection assistant. The HP iPAQ hw6945 supports wireless Internet access, allowing users to check email, send text messages, and read news if desired. The software platform provides plenty of personalization options. However, the same adaptability that can be seen as an advantage will lead to slower implementation because an agency may have to spend significant amounts of time training users on how to manipulate the device to its full capability. The HP iPAQ hw6945 is versatile in different fields. A small screen shows driving directions and a digital map image leading to the correct path. Overall, this device seems more suitable for use at the vehicle operator's terminal, since it can offer very specific navigation instructions.

Figure 15 HP iPAQ hw6945

Specifications:
Processor: Intel® PXA270
Processor 416 MHz
Weight: 179.5 g (6.33 oz)
Dimension: 71 ×18 × 118 mm
Display: 240 × 240 pixels
Operating temperature: -4 °C ~ 60 °C
Operating System: Microsoft® Windows Mobile® 5.

4.6.2 Criteria Judgment

- **Portability**: The HP iPAQ hw6945 is approximately 71 × 18 × 118 mm - slightly larger than other devices. A clip is included that can easily hold the device to a belt.
- **Reliability**: The HP iPAQ hw6945 is programmable, but problems may arise due to conflicts among software applications. The antenna sensitivity is similar to the Motorola i415. Unlike the previously tested cell phone, no significant positioning errors were found due to a low battery level.
- **User Friendliness**: Loaded with multi-media players, games, daily planning tools, and a number of other software applications, users are able to fully utilize their time for work, study, and leisure. However, for users who are less acquainted with PDAs, this device may be a challenge. Seniors with visual impairments may have difficulty reading the small fonts on the screen. Users might press the wrong button and have problems returning to the original application. The high cost may make agencies and passengers reluctant to use this device.
- **Durability**: Even though this device has a higher price and requires strict handling, it promises a longer usable life. It is advisable to insure the device for damage, maintenance, or replacement.
- **Compatibility**: Compatibility is the most promising feature of this product. The device is readily adaptable because program coding can be easily implemented into the operating environment.

Accuracy: Although the PDA is more expensive than most mobile GPS devices, it does not guarantee better accuracy. The majority of measurements fell within a radius of 20 meters with only two measurements were greater than 20 meters from the control marker (**Figure 16** & **Figure 17**). The accuracy of HP iPAQ hw6945 performance was comparable to the other devices tested in this project.

Figure 16 Frequency Histogram for the HP iPAQ hw6945

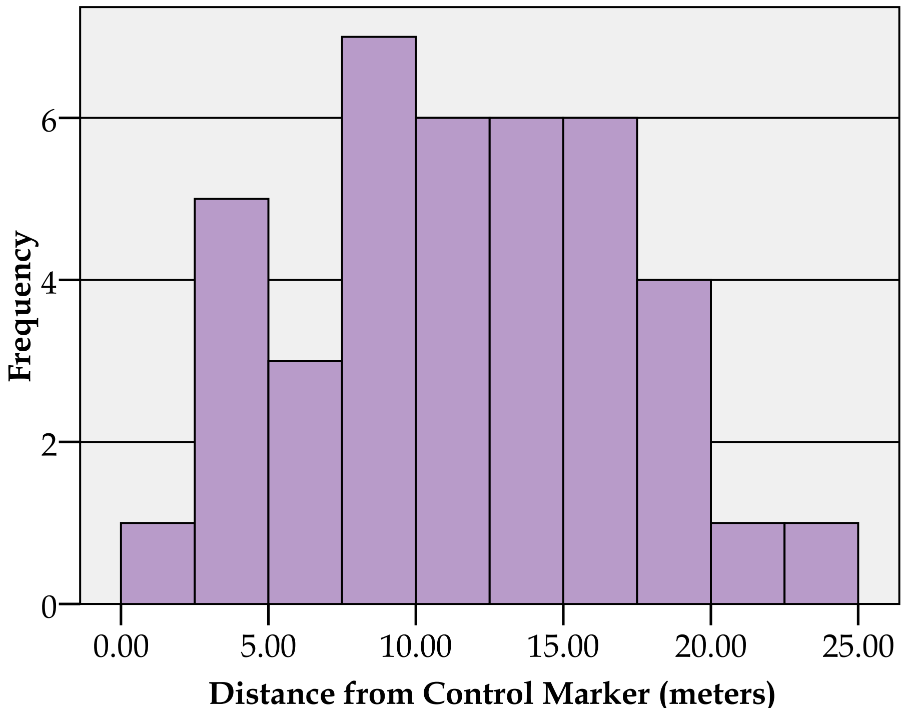
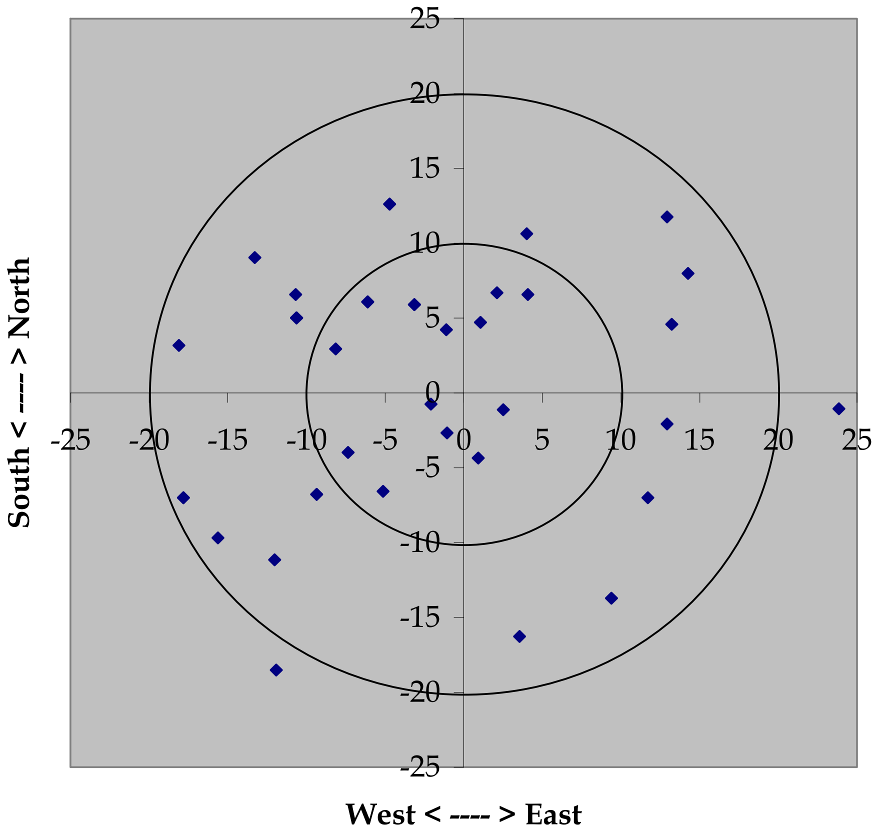


Figure 17 HP iPAQ hw6945 Real Distance Deviation (distance in meters)



4.7 Accuracy Tests

All accuracy tests were performed at a fixed survey marker (**Figure 18**). The local control point for this testing was the Florida Department of Transportation survey marker (identification number PN04A) that has a standard longitude/latitude value of W80.36888 and N25.76909 as defined by geodic authorities. All readings were collected uniformly to provide an adequate basis for comparison. The data were analyzed with the *t* test, in order to calculate confidence interval comparing accuracy limitations.

Figure 18 Image of the Survey Control Marker

Equation 1 was used to estimate the probability that a GPS reading will fall within a certain distance, based on a specified confidence level. Because the sample size is greater than 30 and the data are normally distributed, the sample mean can be approximated to the population mean. Similarly, the population variance can be substituted by the sample variance in the calculation.

Equation 1

$$x - \mu = z \cdot \delta$$

where x = the average from the experiment
μ = the population mean
δ = the standard deviation
z = the z score associated with the degree of confidence selected

Table 4 shows the Deviation distance ranges at different confidence levels; it also provides the probability that an observation will be less than or equal to the specified distances: 10 m, 15 m, and 20 m. The Gemtek device was not included in the accuracy test because the device did not give the user latitude/longitude information. It is designed to provide users with only address information and digital map images. The

Garmin 305 was excluded from testing for its lack of communication abilities. GPS information cannot be sent from the device, it can only be downloaded.

In **Table 4**, δ is the standard deviation of the observed readings and the numbers in the confidence interval columns list the corresponding deviated distance at the 85%, 90%, and 95% confidence intervals.

Table 4 Devices Accuracy Performance

		Motorola i415	HP iPAQ hw6945
$\overline{X}$		9.38 m	11.78 m
δ		4.45	5.47
Deviation distance ranges at different confidence levels	85%	15.25	19.00
	90%	16.97	21.11
	95%	20.30	25.20
Probability of GPS observations within a certain range	10 m	55.57%	37.25%
	15 m	89.69%	72.24%
	20 m	99.14%	93.68%

To further estimate the accuracy performance of the two selected devices, confidence intervals around the mean were calculated. Equation 2 was used to provide the confidence interval of the population mean at a specified level of confidence (**Table 5)**.

Equation 2

$$\overline{X} - z_{\alpha/2} \times \frac{S}{\sqrt{n}} \leq \mu \leq \overline{X} + z_{\alpha/2} \times \frac{S}{\sqrt{n}}$$

Table 5 Devices' Confidence Intervals Around the Mean

Confidence Level	Motorola i415		HP iPAQ hw6945	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
85%, $z_{\alpha/2}$ ~1.44	8.37	10.39	10.53	13.03
90%, $z_{\alpha/2}$ ~1.645	8.22	10.54	10.36	13.20
95%, $z_{\alpha/2}$ ~1.96	8.00	10.76	10.08	13.48

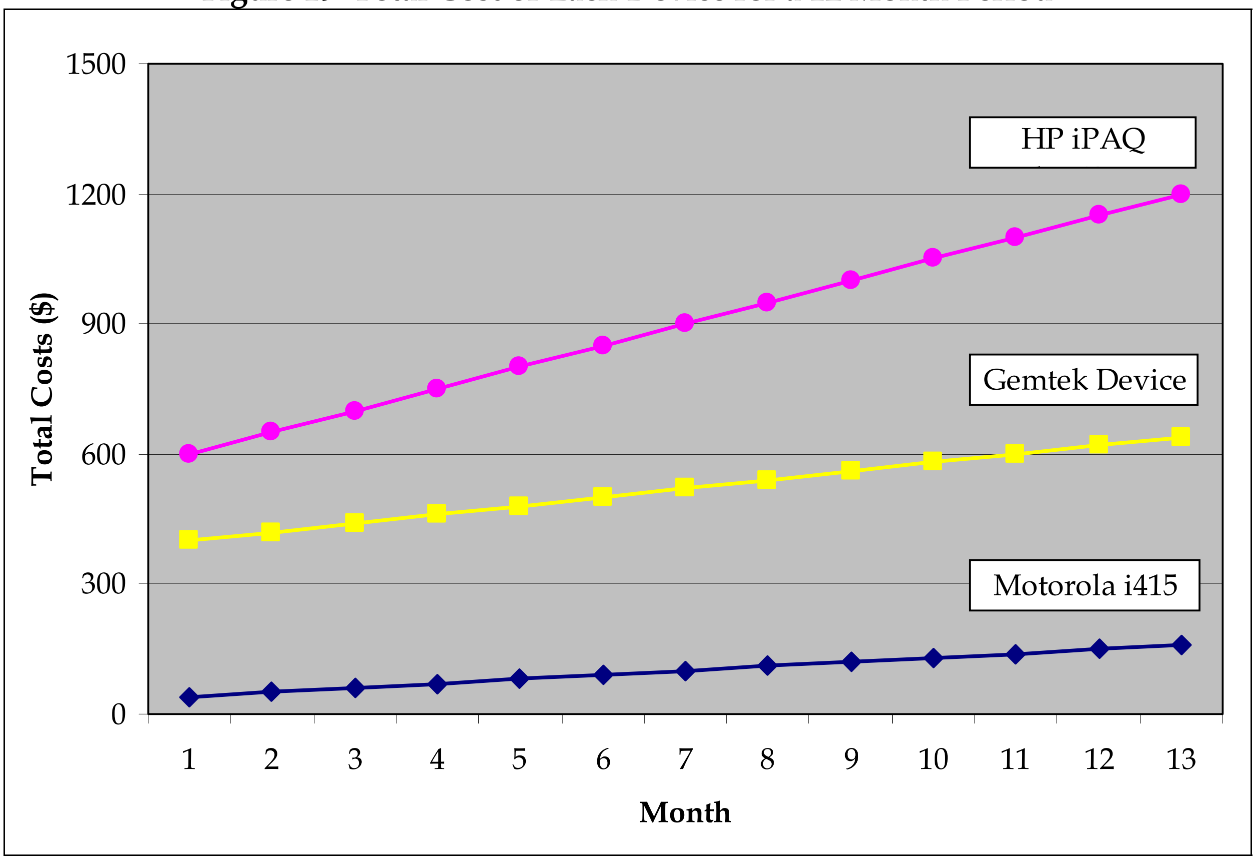
4.8 Benefit Cost Analysis

The total cost of each device in operation is critical in determining whether agencies will accept them. **Table 6** and **Figure 19** show the starting and operating expenses of the three devices. The cost of each device is an influential factor that may govern the willingness of transit agencies to adopt the new concept in real applications. The cost is not limited to the initial investment, but also to the recurring operating costs. Higher costs are usually associated with more functionality, and so a compromise between cost and capability is typical.

Table 6 Devices' Costs Comparisons

Device	Motorola i415	Gemtek Device	HP iPAQ hw6945
Device cost	$40	$400	$600
Monthly fee	$10	$20	$50
First year total costs	$160	$640	$1,200

Figure 19 Total Cost of Each Device for a 12 Month Period



5.0 GPS PROTOTYPE

5.1 Prototype Development

After all devices were tested for their specific functionalities, a GPS prototype was developed to explore the feasibility of integrating multiple devices into a complete working system. The best solutions combined use of the GPS enabled Motorola i415 cell phone and the HP iPAQ hw6945 PDA. This prototype connects the passenger, vehicle operator, and the agency dispatcher together via a central computer. To synchronize these devices, separate programs, namely iTrack and LocateYou, were created. The iTrack application was written in Java for the Motorola i415, and the LocateYou application was written in C# for the HP iPAQ hw6945. The web application prototype was developed in ASP .Net. These software applications were specifically created by LCTR staff to test the capabilities of these GPS devices.

No prior knowledge is required to operate the system. Once the devices are turned on, the iTrack and LocateYou programs are automatically initiated and position information is continuously acquired from satellites and sent to the server. The server translates the position coordinate numbers to point marks on the Microsoft Live Map and Google Map, so that the agency dispatcher can track both the passengers and vehicles. The HP iPAQ hw6945 uses Google Map as a background to indicate locations on its screen. Likewise, the central server computer screen employs Google Earth, including a three-dimensional view, and Microsoft Live Map to display locations. Consequently, both the agency dispatcher and the PDA carrier are able to view the carrier's location in digital map form.

5.2 Functionality

It is important to know how the iTrack and LocateYou programs work with each other. Basically, the mobile device must be GPS enabled and support Java to run this program. The iTrack program is a J2ME MIDlet (*22, 23*) application that supports any J2ME platform of mobile phones. The iTrack has three basic steps in its running thread:

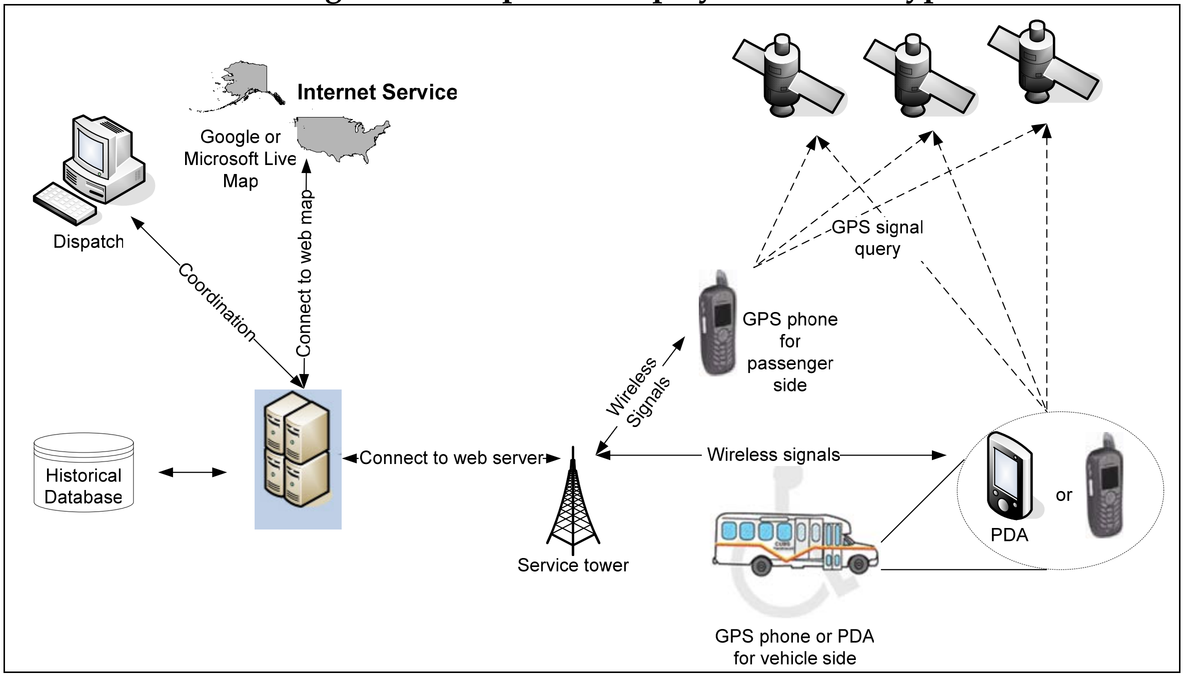
- First, it communicates with the internal GPS device through a serial port and acquires the GPS signal. If the GPS signal is successfully connected, the screen displays a message reading "My GPS:On." Once the signal connection succeeds, the location queries are made automatically every few minutes, depending on how the program is defined.

- Second, an HTTP request is formed and is sent to the server describing the current status of the device. In the case wherein a GPS signal is obtained, this HTTP request includes the current longitude and latitude coordinates. Additionally, moving speed and time information are also appended to the request and sent to the server. On the other hand, if a GPS signal connection fails to connect, an HTTP request describing the current failure status is sent to the server. The server stores all of these data to a database as an activity log for future reference.

- Lastly, the server produces three similar location data packages for the dispatcher, the passengers, and the vehicle operator upon receiving the HTTP request. For the dispatcher, the locations of all mobile devices are marked on Internet maps, specifically Google Earth and the Microsoft MapPoint web service (*23*). Similar data packages are also sent to the vehicle operator and the passenger.

A detailed data flow of the prototype is summarized in **Figure 20**. The central server functions as a hub to effectively maintain communications among the dispatcher, vehicle operator, and passenger. All information from these three parties is initially received, modified, and shared in the central server.

Figure 20 Graphical Display of the Prototype



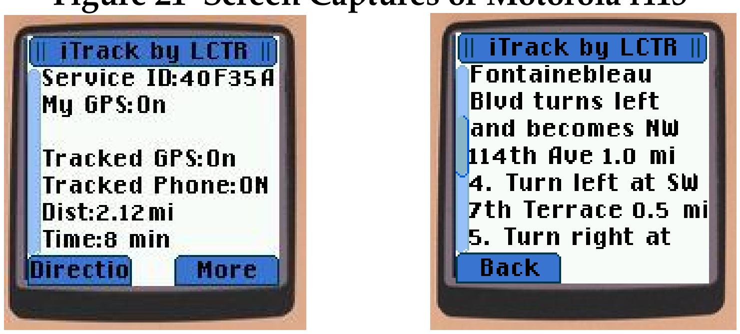
5.3 Prototype Application in Use

During the pickup process, the geographical locations of both the Motorola i415 and the HP iPAQ hw6945 are obtained from satellites and sent to the nearest wireless signal tower. The central server combines the Internet map service and location information from the GPS devices to generate an individual data package for the dispatcher, the vehicle operator, and the passenger. From the PDA screen, the vehicle operator is able to see driving directions as well as the passenger's location on a digital map. Similarly, the passenger receives the waiting time a nd vehicle distance. Therefore, pickups can become more punctual and predictable with the aid of this new approach. At the same time, a service log of all activities is recorded into the system database.

In the historical log, two types of tracking logs are available: real time tracking and historical tracking. Real time tracking means the indicated location markers shown in the iPAQ screen are automatically refreshed as updated information is received. This is very helpful in the middle of the service task when the vehicle operator cannot find a passenger on local streets. Historical tracking, as the name suggests, is the tracking log of the previous services. These datasets are readily accessible whenever evaluation or references for past services are required.

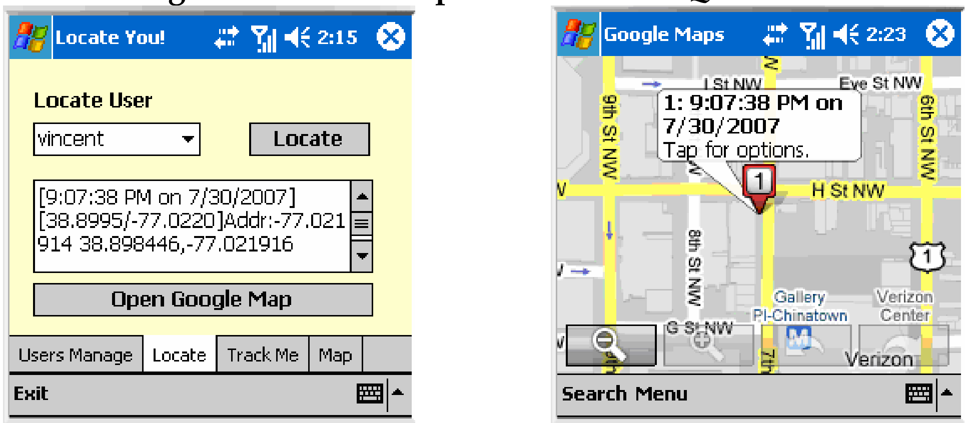
If the Motorola i415 is used by the driver as an option, driving instructions are provided. An example of the data packages received by the device is shown in **Figure 21**. The screen presents the estimated driving time and distance. By clicking the "Directio" button, detailed directions are displayed. Sometimes the other device is not connected to the GPS signal and the screen displays the text Tracked "GPS:Off." Upon seeing this message, users should move around to restore a better GPS signal reception. The dispatcher is also aware of the status of the passenger's mobile GPS and this information allows the dispatcher to call the user or driver with additional instructions if necessary. However, when lacking a map image, only verbal instructions can be communicated to the users.

Figure 21 Screen Captures of Motorola i415



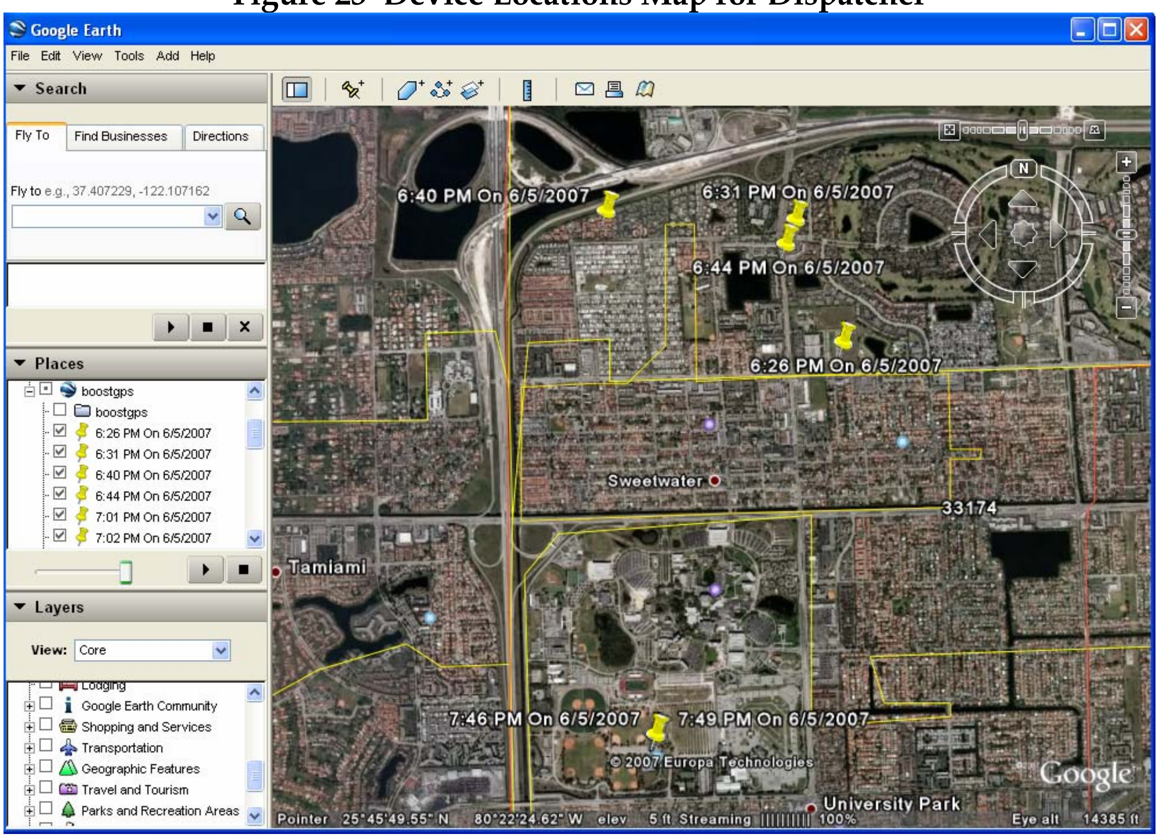
The HP iPAQ hw6945 device was also considered for use by the paratransit driver because complex images on a bigger screen can provide a more detailed passenger location map. The LocateYou program works differently from iTrack by integrating the Google Map application as the mapping template. Hence, directions are provided and users can switch to a digital map image that is returned by the server. Screen captures of the PDA are shown in **Figure 22**. The first screen depicts the passenger's location in longitude/latitude coordinates and the second screen shows where the passenger is waiting on a digital map.

Figure 22 Screen Captures of HP iPAQ hw6945



The dispatcher's computer shows the vehicles' and passengers' information, such as route path travel distance, direct distance, and estimated driving time. An example of the dispatcher's computer is shown in **Figure 23**. The digital map image updates whenever a device reports a new location. With the aid of the tracking platform, it is expected that the occurrence of missed trips will be avoided in some situations.

Figure 23 Device Locations Map for Dispatcher



For demonstration purposes, in this prototype the passenger carries the Motorola i415 mobile phone and the driver carries either another Motorola i415 mobile phone or the

HP iPAQ hw6945. Users need only turn on the mobile GPS devices to ensure that their work status is active. Because the locations of all mobile devices are known instantly, the vehicle operator can promptly arrive at the passenger's location by following the driving directions.

A more detailed demonstration example of this prototype application can be viewed at the following URL: http://gps.transpo.lctr.org.

6.0 CONCLUSION

Because missed trips commonly occur at all paratransit agencies, advanced GPS technology may have a role in relieving such problems in the future. The methodology and prototype developed in this project offer a completely new pickup concept compared with current operation methods. GPS location technology offers an accurate, fast, dependable and feasible alternative tool to help avoid missed pickups resulting from operational errors or pickup requests at ambiguous locations.

After examining the features of four GPS mobile devices, it became evident that some devices are not feasible for assisting with paratransit operations. Two of the devices were considered to be less suitable than their counterparts. The Gemtek device has a good design in many respects, but loses its candidacy due to poor compatibility; it is not programmable and cannot be coded to work with a peer device. The Garmin Forerunner 305, by taking advantage of WAAS, achieves the best accuracy performance among all of the devices. But, it has no wireless channel to communicate with a server and is unable to inform location information to other receptors.

On the other hand, the two programmable GPS devices, the Motorola i415 and the HP iPAQ hw6945, were ready to be used in the development of a computer controlled pickup system. The prototype integrates these two devices and synchronizes them by installing the iTrack and LocateYou programs. Simulations were performed to show that this prototype methodology could be applied in the real world. This prototype presents a potential solution to missed pickups by using GPS tracking technology.

Additionally, the use of programmable devices may assist with other service improvements. Many personal GPS mobile devices come with optional features that can potentially be leveraged to provide further improvements in the future. To attract more passengers, transit agencies might consider exploring additional functionalities such as medical care alarms and appointment reminders. In the future agencies will have the freedom to decide the most suitable technology based on desired functionalities.

There are indeed further challenges to the real world usage of this kind of paratransit pickup service methodology. The complexity of the system requires trained personnel and individuals who are familiar with computer information and technology. The high initial costs of design and purchase, lack of agreed upon data standards, privacy issues and legal concerns are all barriers to deployment. The initial phase of set up and operation may be so complex that even minor employee turnover may spark major setback. However, if these obstacles can be overcome, bringing personal mobile GPS technology into the paratransit industry is a feasible solution for improving the conventional pickup procedure. Implementation of GPS technologies can help improve the level of service and reduce agencies’ operating expenses in the long run.

7.0 FUTURE RESEARCH

7.1 Prototype Improvements

Assisting features were also studied to highlight additional potential advantages of the prototype. All of the following options are available depending on local transit agency preferences.

7.1.1 Alarm Notification

To enhance the prototype performance, alarm notifications can be implemented. A ringing notification will sound if the passenger is close to the driver or the driver is out of the expected path to the passengers. This feature can help the vehicle operator to reach the passenger and gain his or her attention immediately if necessary.

7.1.2 Administrator Website

The administrator webpage is an application built to help transit agencies improve management and operation. It can be integrated with GIS to show the closest vehicles upon request. In this application all mobility devices can be shown on a single screen map. With the assistance of computer programs, agency dispatchers can send the closest vacant vehicle immediately to finish the service task, thereby optimizing vehicle management.

7.1.3 Voice and SMS

The Skype and Microsoft text-to-speech service, as well as the Short Message Service (SMS), can potentially be incorporated to offer voice service. An automated voice service is capable of handling simple phone queries made by vehicle operators or passengers. It can also be used to direct users to the most appropriate personnel. SMS is another alternative communication technique in which users can read and review important instructions in case they are forgotten. For arrangements coming from the agency to the vehicle operator, agency staff can send text messages manually to give instructions, and the message is kept as a reference until the task is finished. This function can help minimize human error.

7.1.4 Historical Log

The communication information for each task, including short messages, location data, and pickup arrangements, can be saved into a historical database for future reference. The historical log collects all statistical information, which agencies can periodically use to evaluate and improve their performance.

7.1.5 Use as a Tracking Device for Persons with Cognitive Disabilities

Although the GPS device is primarily intended to aid with the paratransit pickup process, the system also holds promise for serving as a locating device for persons who suffer from cognitive disabilities. A small but significant percentage of existing paratransit riders suffer from dementia, Alzheimer's disease, or another cognitive problem. Some of these riders may be willing to utilize the tracking device for additional hours during the day. In this situation, the tracking device would then also serve as a valuable tool for locating the individual if he or she becomes lost or confused.

Currently there are several variations of the aforementioned device available in the market. The idea of tracking and monitoring of persons with cognitive disabilities has become more of a popular idea over the last few years. Such a system allows individual with mental disabilities to maintain a high degree of freedom, but provides a safety net in the event of an emergency. If an appropriate prototype GPS website can be developed, riders' friends and family members may be able to determine the exact location of a lost or confused individual on their own, there by circumventing the need to contact emergency personnel.

Certain issues still remain, such as how to continuously power some of the GPS devices. Additional battery technology may need to be developed before additional tracking is feasible. Furthermore, privacy issues and concerns would need to be addressed by all involved parties.

7.2 Cost & Benefit Ratio Evaluation

In business, whether a new alternative is cost effective or not determines its future applicability. In order to determine the value of applying personal GPS devices in paratransit, more information about transit agencies' operational expenses needs to be collected and examined. This will ensure that a cost efficient method of employing new technologies is selected.

One factor which needs to be studied further relates to the pricing of wireless services. Currently, several of the cell phone/GPS service providers charge a standard rate for a specific number of voice calls or minutes of talk time. However, this project depends on sending *data* wirelessly for an undetermined amount of time. Few wireless service providers have structured plans for sending data over their network. The cost of applying personal GPS devices in paratransit may well depend on negotiated rates for sending constant locational data for long periods of time.

7.3 Finding Newer Suitable Devices

All of the testing devices were ready-available technologies when this project commenced. As the civilian GPS market develops, the debut of more powerful GPS devices will provide extra options and support for new operating systems. Newer units and technology may enable the GPS signal to be picked up better in certain environments. Currently, signal problems are often experienced if the user is inside a large building, or in a dense urban environment with a substantial number of tall buildings. Problems have also been noted using GPS devices in heavily forested locations. In the future, newer devices, and the increased usage of assisted GPS will ensure that a clear signal is continuously received.

7.4 Attempting a Pilot Program

In the long run, the pickup process can possibly be combined with service vehicle assignments. If there is a change request from a passenger, the system will immediately determine the most economical way to rearrange the service schedule. Potential benefits include less time needed for reservations and services that are more adaptable to instantaneous changes.

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GLOSSARY

Cool Start - Cool start occurs when a GPS device initiates without any memory about Ephemeris data, such as a completely new start. For more information, refer to hot start.

Differential Global Positioning System (DPGS) - An enhancement to GPS that uses a network of fixed, ground-based reference stations to broadcast the difference between positions indicated by the satellite systems and known fixed positions.

Global Positioning System (GPS) - Developed by the U.S. Department of Defense, GPS is a fully functional Global Navigation Satellite System (GNSS). More than two dozen GPS satellites are in medium earth orbit, transmitting signals that allow receivers to determine their locations, speeds and moving directions.

Global System for Mobile communications (GSM) - is a digital mobile telephony system that is widely used in Europe and other parts of the world. GSM uses a variation of time division multiple access and is the most widely used of the three digital wireless telephony technologies.

Hot Start - A Warm or Hot Start state occurs when a GPS unit has some knowledge of the current Ephemeris data. Only a minor update is required for a warm start and possibly no update for a hot start. Little or no information is required since nearly a complete set of information is present in the unit.

Paratransit – Several types of paratransit services exist. ADA Paratransit, the service most commonly referred to, is mandated by the Americans with Disabilities Act, and requires that public transportation agencies provide complementary public transportation for individuals who are physically or mentally unable to ride fixed route transit. Other hybrid paratransit services, which go above and beyond ADA requirements, are often referred to as demand response, or dial-a-ride services. These services may vary considerably on the degree of flexibility they provide their customers.

Personal Digital Assistant (PDA) - Also known as pocket computers or palmtop computers, PDAs are handheld computers that have both color screens and audio capabilities, enabling them to be used as mobile phones (smart phones), web browsers, or portable media players. Many PDAs can access the Internet, intranets or extranets via Wi-Fi, or Wireless Wide-Area Networks.

SiRFStar III Receiver - SiRFstar III is the latest GPS microcontroller chip manufactured by SiRF Technology. It is distinguished from earlier SiRF chips and other brand chipsets largely due to its faster Time to First Fix (TTFF) and its ability to acquire and maintain a signal lock in urban or densely covered forest environments.

Wide Area Augmentation System (WAAS) - An extremely accurate navigation system developed for civil aviation by the Federal Aviation Administration (FAA), a division of the U. S. Department of Transportation. Originally developed to allow aircraft greater reliance on GPS, the system augments GPS to provide additional accuracy, integrity, and availability within the WAAS coverage area.

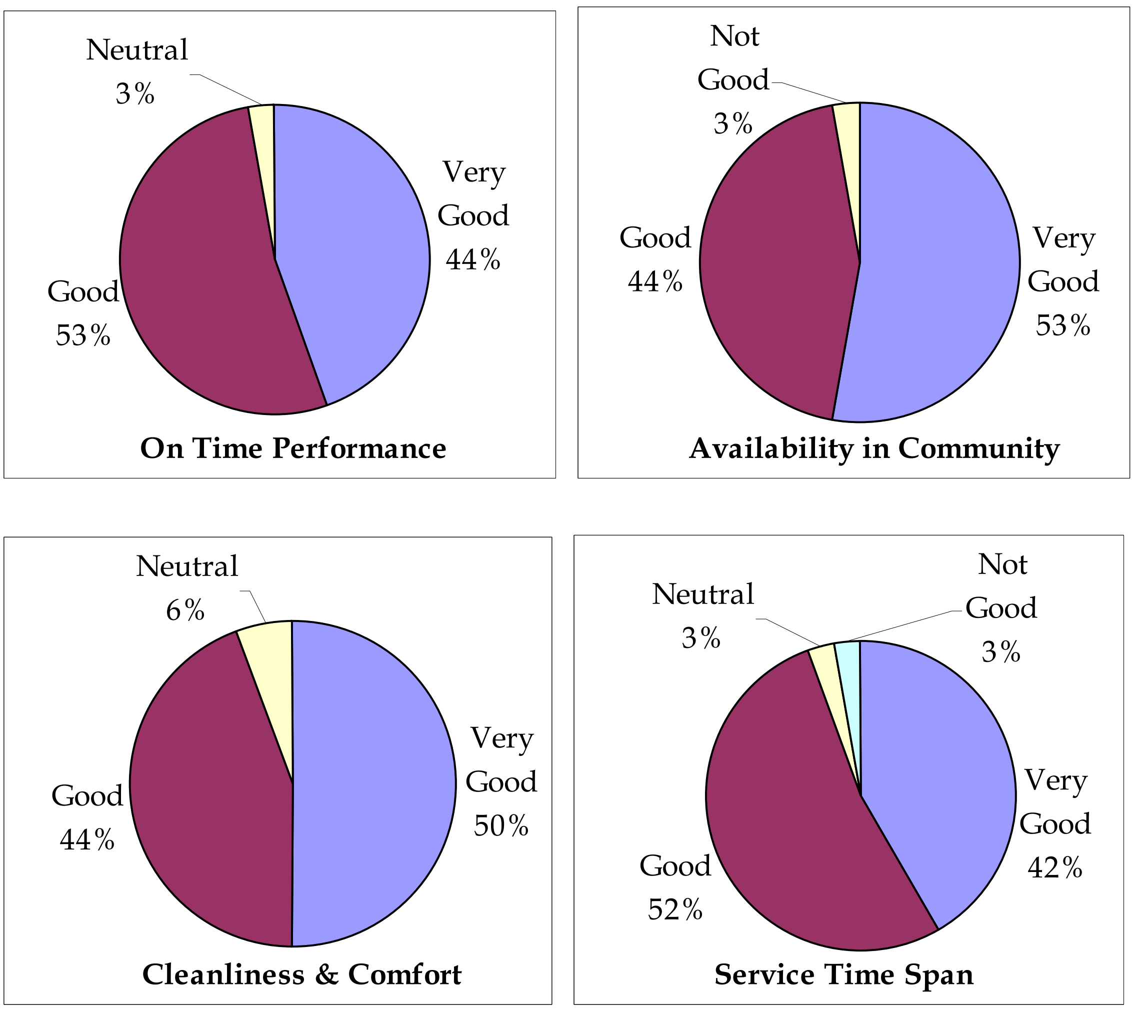
Wi-Fi - The trade name of a wireless technology. Originally licensed by the Wi-Fi Alliance, it describes the underlying technology of wireless local area networks (WLAN) based on the IEEE 802.11 specifications. It is currently used for mobile computing devices, Internet and VoIP phone access, gaming, and basic connectivity of consumer electronics.

APPENDIX A: Additional Survey Results

This Appendix contains extra information obtained from the paratransit survey. The survey was discussed in Section 2.0, however additional specifics are provided below.

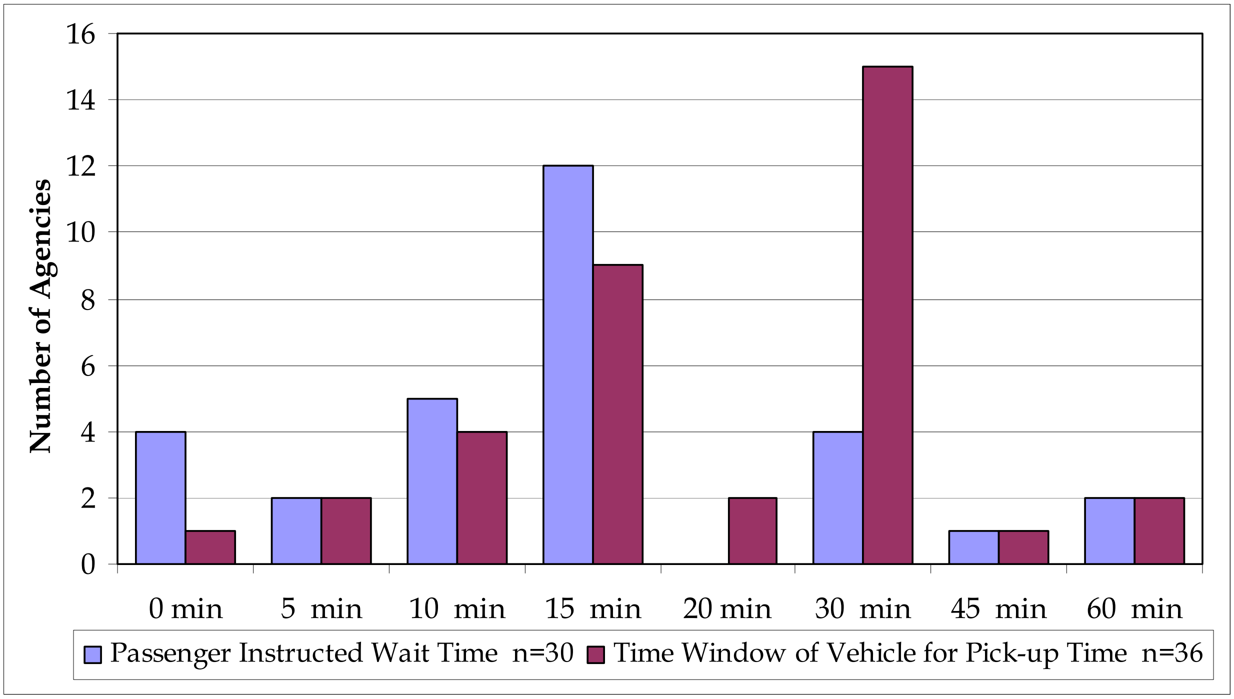
Inquiries about service performance found that most transit agencies rated their paratransit operating characteristics as being either good or very good. Rarely did agencies rate their services as not good, or even neutral (**Figure 24**).

Figure 24 Paratransit Agency Service Evaluations



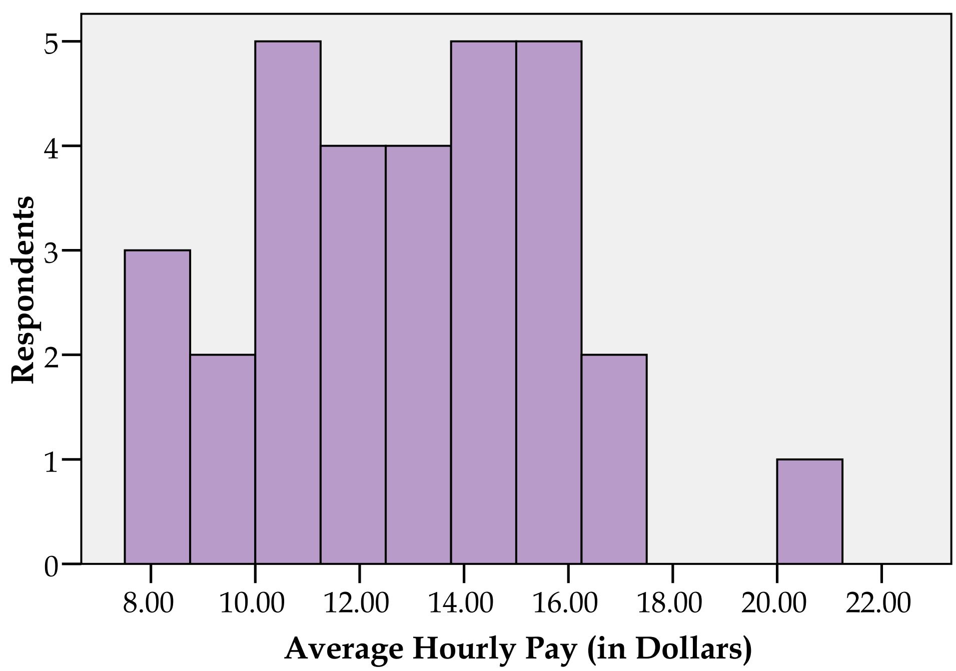
Passenger instructed waiting time and the time window for vehicle pick up vary considerably among agencies (**Figure 25**). Though not indicative of cost, these two measurements give an indication of paratransit service standards. A short instructed wait time, and a more specific time window are likely to be greatly appreciated by paratransit passengers.

Figure 25 Comparison of Instructed Wait Times and Time Windows for Pick-up



Average pay rates for a paratransit vehicle operator ranged between $8 and $18 dollars per hour, but one agency's average hourly pay for drivers was over $20 (**Figure 26**). For the 31 agencies reporting, the average hourly pay for a paratransit driver was $12.86.

Figure 26 Average Hourly Pay for Paratransit Operators (in Dollars)



Statistical information obtained from the remaining survey questions is located in **Table 7**. The number of agencies responding to the question, along with minimums, maximums, means, and standard deviations are provided. Since most of the results have fewer than 30 respondents, the data is not preferable for further statistical analysis.

Table 7 Statistical Summary of Survey Variables

Variable	N	Min.	Max.	Mean	Std. D.
Instructed Time to Wait before Veh. Arrival (mins.)	31	0	60	17.7	15.2
Time Window Vehicles are Scheduled to Arrive (mins.)	36	0	60	23.6	13.4
Mins. Driver is Allowed to Spend Finding Passenger	16	3	15	6.3	3.7
Total Number of No-Shows During Last Year	34	4	108,371	8,023	19,656
Total Number of Passenger Trips During Last Year	35	746	1,584,382	234,992	397,705
% of No-Show Trips to Total Passenger Trips	34	0.02%	9.23%	2.53%	2.26%
Estimated % of No-Shows due to Connection Failures	25	0.00%	80.00%	11.02%	23.13%
Total No-Show Losses per Year	23	$60	$716,000	$88,892	$184,989
Average No-Show Losses per Month	16	$19	$48,922	$6,435	$12,166
Average No-Show Losses per Trip	20	$10.00	$30.15	$19.03	$5.56
Average Hourly Pay for Paratransit Vehicle Driver	31	$7.78	$20.21	$12.86	$2.96
Suspended Passengers	33	0	1,293	59	228
Total Passengers	34	0	692,000	85,552	166,477
% of Suspensions to Total Passengers	30	0.00%	4.44%	0.26%	0.84%

Passenger trip purposes are an important factor known to influence no-show trips. Shopping and medical trips tend to have higher no-show rates because pickup location and appointed pickup time can vary considerably. Visiting or social trips and work trips have slightly higher trip completion rates since residential addresses are more easily found and work trips are often routine appointments at a particular location and time. Results are summarized in
Table 8.

Table 8 Classification of Trip Purposes

Agency	Shopping	Medical	Visiting & Recreation	Work	Other
1	20%	55%	10%	10%	5%
2	38%	50%	5%	7%	-
3	20%	25%	20%	35%	-
4	16%	65%	1%	18%	-
5	10%	20%	15%	27%	28%
6	10%	40%	10%	30%	10%
7	13%	65%	2%	20%	-
8	1%	7%	15%	77%	-
9	15%	50%	5%	30%	-
10	23%	53%	1%	7%	16%
11	10%	50%	5%	30%	5%
12	15%	50%	30%	5%	-
13	35%	40%	2%	3%	20%
14	15%	45%	-	35%	5%
15	4%	28%	2%	18%	48%
16	10%	85%	1%	2%	2%
17	12%	40%	9%	2%	37%
18	22%	52%	14%	12%	-
19	10%	70%	10%	10%	-
20	5%	50%	5%	20%	20%
21	16%	19%	15%	50%	-
22	10%	30%	5%	40%	15%
23	3%	95%	1%	1%	-
24	17%	39%	-	17%	27%
25	18%	30%	5%	45%	2%
26	40%	30%	10%	20%	-
27	5%	30%	10%	55%	-
28	6%	20%	30%	42%	2%
29	5%	23%	33%	27%	11%
30	25%	50%	10%	10%	5%
Summarized Statistical Values					
Min	1%	7%	0%	1%	0%
Max	40%	95%	33%	77%	48%
Avg	14.99%	43.55%	9.37%	23.50%	8.60%

APPENDIX B: Survey Instrument

1. Please fill out the following information
   Full Name of Transit Agency:
   Address:
   Contact Person:
   Phone Number:
   Email:

2. What technology does your agency currently use to communicate between the dispatch center and the vehicle operator? (e.g., telecommunication, walkie-talkie or wireless internet, etc.)?

3. How interested is your agency in applying new technology, such as GPS, to minimize the numbers of connection failures when picking up passengers?

4. How would you rate your agency's service performance? Please use a 1 to 5 scale, with 1 being the poorest and 5 representing the best.

	(5)	(4)	(3)	(2)	(1)
On-Time Performance					
Availability in the Community					
Cleanliness and Comfort					
Service Time Span					

5. How many minutes is a passenger instructed to wait prior to the arrival of the paratransit vehicle?

6. How many minutes is the time window your vehicles are scheduled to arrive at the appointed pickup time?

7. If a driver has difficulty finding the address or pickup location, how much time in minutes is she/he instructed to spend trying to find the passenger before leaving without picking up the passenger?

8. How many no-shows occurred during the most recent fiscal year? And what were the total passenger trips for that year?
   Number of no-shows:
   Total number of passenger trips:

9. Among all the no-shows, please give an estimation of the percentage that are due to connection failures?

10. What is the approximate financial loss per month due to no-shows? And what is the average cost of each no-show? (Answer as many as possible)
    $ Per Year
    $ Per Month
    $ Per Trip

11. Approximately how many passengers had their paratransit privileges suspended in the most recent fiscal year? And how many passengers did you carry last year?
    Suspended number:
    Total passengers:

12. What is the average hourly salary of a paratransit vehicle operator in your agency?

13. Other than the funds from your own agency, are there other agencies that share the paratransit cost? Please provide a rough estimation for each and answer all that possible.
    Hospitals, % they share:
    Rehabilitation Clinic(s), % they share:
    Insurance agencies, % they share:
    Other, please specify: %

14. In general, what are the main purposes for paratransit trips? Please provide an estimated percentage for each type of trip.
    Shopping %
    Medical trip %
    Visiting %
    Working %
    Other, please specify: %

15. The box below is for any additional comments.

APPENDIX C: GPS Readings

The measurements of the GPS readings of each device are listed in the tables below. The longitude and latitude of the control point is (W80.36888889, N25.76909091).

Garmin Forerunner 305

Trial	Longitude	Latitude	Deviated Distance in N-S Direction	Deviated Distance in E W Direction	Spatial Deviate Distance to Control Point
1	80.36888333	25.76908333	0.817109	-1.11382	1.38140247
2	80.36886667	25.76911667	3.265496	3.785888	4.99964102
3	80.36886667	25.76915	3.265496	8.684132	9.27780159
4	80.3689	25.76911667	-1.63275	3.785888	4.1229618
5	80.3689	25.76911667	-1.63275	3.785888	4.1229618
6	80.36888333	25.7691	0.817109	1.336032	1.56609289
7	80.36895	25.7691	-8.98085	1.336032	9.07968104
8	80.36886667	25.76906667	3.265496	-3.56221	4.83247509
9	80.36886667	25.76911667	3.265496	3.785888	4.99964102
10	80.36888333	25.76908333	0.817109	-1.11382	1.38140247
11	80.36886667	25.76913333	3.265496	6.234275	7.03773021
12	80.3689	25.7691	-1.63275	1.336032	2.10970276
13	80.36893333	25.76906667	-6.53099	-3.56221	7.4393011
14	80.36891667	25.76911667	-4.0826	3.785888	5.56781887
15	80.3689	25.76906667	-1.63275	-3.56221	3.91857362
16	80.36893333	25.76913333	-6.53099	6.234275	9.02884444
17	80.36885	25.76906667	5.715352	-3.56221	6.73458271
18	80.36886667	25.76908333	3.265496	-1.11382	3.45022722
19	80.3689	25.76908333	-1.63275	-1.11382	1.97647959
20	80.36883333	25.76913333	8.165209	6.234275	10.2731114
21	80.36888333	25.76911667	0.817109	3.785888	3.87306277
22	80.36885	25.7691	5.715352	1.336032	5.8694319
23	80.3689	25.76908333	-1.63275	-1.11382	1.97647959
24	80.36888333	25.7691	0.817109	1.336032	1.56609289
25	80.36886667	25.76908333	3.265496	-1.11382	3.45022722
26	80.36888333	25.76908333	0.817109	-1.11382	1.38140247
27	80.36893333	25.76908333	-6.53099	-1.11382	6.62528892
28	80.36883333	25.76911667	8.165209	3.785888	9.000199
29	80.3689	25.7691	-1.63275	1.336032	2.10970276
30	80.36886667	25.7691	3.265496	1.336032	3.52823498
31	80.36886667	25.76908333	3.265496	-1.11382	3.45022722
32	80.3689	25.76905	-1.63275	-6.01207	6.22983407
33	80.36886667	25.76911667	3.265496	3.785888	4.99964102
34	80.36886667	25.7691	3.265496	1.336032	3.52823498
35	80.3689	25.7691	-1.63275	1.336032	2.10970276
36	80.36888333	25.7691	0.817109	1.336032	1.56609289
37	80.36886667	25.7691	3.265496	1.336032	3.52823498
38	80.36886667	25.7691	3.265496	1.336032	3.52823498
39	80.36888333	25.76911667	0.817109	3.785888	3.87306277
40	80.3689	25.76908333	-1.63275	-1.11382	1.97647959

Motorola i415 GPS Enabled Mobile Phone

Trial	Longitude	Latitude	Deviated Distance in N-S Direction	Deviated Distance in E W Direction	Spatial Deviate Distance to Control Point
1	80.36882667	25.76920533	9.144465521	16.81602887	19.14157978
2	80.36891733	25.76919467	-4.180089149	15.2484342	15.81100537
3	80.36885333	25.769184	5.22547885	13.68083954	14.64482843
4	80.36887	25.769184	2.776112179	13.68083954	13.95966222
5	80.36881067	25.76917333	11.49585752	12.11324487	16.69986352
6	80.368896	25.769152	-1.044899822	8.978055542	9.038655705
7	80.368944	25.76914133	-8.099075821	7.410460871	10.97770283
8	80.36887467	25.76913067	2.090289522	5.842866199	6.205513332
9	80.36898133	25.76913067	-13.58565715	5.842866199	14.78881894
10	80.36885333	25.769138	5.22547885	6.920587542	8.671802647
11	80.36887467	25.76912	2.090289522	4.275271542	4.758913431
12	80.368896	25.76902133	-1.044899822	-10.22498402	10.27823496
13	80.368944	25.76912	-8.099075821	4.275271542	9.158219036
14	80.36886122	25.76910667	4.066438539	2.315778199	4.67961014
15	80.368896	25.76910667	-1.044899822	2.315778199	2.540599202
16	80.36882667	25.76909867	9.144465521	1.140082199	9.215261097
17	80.3689152	25.76909867	-3.866570221	1.140082199	4.031147814
18	80.36885333	25.769088	5.22547885	-0.427512458	5.242937737
19	80.368896	25.769078	-1.044899822	-1.897132458	2.165854843
20	80.36896	25.769	-10.45046782	-13.36016846	16.96190965
21	80.36882667	25.76907733	9.144465521	-1.995107129	9.359578096
22	80.36887467	25.76907733	2.090289522	-1.995107129	2.889595602
23	80.36896	25.76907733	-10.45046782	-1.995107129	10.63920721
24	80.36878933	25.76906667	14.63104685	-3.562701801	15.05856487
25	80.36896333	25.76906667	-10.93985128	-3.562701801	11.50535485
26	80.36894933	25.76906667	-8.882868255	-3.562701801	9.570694466
27	80.36887267	25.76905333	2.384164524	-5.522195129	6.014888156
28	80.368944	25.76905333	-8.099075821	-5.522195129	9.802533764
29	80.368896	25.76904533	-1.044899822	-6.69789113	6.778905606
30	80.36888267	25.76904533	0.914544526	-6.69789113	6.760039739
31	80.36887467	25.76903467	2.090289522	-8.265485801	8.525700312
32	80.36895823	25.76902133	-10.19034508	-10.22497913	14.43583496
33	80.36889617	25.76909867	-1.070030323	1.140072412	1.563563237
34	80.36891733	25.76912	-4.180040167	4.275271542	5.979187449
35	80.36882667	25.76913067	9.144465521	5.842768234	10.85169067
36	80.36882667	25.76906666	9.144466492	-3.563681538	9.814331028
37	80.36896	25.76909867	-10.45046782	1.140082111	10.51247187
38	80.3688311	25.76909867	8.49293398	1.140072412	8.569112713
39	80.36894418	25.76916	-8.126219702	10.15375154	13.00515732
40	80.36891733	25.76907733	-4.180040167	-1.995112023	4.631760765

HP iPAQ hw6945

Trial	Longitude	Latitude	Deviated Distance in N-S Direction	Deviated Distance in E W Direction	Spatial Deviate Distance to Control Point
1	25.76902385	80.36898708	-15.619524	-9.684036	18.37797821
2	25.76907135	80.36888848	-1.066163995	-2.673036	2.877816381
3	25.76911808	80.36888875	-1.105524	4.224803995	4.367053024
4	25.76916907	80.3687937	12.923856	11.749944	17.46674664
5	25.76907538	80.36879373	12.918936	-2.077716005	13.08494598
6	25.76908438	80.3688954	-2.087064001	-0.749316005	2.217500985
7	25.76905998	80.368875	0.923975999	-4.350756005	4.44778703
8	25.76904353	80.36894462	-9.351936	-6.779268	11.55063555
9	25.769134	80.36885365	4.075235998	6.574104	7.734752216
10	25.76904198	80.36880198	11.701728	-7.008048	13.63976448
11	25.76915068	80.36897128	-13.287444	9.036563995	16.0690901
12	25.76912142	80.36887408	1.059276005	4.716804005	4.834284401
13	25.76911098	80.36900398	-18.113964	3.176843995	18.39043309
14	25.76912938	80.36890252	-3.137976002	5.892192	6.675688725
15	25.76917487	80.36891315	-4.706964	12.606516	13.45658782
16	25.76913067	80.36892262	-6.104736002	6.082596	8.617759323
17	25.76912343	80.36895325	-10.625724	5.013972	11.74929469
18	25.76908183	80.36886422	2.515595995	-1.125696005	2.755977995
19	25.76906247	80.36893112	-7.358844006	-3.984215995	8.36818751
20	25.76912343	80.36895325	-10.625724	5.013972	11.74929469
21	25.76904492	80.368916	-5.127624001	-6.574595995	8.337735927
22	25.76910935	80.36893638	-8.136203997	2.935764	8.64965466
23	25.76914353	80.36878462	14.26455599	7.981223995	16.34556497
24	25.76904198	80.36900198	-17.818272	-7.008048	19.1468941
25	25.76904353	80.36894462	-9.351444005	-6.778776005	11.54994845
26	25.769134	80.36895365	-10.684764	6.574104	12.54523914
27	25.7691615	80.36885413	4.003896004	10.633104	11.36195775
28	25.76913067	80.36892262	-6.104244005	6.082104005	8.617063537
29	25.76912938	80.36890252	-3.137484005	5.892683995	6.675891742
30	25.76912343	80.36895325	-10.625724	5.014463995	11.74950466
31	25.76908225	80.36871963	23.856096	-1.064196	23.87982055
32	25.76917487	80.36891315	-4.706964	12.606516	13.45658782
33	25.76913067	80.36892262	-6.104736002	6.082596	8.617759323
34	25.768964	80.36896198	-11.914764	-18.517896	22.01985634
35	25.76901388	80.36896268	-12.01808399	-11.155116	16.39728502
36	25.76904198	80.36900198	-17.818764	-7.007556005	19.14717189
37	25.76897925	80.36885727	3.541415995	-16.266996	16.64802649
38	25.76899657	80.36881767	9.386375994	-13.71105599	16.61617016
39	25.7691348	80.36886692	2.117075994	6.692184	7.019069557
40	25.76912052	80.36879162	13.23135599	4.583964005	14.00291068

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