PB2001-102755

UTCA Project 99115

# Improving Crash Location, Display, and Analysis by Combining CARE and GPS Technologies


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A publication of the

**University Transportation Center for Alabama**

Report 99115

August 31, 2000

# University Transportation Center for Alabama

**About UTCA** The University Transportation Center for Alabama (UTCA) is designated as a "university transportation center" by the US Department of Transportation. UTCA serves a unique role as a joint effort of the three campuses of the University of Alabama System. It is headquartered at the University of Alabama (UA) with branch offices at the University of Alabama at Birmingham (UAB) and the University of Alabama in Huntsville (UAH). Interdisciplinary faculty members from the three campuses (individually or operating in teams) perform research, education, and technology transfer projects using funds provided by UTCA and external sponsors. The projects are guided by the UTCA Annual Research Plan. The plan is prepared by the Advisory Board to address transportation issues of great importance to Alabama and the region.

**Mission Statement and Strategic Plan** The mission of UTCA is "to advance the technology and expertise in the multiple disciplines that comprises transportation through the mechanisms of education, research, and technology transfer while serving as a university-based center of excellence."

The UTCA strategic plan contains six goals that support this mission, as listed below:

- Education – conduct a multidisciplinary program of coursework and experiential learning that reinforces the theme of transportation;
- Human Resources – increase the number of students, faculty and staff who are attracted to and substantively involved in the undergraduate, graduate, and professional programs of UTCA;
- Diversity – develop students, faculty and staff who reflect the growing diversity of the US workforce and are substantively involved in the undergraduate, graduate, and professional programs of UTCA;
- Research Selection – utilize an objective process for selecting and reviewing research that balances the multiple objectives of the program;
- Research Performance – conduct an ongoing program of basic and applied research, the products of which are judged by peers or other experts in the field to advance the body of knowledge in transportation; and
- Technology Transfer – ensure the availability of research results to potential users in a form that can be directly implemented, utilized or otherwise applied.

**Theme** The UTCA theme is *"MANAGEMENT AND SAFETY OF TRANSPORTATION SYSTEMS."* The majority of UTCA's total effort each year is in direct support of the theme; however, some projects are conducted in other topic areas, especially when identified as high priority by the Advisory Board. UTCA concentrates upon the highway and mass transit modes, but also conducts projects featuring rail, waterway, air, and other transportation modes as well as intermodal issues.

## Disclaimer

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## *Executive Summary*

In the state of Alabama, crash locations are currently estimated by law enforcement officers at the scene of a crash. The locations are typically placed at identifiable points along the roadway such as mileposts and intersections. Because of this fact, a clustering effect is produced along highways which places most crashes at mileposts. The resulting resolution can locate vehicle crashes caused by the same roadway variable as far apart as 1.6 kilometers, making accurate identification of roadway safety hazards difficult.

This research project was initiated through the University Transportation Center for Alabama (UTCA) to investigate improvements to vehicle crash analysis through accurate and inexpensive collection and display of crash locations using global positioning system (GPS) and geographic information system (GIS) technologies. GPS units from $130 to $3300 were evaluated based on cost, accuracy, usability, additional equipment needed, and collection time. From this analysis two GPS units were selected: 1) a hand-held unit, the Garmin GPS 12 Map, and 2) a computer-based unit, the Rand McNally StreetFinder Deluxe. With the recent removal of selective availability, this research has shown that these inexpensive GPS units are capable of locating a crash within an 8-meter radius. An analysis of actual crash location data showed that GPS data provided more information about a crash than conventional estimation methods, specifically at interchanges and along roadway segments.

In addition, both off-the-shelf GIS and accurate basemaps were employed to display the new GPS crash data. Automated procedures were developed to translate the GPS-captured location data into a usable format for the Critical Analysis Reporting Environment (CARE) or GIS. Only two additional data columns are needed by CARE to seamlessly incorporate the new and accurate GPS location data.

In summary, this research project proved that inexpensive GPS units are capable of collecting accurate location data associated with crashes. We recommend that the state of Alabama pursue the implementation and use of these units through an expanded pilot study.

# Section 1

## Introduction and Project Background

Detailed information about vehicle crashes in the State of Alabama is stored and managed in a database entitled Critical Analysis Reporting Environment (CARE) (Brown 2000). Part of the data stored in CARE is the estimated crash location. Currently, the highway patrol officer managing a crash determines the vehicle crash location. In this process, the officer records identifiable landmarks that help explain where the crash took place. The resolution of crash location data for interstate highways and rural roads is on the order of 0.8 kilometers. At this resolution, vehicle crashes caused by the same roadway variable may be reported as far apart as 1.6 kilometers (Graettinger, et al., 2000a).

Figure 1-1 was provided by CARE, and shows a representative 16-kilometer segment of Interstate 20-59 in Alabama from milepost 105 to 115. The interstate is depicted as a horizontal straight line and vehicular crashes are shown as points located along the interstate. If multiple crashes are reported at the same location, the points are vertically stacked indicating the number of crashes. As highlighted by the arrows in Figure 1-1, an apparent clustering of crashes occurs exactly at milepost markers. This clustering is caused by the estimation of crash locations by officers referencing identifiable points.

In addition to the clustering inaccuracy, human error during data entry can introduce inaccuracy into the location data. Every crash report in Alabama is sent to the Alabama Department of Public Safety where the information, which includes the location description, is entered into a database. The location description from the report is read by data entry personnel who translate the description into a 'node' for an intersection and a 'link' for a road segment, or route-mile post. This manual process adds one more level of potential inaccuracy to the stored crash location.

The research presented herein describes a method to collect crash location data that reduces time, increases accuracy, and removes the potential for human error. This process uses GPS units to accurately identify the x and y location of a crash within a short period of time (less than 3 minutes). These inexpensive GPS units are capable of locating vehicle crashes within an 8 meter radius. At this resolution, spatial information associated with crashes can be included in the analysis. This new process automatically downloads location data from the GPS units, translates it into a common format, and stores the data in two new columns in the CARE database, eliminating the need for manual translation of location data. By employing a GIS capable of providing accurate crash locations and attribute data to the CARE system, a more complete crash analysis can be performed.

# Section 2

# GPS

## What is GPS?

The Global Positioning system or GPS is a constellation of 24 satellites in orbit high above the surface of the earth (Hurn 1989). These satellites, placed in orbit by the U.S. Department of Defense, compose the worlds largest location system. The system can be used 24 hours a day under any weather condition. The system is accurate enough to locate a position within the width of an average street, and, if differentially corrected, the accuracy can be found within one centimeter (Hurn 1993).

## How does GPS work?

GPS uses the satellites as reference points in determining location. If the location of a group of satellites and the distance from the satellites to the receiver are known, the location of the receiver can be calculated. The calculations are based on the time it takes a radio signal to travel from the satellites to the GPS receiver. Because the system is entirely based on time, the GPS satellites have extremely accurate clocks (Hurn 1989). A GPS satellite clock will lose or gain 1 second in 160,000 years. Even at this accuracy the clocks can be off a nano-second in a matter of hours, which relates to a distance error of approximately 30 centimeters (Graettinger and Karadi, 1995).

For position determination, a triangulation of three satellites must be obtained. Each satellite of known distance and position limits the position of the GPS receiver to one sphere in space. When two spheres overlap, there is only a small circle in space capable of being the receiver's location. When a third sphere is added, the location position is narrowed to only two points. Geometry states that four satellites are needed for locating one point, but one of the two points located by the three satellites is always extraneous. The receivers are sophisticated enough to determine which of the two points is the correct location. Therefore, as long as three satellites can be obtained, the position of a GPS receiver can be calculated (Hurn 1989).

## What causes errors in GPS accuracy?

The biggest source of location errors obtained by a GPS receiver is the Earth's ionosphere, a layer of charged particles many miles above the earth. The radio signals sent by the GPS satellites slow down as they pass through this dense layer of charged particles several miles thick. The slowing down of the signal causes a time delay which creates a distance error from the GPS receiver to the satellite. An average distance error caused by the ionosphere is on the order of 5 meters (Hurn 1993).

Other sources of accuracy errors can be caused by inaccuracies in the GPS satellite clocks and multipath errors. Even though the GPS satellites use the most sophisticated atomic clocks and are updated regularly, small time errors still occur. Even the smallest inaccuracies in the clocks can cause fairly large errors in GPS accuracy. Also, multipath errors can decrease the location accuracy of the GPS receiver. Multipath errors occur when the GPS signal takes an indirect path from the satellite to the receiver. Multipath errors may occur if the signal is reflected off tall buildings or natural structures. Table 2-1 shows a table of common GPS error sources and their magnitudes (Hurn 1993).

# Section 3

## Equipment Tested

Five GPS units were tested in this study and can be divided into two categories: 1) computer-based units and 2) hand-held units. Computer-based units are defined as GPS units having an external antenna attached to a notebook computer. In this study, a 150 MHz Pentium notebook computer was used. The computer and the installed GPS software calculate locations from satellite signals collected by the external antenna. Hand-held GPS units are self-contained; therefore, they can be carried to a specific location to collect data. Some hand-held units can interface with a computer after data collection, and the location data can be downloaded automatically.

Table 3-1 presents data for the five GPS units tested for this study in order of increasing price (Graettinger, et al., 2000b). The first column in Table 3-1 lists the manufacturer and model name of the five units. The prices of the GPS units tested ranged from \$130 to \$3300 as illustrated in Table 3-1. It was assumed for GPS units that require a notebook computer that the computer already exists; therefore, only the price of the GPS antenna and software are included in the reported price. The third column of Table 3-1 contains average lock time, which corresponds to the amount of time the GPS unit takes to acquire the satellites from the time the unit is activated. Miller and Karr (1997) reported that using GPS units to collect crash locations, on average, increased the amount of time an officer spent at the crash site by an average of 10 minutes. With improved GPS units and software, and selective availability removed from the GPS signal, the average time to collect location data dropped to less than 3 minutes. The map display column in Table 3-1 indicates whether or not a map can be accessed while collecting GPS locations. Both of the computer-based GPS units have superior display capabilities when compared to the hand-held units. The Garmin GPS 12 Map comes with base maps of the entire United States. Additional software is available to install more detailed maps. The automatic download column indicates the method (if any) for downloading location information from the GPS unit to a computer. The sixth column in Table 3-1 presents the power source required for each unit. Column seven describes the ease of use and is followed by a comments column that provides additional information about the GPS units tested.

# Section 4

# Procedures

The procedures for collecting crash location data vary slightly from one GPS unit to another. Regardless of which unit was used, consistency in recording the same location data from crash to crash was important. Typically a crash occurs over a distance that can be described by 1) first harmful event, 2) first point of impact, and 3) final resting position of the vehicles (Miller and Karr, 1997). Because the purpose of this study was to improve crash location accuracy from hundreds of meters (based on an estimation) to a few meters (based on a GPS), it was assumed that one point is sufficient to describe a crash location. The first point of impact was determined to be the best single point to describe a crash.

Computer-based GPS units have both advantages and disadvantages over hand-held units while collecting data. The procedures for collecting data between these two types of units are slightly different. A computer-based GPS unit must have the computer booted up and the software running before any location can be recorded. This step may take several minutes. Also, both the Rand McNally and Delorme GPS units are capable of recording a series of points that can be employed to obtain an average point. This feature provides for a more accurate location if the data tends to drift. A generalized procedure for computer-based GPS units is shown in Table 4-1.

The main disadvantage of computer-based GPS units is that the computer and antenna are mounted inside the police car; therefore, the recorded location is that of the police car and not necessarily that of the crash. An important fact to remember, however, is that even though the exact location is not being collected, the location is still more accurate than the current estimation process.

Hand-held GPS units are self-contained and do not need a computer for data collection. The location procedure typically begins when the unit is turned on. Points are generally recorded as single “waypoints” or “landmarks” instead of a continuous string of data. These saved “waypoints” can then be accessed within the unit itself, or in some cases they can be transferred to a computer. Additional software and a cable link are needed to download the location data from the GPS directly into a computer.

As shown in column 5 of Table 3-1, some GPS units allow for automatic downloading of location data. The downloaded GPS data can be in many formats and must be converted into a common format for use in CARE and GIS. First, latitude and longitude values in the data files are extracted. Figure 4-1 shows a small portion of the raw data captured by one of the computer-based units, the Rand McNally GPS unit. The highlighted values in Figure 4-1 are the latitude and longitude data of the captured location. A visual basic program was written to remove these values from the file and to convert the data into a common format. The longitudinal coordinates were then converted into a common state plane coordinate system using a downloaded program from the U.S. Army Corps of Engineers called Corpscon (Corpscon 2000). The standardized location data was then ready to be inserted into the CARE system or onto a GIS basemap. Two additional fields in CARE store the northing and easting values, in feet, of each crash.

# Section 5

## Selective Availability

On May 1, 2000, President Clinton requested that selective availability (SA) be removed from the satellite signals captured by civilian GPS units. The removal of this signal scramble improved the accuracy of civilian GPS units by approximately 10-fold (Travis, 2000), including the units tested for this project. With SA activated, GPS recordings collected over time drifted while the unit was stationary. The size of this drift varied from location to location and also changed throughout the day. Inexpensive units that simply capture one point and do not allow for post processing or differential correction were greatly affected by SA. None of the data collected in this study, either with or without SA, were differentially corrected. However, data from GPS units that allowed for continuous capture of location information were averaged to improve accuracy.

An example of the SA drift captured before May 2000 is shown in Figure 5-1. The solid black dots represent 600 data points taken at one location with the Rand McNally StreetFinder Deluxe over approximately a 10-minute interval with SA activated. These points span 150 meters in the east and west direction and 45 meters in the north and south direction. An average of these 600 points was calculated and is shown as a solid black triangle in Figure 5-1. When the same location was captured again with the Rand McNally GPS unit after SA was removed, a 10-minute record period produced 600 points all at the same location. The point collected without SA is shown as a plus sign in Figure 5-1. The distance between the average location with SA and the single location without SA is more than 17 meters. This figure clearly shows how the precision of civilian GPS units was improved by the removal of SA.

# Section 6

## GPS Unit Accuracy

Accuracy tests were conducted on each of the five GPS units after the removal of SA. Five geodetic survey markers were located in Tuscaloosa County, Alabama, and were used as known coordinate points. The five points were located on The University of Alabama campus, at the Tuscaloosa County Courthouse, Crestwood Elementary School, Snow Hinton Park, and the Tuscaloosa Airport. Surrounding features at each of these locations were different. All five units were tested at the five points at three different times of the day, resulting in 15 initial trials for each unit. The location data collected by the units were compared to the coordinates of the geodetic survey markers, and an accuracy range was calculated. The results of the accuracy tests along with the manufacturer's reported accuracy are shown in Table 6-1.

Forty-five data points were collected with five GPS units over a one-week period. The x-y offset from each marker was calculated and is shown in Figure 6-1. In Figure 6-1, each survey marker is located at (0,0), indicated by the crossing dashed lines. The symbols correspond to the positions given by the five GPS units. A roadway intersection is presented on the figure for size comparison. Due to the rounding of locations to the nearest second by the Casio GPS unit, not all of the Casio recorded points fit on Figure 6-1. As shown in Figure 6-1, most points are within one car length from the actual location. For the purpose of locating crashes, it was assumed that an accuracy of ± 8 meters (approximately the size of a car) is adequate to locate a crash. Based on this criteria, GPS units as low as $130 can be employed to accurately collect location data.

# Section 7

## GPS Unit Recommendation

After determining that inexpensive GPS units are capable of recording accurate crash locations, the top two GPS units were chosen for further study. GPS units were selected on four criteria:

- accuracy
- price
- data download
- ease of use

One computer-based unit, the Rand McNally, and one hand-held unit, the Garmin, were selected. Approximately 70 accuracy tests were run on each unit, and complete procedures were developed for transferring data from each unit and converting it into usable GIS format.

Figure 7-1 shows a scatter plot of the locations collected by the Rand McNally and Garmin GPS units in relation to the actual location of the test (0,0). It indicates that the majority of the data is within 8 meters and, as expected, that there is no apparent trend to the data. Figure 7-2 is a histogram showing the distribution of the number of points in relation to the distance from the actual test location. A total of 67 test points were collected with the Rand McNally GPS unit and 71 points were collected with the Garmin. New accuracy values for the two units were calculated by averaging the distances from the actual point.

An average accuracy value of 14.7 meters was calculated for the Rand McNally unit, while an average value of 7.6 meters was determined for the Garmin GPS unit. The accuracy value for the Rand McNally unit is almost twice the distance previously determined. Although the average distance increased, 88% of the location data collected with the Rand McNally and 76% of the location data collected with the Garmin are within 10 meters of the actual location, as shown in Figure 7-2. The reason for this discrepancy is that a few points have inaccuracies greater than 30 meters. Two locations in this study, the courthouse and the school, produced a larger percentage of inaccurate points than the other known locations. Several readings taken at the courthouse were over 30 meters from the actual location. This discrepancy could be caused by a satellite signal reflecting off one of the nearby buildings. A signal reflection causes a time delay, thus decreasing accuracy of the position. At the school location, the geodetic survey marker was under a bush. A thick leaf and stem cover may have prevented a strong satellite signal, thus causing a decrease in accuracy. Accuracy values of the two units were recalculated with the removal of the courthouse and school data. The recalculated values were 7.3 meters and 7.5 meters respectively for the Rand McNally and Garmin. Only six of the 138 points collected by the two GPS units were questionable (greater than 30 meters). Even with the random errors over 30 meters, the location is still superior to the current crash location estimation method. This study demonstrates that the accuracy level provided by these inexpensive GPS units is capable of improving the determination of crash locations.

In addition to accuracy, the price, ease of use, and data download capabilities were evaluated to select the best GPS units. The price and ease of use for the GPS units tested were all comparable; therefore, data download became an important factor. Both the Rand McNally and the Garmin allowed for easy downloading of GPS location data. As shown in Figure 4-1, the Rand McNally location data are stored in an ASCII file that was processed through a visual basic program to extract the needed data. The Garmin allows for "waypoint" locations to be downloaded to a computer and displayed in a table. A simple "cut-and-paste" places the location data into an ASCII file, which is translated into state plane coordinates and stored in CARE or displayed in a GIS.

## Section 8

## Data Display With GIS

In addition to improving the recorded accuracy of crash locations, this research also investigated techniques for improving display and analysis of crashes. Because crash data has attributes that are associated with a location, a logical choice for display and analysis is a GIS. The location information and specific attribute fields from CARE were imported into an off-the-shelf GIS using features available within the GIS. The crash data were then displayed and queried directly in the GIS.

The frame of reference upon which crash data is displayed in a GIS is the basemap. Many potential basemaps exist for areas across the United States. An important factor to be considered when mapping GPS data is that the basemap employed has accuracy similar to the data being mapped. For the example employed in this study, the basemap was produced by the City of Tuscaloosa, Alabama, from orthocorrected aerial photographs. The compatibility of the basemap and GPS locations was field verified by collecting 20 points at intersections and road segments with the GPS and then displaying that data on the GIS basemap. In all cases, the GPS points and basemap correlated very well.

After verification of the basemap/GPS data compatibility, an officer collected actual crash location data with a computer-based GPS unit. The unit was mounted in the officer's car, and crash locations were collected for one week. One of the actual crash locations collected during the test program is presented in Figure 8-1. Figure 8-1(a) is a small portion of the node-link basemap in vector format for the City of Tuscaloosa, while Figure 8-1(b) is the orthophoto of the same area as a raster image. Figure 8-1(a) shows intersections as solid dots with associated node numbers and road segments as lines with associated link numbers. For the specific crash presented in this figure, the nearest node that describes the crash location is number 0196, which is at the intersection of the off-ramp and University Boulevard. As shown by the GPS location, the officer parked the patrol car behind the crash on the small ramp. The GPS location provides additional information, over the node-link information, by placing the recorded crash location on the ramp rather than generalizing the location to a node that describes the entire intersection.

Comparing Figure 8-1(a) with Figure 1-1 clearly shows the benefit of employing a GIS to display crash data. Historical node link data that do not have an associated GPS location can also take advantage of GIS display capabilities. For example, the official crash location shown in Figure 8-1(a) is recorded as node 0196. The CARE system can be queried to export node-link data in a format that can be loaded into a GIS. If the GIS system is coded with node-link graphical information, as the system shown in Figure 8-1(a), then the crash locations will appear exactly at the node that identifies an intersection. The map resulting from this analysis can then be employed to identify "hot-spots" where multiple crashes have occurred in the past.

## Section 9

## Conclusions

Based upon the accomplishments presented herein, the following conclusions are advanced:

1. Accuracy of crash locations was improved from 1 kilometer to 8 meters by employing GPS technology. Inexpensive GPS units are capable of collecting accurate crash location data (within 8 meters) in approximately 3 minutes. Several GPS units tested feature automatic downloading of the locations into a computer, which eliminates possible human error during data entry, thereby improving accuracy. With the recent removal of Selective Availability, the non-corrected locations improved approximately 10-fold.
2. Hand-held GPS units are preferred to computer-based GPS units for collecting the exact crash location because hand-held units can be carried to the point of first contact. Computer-based GPS units are generally less expensive and have superior on-screen maps.
3. The existing CARE system is capable of storing the new "x- y" crash location data. Two additional fields are needed in CARE to store the new GPS location data. To ensure that location data is compatible with CARE, every location was processed through a translation program that converts locations to the state plane coordinates system.
4. The GIS provided an excellent environment for displaying and analyzing both new (GPS) and old (node-link) crash location data. When mapping GPS locations, the accuracy of the GIS basemap must be comparable to the accuracy of the GPS data.

## Section 10

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**Table 2-1. GPS error sources**

| Per Satellite Accuracy | Standard GPS (meters) |
|---|---|
| Satellite Clocks | 1.5 |
| Orbit Errors | 2.5 |
| Ionosphere | 5.0 |
| Troposphere | 0.5 |
| Receiver Noise | 0.3 |
| Multipath | 0.6 |
| Selective Availability | 30.0 |

**Table 3-1. Comparison of five GPS units**

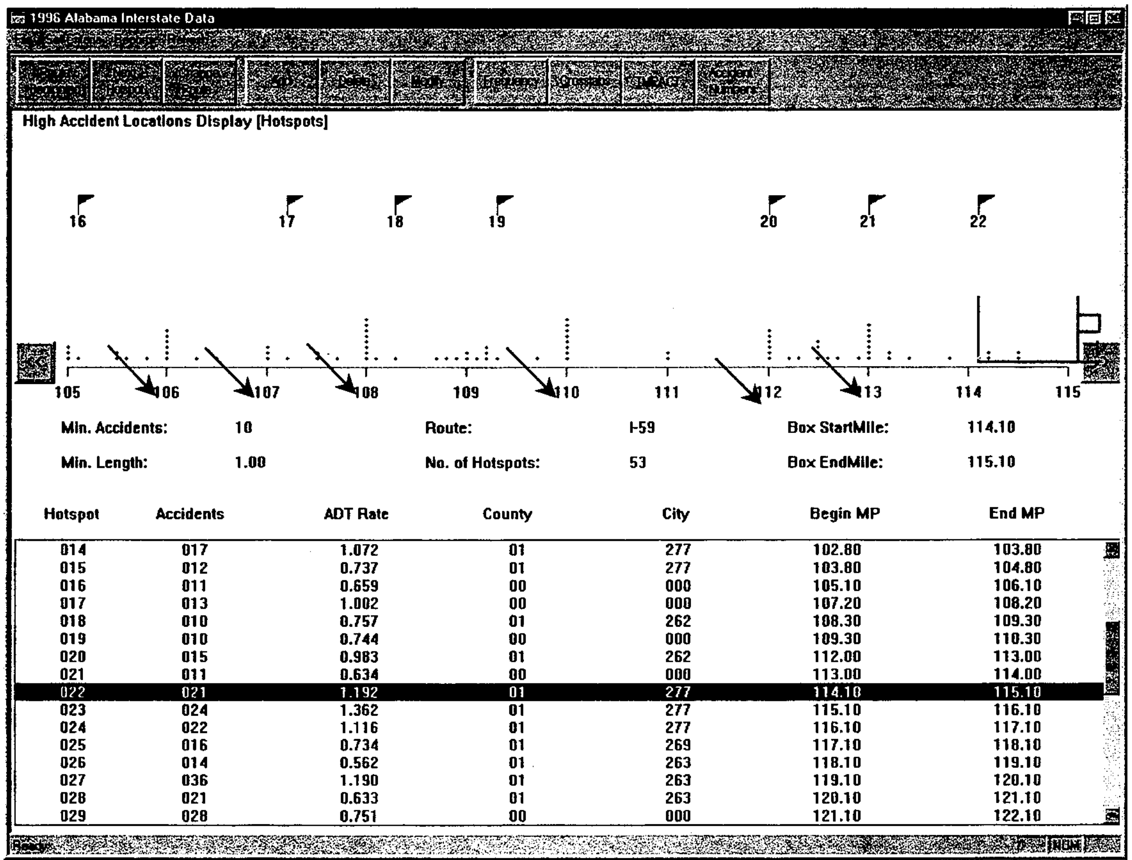
| Unit | Price | Average Lock Time | Map Display / Display Accuracy | Automatic Download | Power Source | Ease of Use | Comments |
|---|---|---|---|---|---|---|---|
| **Rand McNally Street Finder Deluxe** | $129 w/software computer-based | 44.8 sec | Yes * .01 sec | Already in computer. ASCII text file output | Notebook computer | Simple | * recording accuracy Display accuracy to 1 min |
| **DeLorme** | $130 w/software computer-based | 80.5 sec | Yes .01 sec | Already in computer. Proprietary format. | Notebook computer and 4 AAA batteries | Simple | Variety of software programs available |
| **Casio** | $403 hand-held | 31 sec | No 1 sec | No download capabilities. | Nickel-cadmium battery | Simple | Inaccurate recording precision |
| **Garmin GPS 12 Map** | $350 GPS $130 software hand-held | 27.5 sec | Yes .1 sec | Easy transfer of data from unit to computer. | 4 AA batteries | Simple | Small – easy to handle |
| **Trimble Geo Explorer 3c** | $3380 w/software hand-held | * 62.5 sec | Yes .001 sec | Easy transfer of data from unit to computer. Exportable in many formats. | Rechargeable battery | Relatively Complicated | * may change with GPS precision setting Must be in open area for satellite lock-at least five satellites |

**Table 4-1. Generalized procedure for computer-based GPS units**

1. Begin the software program by choosing the correct icon.
2. Select the program's GPS function menu.
3. Select Start GPS to begin tracking satellites.
4. Wait until a lock is achieved and the current position cursor is shown.
5. Move to location to record with GPS.
6. Choose the log or record function to begin data collection.
7. Allow the GPS to record data.
8. Select Stop GPS function when data collection is complete.

**Table 6-1. Accuracy of five GPS units tested**

| Unit | Avg. Distance from known point without SA (after May 2000) | Manufacturer's reported accuracy |
|---|---|---|
| **Rand McNally Street Finder Deluxe** | 7.2 m | 100-150 m |
| **Garmin GPS 12 Map** | 8.2 m | 15 m |
| **Casio** | 31.0 m | 30 m |
| **Trimble GeoExplorer 3c** | 3.5 m | 1-5 m after differential correction |
| **DeLorme** | 7.9 m | 100-150 m |




| Hotspot | Accidents | ADT Rate | County | City | Begin MP | End MP |
|---|---|---|---|---|---|---|
| 014 | 017 | 1.072 | 01 | 277 | 102.80 | 103.80 |
| 015 | 012 | 0.737 | 01 | 277 | 103.80 | 104.80 |
| 016 | 011 | 0.659 | 00 | 000 | 105.10 | 106.10 |
| 017 | 013 | 1.002 | 00 | 000 | 107.20 | 108.20 |
| 018 | 010 | 0.757 | 01 | 262 | 108.30 | 109.30 |
| 019 | 010 | 0.744 | 00 | 000 | 109.30 | 110.30 |
| 020 | 015 | 0.983 | 01 | 262 | 112.00 | 113.00 |
| 021 | 011 | 0.634 | 00 | 000 | 113.00 | 114.00 |
| 022 | 021 | 1.192 | 01 | 277 | 114.10 | 115.10 |
| 023 | 024 | 1.362 | 01 | 277 | 115.10 | 116.10 |
| 024 | 022 | 1.116 | 01 | 277 | 116.10 | 117.10 |
| 025 | 016 | 0.734 | 01 | 269 | 117.10 | 118.10 |
| 026 | 014 | 0.562 | 01 | 263 | 118.10 | 119.10 |
| 027 | 036 | 1.190 | 01 | 263 | 119.10 | 120.10 |
| 028 | 021 | 0.633 | 01 | 263 | 120.10 | 121.10 |
| 029 | 028 | 0.751 | 00 | 000 | 121.10 | 122.10 |

**Figure 1-1. Clustering of vehicular crashes at mileposts indicated by arrows**

```
$GPRMC,170506,A,3313.5545,N,08736.9808,W,0.000,0.0,140600,1.1,W*70
$PRWIZCH,10,7,24,7,05,7,18,7,30,7,13,7,17,0,26,6,07,4,06,7,04,7,00,0*42
$GPGGA,170507,3313.5545,N,08736.9808,W,1,08,1.26,44.5,M,-28.6,M,,*7D
$GPGSA,A,3,10,24,05,18,30,13,06,04,,,,,2.19,1.26,1.79*0A
$GPRMC,170507,A,3313.5545,N,08736.9808,W,0.000,0.0,140600,1.1,W*71
$PRWIZCH,10,7,24,7,05,7,18,7,30,7,13,7,17,0,26,6,07,0,06,7,04,7,00,0*46
$GPGGA,170508,3313.5545,N,08736.9808,W,1,08,1.26,44.4,M,-28.6,M,,*73
$GPGSA,A,3,10,24,05,18,30,13,06,04,,,,,2.19,1.26,1.79*0A
$GPGSV,3,1,11,10,84,186,45,24,54,029,46,05,42,241,39,30,35,287,43*77
$GPGSV,3,2,11,13,31,103,43,04,26,063,40,06,19,314,37,18,13,049,40*72
$GPGSV,3,3,11,07,08,129,30,26,02,179,29,17,01,263,00*4D
$GPRMC,170508,A,3313.5545,N,08736.9808,W,0.000,0.0,140600,1.1,W*7E
$PRWIZCH,10,7,24,7,05,7,18,7,30,7,13,7,17,0,26,6,07,4,06,7,04,7,00,0*4
```

**Figure 4-1. Raw data from Rand McNally GPS unit**

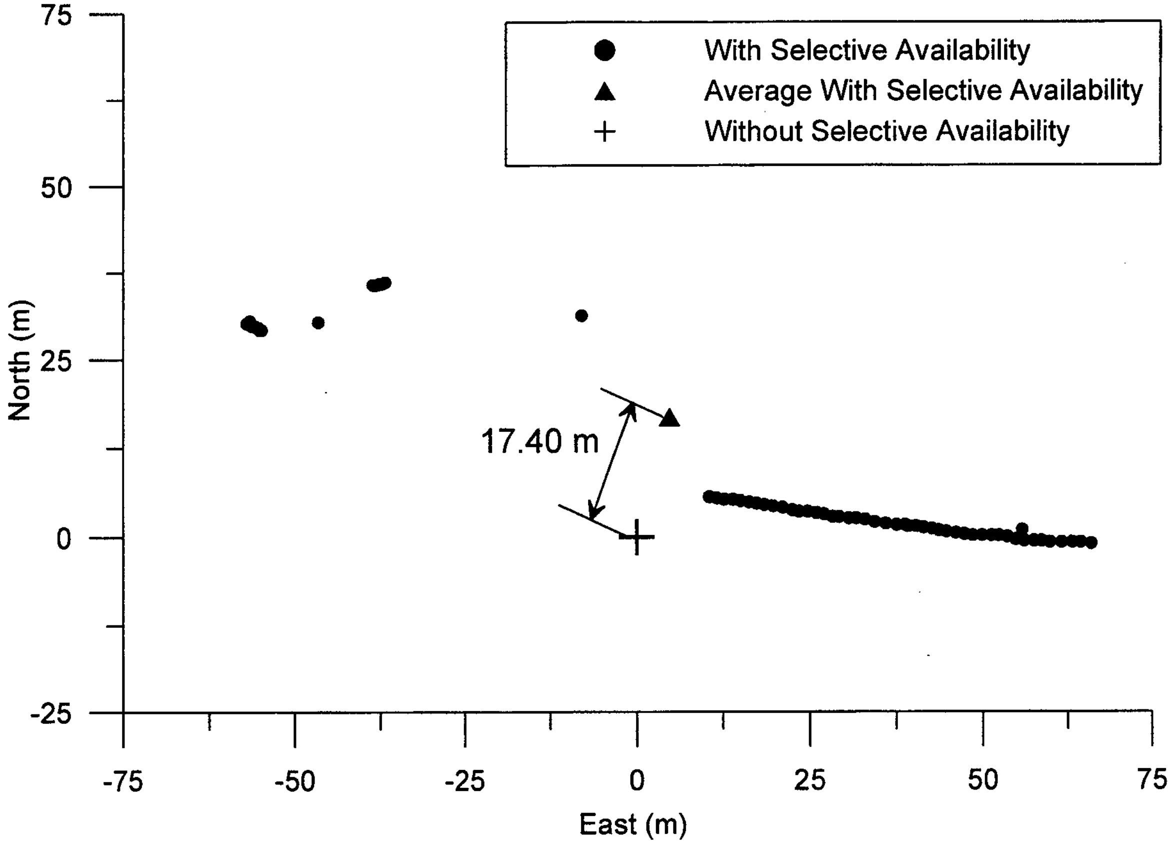



**Figure 5-1. GPS drift before and after SA was turned off in May 2000**

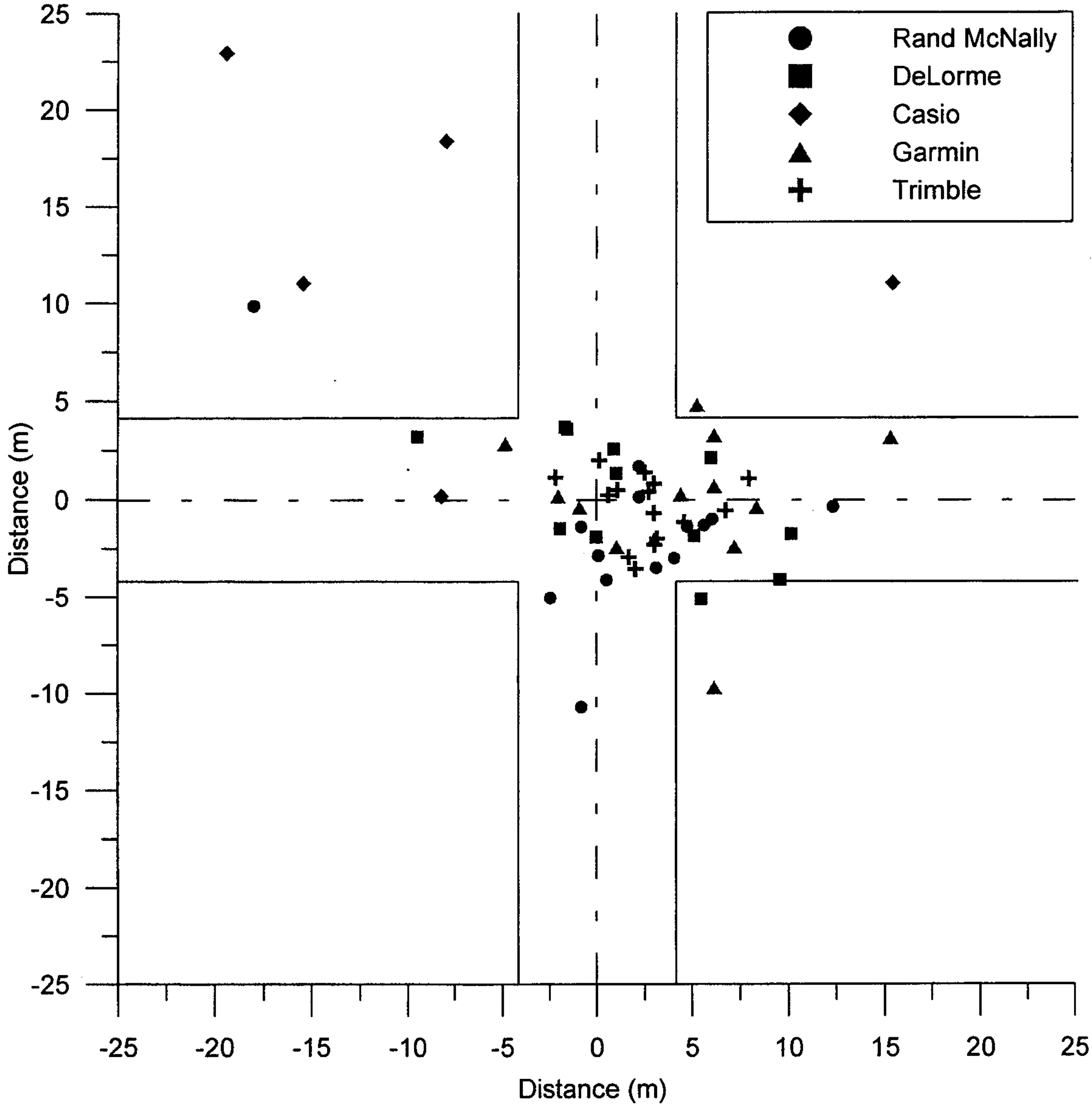



**Figure 6-1. Scatter of locations collected by five different GPS units around five known control points at three different times**

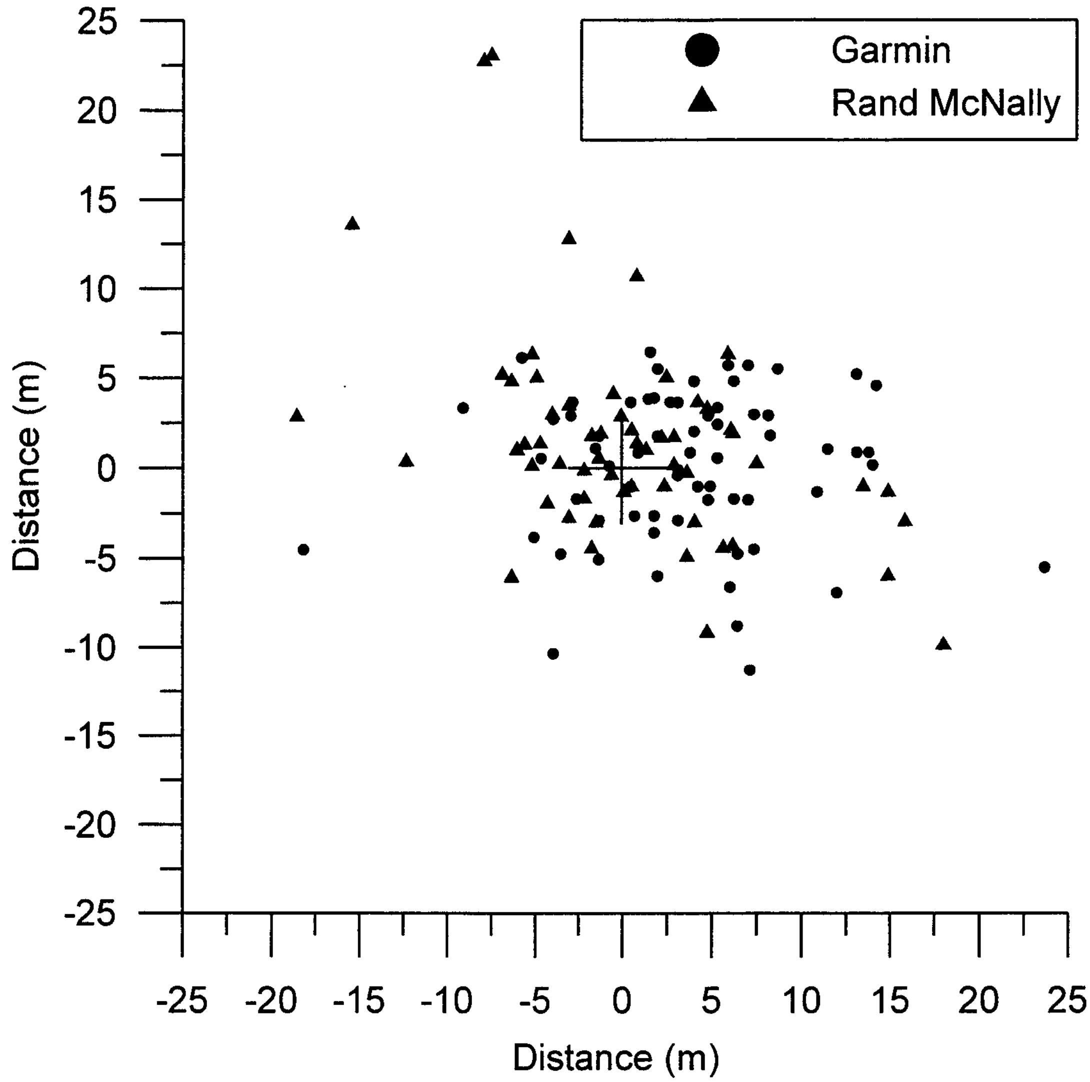



**Figure 7-1. Scatter of locations collected by Garmin and Rand McNally GPS units over a six-week period**

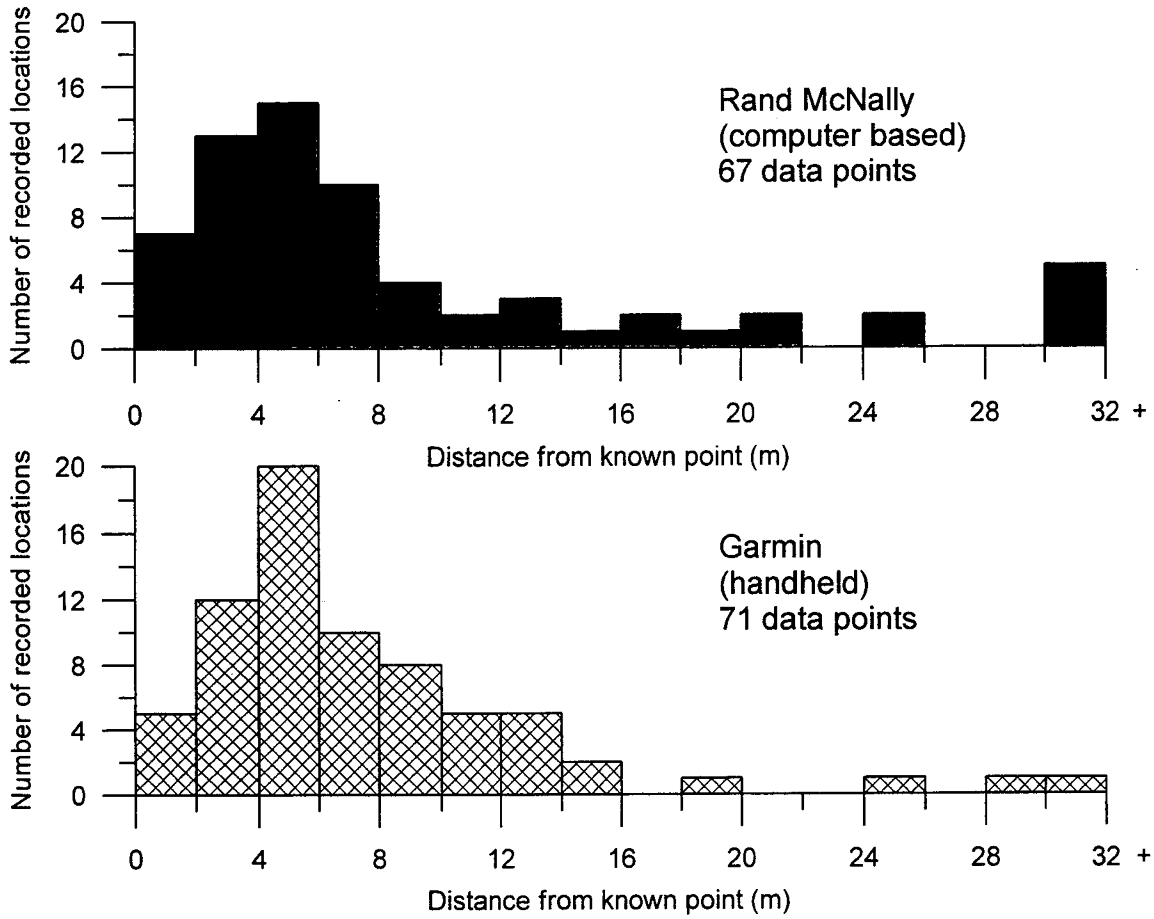



**Figure 7-2. Histogram showing accuracy of Rand McNally and Garmin units**

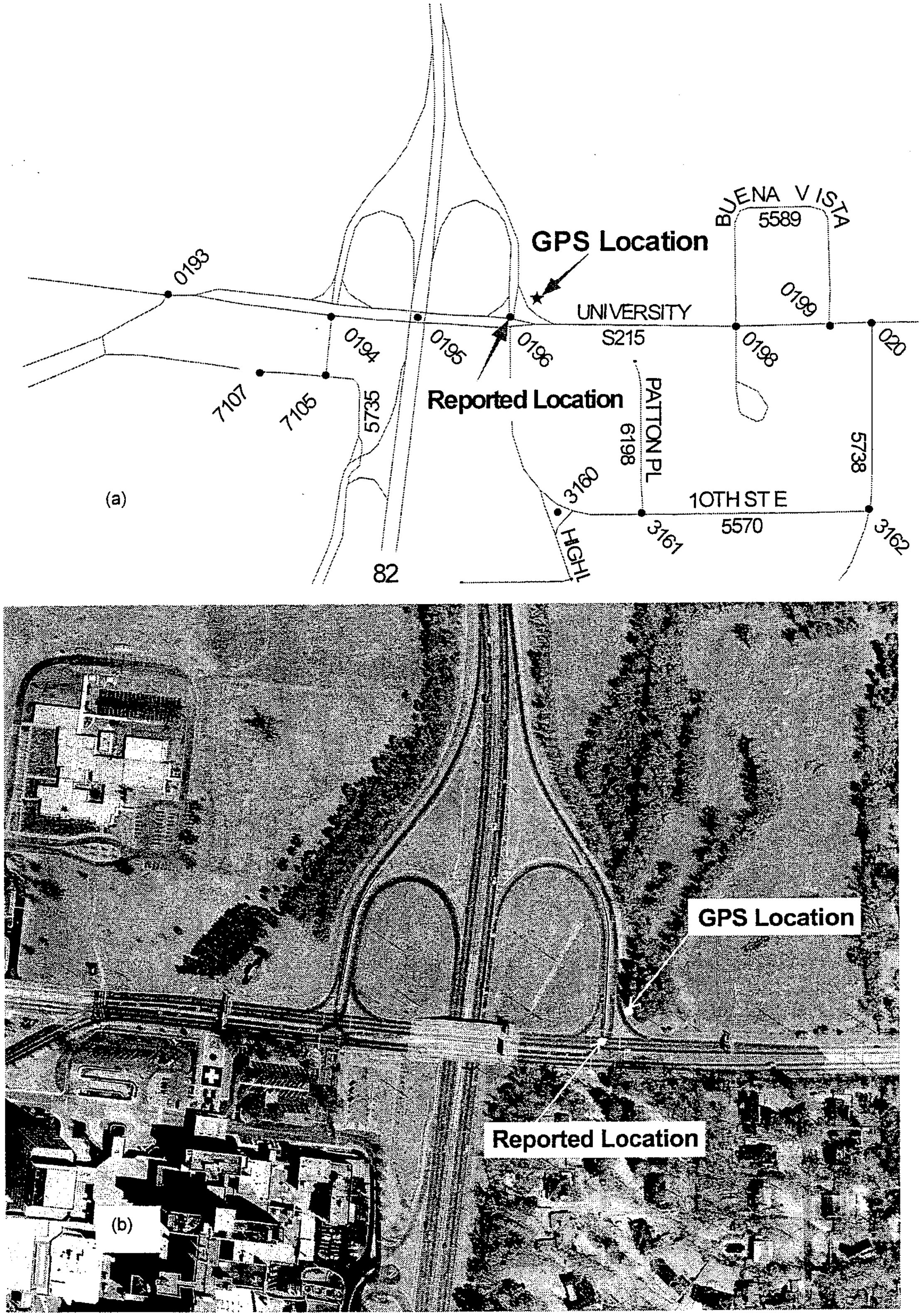



**Figure 8-1. (a) GIS vector basemap with GPS crash location and reported node location. (b) GIS orthophoto of the same interchange**

# University Transportation Center for Alabama

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