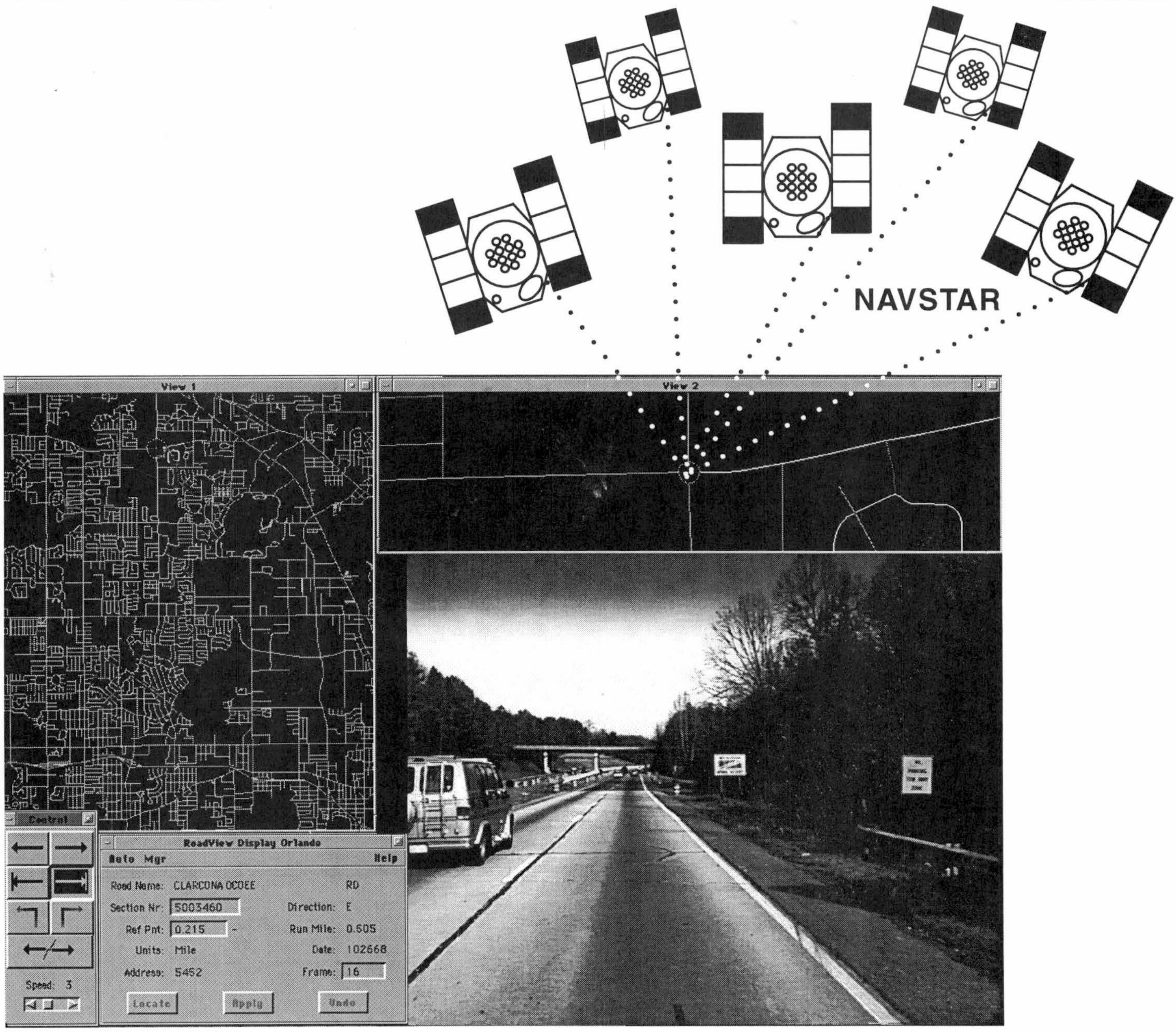
U.S. Department
of Transportation

Federal Highway
Administration

Demonstration Project No. 85

Automated Collection of Sign Inventory Information by Integrating Global Positioning System (GPS) With Videologging Data Collection Activities



Work Order No.
DTFH71-92-DP85-IA-35

January 1995

GPC20403
10/18/95

January 1995

AUTOMATED COLLECTION OF SIGN INVENTORY INFORMATION by INTEGRATING GLOBAL POSITIONING SYSTEM (GPS) WITH VIDEOLOGGING DATA COLLECTION ACTIVITIES

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Federal Highway Administration
Demonstration Project 85
Work Order: DTFH71-92-DP85-IA-35

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
Automated Collection of Sign Inventory Information by Integrating Global Positioning System (GPS) With Videologging Data Collection Activities

5. Report Date
January 1995

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
Iowa Department of Transportation
Office of Planning Services
800 Lincoln Way
Ames, IA 50010

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTEH71-92-DP85-IA-35

12. Sponsoring Agency Name and Address
Federal Highway Administration
Demonstration Projects Division
400 Seventh St. S.W.
Washington, DC 20590

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with US Department of Transportation, Federal Highway Adm.

16. Abstract

Advances in communication, navigation and imaging technologies are expected to fundamentally change methods currently used to collect data. Electronic data interchange strategies will also minimize data handling and automatically update files at the point of capture.

This report summarizes the outcome of using a multi-camera platform as a method to collect roadway inventory data. It defines basic system requirements as expressed by users who applied these techniques and examines how the application of the technology met those needs. A sign inventory case study was used to determine the advantages of creating and maintaining the database and provides the capability to monitor performance criteria for a Safety Management System.

The project identified at least 75 percent of the data elements needed for a sign inventory can be gathered by viewing a high resolution image.

17. Key Words
Global Positioning System (GPS)
Dead Reckoning, Videologging,
Navigation, Roadway Inventory,
Imaging

18. Distribution Statement
No restrictions. This document is available to the public through NTIS, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	74	

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

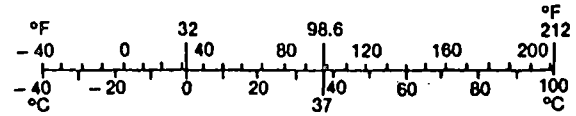
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.093	metres squared	m²
yd²	square yards	0.836	metres squared	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	kilometres squared	km²
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.028	metres cubed	m³
yd³	cubic yards	0.765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
ha	hectares	2.47	acres	ac
km²	kilometres squared	0.386	square miles	mi²
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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Acknowledgment

A project which involves the application of leading edge technology could not be done without the assistance of many people. Resources were made available by Federal Highway Administration; U.S. Geological Survey, Mandli Communications Inc., Rockwell International, Motorola Communications & Electronics Inc., Trimble Navigation, John E. Chance & Associates Inc., Differential Corrections Inc., and Land Information Technology Company LTD. All of these organizations have our sincerest gratitude for their support.

We are especially grateful to William Ehrich, Mandli Communications Inc., for striving to find low-cost solutions and taking the time to share his expertise.

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EXECUTIVE SUMMARY

Introduction and Purpose

This report summarizes the outcome of using a multi-camera platform as a method to collect roadway inventory data. It defines basic system requirements, as expressed by users who applied these techniques, and examines how the application of the technology met those needs. A sign inventory case study was used to determine the advantages of creating and maintaining a database using video images with geo-referenced coordinates.

The purpose of this report is to present the results of investigating several emerging technologies. The basic concepts used are discussed, test procedures are described, and results are presented. The goal is to determine the practicality of integrating these technologies into existing data collection methods.

The three technology groups investigated involve:

Global Positioning System (GPS)
High Resolution Images Using A Multi-Camera Platform
Integrated Software Environment

Conclusions

GPS and high resolution imaging technologies are evolving at a very rapid pace. Solutions with proved performance and lower cost will continue to evolve. Management should use a two-year or less payback as a general rule to follow when evaluating emerging technologies.

The DGPS Strategy for the videologging van application include:

Installing a GPS reference receiver (at the central office) to collect DGPS corrections (distance-based DGPS) and establish two independent data links on board (in the vehicle) to receive DGPS corrections.

Establishing on-board DGPS data links will increase absolute accuracy by correcting for local ionospheric and tropospheric errors. Gaps caused by blockage of the data link or GPS signal will require post-processing to complete the coordinate file. Having expanded data available from the distance-based GPS data collection system will also allow data to be extrapolated to help fill in the gaps.

The Department of Defense should adopt a rational approach to applying Selective Availability. By eliminating SA, many transportation applications would be adequately supported with a 5- to 10-meter accuracy range without requiring a DGPS data link.

The project also identified at least 75 percent of the data elements needed for a sign inventory can be gathered by viewing a high resolution image.

The benefits from standardizing an approach for collection and analysis of sign data are: added credibility, enhanced ability to verify sign locations, the data can be used as a quality check to assist field staff in maintaining the database, and provides the capability to monitor performance criteria for a safety management system.

CHAPTER 1

Project Overview

1.1 Introduction

Advances in communication, navigation and imaging technologies are expected to fundamentally change methods currently used to collect data. Electronic data interchange strategies will also minimize data handling and automatically update files at the point of capture. However, when to invest in emerging technology will always be a difficult decision. This decision can be further complicated by using an approach of "let's wait until the optimum solution has been developed." But, in fact, solutions never remain optimum because technology innovations will continue to advance the state of the practice. The purpose of this report is to present the results of investigating several emerging technologies. The basic concepts used are discussed, test procedures are described, and results are presented. The goal is to determine the practicality of integrating these technologies into existing data collection methods.

This report summarizes the outcome of using a multi-camera platform as a method to collect roadway inventory data. It defines basic system requirements, as expressed by users who applied these techniques, and examines how the application of the technology met those needs. A sign inventory case study was used to determine the advantages of creating and maintaining a database using video images with geo-referenced coordinates.

The Iowa Department of Transportation (Iowa DOT) laser disc videologging van was modified to evaluate this approach. The van collected video at highway speeds using a multi-camera platform. Each image has a Global Positioning System (GPS)-derived coordinate, providing the ability to link video with other geo-referenced data sources. Video images were used to create sign inventory and milepost databases which were linked with other historical information. The unique reference coordinate allowed comparisons to be made to previously linked data. The following tasks were completed:

Task 1	Install subassembly components on the video van (GPS, dead reckoning and side camera)
Task 2	Perform accuracy and repeatability test of GPS
Task 3	Transfer location reference files for comparison with existing information from GPS-referenced video images
Task 4	Identify sign inventory data elements and evaluate video as a data source for providing sign information
Task 5	Develop user requirements based on level of accuracy acquired
Task 6	Prepare final report

The three technology groups investigated involve:

Global Positioning System
High Resolution Images Using A Multi-Camera Platform
Integrated Software Environment

The listed technologies are complex and based on high level mathematical equations involving satellite, ephemeris, clock off sets, ionospheric and atmospheric delays, image processing and complex technical methods requiring specialized skills to apply. The report is intended to expand the readers' knowledge without requiring them to become fully immersed in the disciplines associated with development and deployment of these concepts.

Using automated machine processing techniques and office-based workstations, data handling and collection costs can be reduced, and safety of the field staff and traveling public can be significantly improved. Initiating a sign inventory program, for example, is an intensive data collection and data maintenance effort which in the past required a crew to stop along the roadside to collect appropriate information. Each time a crew stopped represented a potential roadside safety risk and a reduced level of productivity. By using images captured at highway speeds and processed on an office workstation, roadway features can be referenced and standard evaluations can be performed. This approach will result in improved performance and safety.

1.2 Problem Statement

Utilizing advances in technology and building a more forward-looking framework to collect and process data will assist transportation agencies in monitoring and determining the potential impacts of alternative transportation policies. Given the broad impact of transportation decisions, it is very important to keep data as accurate and timely as possible.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) requires data on the state's transportation system so that it is economically competitive, energy efficient, environmentally and socially responsible, and financially feasible. It also mandates that each state develop, establish and implement six transportation management systems and a traffic monitoring system. These systems require reliable data that is readily accessible by decision-makers to evaluate needs and monitor performance. Every incremental improvement in high-resolution video cameras, geo-referencing techniques, computer and storage devices will reduce the burden of data collection, maintenance and reduction. Successful deployment and continued support of the transportation management system will require adoption of better data handling techniques to improve the use of the data collected.

In 1985 static and navigation tests were conducted by U.S. DOT, Transportation Systems Center (DOT-TSC-RSPA-86-1). The objective of the tests was to gather data to determine the viability of the GPS as a "stand-alone" referencing system. The study concluded that GPS could not serve as a "stand-alone" system under typical land application environments. GPS failed to provide a continuous position solution due in part to signal blockage (urban canyons) or the availability of satellites within the horizon.

Several advances have occurred since these tests were performed. First, the GPS constellation has been fully deployed and coverage for most areas provides more than 5 satellites above the minimum 7.5 degrees elevation angle. Second, low cost inertial sensors used to fill in the signal blockage gaps (dead reckoning) are readily available. Differential global positioning techniques have also been expanded to increase the accuracy. While the technology improvements referenced above have not changed the 1985 conclusion that GPS cannot "stand alone", the changes that have occurred need to be investigated to determine the practicality of using a GPS-based referencing system for land applications.

1.3 Objectives

The project deals with one of the barriers pertinent to the integration of GIS/GPS into decision making tools; that is, the high cost of collecting and maintaining the database. It is thought that by reducing the cost to collect and maintain data, adoption of these techniques will be facilitated.

The goals are to:

1) Assess the viability of GIS/GPS technology in a production environment.

2) Identify critical skills and/or agency protocols required to apply these techniques.

3) Promote interaction between technology providers and transportation system managers to further refine system performance and enhance features.

4) Measure effectiveness and productivity gains of integrating GIS/GPS into the data collection process.

5) Identify additional applications for GIS/GPS technology.

The purpose of integrating GPS and a side-view camera to the front view videolog van was to enhance the field of view and link a visual database with analysis tools. Leveraging the ability to easily locate roadway features using geo-referenced roadway images expands the value and use of the information. The project examined emerging technologies used to geo-reference and place an image into a feature-based information source.

A major project objective was to support and facilitate transferring knowledge to technology providers. A better understanding of the capabilities and operating environment required to meet transportation applications will provide a product tailored to meet the transportation environment.

The expected outcome is the availability of a low-cost method to gather data which will meet the needs of a transportation agency.

1.4 Approach

GPS, while based on complex technology, is living up to the promise of being low cost and a universally accepted method to locate points on the surface of the earth. While still in the early stages of development, GPS is being used to improve, and in some cases introduce, entirely new services involving surveying, aerial photo control, in-vehicle navigation, accident reporting, vehicle dispatching and infrastructure management, and in general solving many location/transportation-related problems. However, it also serves as an example of how integration of advanced technology requires a broad range of skills. Such skills are not always available in the government ranks. One approach to acquire these skills is to seek out strategic relationships and establish a technology transfer program with universities and the industrial community.

One of the major benefits of this project was the partnerships that have been established with service providers, equipment manufacturers and system integrators. These relationships have provided access to information to help assess operation and performance characteristics of GPS. This has also provided a unique forum to exchange information about how GPS performs in a new application environment. Through this exchange of ideas, the performance of the equipment has been improved.

In 1992 the Iowa DOT, in cooperation with FHWA, began to investigate the value of using GPS and side-view video images as a method to improve the collection of roadway data. The existing Iowa videologging van was modified and tests conducted during 1993 and 1994.

Mandli Communications Inc., system integrator for the original Iowa video van, performed the modifications to the van and assisted in the evaluation of dead reckoning sensors and GPS receivers. The unique full-frame image capture technique developed by Mandli remains at the leading edge of technology in the industry, providing highest resolution images. High resolution images are a critical factor in the evaluation of this concept.

Both urban and rural corridors were used to establish performance of GPS in the areas of reliability and accuracy. Problems were encountered and proposed solutions tested to improve the performance of each subcomponent. A one-year videolog cycle was completed with the equipment design.

Overall, the issues involved: imaging, i.e., camera mounting, perspective and overlap; and one recorder versus two. These issues were easier to resolve than location issues dealing with a low-cost device to track change in direction for the dead reckoning sensor, and to implement a differential GPS solution.

The Iowa DOT has not selected a preferred agency-supported geographic information systems (GIS) platform. However, for the purpose of this analysis, a system was assembled using software and hardware components acquired through earlier evaluations. The GIS workstation was connected to the video laser disc player to demonstrate the integrated software environment. Evaluation of the platform was conducted to determine the range of data elements that could be accurately input from the image.

1.5 Conclusions

Geographic Information System/Image-Based Support Environment

1. At least 75 percent of the data elements needed for a sign inventory can be gathered by viewing a high resolution image.

2. The benefits from standardizing an approach for collection and analysis of sign data are: added credibility; enhanced ability to verify sign locations; the data can be used as a quality check to assist field staff in maintaining the database; and provides the capability to monitor performance criteria for a safety management system.

3. A geographic information system/automated data entry environment facilitates building a database by connecting data fields with predefined values. For example entering R1-1 (stop sign) into a data field allows the program to automatically fill in several data fields such as foreground/background colors, size etc. This technique simplifies data input and reduces the chance for errors.

4. USGS 7.5 minute Quad Maps (1:24,000) are not adequate for displaying 3- to 5-meter geo-referenced features.

5. It's important to adopt an agency/statewide coordinate system.

GPS

1. GPS and high resolution imaging technologies are evolving at a very rapid pace. Solutions with proved performance and lower cost will continue to evolve. Management should use a two-year or less payback as a general rule to follow when evaluating emerging technologies.

2. Sorting out performance issues is easier when GPS manufacturers provide technical manuals that describe operational characteristics of their equipment. The quality of the manuals is also a good indicator of the technical support that can be expected from the GPS manufacturer and/or system integrator.

3. DGPS Strategy for the Videologging Van

> Install a GPS reference receiver (at the central office) to collect DGPS corrections (distance-based DGPS) and establish two independent data links on board (in the vehicle) to receive DGPS corrections.

Establishing on-board DGPS data links will increase absolute accuracy by correcting for local ionospheric and tropospheric errors. Gaps caused by blockage of the data link or GPS signal will require post-processing to complete the coordinate file. Having expanded data available from the distance-based GPS reference receiver will also allow data to be extrapolated to help fill in the gaps.

4. As of this date the dead reckoning sensors tested did not provide a complete solution for this application. However, modifications are currently under development and it is anticipated that one of the sensors will soon be retested. A more robust sensor will enhance the ability to provide accurate navigation positions for longer distance when satellite signals are lost. It will also be useful in relocation and/or identification of specific locations where additional data collection is required.

5. The civilian signal (Standard Positioning Service) must be given the same quality assurances as the military's (Precise Positioning Service) signal. This requires the same verifications and standards Department of Defense performs to be applied to the civilian signal.

6. Department of Defense needs to adopt a rational approach to applying Selective Availability (SA). By eliminating SA, many transportation applications would be adequately supported with a 5- to 10-meter accuracy range without requiring a DGPS data link.

CHAPTER 2

Technology Review/Navigational Global Positioning System

2.1 NAVSTAR Global Positioning System (GPS)

Many articles and reports have been published on GPS. For the purpose of this report, a brief overview of key elements will be covered.

GPS is based on a constellation of satellites orbiting the Earth in 12-hour orbits. Illustration 1 provides a view of the system.

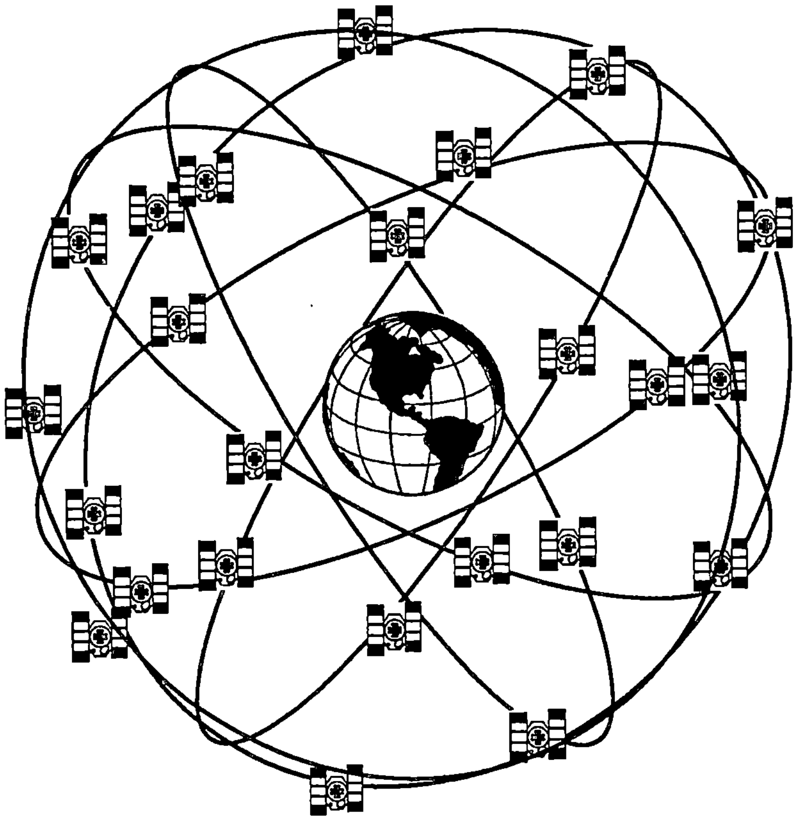


Illustration 1

The NAVSTAR Global Positioning System uses radio-ranging measurements from 24 satellites to triangulate positions anywhere on the surface of the Earth. Each satellite broadcasts a passive time code signal. Since the signal is passive it does not degrade as more ground units receive the signal. The only requirement is a GPS receiver equipped with an antenna to process the spread spectrum signal.

Two signals are transmitted from each satellite. First, the P-code is used only by the military (Precise Positioning Service) and has a higher precision than the second, Coarse Acquisition code (Standard Positioning Service), which is available to civilian users. The broadcast frequency falls within the microwave spectrum which can be blocked by buildings, trees or other obstacles in the line of sight.

The system provides global, all-weather, 24-hour navigation information. Position accuracy depends on the number of satellites in view, the geometry of the satellites, the environment and SA, which is controlled by the Department of Defense. SA is a scheme that can intentionally degrade the performance up to 100 meters.

Calculating longitude and latitude requires four satellites, or three if altitude is known exactly. More than five satellites at a given time are available in most areas to be tracked. Additional satellites increase the precision of the solution. Illustration 2 provides a 24-hour plot of satellites available in central Iowa.

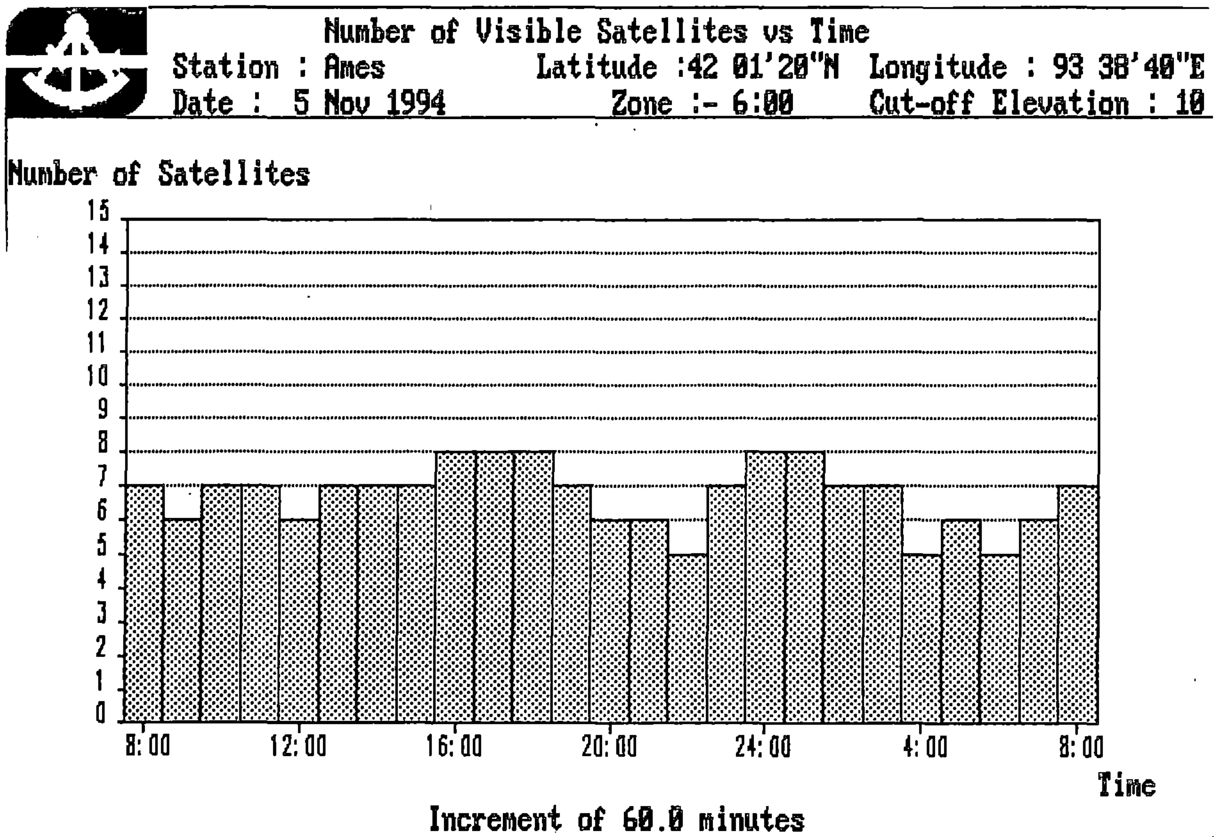


Illustration 2

Multi-channel GPS receivers improve the accuracy by using all satellites that are in view. Position dilution of precision (PDOP) is a value associated with the distance the satellites are separated from each other and these locations relative to the ground location. Three satellites at the corners of an equilateral triangle centered over the ground location, with the fourth satellite being directly overhead, will provide a low PDOP. The wider the separation, the better the geometry and the lower the PDOP value. Values considered "good" for positioning are in the 2 to 5 range, while values greater than 7 are considered poor.

The GPS signal contains error from several sources. Satellite clocks need to measure nanoseconds (in terms of navigation accuracy, one nanosecond of time error is equivalent to approximately 0.3 meters or 0.948 feet of range error) and are not always in sync. Orbit errors and changes in the environment dealing with the ionosphere and troposphere also impact accuracy. Receiver noise and receiver location may also cause multipath (reflections). Finally, dithering, which is a term used to describe the intentional degrading of GPS signals for the purpose of national security, affects accuracy. All of these can affect accuracy to 100 meters. Table 1 provides a summary of GPS error sources for horizontal positions.

Summary Of GPS Error Sources (Static Mode) Table 1

Typical Error Budget For	GPS (Meters)	Differential GPS (Meters)
Satellite Clocks	1.5 - 3.0	0
Orbit Errors (ephemeris)	2.0 - 2.6	0
Ionosphere & Troposphere	5.0 - 7.0 plus	.02 - .06
Receiver Noise	0.3 - 2.5	.03 - 2.4
Multipath (reflections)	0.6 - 3.0	.06 - 3.0
Selective Availability (SA)	30 plus	0

A technique known as Differential GPS (DGPS) has been devised to improve the positional accuracy of GPS. DGPS is a method of placing a GPS receiver at a known surveyed point, compare the GPS-derived solution to the known location for each satellite, and broadcast the error corrections to improve the solution. Table 1 demonstrates the potential improvement to GPS when DGPS is used.

GPS-derived positioning is generally expressed in latitudes and longitudes, based on a WGS-84 Geoid. In most cases these latitudes/longitudes are related to geographic location by means of map projections.

2.2 Spheroids, Datums and Map Projections

There are a number of different coordinate systems being used. These coordinate systems do not use the same units, nomenclature for the units, or the same origin.

The following are a few examples of how the coordinate systems can be defined in a number of different ways:

- Latitudes and Longitudes
  - Degrees, minutes, seconds and fractions of a second
  - Degrees, minutes and fractions of a minute
  - Degrees and fractions of a degree
  - Radian
- Eastings and Northings (x and y)
  - Feet
  - Meters
  - Miles
  - Kilometers

Mixing these units with the different spheroids, datum and projections makes the process of converting data from one system to another quite complex.

For example, in order to do an inverse calculation to change latitude and longitude into UTM (Universal Transverse Mercator), it is necessary to perform a large number of complex calculations involving trigonometry. For a more detailed discussion on how to convert from one system to another, see Map Projections-A Working Manual, U.S. Geological Survey Professional Paper 1395.

Spheroid/Geoid

The Earth is an oblate (flattened or depressed at the poles) spheroid. A number of different spheroids exist. The Clark 1866 ellipsoid was the most widely used in the United States and is associated with the NAD27 (North American Datum 1927), which will be discussed in the next paragraph. This ellipsoid is being superseded by the GRS 80 (Geodetic Reference System 1980), which is used in NAD83. In addition to GRS 80, WGS 84 (World Geodetic System 1984) was developed by U.S. military agencies for the world. In general, refinements to the spheroid were brought about because artificial satellites have given us a better definition of the surface and location of the center of gravity of the Earth. In addition to spheroids, another common geodetic term is the geoid. A geoid is the shape of the Earth would assume if it was all measured at mean sea level. Elevations and contours are all measured relative to the geoid. The usual measure of location for the spheroid is latitude and longitude.

Datum

A datum ties the spheroid to one or more reference points on the surface of the planet. NAD27 and NAD83 are the most common datums used in North America. NAD83 is rapidly displacing the older NAD27. These datums both use Meades Ranch in Kansas as their origins. However, because of changes in the spheroids (Clark ellipsoid 1866/GRS80), the distance in meters from Meades Ranch can be considerably different.

Projection

A map projection is a two-dimensional display of the three-dimensional surface of the Earth. Since a spherical object cannot be flattened without distortion, map projections only approximate the area they attempts to display. With the exception of Alaska, U.S. map projections are either Lambert or Transverse Mercator projections. Another common projection is the UTM (Universal Transverse Mercator).

The discussion that follows will explain how the coordinates and illustrations of the locations were developed.

The data from the GPS receivers is in latitudes and longitudes, based on the WGS 84 spheroid. The data from the two receivers used was based on proprietary formats provided by the GPS manufacturer. This data was then processed to do differential and/or dead reckoning corrections, and a standard output string containing latitudes and longitudes in the form of degrees minutes seconds (DDMMSS.ssss) was created. This output was then processed by a conversion program which output the data into a UTM projection in meters. The UTM projection was selected because a digitized quad map based on a NAD83 datum and UTM coordinates had been purchased from a vendor. The map was available to use as a quick check on accuracy for the Ames West area of the study site. The UTM coordinates were then translated into a format that CAiCE (Computer Aided Civil Engineering) could understand. CAiCE was used to produce an autocad DXF file. This file was then imported into image processing software. The vector image developed by using GPS and the video van was then overlaid on the digitized quad map and the accuracy of the locations were assessed. Additional assessments were made by printing the images developed by CAiCE for a large number of files for the test location. (See Chapter 6, Section 5.)

2.3 GPS Receiver Components & Quality Issues

GPS receivers require an antenna, signal processor, power supply, application processor, display and keypad for user input. Illustration 3 provides an example of a typical system architecture.

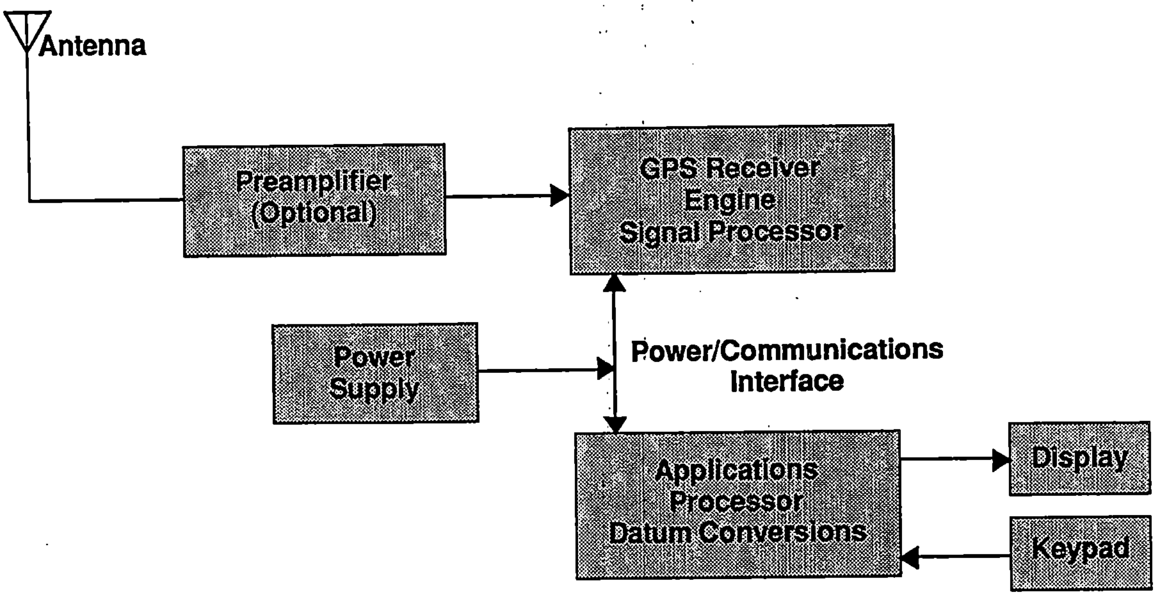


Illustration 3

A wide range of GPS receivers are now available in the marketplace. Each receiver manufacturer uses a defined customer base to customize the functional capabilities of the unit. The requirements for collecting data at highway speeds are different than those of a static application, so price can not be the sole criteria used to evaluate GPS equipment. Key factors to consider include:

1. A signal processing scheme which uses parallel tracking and firmware that supports individual channel tracking of available satellites
2. Time to first fix and signal reacquisition time
3. Number of channels
4. Guides to select compatible antennas and placement that reduces signal attenuation
5. Filters to minimize coasting when satellites drop out of the constellation
6. Low signal-to-noise ratio
7. File outputs that provide raw measurement data at one time pulse per second

8. Ability to measure quality of position, evaluate and eliminate poor coordinates
9. Ability to easily upgrade firmware

Accuracy is a function of the entire GPS system at the time of measurement. GPS receivers contribute to the level of accuracy that can be achieved. Receiver performance and cost is affected by the number of channels, the signals tracked and the processing performed on those signals.

Accuracy for the purpose of this evaluation is defined in terms of the ability to find or locate a physical feature on the ground. Evaluation of this requires measuring the repeatability of locating the same position. This can be measured as either absolute or as relative accuracy. Absolute accuracy assures the user that the data can be matched to real world coordinates. While relative accuracy indicates it is in correct placement with its neighbors, it may not always reflect its location in a real world coordinate system.

2.4 Dead Reckoning

Dead reckoning is a technique used to fill in gaps when GPS satellite lock is lost. As explained previously, physical obstacles can block satellite reception. Heading and distance sensors back up the GPS receiver to provide continuous horizontal tracking. An altimeter sensor is another independent measure used to smooth and fill gaps when a fourth satellite is needed to determine position.

There are low-cost devices available to measure heading. A commonly known device is the flux gate compass, which uses a magnetic field to determine a directional heading. However, several additional sensors using different approaches are now available in the marketplace: one based on a oscillating quartz element and another which uses a fiber optic gyroscope.

The oscillating quartz element is a inertial angular rate sensor. A quartz crystal is sealed along with micro-electronic sensors to measure rate of turns.

The fiber optic gyroscope utilizes the interference of light waves for precise determination of small linear displacements of vehicle turning angles.

2.5 Differential GPS

GPS accuracy is enhanced by using differential GPS (DGPS). DGPS can be performed by placing a GPS receiver/computer combination on a surveyed point. The reference receiver or base station measures the GPS error which can be used by other GPS units to improve the position solution.

Differential corrections can be obtained by using a data link which transmits the corrections in real time to the roving GPS receivers, or by using a post-processing strategy that stores the information for later use. One hundred and sixty kilometers is the effective range of the differential correction; any farther and atmospheric errors will not be canceled. The term distance-based DGPS will be used to describe this method. If corrections are used from a reference receiver greater than 160 kilometers an additional error of 1 meter can be expected. Wide-area DGPS is another term used when more than one reference receiver is used to determine position.

DGPS must meet several tests before users begin to gain confidence in the approach that is selected. First, reliability and repeatability must be demonstrated; second, accuracy must satisfy user requirements; and the last issue deals with the ability to maintain the system. A system that requires continuous operation places increased value on configuring a reference station with a backup power supply and a redundant base station. Application of good file management techniques will also be critical to the level of reliability and accuracy that can be achieved.

2.5a Post-processing

This strategy uses raw GPS, distance measuring instrument (DMI) and dead reckoning data (gathered from the van) to process corrections from a base station to improve the position solution. Correction data is collected and stored for later processing from either a local, distance-based or wide-area reference station. This method is used when it is not critical to locate points while out in the field, but still requires a high level of accuracy.

2.5b Real time

This strategy requires a data link to transmit corrections. The data link should be capable of transmitting the data at approximately 50 bits per second to the roving GPS receivers. The transmission is usually the weakest link in this method. Blockage of either GPS or the data link can occur when line of sight is lost.

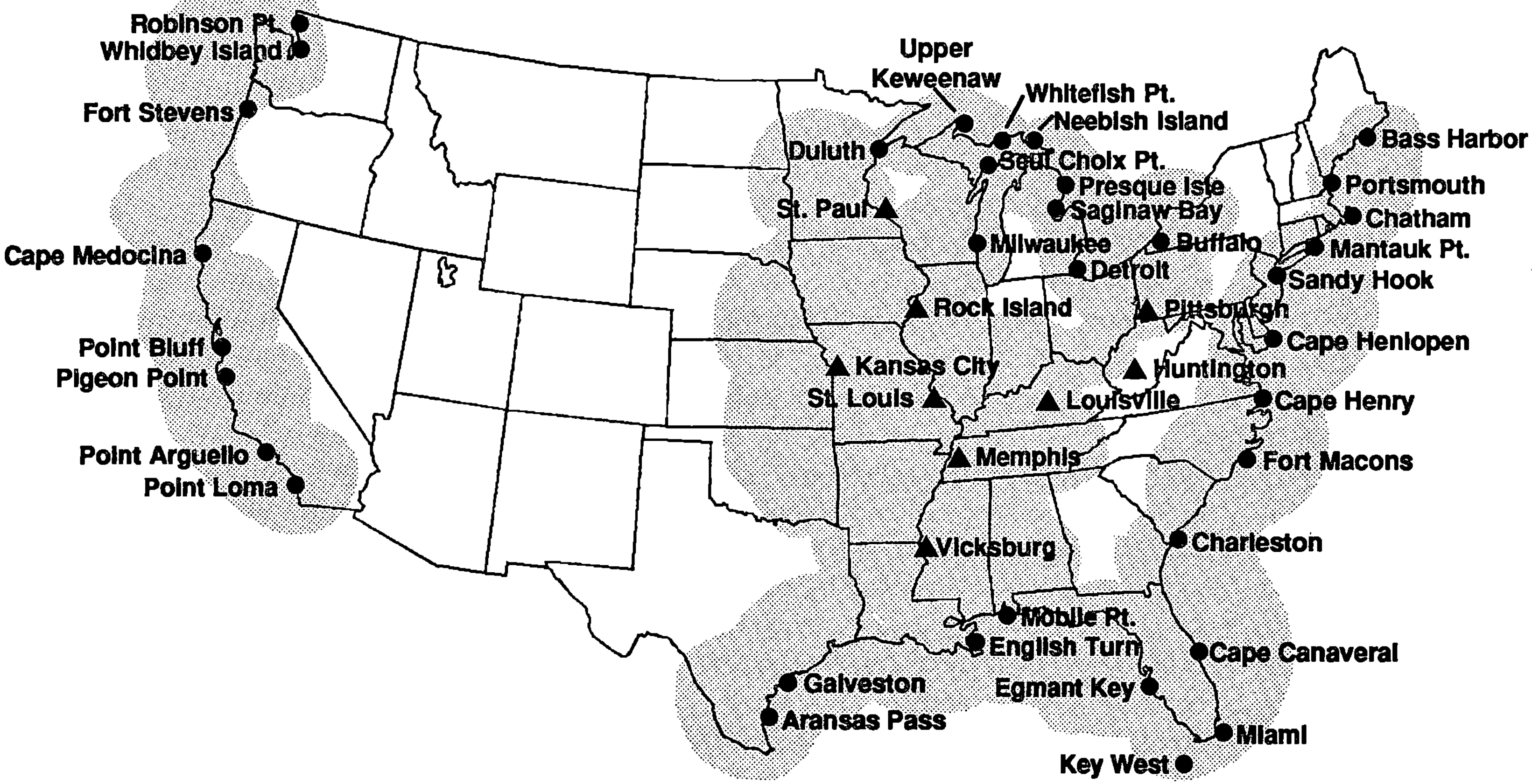
Some of the DGPS broadcast strategies used to create a real-time data link include:

A. Transmission and Referenced GPS Base Stations Are User Provided and/or Owned

1. Low-watt UHF, VHF (expected coverage of up to 40 km) or HF (expected coverage of 60-80 km) radios with radio modems to receive corrections

2. High-watt UHF, VHF (expected coverage of 60-80 km/FCC license required)

Location & Coverage Provided by Coast Guard & Army Corps of Engineer DGPS Base Stations



●Coast Guard DGPS Base Stations

▲Coast Guard DGPS Base Stations operated jointly with the Army Corps of Engineers

Iowa Department of Transportation

GPC20313

B. User-owned Hardware and Subscription DGPS Service

1. Single site reference station using radio broadcast data system (RBDS)/FM radio subcarrier signal (with an expected coverage of 60 - 80 km). RBDS protocols allow conventional FM radio broadcasts to carry digital data, including DGPS corrections on an inaudible portion of the FM signal. A network of FM stations will allow continuous DGPS service. As of this date, Iowa has limited coverage with four FM stations broadcasting DGPS.

2. Multi-site reference station using C-band satellite (with an expected coverage of North America). Data from the network reference stations are transmitted by land lines to a control center, checked for validity and uplinked to the communications satellite. Corrections are sent every 2 to 3 seconds.

C. Future Options

1. 1995 (estimate) Coast Guard's dual-frequency DGPS network transmitting in the lower range of the radio spectrum. Map 1 provides coverage of the proposed system

2. 1997 (estimate) National DGPS Wide Area Augmentation System (FAA-installed system).

The choice of the data link depends on the application, distance and terrain between the reference station and the mobile receiver. Each broadcast method must be evaluated on its ability to transmit error-free data, timeliness of the correction data when it arrives at the mobile receiver, and the frequency of the update rate. It has been estimated that to achieve accuracies in the 2-meter range, frequency of the corrections must not exceed 2 to 3 seconds. Methods that deal with real-time corrections have a higher level of complexity than post-processing so appropriate technical expertise support must also be provided.

2.5c RTCM 104 Standard

The Radio Technical Commission for Maritime Service (RTCM) established Special Committee 104. This committee addressed the methods used to provide differential GPS code (pseudo-range) and define the data link format between the base station and roving GPS receivers. The recommended standard provides GPS equipment manufacturers with common data messages and formats if they choose to adopt the standard. Most equipment on the market today state they are RTCM 104 compatible. However, some manufacturers interpret the standard differently. This can be a problem if equipment is purchased from several manufacturers and data is combined.

CHAPTER 3
Technology Review/Imaging

3.1 Technical Background

Collecting images of a highway and its environment, and at the same time recording specific data about the route, began in the early 1960s. This process is known as photologging. Photologging (see NCHRP Report #94, "Photologging" by William T. Baker) originally used 16mm film.

Photographs are taken every 0.016 km (.001 mile), and route data is collected simultaneously (milepoint, route number, date, etc.) and recorded on the film. Later systems used 35mm systems. A color negative film is used and can be viewed on microfilm or stop-motion projectors. The projector allows the photolog to be displayed in a way that approximates a motion picture.

Later image collection systems used video-based imaging technology. Video-based systems are appealing due to high frame rates, a variety of equipment choices, and the ability to adjust to fast changing lighting conditions. Many video-based systems conform to the interlaced NTSC video standard. These products record images based on time, rather than distance. This creates a jittery image due to vehicle movement while the images are collected. For example, if the vehicle is being driven at 50 mph, a conventional video-based system will collect an image with two parts, the odd field and even field. The fields will be 0.372 m apart and will result in a jittery image when the fields are combined. The solution is to discard half the image, with the resulting loss in resolution. Traditional NTSC-based videotape systems have less than half the resolution of 35mm film-based images.

The traditional recording format for interlaced video-based systems is videotape. Videotape provides a very inexpensive recording media, but one that is virtually impossible to use outside of the television environment.

The image capture process is the weakest link in a image system, but enhancements to the conventional NTSC video environment make the use of video technology practical as a replacement for film-based photolog systems. Mandli Communications has implemented a full-frame process on broadcast- quality NTSC video cameras. This eliminates the jitter problem that conventional video systems suffer. Also, to overcome limitations of tape access, an optical disc recorder is used.

The goal is to obtain and retain the highest pixel count. A higher density image equates to images that contain more information which can be used to evaluate additional conditions. Illustration 4 shows the pixel density for some of the existing video formats.

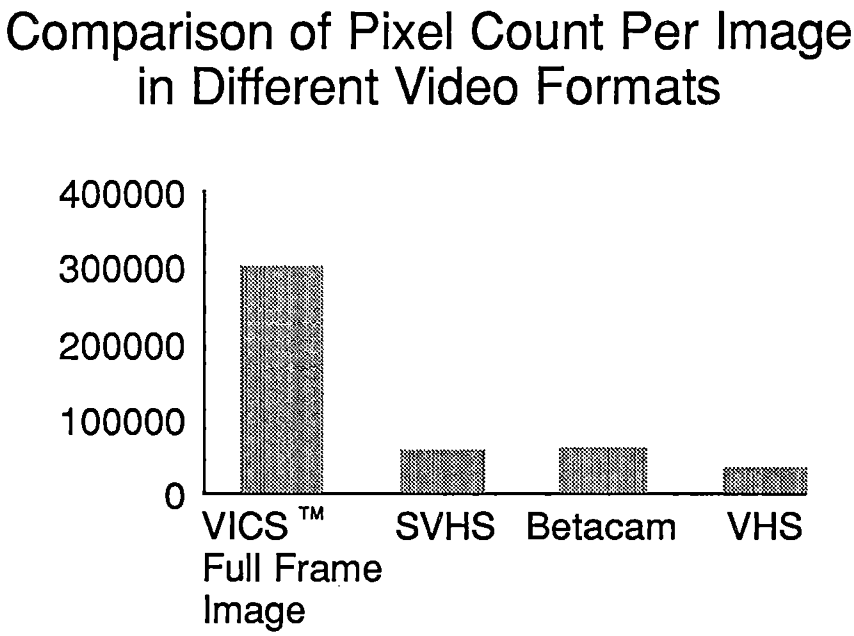


Illustration 4

Several additional imaging processes have been applied to highway imagery in recent years. For example, still digital cameras have been used for project work. These cameras are currently limited by their storage space, generally 96 images or less than 2 km of imaging; their lack of viable image compression technology; and their inability to move the images from the camera to mass storage devices fast enough to work in a highway environment. But all of these limitations will have solutions and digital systems will have the quality and practicality to replace the full-frame optical disc system.

CHAPTER 4

Test Environment

4.1 On-board Systems

Iowa DOT uses a Video Image Capture System (VICS™) to collect the full-frame images and route information. The department has used this approach since 1988. The system was enhanced in 1993 to include a second, right of way full-frame capture camera and GPS with inertial system. The VICS™ is currently mounted on a one-half ton 1990 Ford Club Wagon.

The VICS™ is designed to capture very high quality, full-frame images at highway speeds. The system features two full-frame capture, three-chip charged-coupled device (CCD) analog video cameras. Unlike conventional video cameras, the VICS™ cameras capture a full-frame image, or five (5) times the resolution of standard video cameras. Images are captured directly to two optical disc recorders. Illustration 5 shows the system architecture.

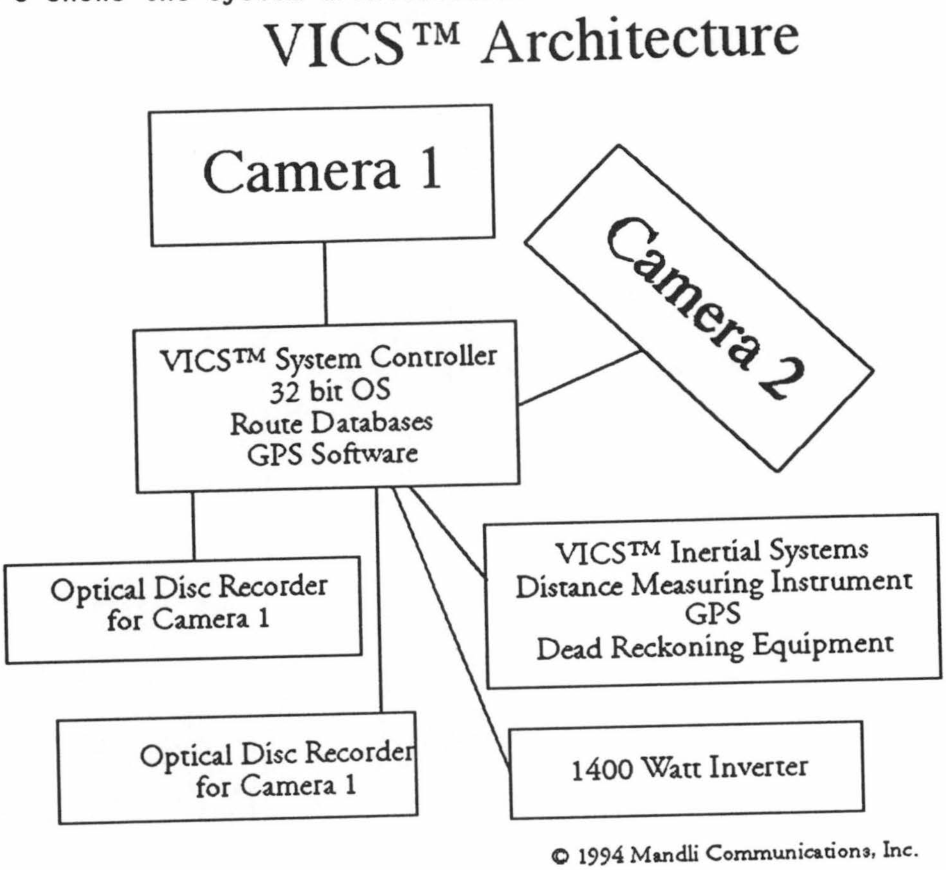


Illustration 5

The capture rate can be selected intervals in English or metric units. Typical distance between frames is 8 meters, but the system is capable of 3-meter capture if required. The system utilizes a 6-channel GPS receiver. A distance measuring instrument (DMI) and other inertial systems are also used to capture data. Reference data, including route ID, county, direction of travel, date, time and kilometer point data, are collected.

Differential GPS can be collected with a real-time system or a base station. Post-processing software is used to provide the final data output. The VICS™ system CPU with a 32-bit operating system controls the video and data subsystems and builds a route database as the images are captured.

Photo 1 shows the layout of the equipment and camera angles. Photo 2 is a close-up of the side camera. This camera can be positioned at a near 45° angle or pivot to a full 90 degrees. The current practice is to leave a small overlap between the two images.

Photo 1

Photo 2

The data collection system consists of a GPS sensor with antenna, a dead reckoning sensor, a data processor, and a data link receiver with antenna. Illustration 6 shows a block diagram of how the signal is processed for GPS and differential data link.

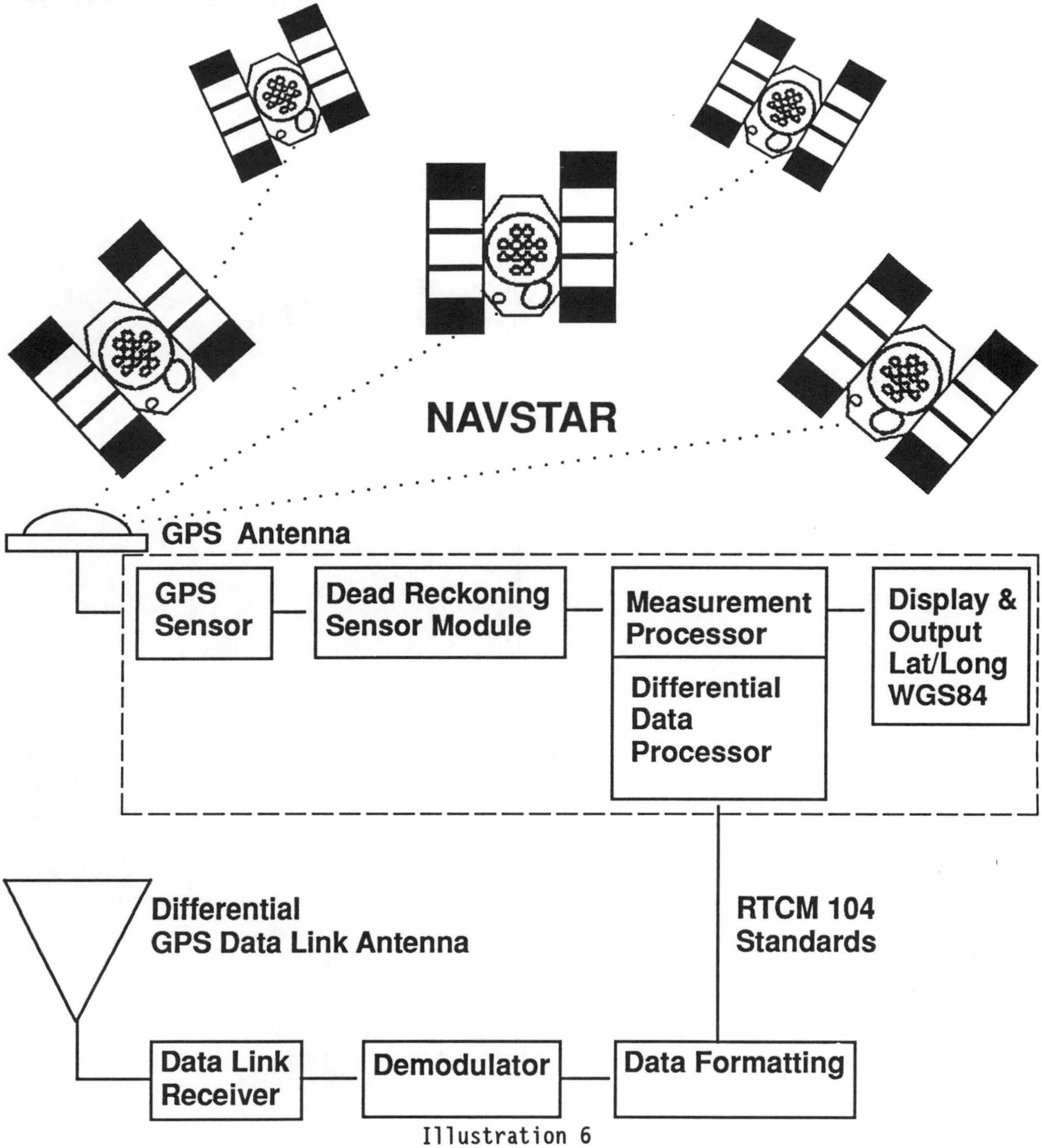


Illustration 6

Two methods were used to receive differential corrections on board in the vehicle. Both are services currently being offered by commercial enterprises. The first system uses Radio Broadcast Data Services (RDBS) to broadcast DGPS from a single reference station over conventional FM radio (Differential Corrections Inc.). The second system uses multiple-reference stations (Wide Area) and broadcasts corrections over a communication satellite (OMNISTAR).

Each service provided recommendations for the placement of the data link antenna. This was to increase system performance and receive the maximum signal range from each system. Photo 3 shows the placement of the OMNISTAR communication satellite antenna.

Photo 3

4.2 Work Station Platform

Hardware and Software Used

The software configuration tested (RoadView IV®) was run inside MicroStation® and was tested on an IBM PC model 90 with 24 meg of RAM, a 540 meg hard drive, and a Micro Channel® ethernet card. The software was linked to an Oracle® database residing on a server via the ethernet card. In addition to the PC, a Panasonic TQ 3032F optical disk player and a Sony monitor were used to display the video images. The PC controlled the optical disk through the serial port.

Software Operation

The intelligent base map is loaded and displayed after PC startup and appropriate connections on the server made. See Illustration 7 for a picture of the interfaces being discussed in this paragraph. The appropriate optical disk, date and route is selected by using the Road View tool bar. Pointing to a position on the intelligent base map and clicking on the *apply icon* will cause an image of that location to be displayed on the monitor attached to the optical disk player. The user can then "drive" forward, backward, accelerate, decelerate, turn onto intersecting routes, and flip around and view the opposite direction by using the control tool bar. An icon on the map shows the user location as he/she travels on the road system.

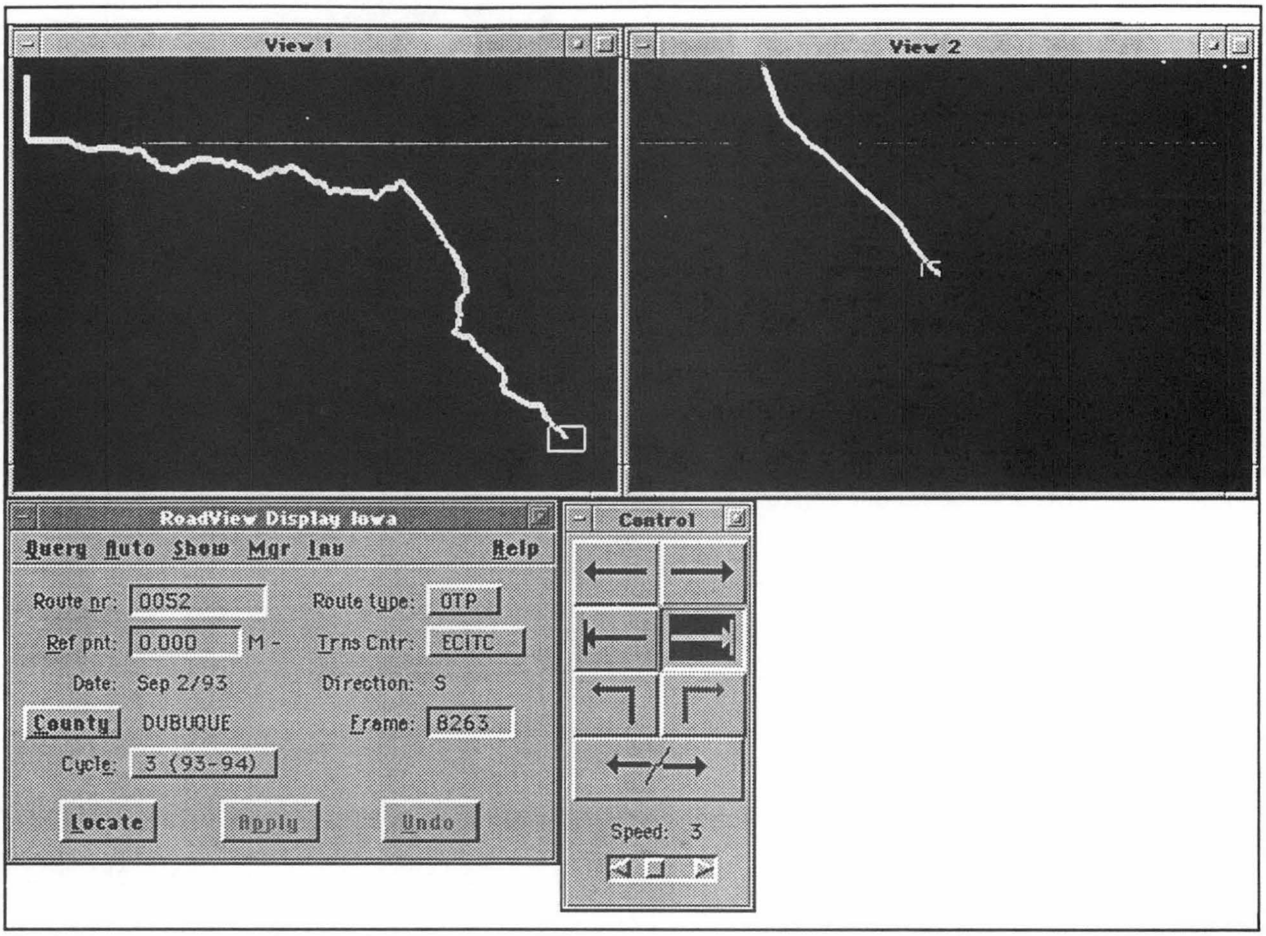


Illustration 7

At the same time, an image is displayed on the monitor attached to the optical disk player. See Illustration 8. These video images are taken at fixed intervals (26.4 feet or 8.04 meters). This image is geo-referenced and the referencing information can be displayed by using the pull down menus on the Road View tool bar.

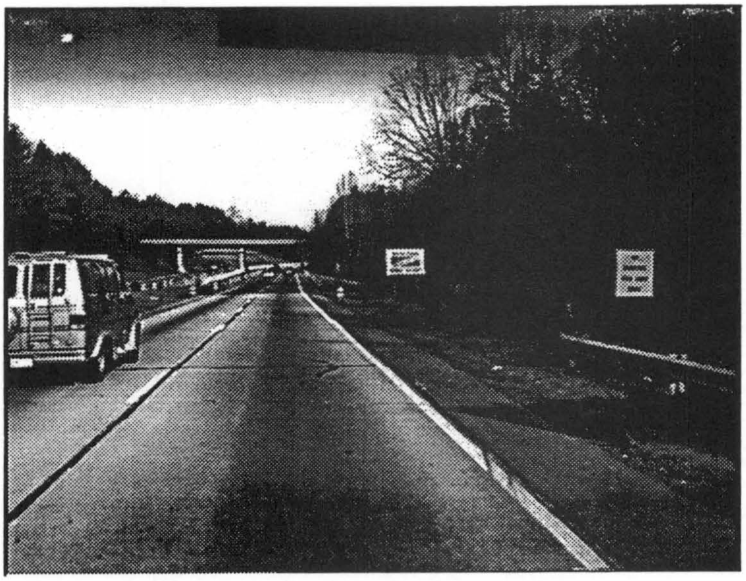


Illustration 8

Once a feature has been identified (signs will be used for this example), a user can also locate or create records in the server relational databases for information on signs, traffic counts, pavement conditions, features, bridges and other transportation data by using the pull down menus on the Road View tool bar. First a sign assemblage screen will be displayed which contains information about the support(s) for the sign. See Illustration 9.

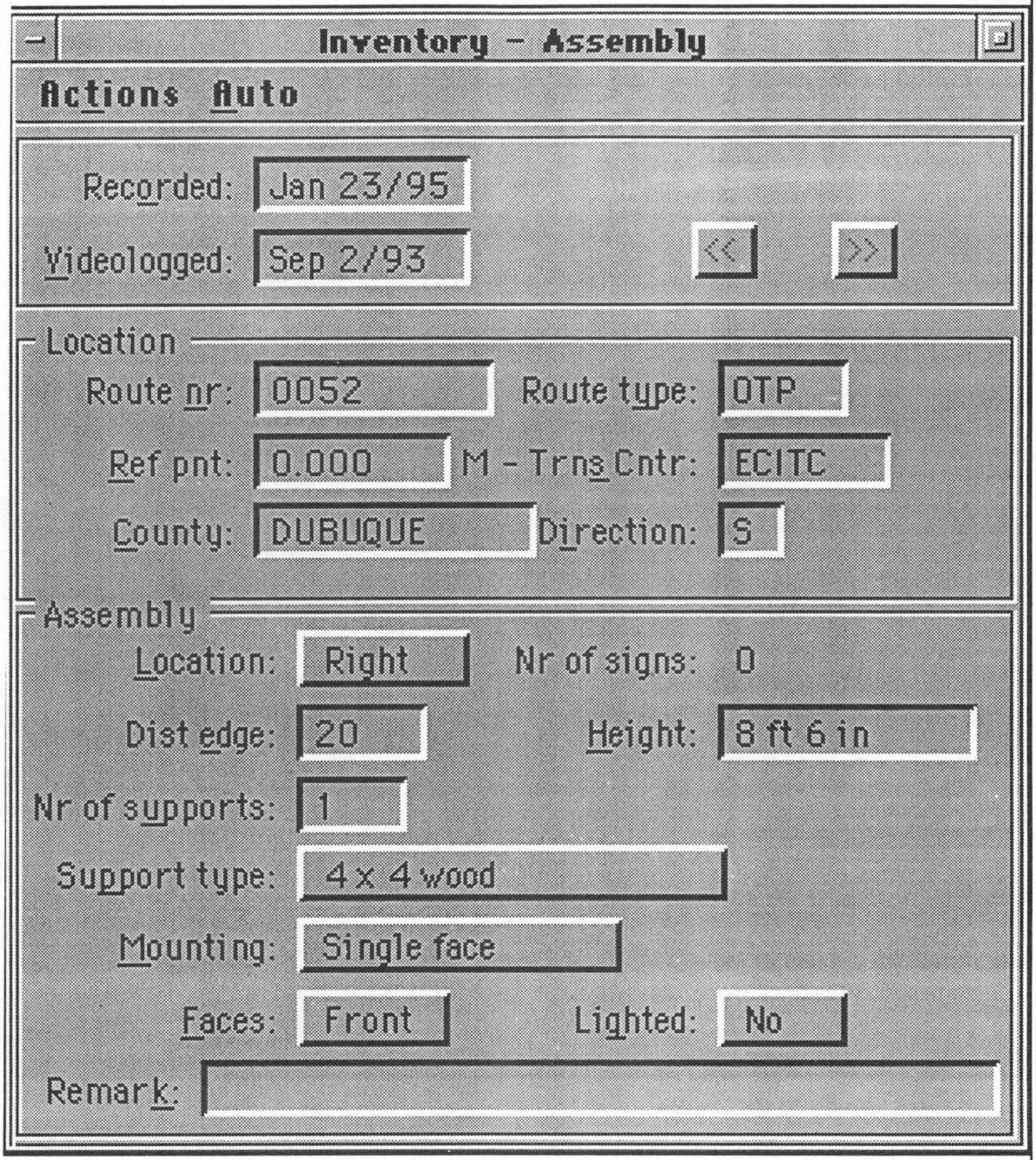


Illustration 9

After this popup window has been viewed/modified, another window will be displayed showing the information about the sign. See Illustration 10.

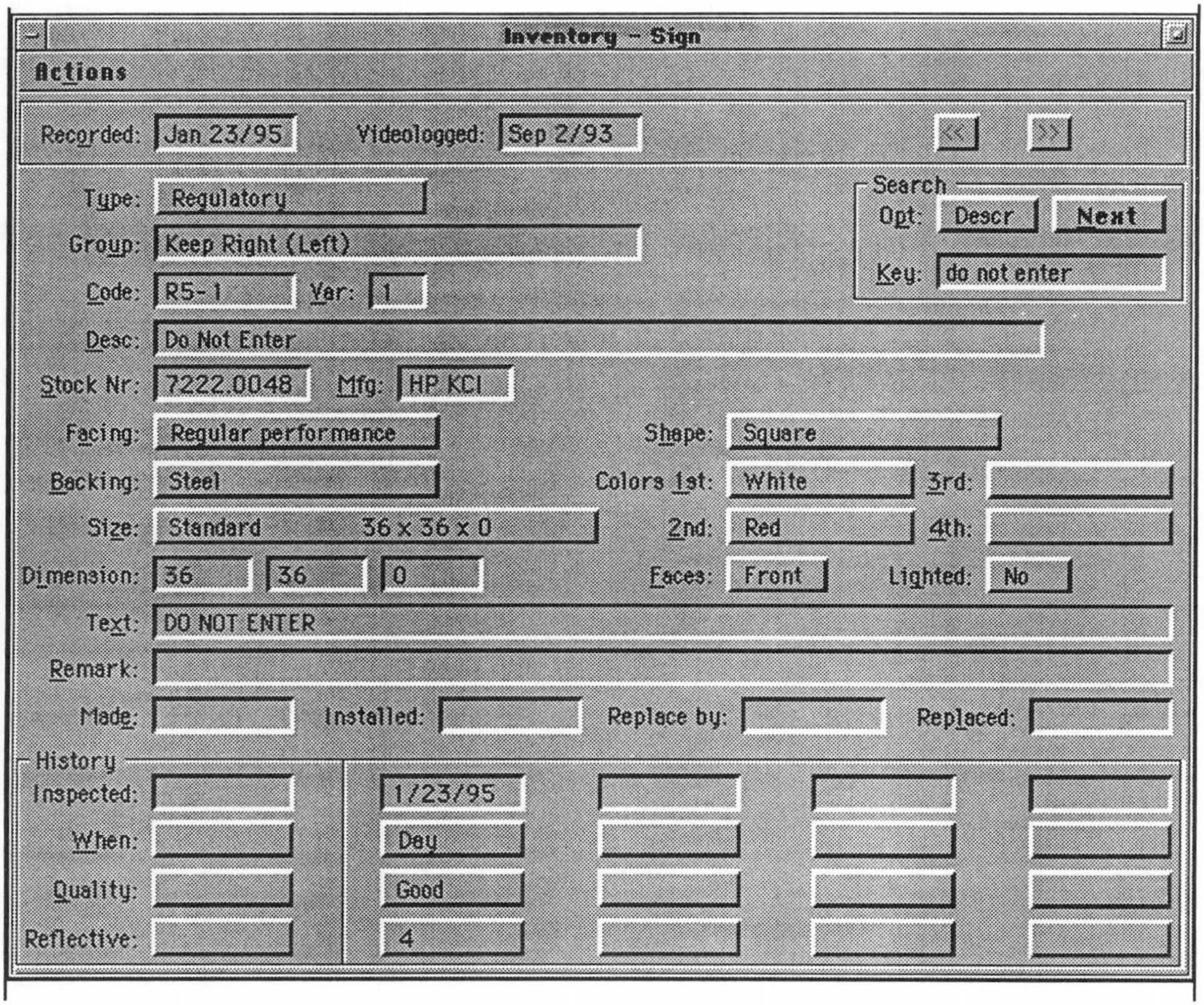


Illustration 10

If the user needs additional help entering data into the sign popup window, a help window is available with a graphic view of the signs along with the associated information. See Illustration 11. If the user enters information such as the sign code R1-1 (stop & yield), most of the information about the sign is automatically entered into the record (color/size/etc.).

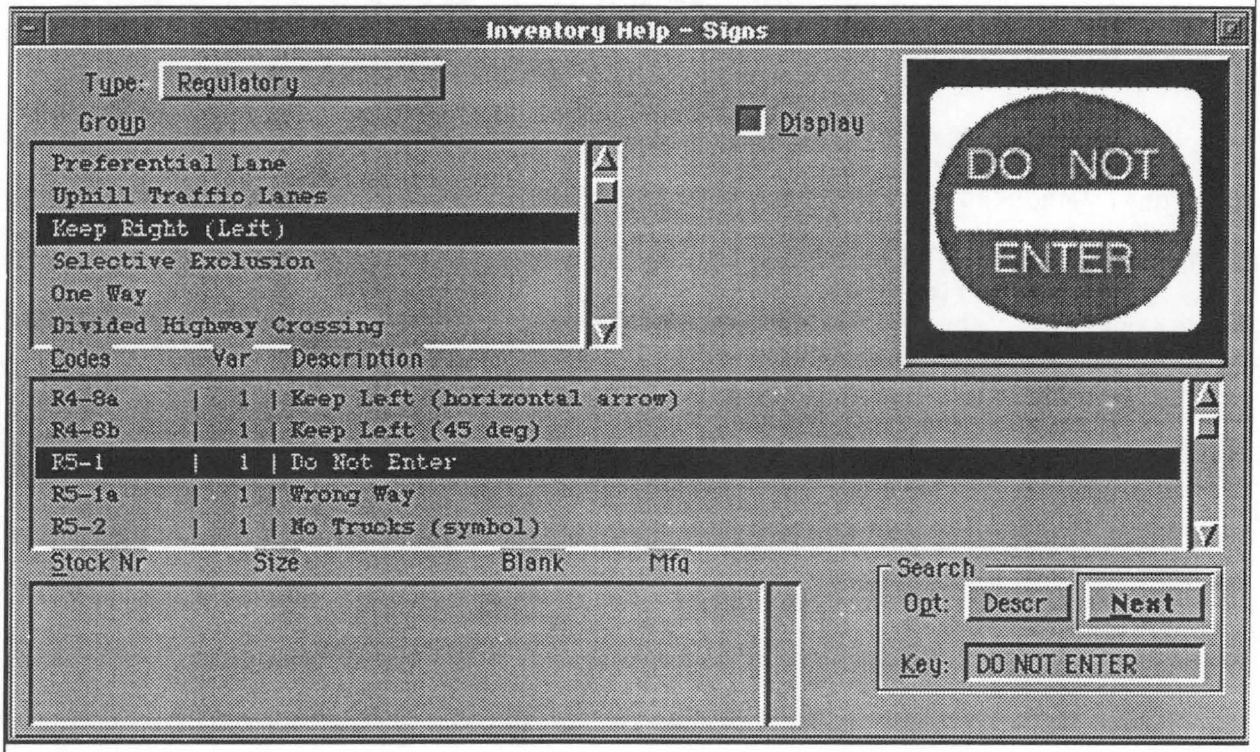


Illustration 11

4.3 Study Area

Navigation tests were made in several corridors to evaluate operating characteristics of inertial sensors as well as open road performance of DGPS services.

Two FM radio stations in western Iowa broadcast the DGPS FM subcarrier signal. The van drove between these stations to evaluate coverage area and signal conflicts between the two frequencies.

Site 105 is located at Latitude 42 1 44.47 Longitude -93 39 8.04 on the Iowa State University campus. The point was used in a previous GPS study and is a National Geodetic Survey benchmark with known mean sea level elevations.

The Des Moines Central Business District provided long periods of signal blockage (urban canyon). Illustration 12 demonstrates gaps that can be caused by this type of operating environment. Illustration 13 shows this same corridor enhanced with dead reckoning data.

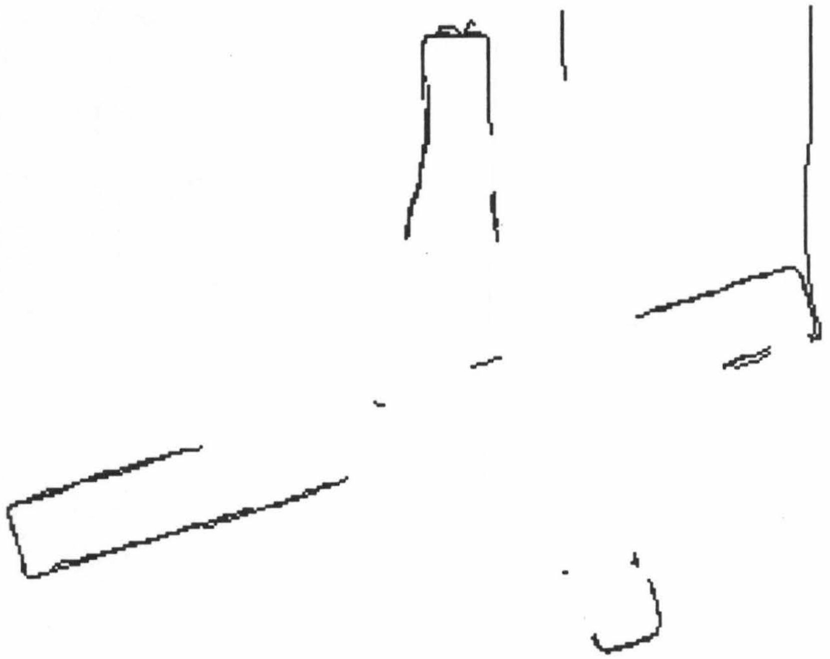


Illustration 12

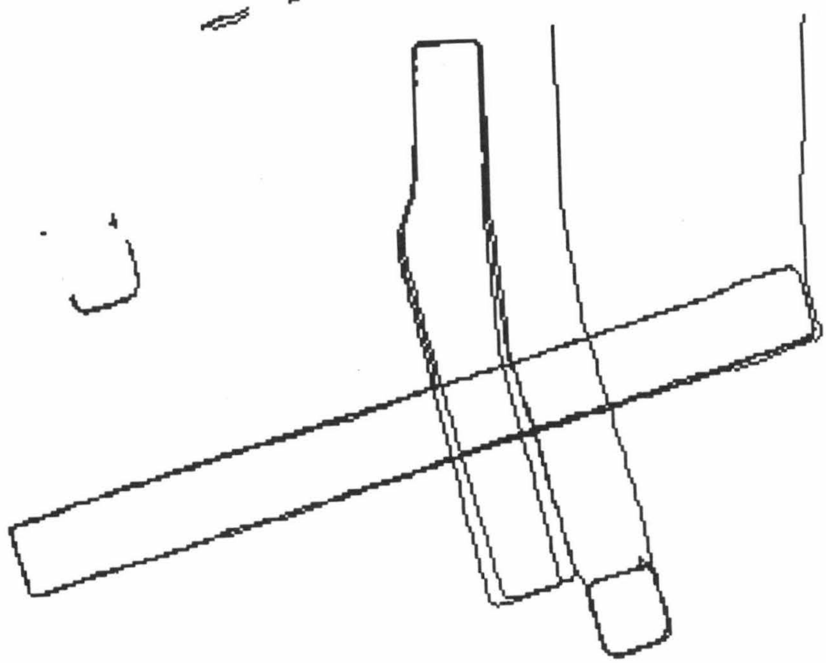
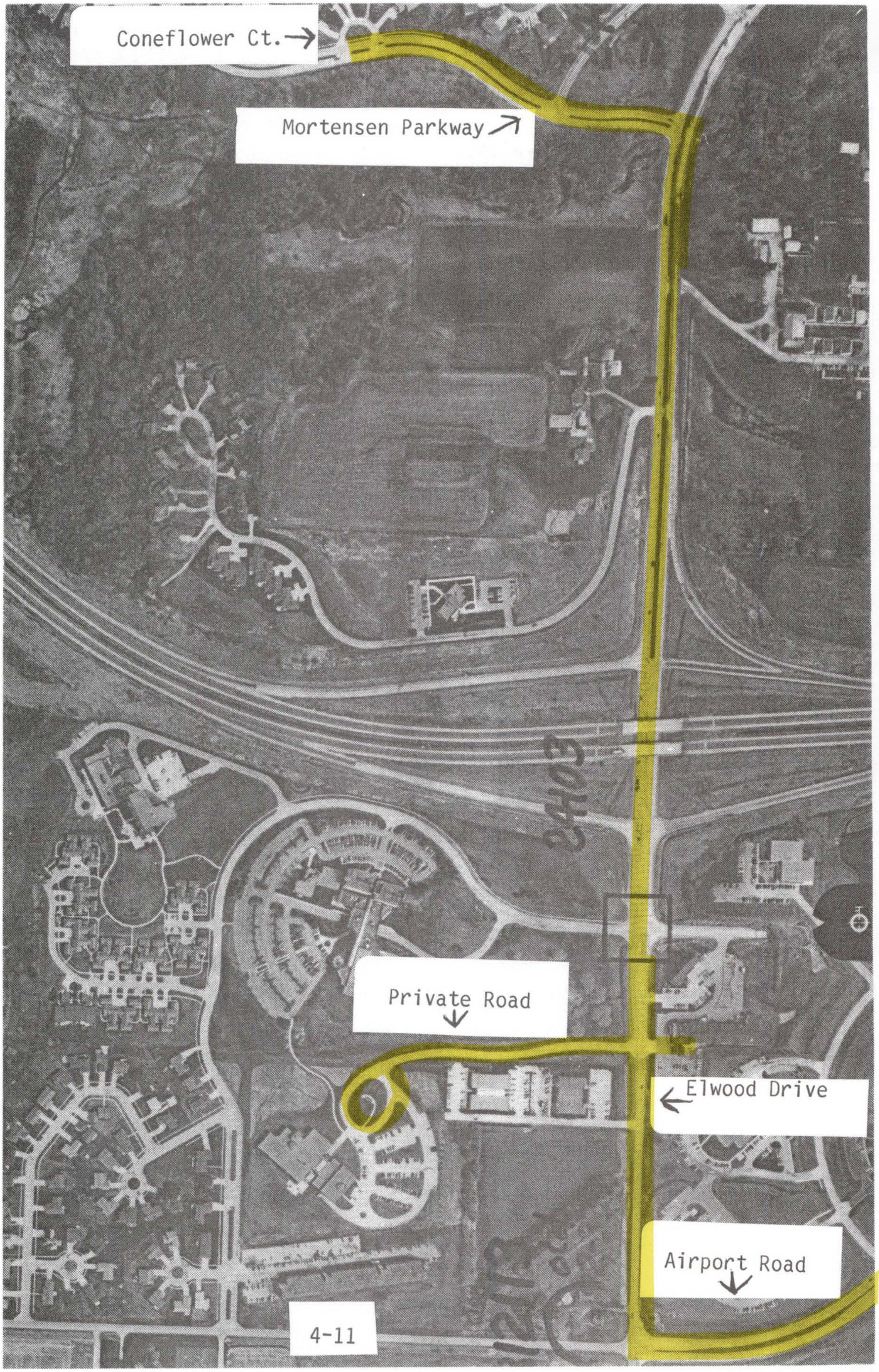


Illustration 13

Story County orthophotos and the USGS 7.5 minute Quad Map (West Ames) were used to establish ground truth. Illustration 14 shows the West Ames study area.

Illustration 14



The West Ames area was selected because of previous aerial photogrammetric flights. Orthophotos are corrected by removing errors due to radial distortion and changes in elevation. As a result, this data provides accurate relative and absolute measurements. Relative accuracy is the distance between features in an image, while absolute accuracy is the ability to match a known coordinate system.

The USGS 7.5 minute Quad Map (1:24,000) was used to verify GPS output to a known coordinate system. However, the geo-referenced orthophotos were not available as a backdrop to evaluate the data from the GPS receivers.

CHAPTER 5

User Requirements

5.1 Applications Evaluated

Geographic Information Systems span all types of applications, each requiring a different level of spatial database precision. Illustration 15 shows the range of spatial databases with the expected precision for each application. To track roadway features users have expressed a need to have a relative accuracy of 3 to 5 meters.

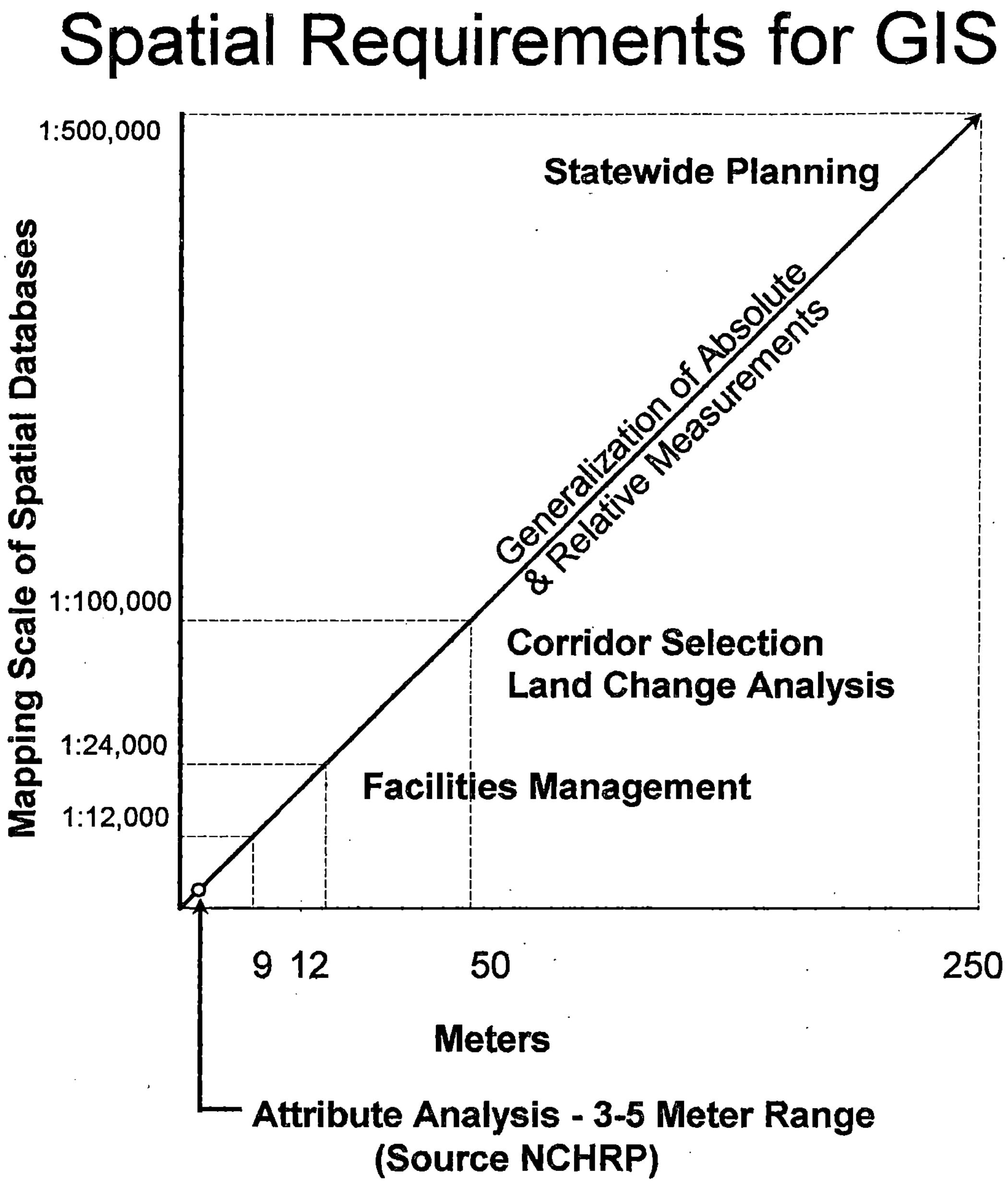


Illustration 15

Illustration 16 provides an example of a USGS 7.5 Quad (1:24,000) map used as the backdrop for the DGPS van trace. Displaying 3- to 5-meter geo-referenced features will require a higher resolution mapping product.

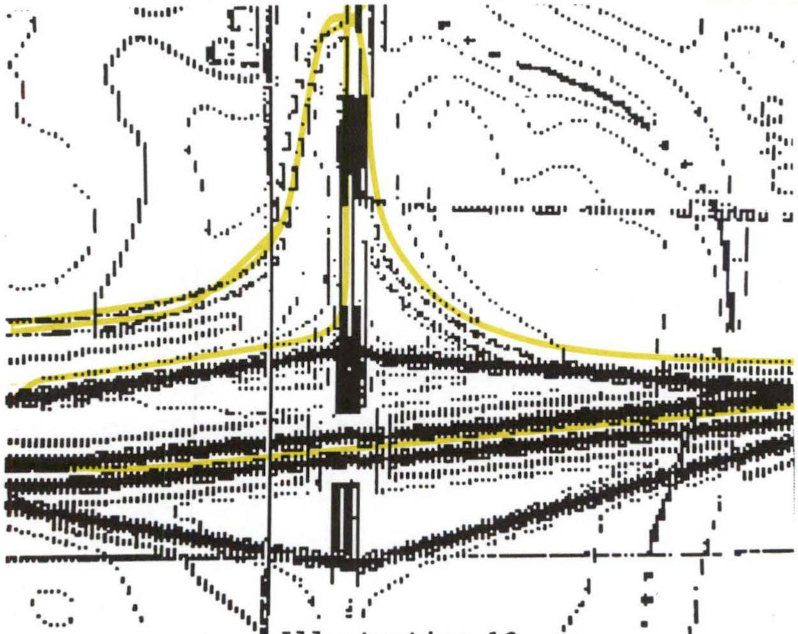


Illustration 16

Sign inventory and calibration of the milepost markers were the two applications used to test the capabilities of the system. Currently, there is no standard statewide sign inventory program. Various methods are currently in use from no inventory to paper copies to various "homemade" and pre-packaged computer programs. A tool is needed to bring these initiatives together. Also, the pavement management system relies on a milepost reference system to maintain specific road sequence checks from year to year. Both applications require verification of roadside elements to maintain the integrity of the database.

5.2 Hardware/Software

Integration of all transportation management systems is critical. These systems should be attached to a reference "base" system which utilize GPS coordinates and GIS mapping. This would allow users throughout the department to access any of the management systems by first entering the base system. All systems would use the windows environment so users wouldn't have to learn how to operate individual programs.

The program needs to be flexible and accommodate the department's sign numbering system. It should have the capability of including signs that are not already in the tables. The program should contain enough storage for many years' worth of inspection, replacements, etc., of the sign.

Being able to attach (electronically) a picture of the sign would greatly improve user acceptance. Also, certain fields should be a "required entry" so that essential information is not overlooked.

A field review would still be required to check for missed signs, include installation dates, and to check offset, height and size. However, it would be useful to be able to gather some of the dimensions from the images.

An off-route reference is needed when the videolog is detoured and does not capture primary highway signs.

For each route, ensure that an accurate GPS coordinate has been collected. This will allow previous data to be correctly matched. It would also be important to add adjusted reference points if required for each frame, using a linear equation. This will allow adjustments for kilometer errors, route changes and frames per kilometer drift.

Also, starting with the 1995 videologging season, images will be captured at 100 frames per kilometer and each frame will have a kilometer point. Since the signing will remain on the English system for the foreseeable future, we will need to display all frames in both English and metric systems.

It was also noted that experienced users preferred to use the keyboard and would like to see keyboard equivalents to the common mouse operations.

5.3 Information From Videolog

Entry fields obtained using the videolog:

- Route Name/Number
- Location, Reference Point
- County
- Transportation Center
- Direction of Travel
- Position (right, overhead, left)
- Support Type (steel breakaway, overhead truss, wood)
- Number of Supports
- Sign Orientation/Direction Sign Faces
- Lighting
- Colors
- Legend/Message
- MUTCD Designation Number
- Stock Number

Entry fields not obtained using the videolog:

- Installation Date
- Condition
- Backing Material (aluminum, wood)
- Sheeting Type (encapsulated lens, embedded lens, etc.)
- Offset, Height & Size (future enhancements will allow these to be obtained)

5.4 Advantages/Usefulness

The Sign Inventory Program was easy to use and was nicely put together. The procedures were logical, straightforward, and included all of the required data entry locations needed to perform a complete survey. Unfortunately, only 100 signs were inventoried before a glitch in the hardware platform prevented adding more signs. This glitch also prevented documentation of reaction from field personnel who had experience gathering sign inventory data using in-the-field techniques. Estimates of speed at which the signs could be entered could not be independently verified, but discussion with the system integrator/service provider stated that trained personnel can enter 45 signs per hour without using the measuring tool and 15 signs per hour if measurements are included. However, experience that was gained did demonstrate that it did not take long to become proficient with the system.

Following are additional comments/observations:

A uniform approach to collect and analyze sign inventory will add credibility and increase the use of the sign inventory data. However, having other states or jurisdictions adopt it would make upgrading and future serviceability of the program more practical with additional users.

Being able to locate signs or knocked down signs, using GIS/GPS would be an advantage to maintenance personnel. Central and field office personnel could check sign spacing, locations, etc., in the office rather than traveling to the site.

When initially setting up the data base, most of the data could be entered at a computer rather than in traffic. The system would establish consistent methods to handle special circumstances, e.g., locating signs on crossroads or ramps. This process would also be beneficial for field offices because someone in the central office would provide the field office with an inventory that would be 75 percent completed.

CHAPTER 6

Test Results

6.1 Inertial Sensors

Three different categories of sensors were tested. The first type tested used a flux gate compass which provided the following results:

1. Three-degree errors were caused by curvatures in the roadway.
2. Passing vehicles (large trucks) caused more than three-degree errors.
3. Large steel buildings caused more than 10-degree errors.

The oscillating quartz angular rate sensor was the next sensor tested. This sensor eliminated problems experienced with the flux gate compass but introduced another set of problems which involved a variable drift rate of the heading. When the data was analyzed it appeared that the accumulation of the position error was proportional to the square of the gaps length. Illustration 13 on page 4-10 and Illustration 32 on page 6-21 shows the rate of drift.

During preliminary bench tests of the fiber-optic gyroscope it was noted that it took over an hour to raise the internal temperature of the device up to its operational temperature of 30 degrees Celsius. From a operational standpoint, the time it took to stabilize and begin receiving valid data was not reasonable. The manufacturer is currently working to resolve this issue.

6.2 Static Tests

A number of tests were conducted at fixed locations to assess the accuracy of the different configurations tested.

The first test took place at site 105, which is located on the Iowa State University campus in Ames, Iowa. Eight hundred and sixty-eight satellite readings were taken at 1-second intervals.

Variable	Mean	Std. Dev.	Minimum	Maximum
Northing	4,653,204.77	0.2003871	4653204.38	4653205.30
Easting	446,012.83	0.1364259	446,012.43	446013.13
Ndiff	-0.4411279	0.2003871	-0.8400000	0.0840000
Ediff	0.7904839	0.1364259	0.3890000	1.0930000

All values are in meters and are based on a UTM projection using a GRS 80 spheroid and were taken using the OMNISTAR receiver. The mean and std. dev. (standard deviation) are the normal statistical terms. The variables Ndiff and Ediff are the difference from the known location. The following paragraph discusses the reasons for the systematic bias in the readings from the GPS receiver and the known location. As can be seen from the table the range of values for northings was 92 cm and for eastings it was 70 cm. Illustration 17 shows the dispersion of points for all of the 868 observations. The reason that there are only 20 points displayed is that many observations fall at the same locations.

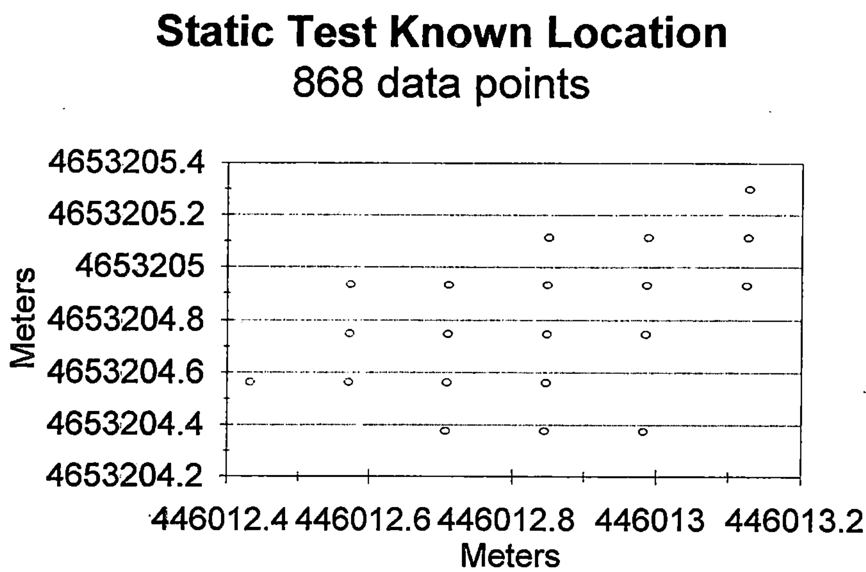


Illustration 17

Illustrations 18 and 19 display the first 100 observations in chronological order for the northings and eastings, respectively.

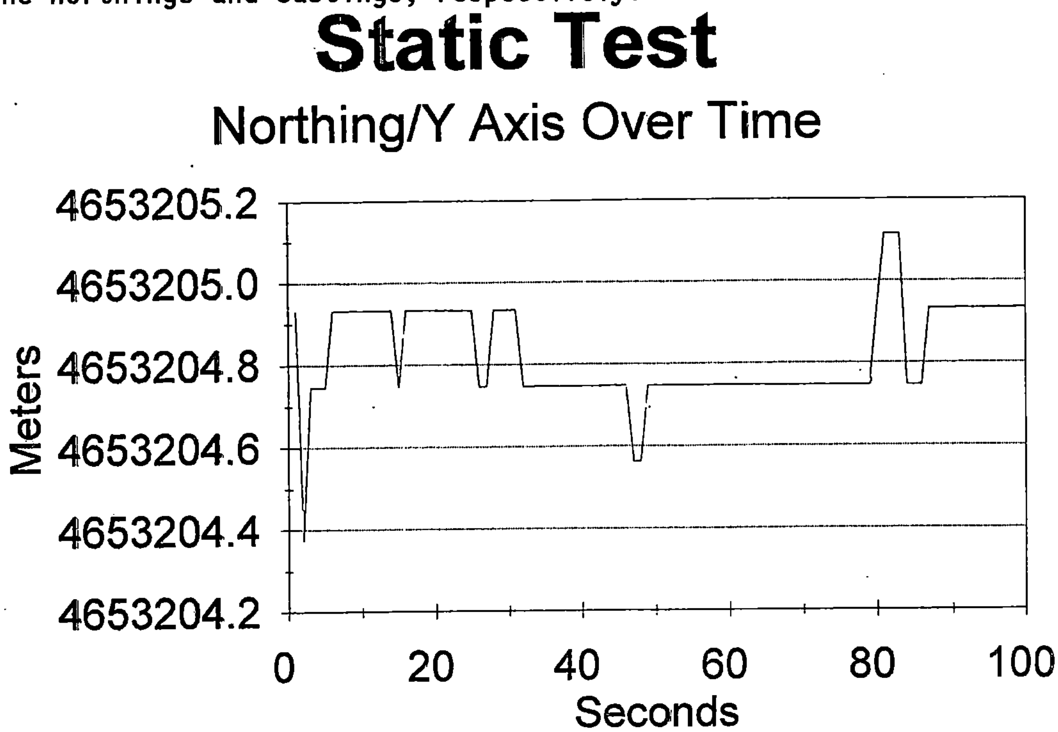


Illustration 18

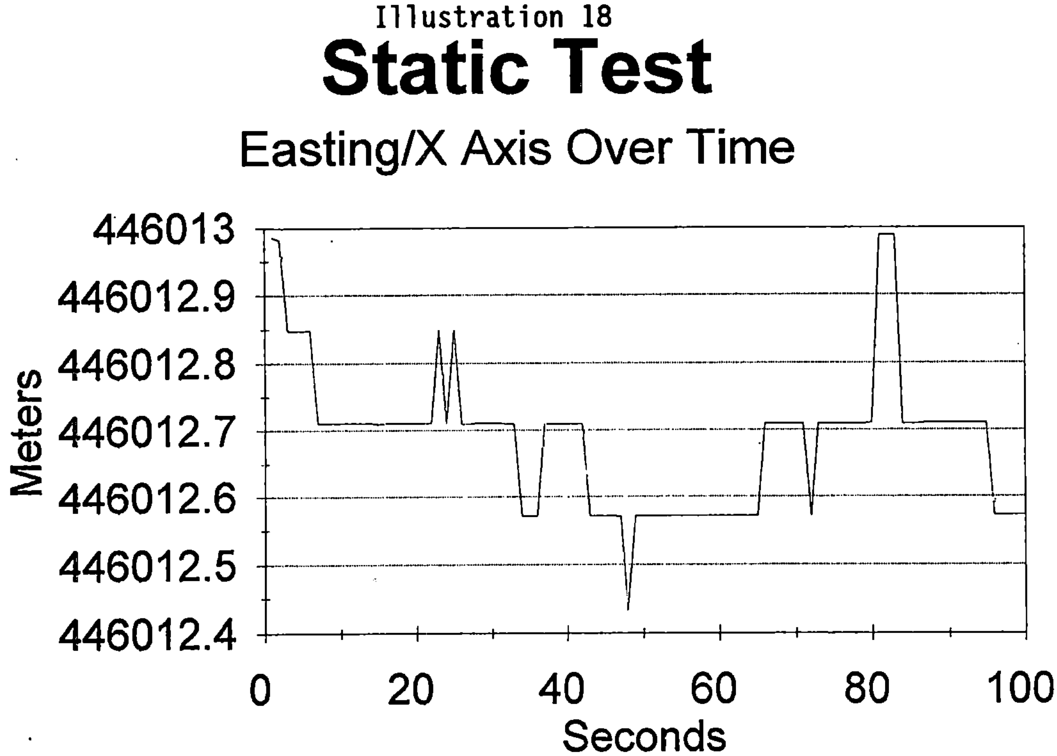


Illustration 19

In this case, the differences as shown in the mean values for **Ndiff -0.4411279** and **Ediff 0.7904839** were not zero, which indicates a systematic error is present. These differences were derived by comparing the OMNISTAR dataset to reference point 105. These systematic errors may be explained by the fact local NAD 1983 and NGS control was used to initially establish the location of point 105, whereas OMNISTAR utilizes higher order remote control for locational reference. These procedural differences in determining the location of point 105 will complicate accuracy comparisons. As a more global reference system is adopted, it is expected this systematic discrepancy will not continue to be a factor.

The next static test took place in the Iowa DOT parking lot. Over 2-1/2 hours of data (9,350 observations) were taken by the OMNISTAR DGPS service using a 12-channel GPS receiver.

Variable	Mean	Std. Dev.	Minimum	Maximum
Northing	4,652,410.15	0.5347776	4,652,408.41	4,652412.85
Easting	448,448.64	0.6006422	448,446.88	448,450.73

The values are in meters based on a UTM projection using a GRS 80 spheroid and were taken using the OMNISTAR system. The point was chosen at random in the Iowa DOT parking lot so there is no known reference point and no differences from a known location were computed. The range in northings was 4.44 meters and in eastings was 3.85 meters. Since all points were used without evaluating PDOP values or performing other quality checks on the data, this range appears reasonable. The standard deviation indicates you can achieve about a 1-meter system with a 95 percent confidence interval; but, as shown, the data has points located outside that range.

The following table shows the displacement in seconds for latitude and longitude, and the displacement in meters for altitude for different receivers with and without differential correction. All latitudes and longitudes are based on the WGS 84 spheroid. All displacements are shown as standard deviations.

Receiver	Number	Latitude	Longitude	Height
Differential >300 km	3859	0.8	0.7	1.1
Differential >300 km	2673	1.9	0.9	2.6
OMNISTAR R.T.	3862	2.0	1.7	4.1
OMNISTAR R.T.	2738	5.3	2.2	12.8
OMNISTAR Post	3859	.7	.7	1.0
OMNISTAR Post	2681	1.5	.7	1.8
Raw Data	3859	41.7	14.1	68.4
Raw Data	2673	38.7	24.7	80.3
Local Differential	3805	1.3	.8	1.6
Local Differential	2673	1.6	.7	1.8

For reference purposes, a difference of 1 second of latitude at the test site translates into 31 meters and a 1-second difference in longitude is 22.76 meters.

6.3 DGPS/FM Subcarrier Broadcast

The effective range of the broadcast corrections is strongly affected by the type of terrain and, most importantly, the type and installation of the data link antenna. Since the top of the video van is fiberglass, placing a ground plane on top of the van proved to be a critical factor. After the antenna was placed on a piece of metal, the DGPS broadcasts reached the expected range advertised by the service provider.

Several trips were made between two radio stations to determine the gaps that would occur as the signal switched to the strongest signal. The first attempt required several minutes before the new station signal was locked on. This equipment did have a feature that allowed storage of radio frequencies of the frequencies that provided the service, but we also programmed the system to automatically switch to the closest frequency using the positioning solution available from the system. Both approaches eliminated the frequency searches and DGPS corrections were instantaneously available while moving from one coverage area to another.

6.4 DGPS/C-Band Broadcast

This service provided a reliable real-time statewide coverage data link. However, if the C-Band signal lock was lost for more than 5 to 6 seconds the communication receiver would go through a 30- to 40-second lock-up routine and DGPS corrections were not available during this time period. Of course, the gap is filled in by the dead reckoning sensor, but this placed a greater need for a accurate dead reckoning sensor. From operational experience driving at highway speeds, any overhead structure would cause both the data link and the GPS signal to be blocked. But, normally the data link signal would lock back up and was not any more noticeable than the loss of the GPS signal.
Postscript: The service provider has improved the acquisition algorithm since the operational tests took place. The new specifications require less than 8 seconds to cycle through the lock-up routine and re-establish the data link anytime during 75 seconds of a signal blockage. However, if the signal blockage is longer than 75 seconds it will take over two minutes to cycle through the lock-up routine.

6.5 Repeatability Tests

All of the following illustrations were produced by CAiCE and a UTM projection in meters based on a GRS 80 spheroid. CAiCE is a software program which was used to make an autocad DXF file from the data gathered by the GPS Systems.

The West Ames study area was driven a span of several days at different times of the day to evaluate the performance of the system. The illustrations provide examples of what can be expected using different techniques to process GPS data. Each illustration shown is derived from the same data (with one exception noted).

The following labels are used to identify the different techniques that were applied.

LABEL	TECHNIQUE	ILLUSTRATION(s)
raw	No Differential GPS	Overview/Zoom
dif	Real-Time DGPS Using OMNISTAR	Overview/Zoom/Zoom +
omn	Post-Processed With OMNISTAR, Without Dead Reckoning	Overview/Zoom/Zoom +
om-	Post-Processed With OMNISTAR, Gaps Filled With Dead Reckoning	Overview/Zoom
dat	Post-Processed With Distance Based DGPS > 300 km Without Dead Reckoning	Overview
da-	Post-Processed With Distance Based DGPS > 300 km Gaps Filled With Dead Reckoning	Overview/Zoom
as-	Post-Processed With Local DGPS Gaps Filled With Dead Reckoning	Overview/Zoom/Zoom +

The term Overview denotes the entire West Ames study area, Illustration 14. (See section 4.3 for an aerial view.) The term Zoom denotes a circle drive within the study area. The graphs of the circle are based on an origin of 446719.177 (easting and also referenced as x) and 4649854.951 (northing and also referenced as y) in meters. All of the illustrations are slightly adjusted to avoid distortion along the axes (one meter on the x axis is approximately equal to one meter on the y axis). The term Zoom + is a close-up of the northern part of the circle graphs.

The data used to create the plots in this section came from the dataset collected on Nov. 5, 1994. However, to compare various DGPS solutions the files were processed using different techniques. Please note that Illustration 31 labeled "Dat" used a different dataset to compare the results of the distance-base DGPS process. The Nov. 5, 1994, "Dat" was missing some information so data from tests conducted on Oct 31 were substituted.

The following descriptions highlight specific areas of interest for each illustration:

raw

This plot highlights how selective availability (SA) impacts GPS. The beginning point of the data file starts with the van going west on Mortensen Pkwy., marked with an X. The relative position should be north of the other track but, as shown, is south of eastbound direction on Mortensen Pkwy. SA also shifted the tracks in a similar way on Airport Rd.

raw/Zoom

SA also makes it difficult to sort out the circle. The path was driven 10 times using the inside curb as a guide.

dif

The trace accurately represents the relative position of the van. However, the data link was lost on the northbound segment on Elwood Drive and this part of the trace represents standard GPS data.

dif/Zoom

One path clearly lost some of the data and was not as smooth as the other paths. dif/Zoom + shows at times the path was over 5 meters from the other paths.

omn

The trace is smoother and shows less distortion. Notice the gap missing on the northbound segment on Elwood Drive; again, as previously identified in the dif file, this section lost the data link.

omn/Zoom

Again, one path clearly lost some of the data. omn/Zoom + shows a close-up of the path.

om- & om-/Zoom

The trace is smoother and the gap on the northbound segment on Elwood Drive has been filled in by dead reckoning.

dat

Demonstrates how critical data continuity and file management is at the reference station. Data was missing in the middle of the trace. The beginning point of the missing data has been identified with an A and the ending point has been marked with a Z. The remainder of the trace shows data was available from the reference station to correct the on-board data.

dat (Oct. 31, 1994)

The trace accurately represents the relative position of the van.

da-

Data was missing in the middle of the trace so the gaps were filled with dead reckoning. The trace does not represent relative position of the van. Notice the drifting of the heading on Airport Rd. da-/Zoom shows the same drifting on the circle.

as-

The traces accurately represent the relative position of the van.

as-/Zoom & Zoom +

The scatter diagrams confirm that the system is capable of 2- to 3-meter accuracy.

Raw
November 5, 1994

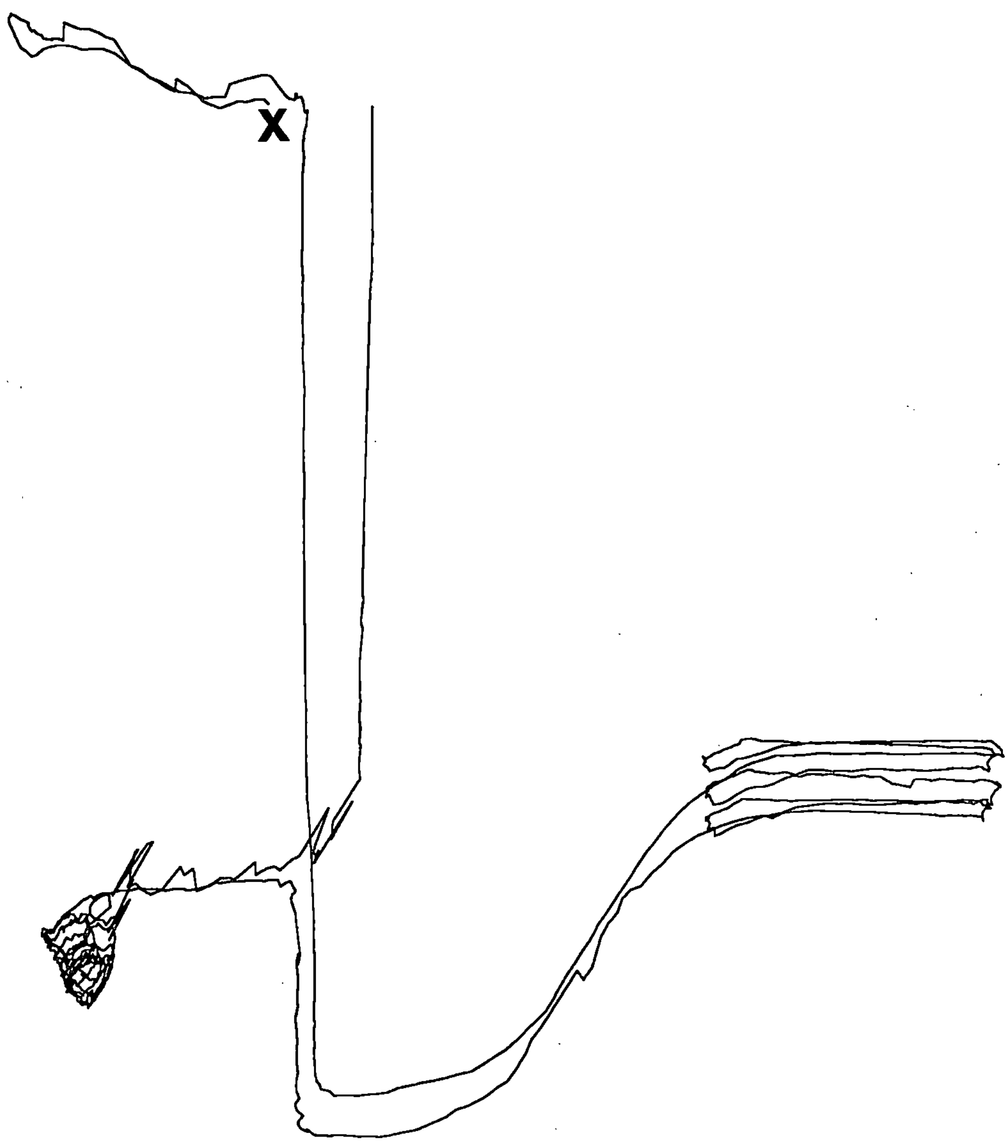


Illustration 20

Raw/Zoom

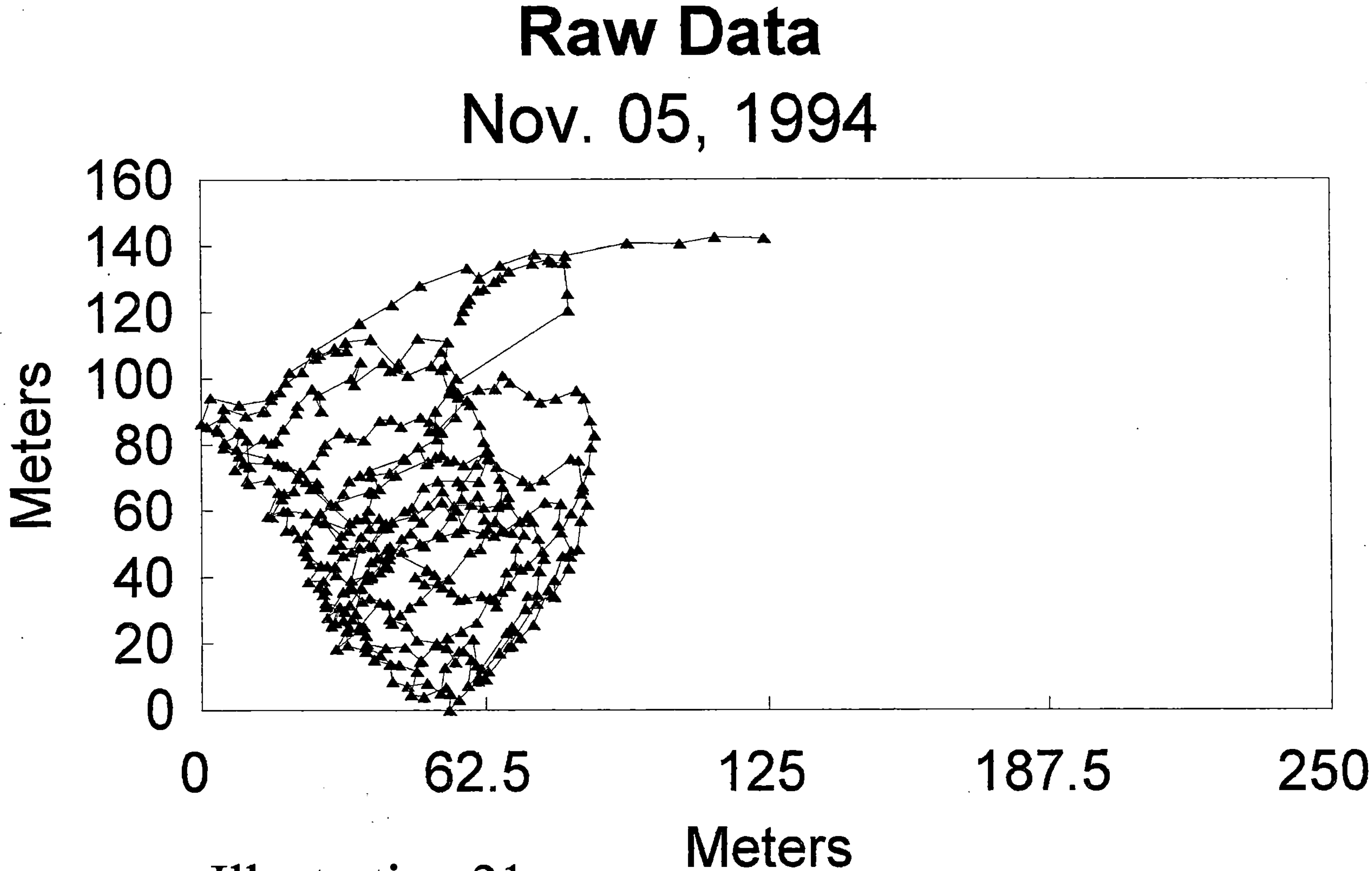


Illustration 21

Dif
November 5, 1994

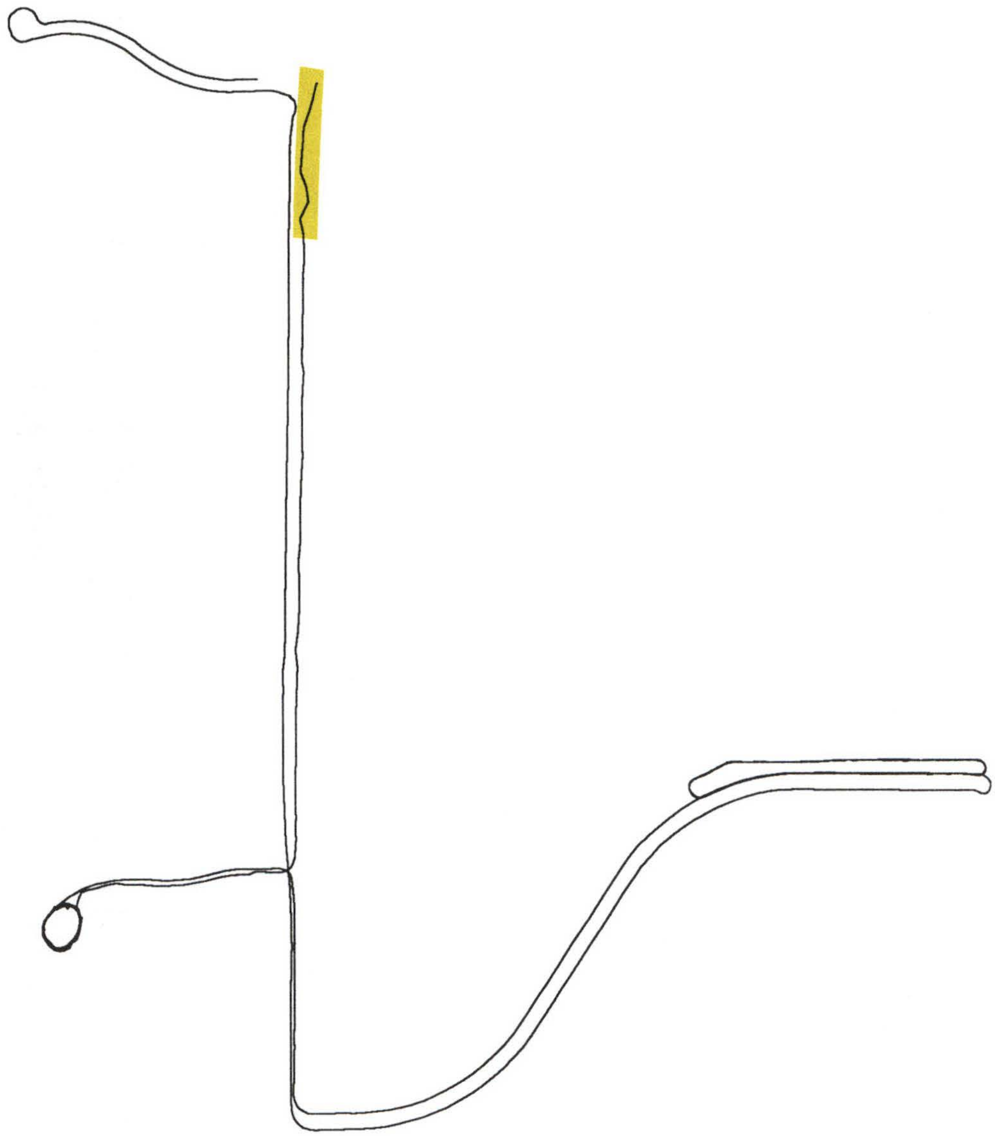


Illustration 22

Dif/zoom

Real Time DGPS - No Dead Reckoning

C-Band SIgnal - Nov. 5, 1994

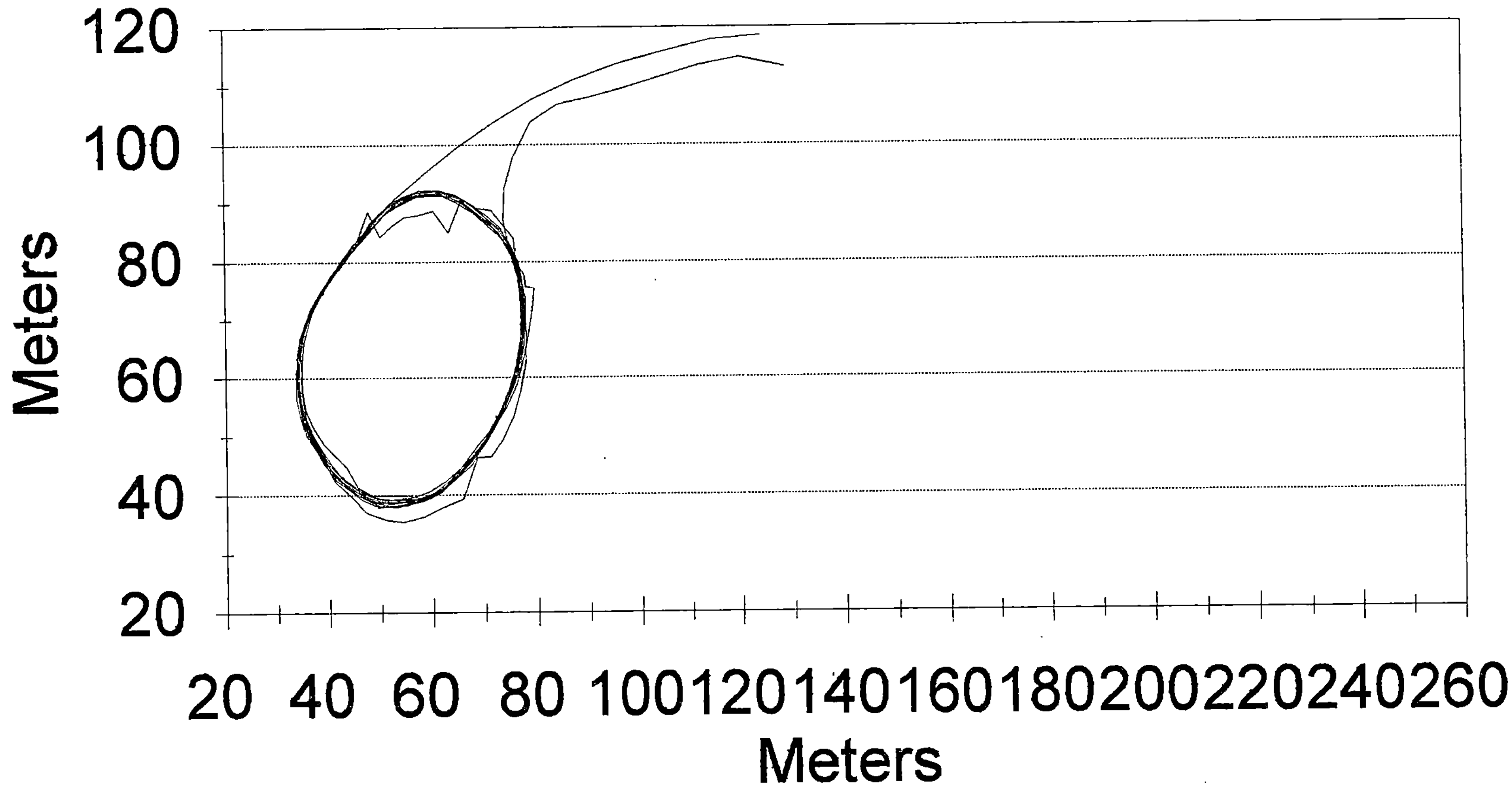


Illustration 23

Dif/Zoom+

Real Time DGPS - No Dead Reckoning

C-Band Signal - Nov. 5, 1994

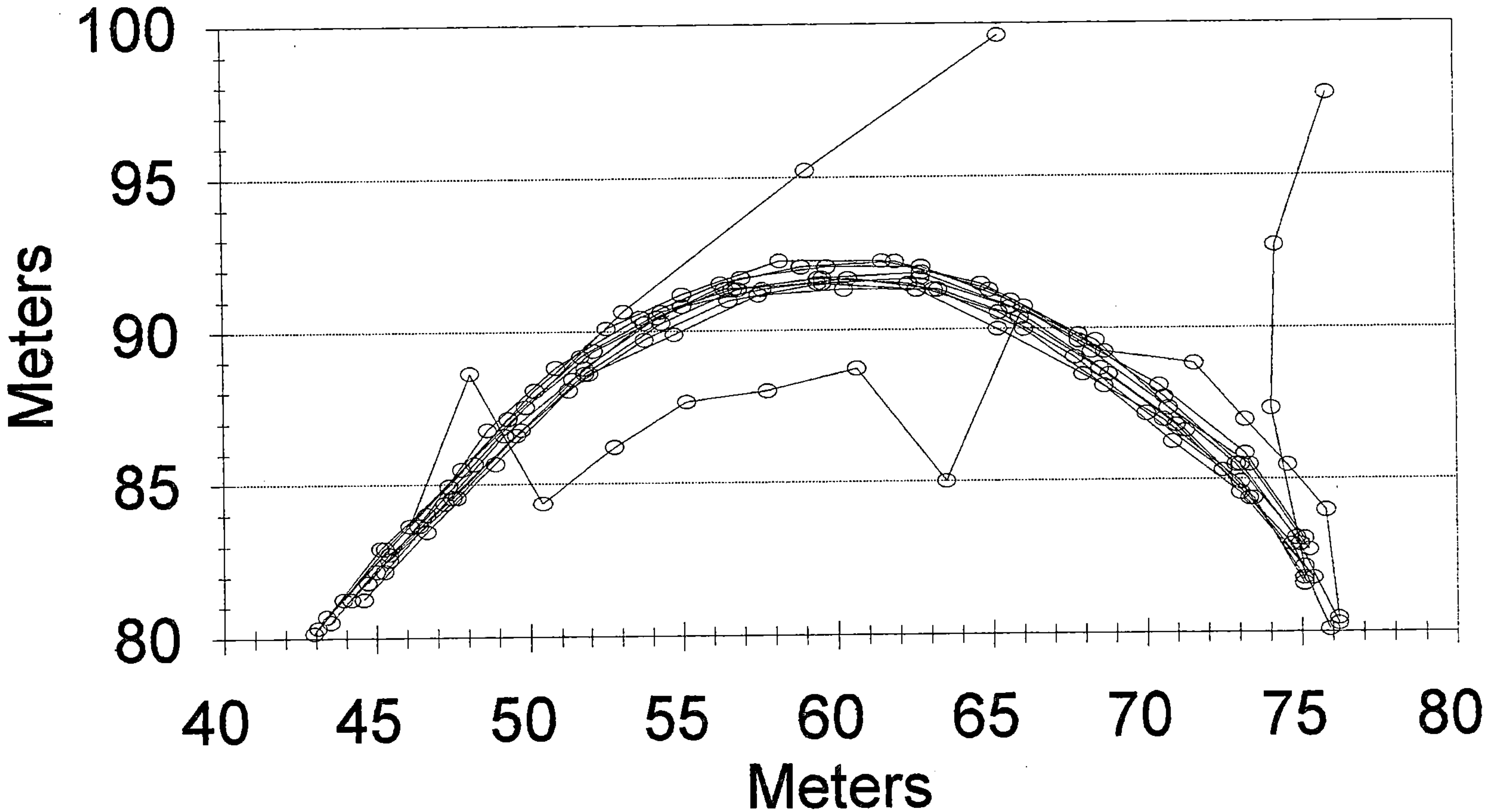


Illustration 24

Omn
November 5, 1994

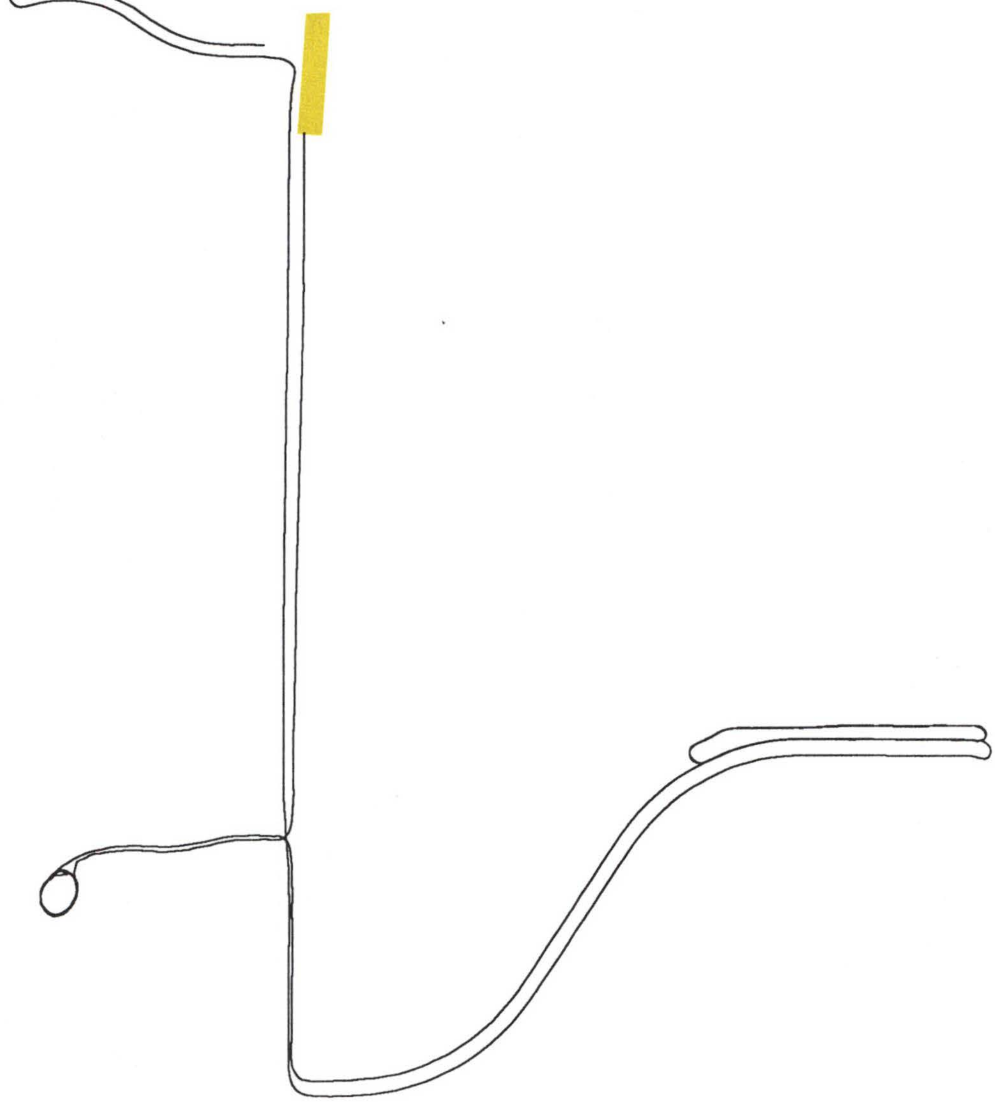


Illustration 25

Omn/zoom

Post Processed -DGPS/No Dead Reckoning

C-Band Signal - Nov. 5, 1994

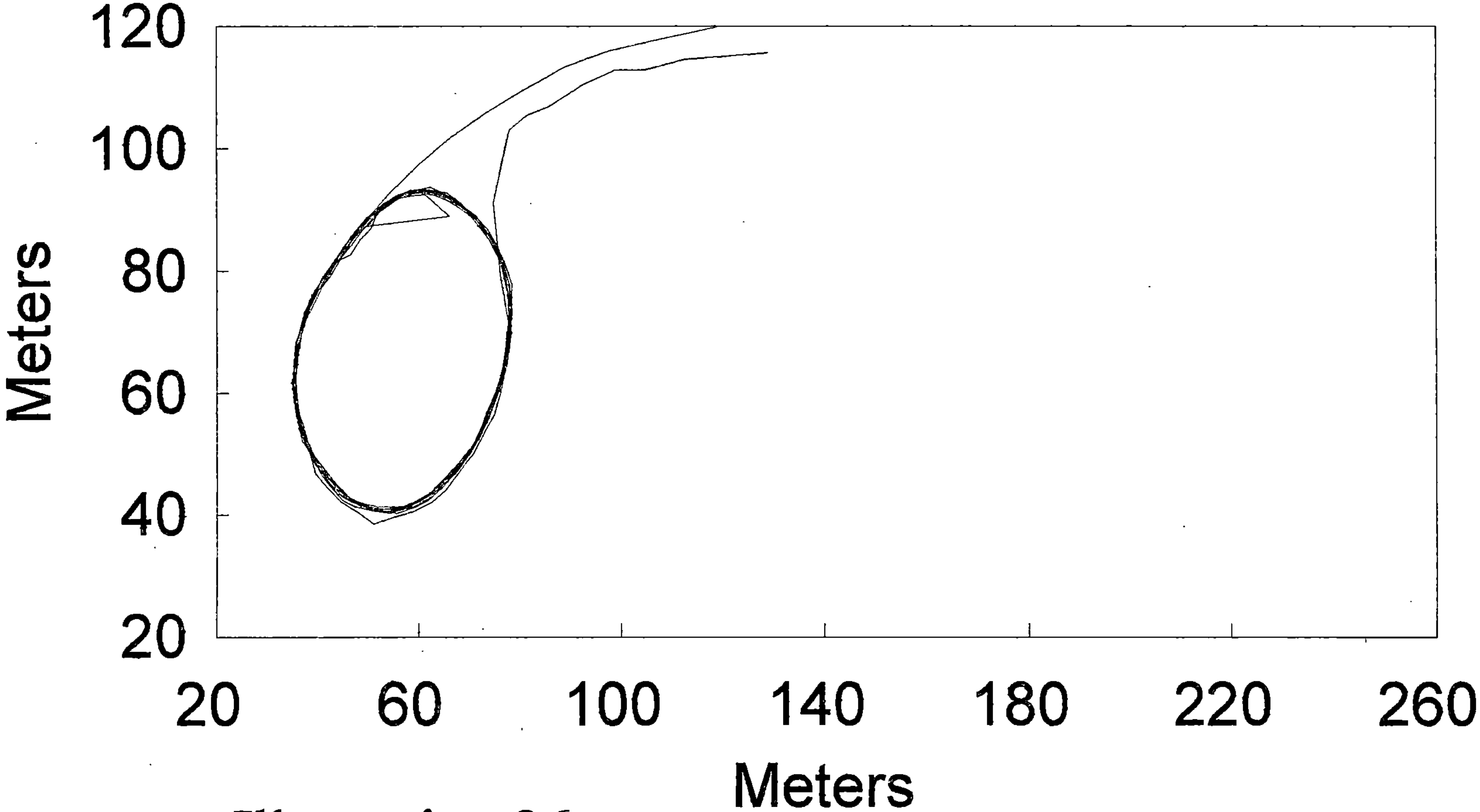


Illustration 26

Omn/zoom+

Post Processed-DGPS/No Dead Reckoning

C-Band Signal - Nov. 5, 1994

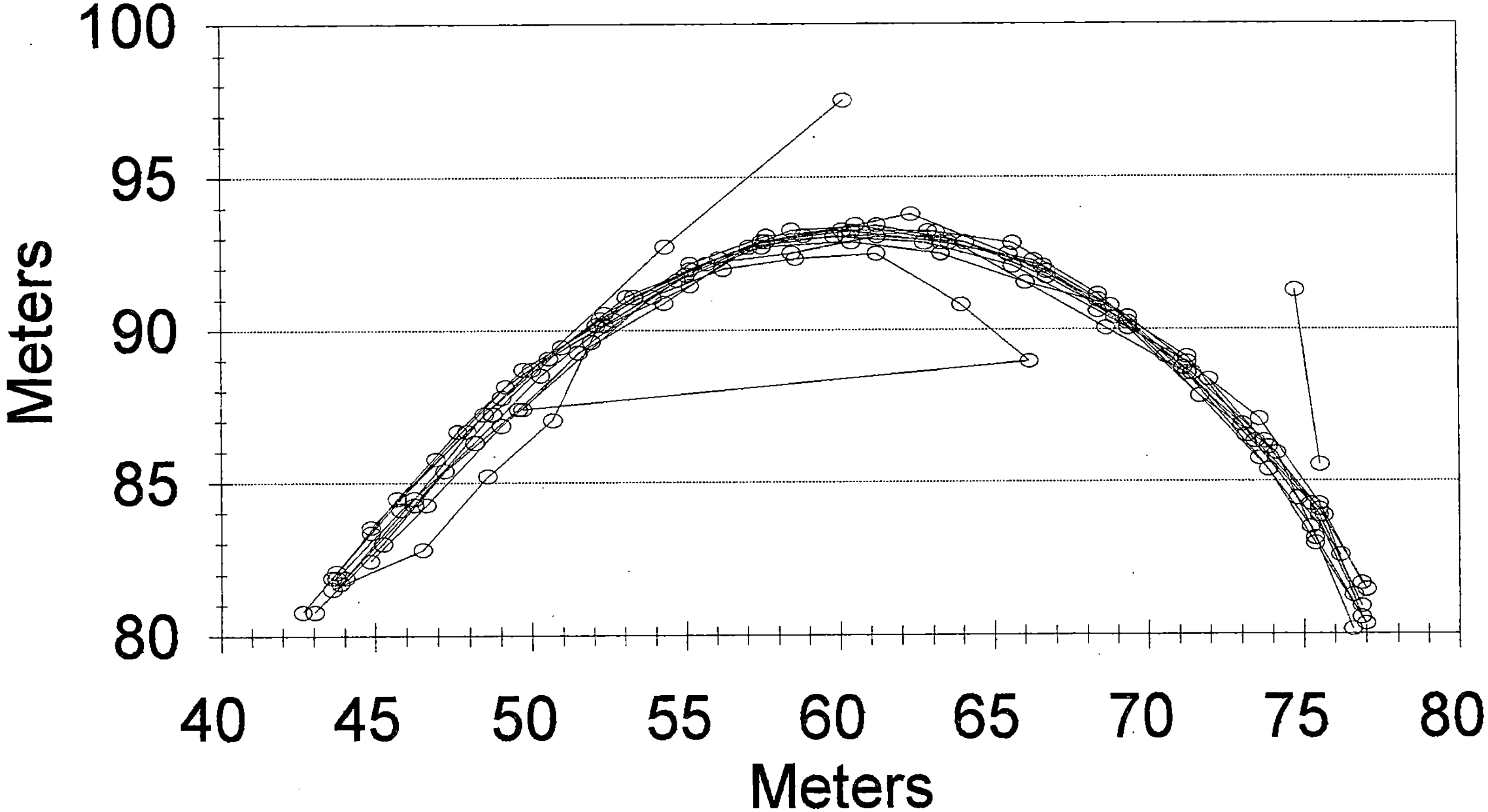


Illustration 27

Om-
November 5, 1994

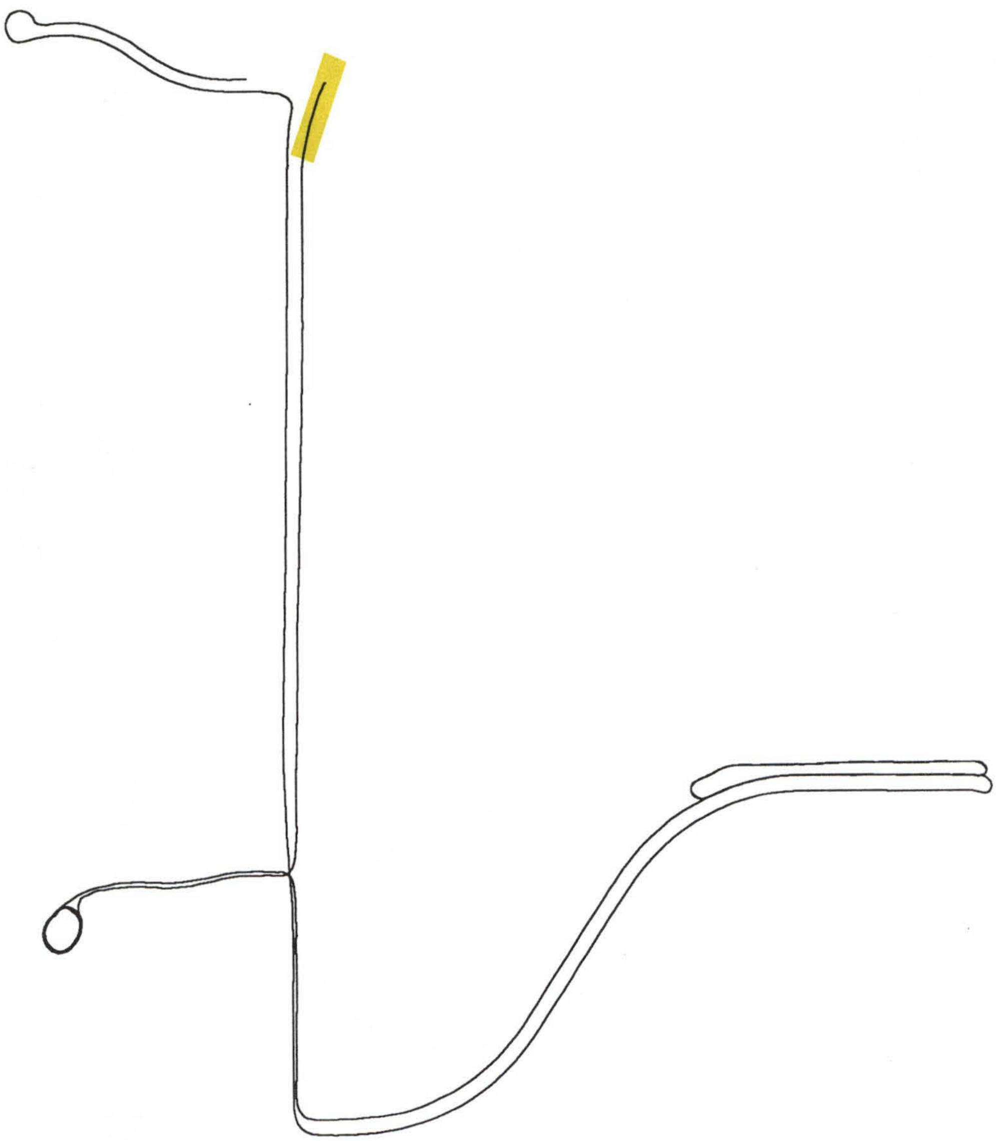


Illustration 28

Om-/zoom

Post Processed - DGPS/Dead Reckoning

C-Band Signal - Nov. 5, 1994

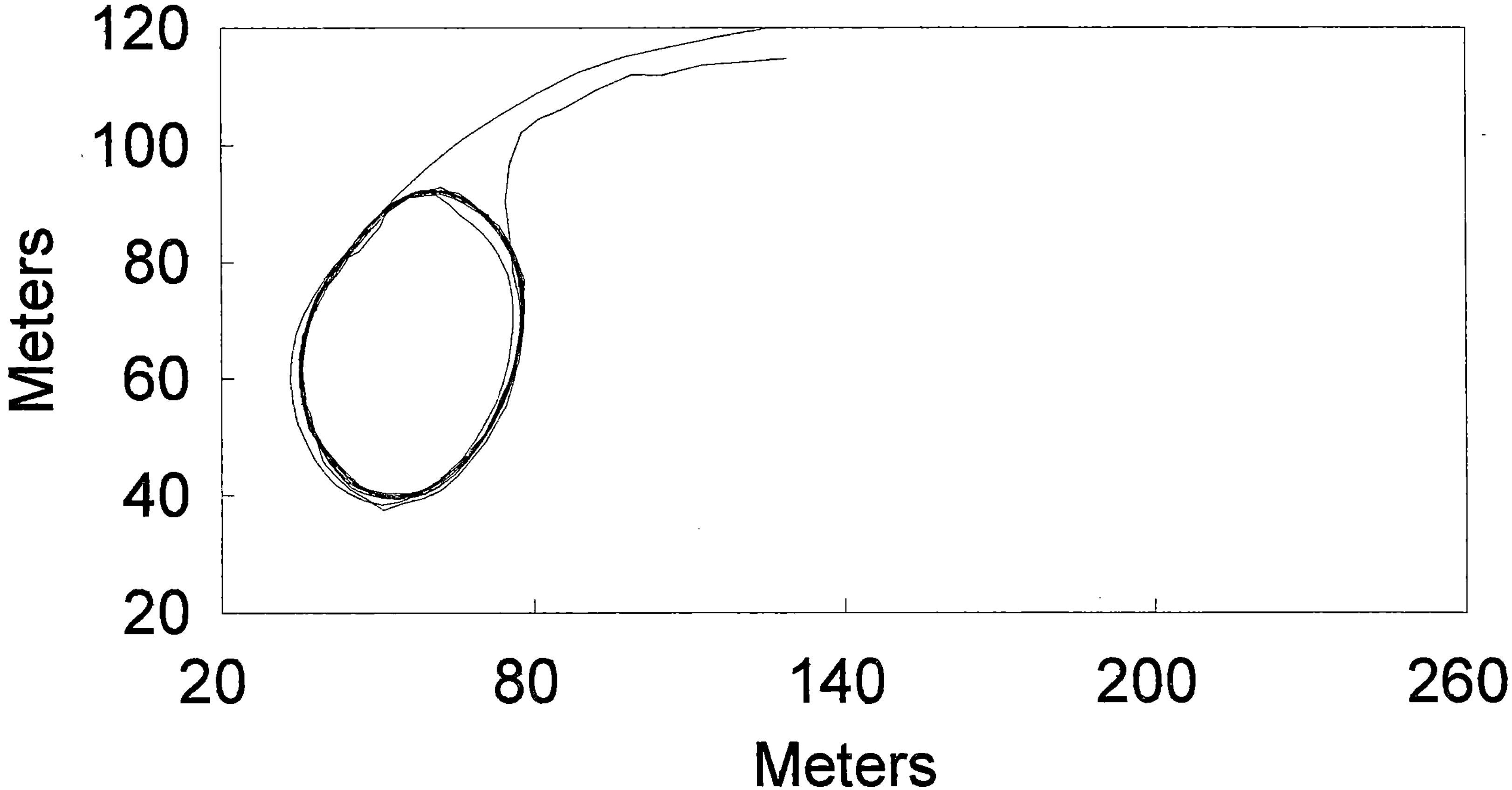


Illustration 29

Dat
November 5, 1994

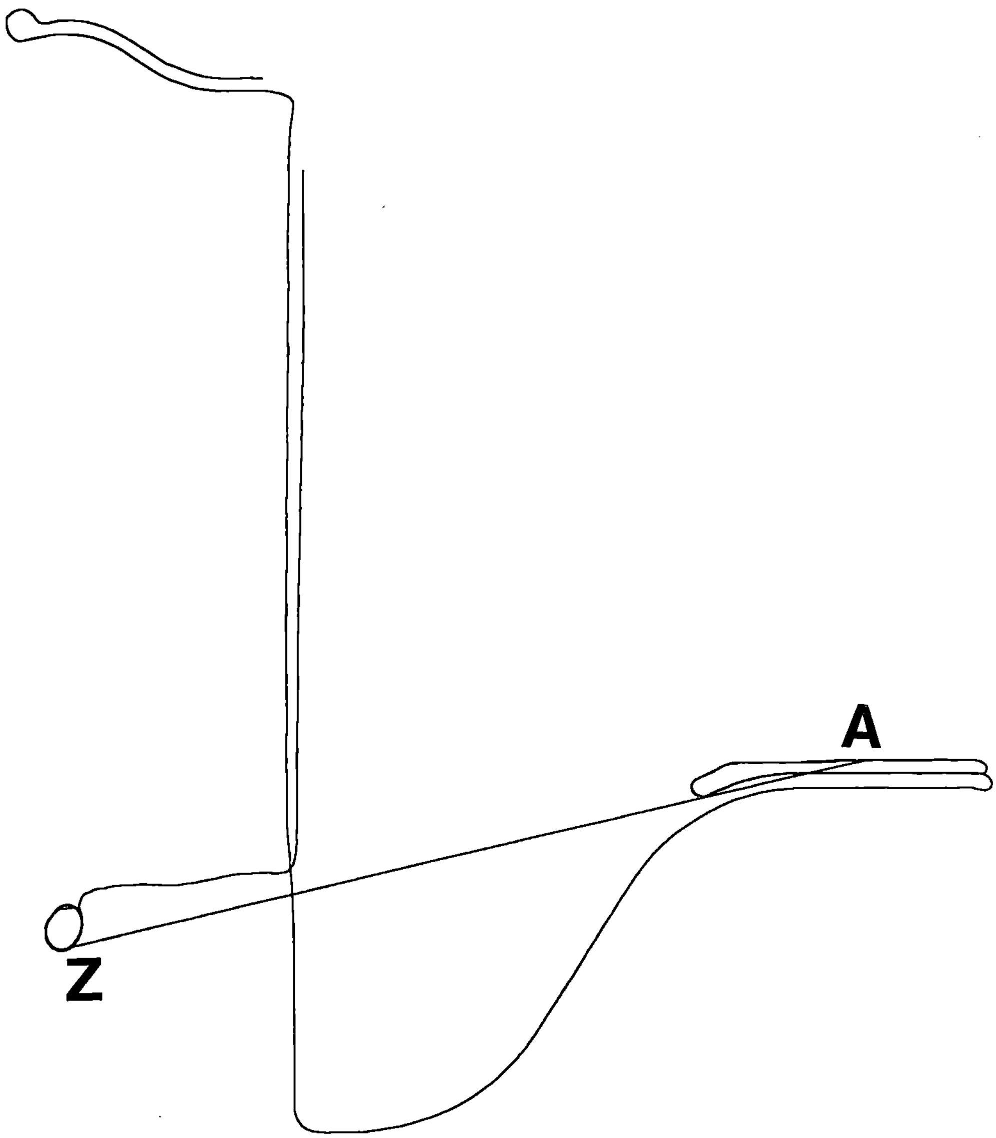


Illustration 30

Dat
October 31, 1994

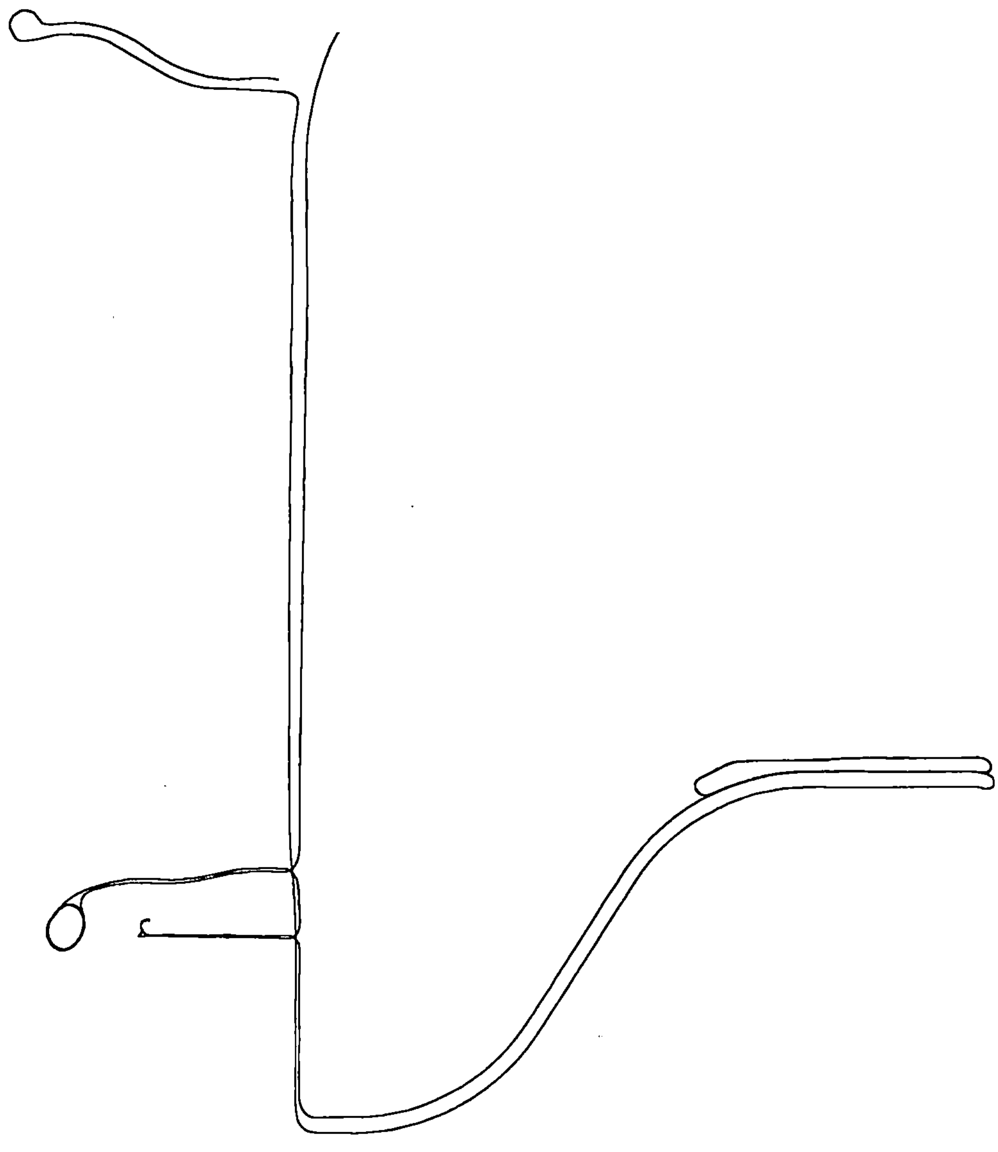


Illustration 31

Da-
November 5, 1994

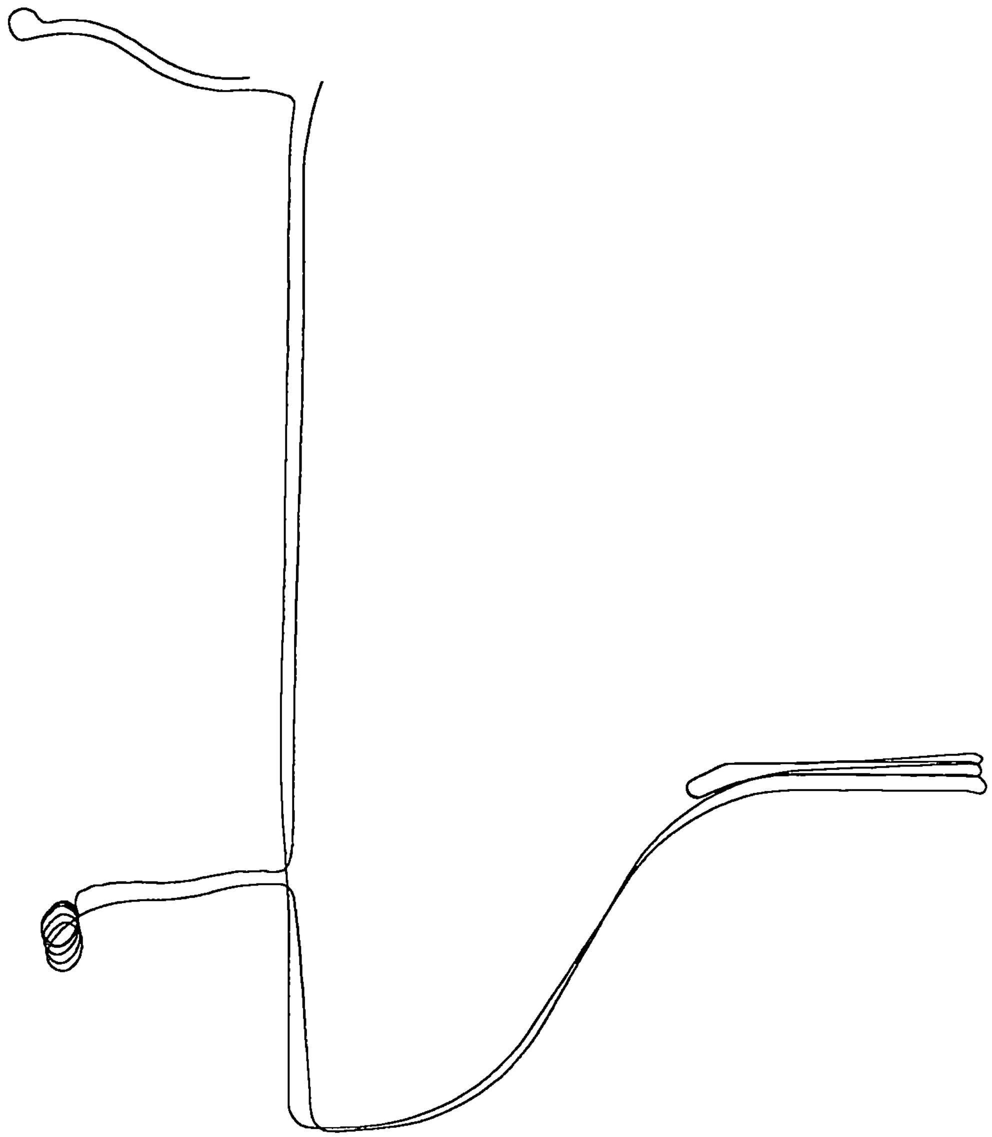


Illustration 32

Da-/zoom

Post Processed - Dead Reckoning

Ref. Station > 300 km - Nov. 5, 1994

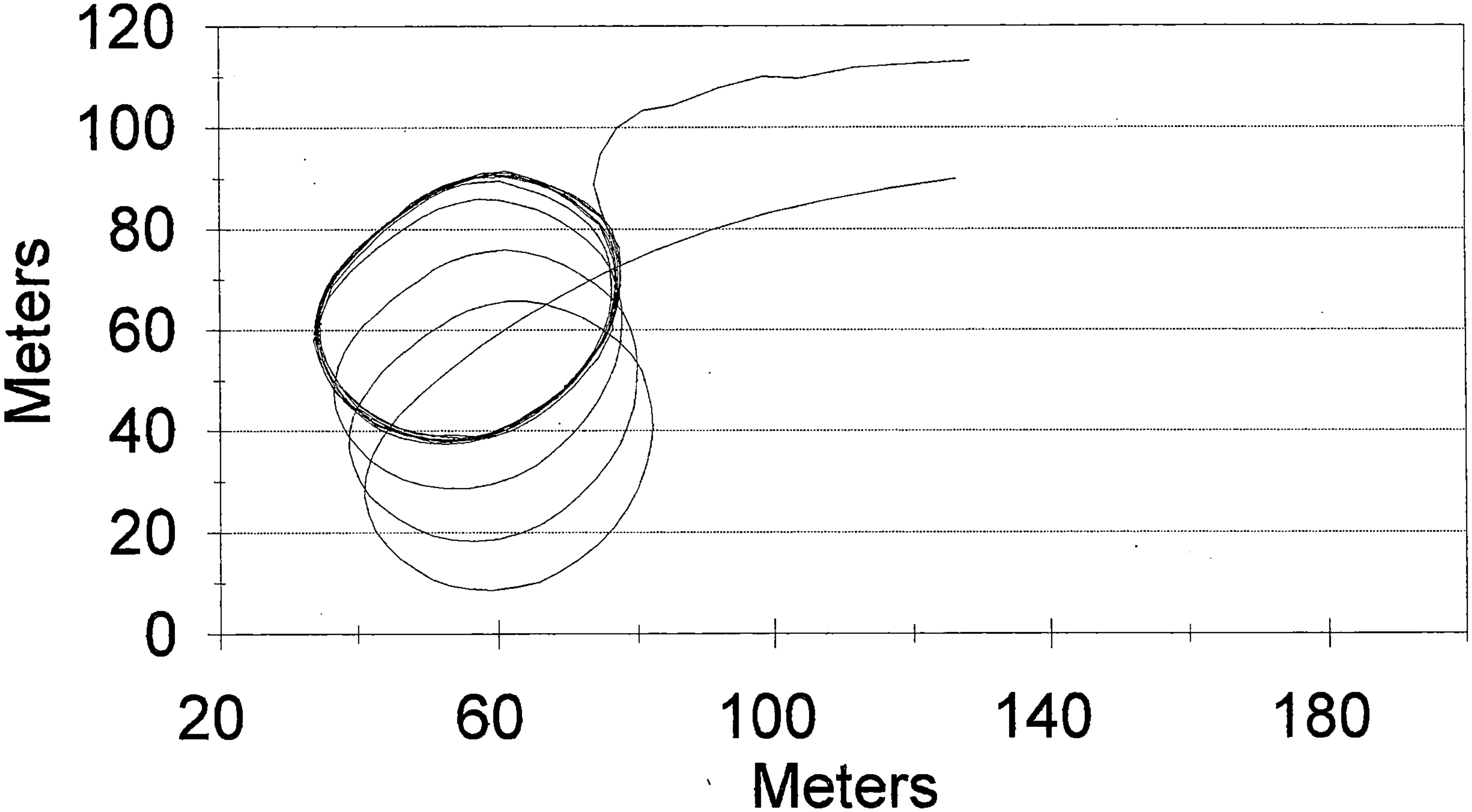


Illustration 33

As-
November 5, 1994

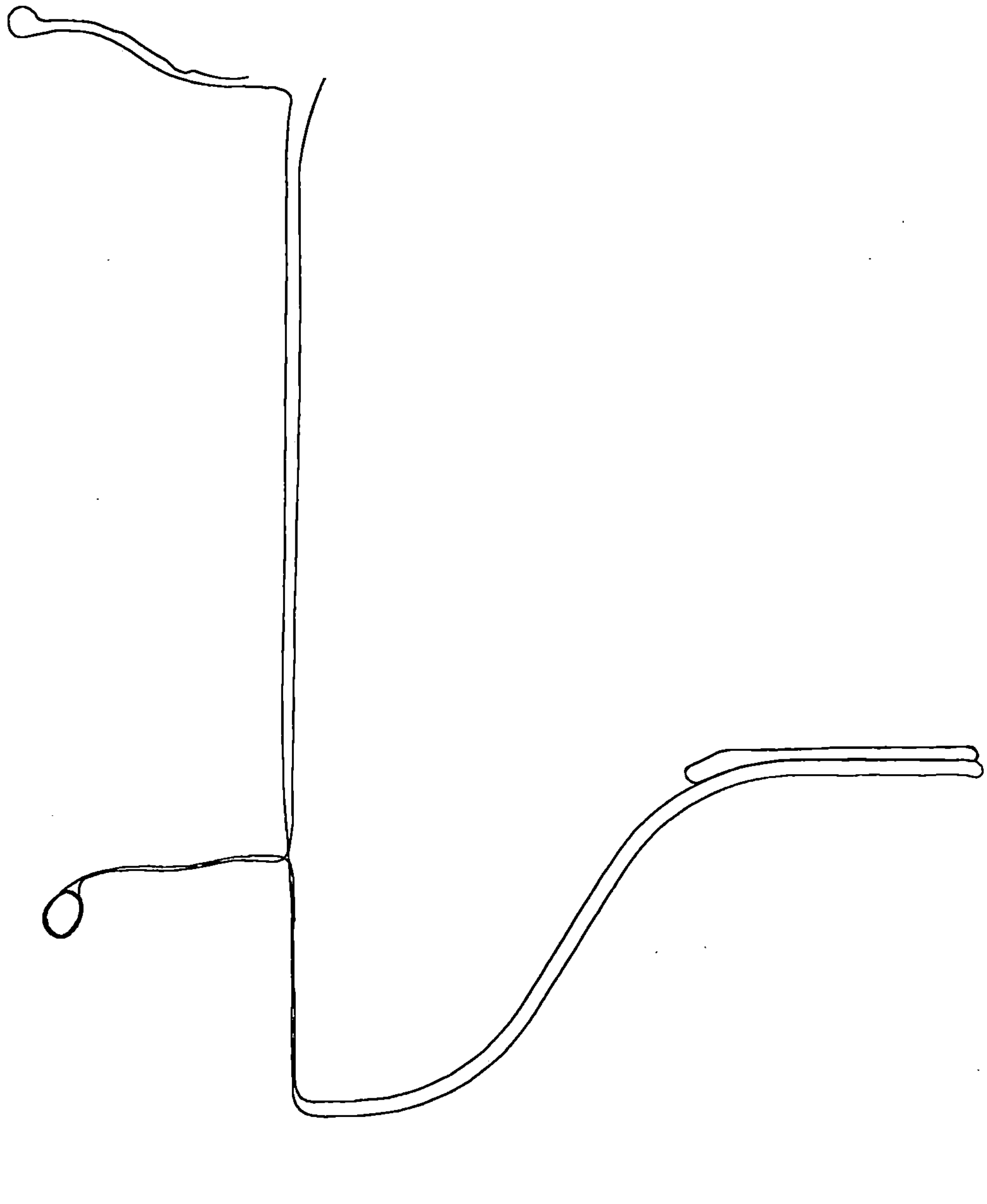


Illustration 34

As-/zoom

Post Processed - Dead Reckoning

Local Ref. System - Nov 5, 1994

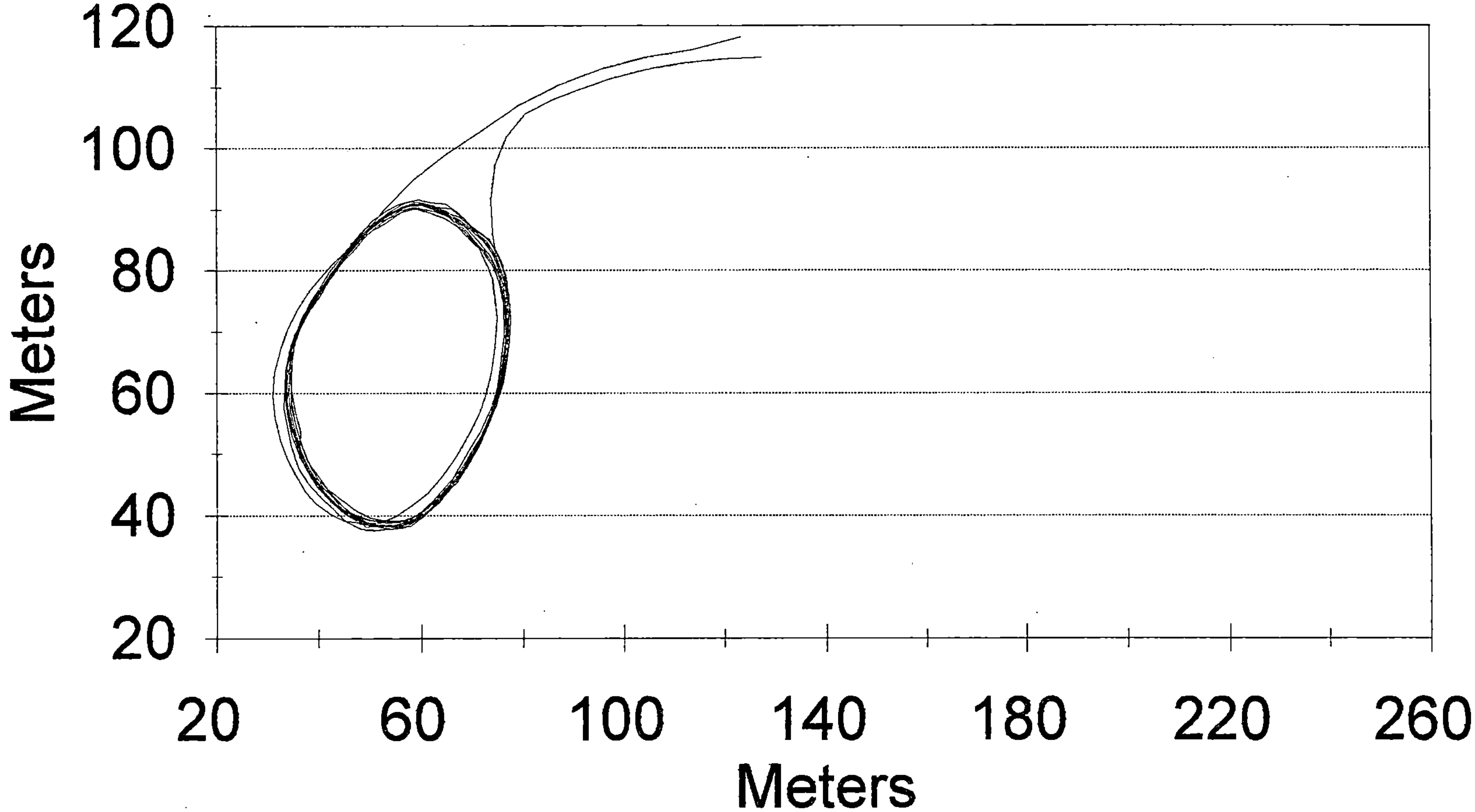


Illustration 35

As-/zoom+

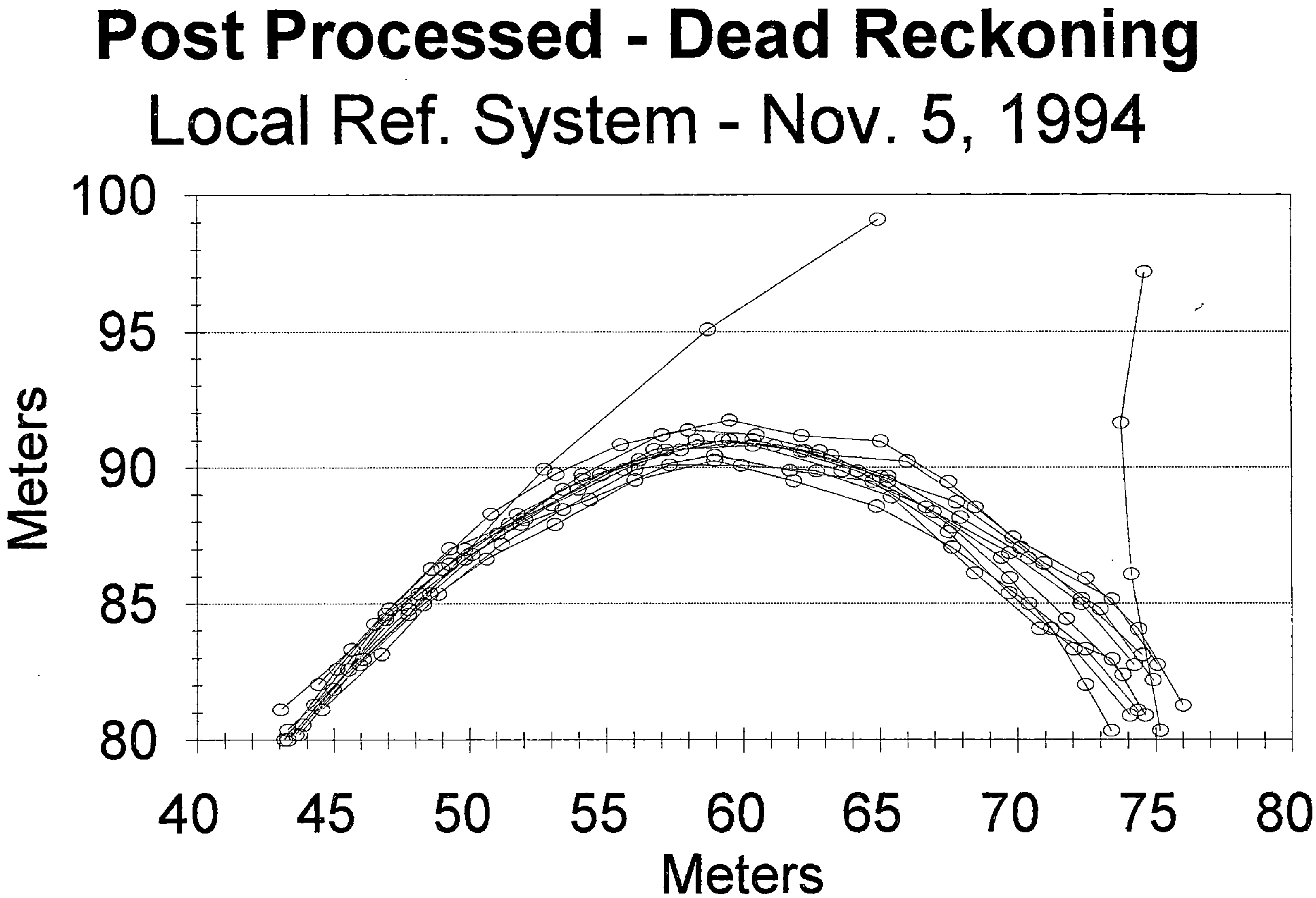


Illustration 36

CHAPTER 7

Summary

The project demonstrated the data collection process for transportation management systems can be enhanced by adopting a statewide Differential GPS (DGPS) solution along with integration of a high resolution image data base. It also became apparent that there is a broad-base support within the transportation agency for the application of GPS technology. Planning and engineering functions require different levels of accuracy, equipment type and costs (single [$] vs. dual carrier [$$$] frequency receivers). It may not be feasible to integrate activities that do not need the same level of accuracy, but developing a single strategy that involves all GPS interests will improve the use of the technology.

Differential GPS (DGPS) eliminates position errors caused by selective availability (SA), environmental and satellite orbit errors. Removing the errors improves the ability of GPS to locate roadway features with repeatability. The initial step in establishing a GPS-based data collection system requires the transportation agency to select a DGPS solution.

The DGPS approach selected will be strongly influenced by availability of specific resources. For example, if the creation of a DGPS reference base business station network fits into the core strategy of your department, acquisition of experience and knowledge about this technology can be easily justified. Skills can be acquired through training or adding staff with geodetic experience. If core business areas have not been established, using a service-based system may be the appropriate strategy to reduce the up-front, long-term investment in development and maintenance of the base station technology and the appropriate knowledge base. This could eliminate a potential barrier, while at the same time providing an opportunity for management to assess the value and importance of GPS technology. Ultimately, each organization must determine the approach best suited to meet its objectives.

The goals of simplifying file management chores and adopting a low-cost strategy to get a DGPS data link established are important factors to consider when deploying a GPS data collection system. But, with today's technology a post-processing strategy is still required to fill in the gaps. At first glance this may limit the value of receiving DGPS corrections on board the vehicle. But as dead reckoning sensors and computing power continue to improve, this task will soon be performed in the vehicle. Of course, this option will only become practical for roadway data collection activities when an accurate low-cost dead reckoning sensor is available to fill in the gaps.

As previously discussed, the goal is to ultimately correct GPS coordinates as they are collected.. As more attributes become geo-referenced, a greater value will be placed on higher-accuracy DGPS capability as well as real-time location while traveling along the highway. For example a pre-loaded "smart" database in the vehicle could turn sensors on and off to collect data only when necessary. In the near term, however, a more cost-effective solution would be to establish a DGPS data link on board rather then set up several local GPS base station receivers. Using the on-board strategy reduces and may even eliminate the need for an agency to install its own statewide DGPS base station network.

Uncertainty during the next two years over proposed national DGPS data links and only a few devices in the field which need access to DGPS corrections makes using a DGPS service an attractive option. For example, to achieve the same level of accuracy in Iowa, a minimum of six reference receivers would need to be installed and maintained. The estimated cost for a typical (planning accuracy) single carrier frequency reference receiver bundled with a computer system is $15,000. This price does not include the ability to broadcast DGPS corrections or staff required to maintain the network.

On the other hand, an on-board, in-vehicle DGPS data link will cost $400 for the FM/RDBS receiver and $600 for the 1-meter yearly subscription service, while the wide area system cost $4,000 for the receiver and $3,000 for the 1-meter yearly subscription service. Justification for using both data links is related to system performance of each service. The FM subcarrier system provides better coverage in urban areas, but has limited coverage (the network is currently being installed), while the wide area system provides coverage in rural areas and currently covers all of North America.

As part of Iowa DOT's DGPS (planning accuracy) solution, a single-carrier frequency reference receiver will also be installed at the Iowa DOT central office complex. This strategy will allow staff to gain experience with a GPS reference receiver, create a public access data base for DGPS corrections, and back up the on-board data link in the vehicle. While it was demonstrated that the distance-based processing technique selected will not be as accurate as several local DGPS receivers located around the state, it will support the accuracy required for the Iowa DOT's videolog application and provide a DGPS database for other post-processing needs, such as accident location and bridge maintenance activities.

During the project, multiple coordinate systems were used. The processes involved in converting one coordinate system to another introduced an additional level of complexity. Problems caused by different coordinate systems caused delays in completion of the project. While computer programs are available to convert one coordinate system to another, a basic understanding of the concepts involved is still required. Adoption of a statewide coordinate system would have avoided some of the problematic errors and would have reduced the number of translations required.

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