SD92-05-F1

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SD Department of Transportation
Office of Research

# Location of Highway Attributes by Global Positioning Study SD92-05-F1 Final Report

Prepared by
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March, 1993

***Disclaimer:***

## South Dakota Department of Transportation
## Research Implementation Recommendations

**Study Number:** SD92-05
**Title:** Location of Highway Attributes by Global Positioning

**Research Review Board Action:** 08/05/93
**Secretary of Transportation Directive:** 11/18/93

| # | Research Review Board Recommendation | Secretary's Directive | Responsible Division | Responsible Office | Action To Date | Date Completed |
|---|---|---|---|---|---|---|
| 1 | The Department should retain its present system of "MRM+displacement" location tags for collection of most highway attribute data. | Approved | Planning | Data Inventory | The reinventory & Quality Control Review was completed. | 05/01/94 |
| 2 | The Department should adopt and use NAD83 as its standard datum and GIS reference datum. | Approved | Engineering | Roadway Design | Done. To be put in survey manual. | |
| 3 | The Department should establish a centralized management function to lead the development of GIS applications. The Secretary of Transportation should appoint a technical advisory group to guide operation and maintenance of the GIS. Initially, the Office of Data Inventory should be assigned responsibility for beginning the GIS. | Approved | Secretary | Secretary | The Secretary of Transportation established the GPS/GIS Technical Advisory Group. | 10/04/93 |

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16. Abstract:


SDDOT uses a sign-oriented, link-node signpost location method in which "uniform" Mileage Reference Markers (MRM) are placed at approximate intervals of one mile and "special non-uniform" MRM's are placed at intersections, structures, county lines, municipal and urban limits and at roadway discontinuities. The location of a particular inventoried highway attribute is its displacement, in increments of one thousandth of a mile, from the nearest MRM marker.

Two primary objectives were established for this 10-month research project conducted during 1992. The first was to demonstrate how a combination of Global Positioning System (GPS) technology and current elapsed-distance technology can be applied within SDDOT to cost-effectively generate geographic coordinates for the existing MRM-based highway attribute data. This process will make the complete MRM attribute database usable in the State's developing Geographic Information System (GIS) applications. This objective was accomplished using a test segment on US Highway 12 in the Aberdeen Region for GPS data collection, and existing MRM-tagged highway attribute data for the test area from a variety of SDDOT sources. Both the GPS data and the GPS-tagged MRM attribute data were imported into the Department's Intergraph MGE GIS environment to demonstrate the techniques. This process is summarized in the Research Task 5, 6, 7 and 8 sections of this report.

The second objective was to analyze SDDOT application opportunities and prepare a GPS technology implementation plan for consideration by SDDOT management. The results of that analysis and an outline of the implementation plan are described in the Research Task 2, 3, 4, and 9 sections of this report. Task 9 includes the research team's policy and procedures recommendations for a successful implementation within SDDOT.

This project has been structured to provide SDDOT with direct and "hands-on" experience with GPS and to validate the use of GPS in South Dakota in SDDOT applications. All program objectives were accomplished.


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# *TABLE OF CONTENTS*

# SECTION I. INTRODUCTION AND ACKNOWLEDGMENTS

This document is the final report of the work accomplished under SDDOT Contract No. 310118, for Project 92-05 Entitled "Location of Highway Attributes by Global Positioning". The work was performed by a team composed of Navstar Mapping Corporation located in Austin, Texas, Time & Place Tags, Inc. located in Chevy Chase, Maryland and Cooper Technology, located in Dallas, Texas. The principal investigators for this R&D project were Bob Lewis, Bill Beanland, and Frank Cooper, who are the Presidents of these respective companies. Navstar Mapping Corporation (NMC) served as prime contractor for this project.

Our Project Engineer was Daris Ormesher from the SDDOT Office of Research, and his cooperation and assistance have been instrumental in helping us to successfully complete the project task plans documented in this report.

The following individuals served as the Technical Panel for this project:

Norm Humphrey, Operations Engineer-Aberdeen Region, SDDOT
Bob Willert, Photogrammetry and Survey Engineer-Roadway Design, SDDOT
Bob Thielan, Senior Engineer-Roadway Design, SDDOT
Rudy Persaud, Transportation Analyst-Data Inventory, SDDOT
Creighton Miller, Statistician IV-Accident Records, SDDOT
Ron Woodburn, Senior Data Analyst-Dept. of Environmental & Natural Resources
Jim Robertson, Project Services Engineer-City of Sioux Falls

In addition, the special support provided by Dave Huft, Dennis Winters and Howard Knipling in collecting SDDOT data and preparing for the demonstration phases of the project is gratefully acknowledged.

## SECTION II. PROBLEM STATEMENT AND PROGRAM OBJECTIVES

### *The Problem*

The Request for Research Proposal for SDDOT 92-05 specifies the need for a solution to a two-sided problem in the physical location of assets, the first of which flows from the nature of SDDOT's Mileage Reference Marker (MRM) system. The MRM structure is a sign-oriented, link-node location method in which "uniform" reference markers are placed at approximate intervals of one mile and "special non-uniform" markers are placed at intersections, structures, county lines, municipal and urban limits and at roadway discontinuities. The location of a particular inventoried highway attribute is its displacement, in increments of one thousandth of a mile, from the nearest MRM marker. As with all signed linear reference approaches, errors in MRM location can occur from a variety of causes and frustrate the accurate location of highway attributes during inventory. Inventory inaccuracies can degrade or completely negate the validity of information systems outputs and, among other things, the Construction Program Process based on these inventories. The need for a revised location method based on the use of geodetic coordinates was addressed in SDDOT's 1991 Historical Data Base Study.

Guidance in the implementation and uses of Global Positioning System (GPS) location methods is the second problem area that SDDOT asked to be addressed in Project 92-05. The Department has acquired a basic familiarity with GPS from its participation in the 1989-1991 pool fund study, "Application of the Global Positioning System (GPS) for Transportation Planning," and from other activities. GPS is a powerful, swiftly evolving and complex new tool that is approaching full operational status.

Some observers believe GPS will provide a much better way to automatically acquire accurate and reliable data, and in doing so, fundamentally change the nature of information systems, particularly those information systems that reflect geographically dispersed assets, activities, and events. Others believe that GPS offers an evolutionary change that will significantly enhance, but not replace, current distance-based attribute location and information systems.

RFP 92-05 states, "The Department of Transportation has a need to become familiar with Global Positioning System (GPS) Technology." This project has been structured to provide SDDOT with direct, "hands-on" experience with GPS and to validate the use of GPS in South Dakota in SDDOT applications.

### *Background*

The genesis of Project 92-05 occurred at the beginning of the 1992-1993 SDDOT Annual Research Program Cycle. Requests for Proposals were distributed in November of 1991 and, after the proposal evaluations and contractor selection, work on the project began in March 1992. The final project report was completed in January

1993. These dates are important because they overlap the occurrence of major legal, political, economic, technical and institutional changes that directly impact the considerations for better location of transportation attributes. Concurrent events directly impacted the conduct of this research.

On December 21, 1991, Public Law 102-240, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) came into force. Among other things, this benchmark legislation requires state transportation agencies to conduct their activity with an "intermodal" span of attention in conjunction with local and other planning agencies. It mandates conformance to environmental and other legislation outside the domain of the U.S Department of Transportation. It further places a new emphasis on State-to-Federal reporting in the definition of six new management systems that States are required to implement. The law establishes a new bureau at the administration level in the USDOT which, like the Bureau of Labor Statistics in the Department of Labor, will be responsible for ensuring that data is acquired "in a manner that will maximize the ability to compare data from different regions and for different time periods."

In 1992, a new President and Congress were elected and a new Secretary of Transportation was named. Rebuilding the infrastructure was considered as a first step in economic recovery and the need for new ways to account for publicly owned capital assets were discussed in several forums. Defense industry corporations struggled to find their place in a new civilian economy.

The data processing and communications industries experienced real turmoil and more and more began to reflect a component, rather than a systems perspective. In December 1992, IBM announced that it was targeting large personnel reductions and other cuts in its mainframe computer division. It doing so, it signalled to the world that the era of the mainframe was finally over. Users continued, at a greater pace, to be their own systems engineers. Personal computers were becoming commodities that were bought primarily on the basis of price. New notebook computers, memory devices, processors, relational database managers, printers, digital communications services, voice recognition software, very large capacity storage devices – and on and on – were introduced at avalanche rates. For users, determining the best thing to buy became a mind boggling kind of activity. For suppliers, dealing with obsolescence in a market place where product half life is measured in months became an almost daily go/no-go kind of decision process. It seemed that nobody was offering a complete information system, or for that matter, even a complete information sub-system.

The second adjustment of the national geodetic network since 1974, using GPS surveying methods, continued to expand. This State-by-State implementation of High Accuracy Reference Networks (HARN) – progressed to cover more and more of the lower 48 states, and field work for a 21 station HARN in South Dakota is now scheduled for August/September 1993. The National Geodetic Survey, the federal agency most directly involved in civil GPS use, was in the midst of its own organizational turmoil, and there was a real possibility that its State advisor program would be ended. Many and varied new uses for GPS location methods were reported, but the prime civil customers for GPS were still land surveyors, many of whom were in State transportation agencies.

In South Dakota, there was new momentum in the planning for a statewide Geographic Information System. The State's Information Processing Service was evolving from a wholly operational kind of activity to an in-house consulting service for state agencies. In the DOT, the allure of custom software was fading rapidly and impelled by the Data Services group, there was a rapidly growing interest in using general purpose commercial software. Perhaps most important, there was a growing impatience among senior managers with a kaleidoscopic mix of bits and pieces of new management system requirements and bits and pieces of new information technologies that seemed to defy every attempt to make them fit together. Senior DOT managers were insisting that new technologies be implemented in a timely and non-chaotic fashion. Their requirement that new technologies become productive in the shortest possible time became an overriding statement of the conditions that would be placed on use of GPS by the South Dakota Department of Transportation.

## GPS System Overview

The NAVSTAR Global Positioning System (GPS) is a space-based radio positioning system which provides suitably equipped users with highly accurate position, velocity and time data. The system is being developed under the cognizance of the Department of Defense (DOD) primarily for military applications, but the satellite signals are freely available to anyone with suitable GPS receivers. When fully operational in 1994, this position locating service will be available world-wide, continuously and under all weather conditions to users at or near the surface of the earth.

GPS receivers operate passively, thus allowing an unlimited number of simultaneous users. The GPS has features, designed for its primary military applications, which can deny its highest accuracy service to unauthorized users and reduce the system susceptibility to external spoofing or jamming. The Global Positioning System is comprised of the three major segments illustrated in Figure 1.

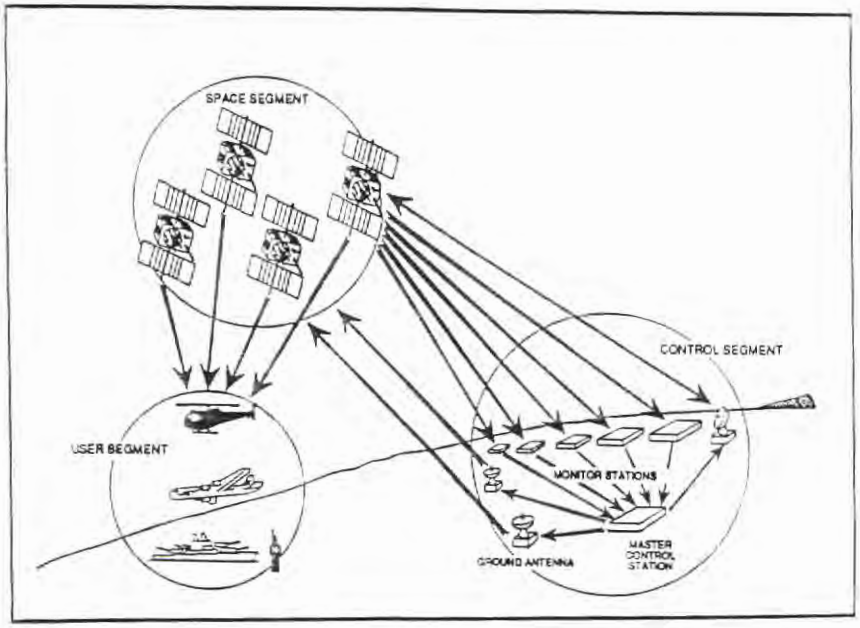



**Figure 1. Segments of the Global Positioning System**

The **Space Segment** consists of a continually shifting constellation of 21 satellites in 12-hour orbits around the earth. Each satellite broadcasts radio-frequency ranging codes and a navigation data message.

The **Control Segment** consists of a Master Control Station and a number of monitor stations located around the world. This Segment is responsible for tracking, monitoring and managing the satellite constellation and for updating the navigation messages broadcast by the satellites.

The **User Segment** consists of a wide variety of radio navigation receivers specifically designed to receive, decode and process the GPS satellite ranging codes and navigation data messages. The same codes and data messages from the satellites can be processed by GPS receivers in two basicly different ways to achieve dramatically different results for a variety of DOT uses.

GPS receivers designed for precision engineering survey applications collect data simultaneously from one receiver placed over a fixed unknown point for 2 minutes to 2 hours, depending on the accuracy desired, and a second receiver positioned over a known survey point. This class of receivers can determine the location of the unknown point by precisely computing its relative distance from the known reference point. This "translocation" process can produce absolute position accuracies of a few centimeters.

### *RESEARCH OBJECTIVES*

During the past four years both GPS and GIS technologies have been expanding rapidly, with typical product life cycles of 1 to 2 years before their replacements arrive. Both of these technologies have now accelerated to the point where they have far outdistanced the implementation process that can achieve their promised benefits.

The use of GPS technology to generate location tags for highway attributes has been demonstrated in a variety of methods and accuracies over the past six years. From our perspective, the technical credibility has already been well established.

However, there are few benefits to be achieved from the process of adding GPS coordinates to highway attribute data **if the process stops there** – adding latitude/longitude/altitude coordinates only makes the data files bigger. The real benefits come from using these spatial coordinates to move the data into a three-dimensional GIS environment where computer processing speed and capacity can be used to replace human processing speed and capacity.

This research program plan has been designed to demonstrate the process of applying GPS technology to aid in the GIS implementation process for SDDOT applications. The field demonstration phase was conducted using Navstar Mapping Corporation's ***ROADMAPPER*** GPS/LOGMILE data collection system that features a patented Voice Data Entry System (US Patent # 5170164). The GIS demonstrations were conducted on SDDOT's Intergraph MGE Computer Graphics facility and on personal computers using commercial software.

The Research Objectives for this R&D contract are shown in Figure 1.

## RESEARCH OBJECTIVES: LOCATION OF HIGHWAY ATTRIBUTES by GPS

1. Provide a reference summary of the various kinds of GPS system applications currently in use or planned for use by other DOT's

2. Define the SDDOT needs that can be met by the application of GPS/GIS technology

3. Demonstrate the procedures for tagging MRM's and other highway attributes directly with GPS coordinates

4. Demonstrate the procedures for using the ***ROADMAPPER*** data collection system to capture a GPS/LOGMILE skeleton road network

5. Demonstrate the procedures for extracting GPS coordinates from this skeleton network for existing MRM-tagged highway attribute data

6. Demonstrate the procedures for importing both the new and existing GPS-tagged data into the Intergraph MGE GIS environment for planning and decision-making use.

7. Recommend changes to SDDOT policies and procedures as necessary to implement the use of GPS/GIS technologies and equipment and reap the benefits of their use.

**Figure 1. Research Program Objectives**

# SECTION III. RESEARCH PLAN

The research plan was based on implementation of a concept that has been developed by the research team through contacts and working relationships with over 40 other State DOT's during the past 6 years. This concept is to use a combination of GPS and elapsed distance or LOGMILE data to form a skeleton road alignment network. This network then serves as the foundation for both computer generation of road maps and for importing existing logmile-based inventory data into GIS systems.

Our basic premise is that, when compared to currently used techniques, this concept offers a significantly more cost-effective method for development of GIS applications focused on the DOT planning and decision making tasks that use highway attribute data.

The research tasks were structured to demonstrate the methods and procedures, investigate the potential for application within SDDOT, and recommend an implementation plan for consideration by SDDOT management. The program was conducted over a ten (10) month period on the time-phased schedules shown in Figure 2.

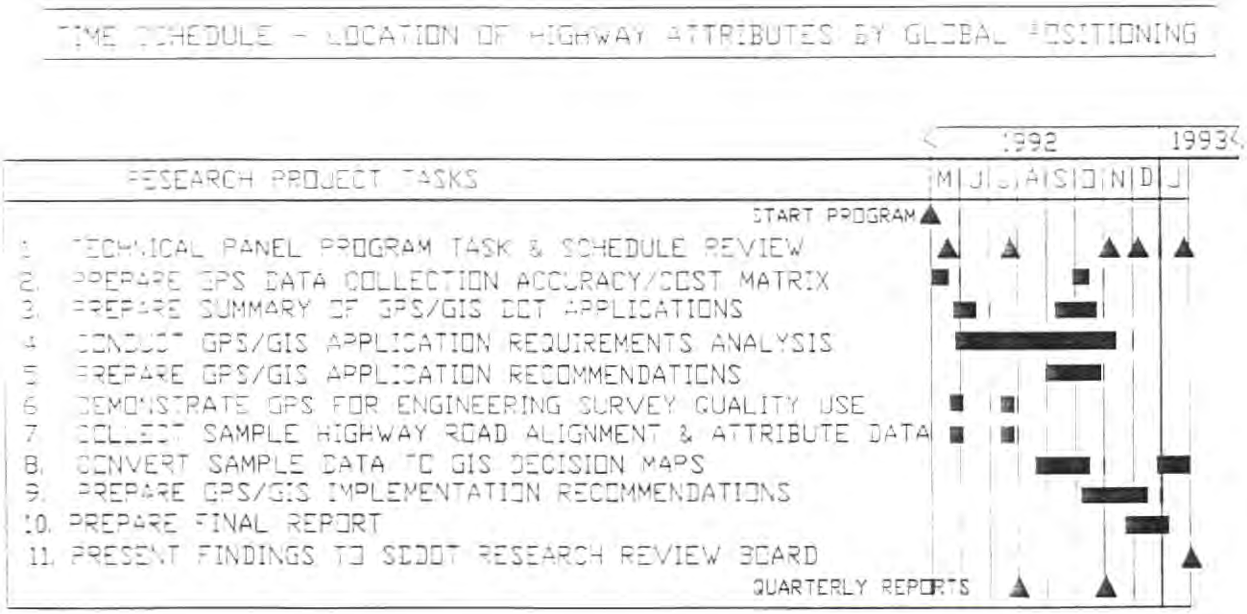



Figure 2. Research Plan Time schedule

Detailed descriptions of the various task activity and supporting material was included in the two previously submitted Quarterly Progress Reports and their Appendices.

The following subsections provide a summary of the results of each of the research task plans in order.

## TASK 1. PROGRAM TASK AND SCHEDULE REVIEWS

### Program Kick-Off Meeting

An overview presentation of the program research objectives and task plans was made by Bob Lewis to the Research Review Board during their scheduled meeting on the morning of May 21, 1992, in Pierre. The program kick-off meeting was conducted during that afternoon.

A detailed presentation was made to the Technical Panel to review and obtain approval for the program objectives, task plans and schedule.

The 105-mile segment of US 12 from Bowdle to Groton in the Aberdeen Region was selected as the demonstration test area.

During the kick-off meeting it was decided that data from the Roadway Environment Systems (RES) database would be used for demonstrating the process of applying GPS latitude/longitude/altitude coordinates to existing MRM distance-tagged data. The 30-mile segment of US Highway 12 in the Aberdeen test area from the Edmunds/Brown County Line through Groton was selected as the test segment to use for this purpose. This section contains both rural and city culture and a mix of two-lane, four-lane, and divided highway segments that was considered by the Panel as being a representative cross-section sample for demonstration purposes. Geographic coordinates or GIS "tags" for a representative sample of these data files would be extracted from the ***ROADMAPPER*** skeleton road track collected from this section of Highway US 12.

Frank Cooper conducted a demonstration on the SDDOT Intergraph MGE work station of the Needs Analysis that he is currently working on as a consultant to the Nebraska Department of Roads. He also outlined the procedures that will be used for importing GPS-tagged inventory data into the system as part of Task 8 and introduced SDDOT management personnel to new GIS tools available from Intergraph.

### Program Status Review #1

A program status presentation summarizing the contents of Interim Report #1 was made to the Panel by Bob Lewis on July 21, 1992, in Pierre.

The GPS/LOGMILE test data from the US Hwy 12 test area surrounding Aberdeen was reviewed with the Technical Panel. On the basis of that review, it was decided by the Panel that the accuracy and quality of the test data were consistent with SDDOT standards and sufficient for the demonstration purposes of the program. Plans were established for using this sample skeleton road track network to generate GIS tags for a variety of existing RES and other "MRM + Displacement" data files. The Dynaflect - Rut Depth - Skid Test (DRS) file was used as the primary source for sensor-based inventory data. Paper plots of GPS-tagged DRS Rut Depth files and ADABAS accident records were presented to the Panel to illustrate the techniques to be implemented later in the Intergraph MGE demonstrations.

Results of the GPS Engineering Survey tests under Task 6 were also reviewed and approved by the Technical Panel.

### *Program Status Review #2A*

Bob Lewis and Frank Cooper returned to Pierre on November 2-3, 1992 to review the task status information summarized in Interim Report #2.

A summary was presented of interim results from the Task 2 GPS Cost/Accuracy comparisons, Task 3 GPS Questionnaire responses, Task 4 Requirements Analysis work and Task 9 Recommended GPS/GIS Implementations.

Frank Cooper and Howard Knipling laid the ground work for the planned Task 8 GIS demonstrations during this trip.

### *Program Status Review #2B*

Bill Beanland visited Pierre and Aberdeen on December 7-9, 1992 to review the final results of the Task 8 Requirements Analysis effort and discuss further Implementation recommendations with the Technical Panel members.

### *Program Final Review and GIS Demonstration*

The research team returned to Pierre during the weeks of February 8 and 14, 1993 to summarize the Final Report and discuss the GPS/GIS implementation recommendations. A GIS demonstration of data collected and processed during the program were given to the Technical Panel members.

A summary presentation of the program and GIS demonstration was given to the SDDOT Research Review Board on February 19, 1993.

## TASK 2. PREPARE GPS DATA COLLECTION ACCURACY/COST MATRIX

The objective of this task was to begin to establish a basis for evaluation of the accuracy, speed and cost of GPS inventory data collection methods versus the various methods in use today by DOT's.

Figure 3 shows a simplified graphic comparison of GPS positioning accuracy ranges achievable versus an approximation of the current costs of collecting and processing the different categories of GPS data. The data suggests an exponential relationship between GPS data collection time and accuracy, and, not surprisingly, that a similar relationship exists between cost and accuracy. (Lat = latitude, Lon = longitude)

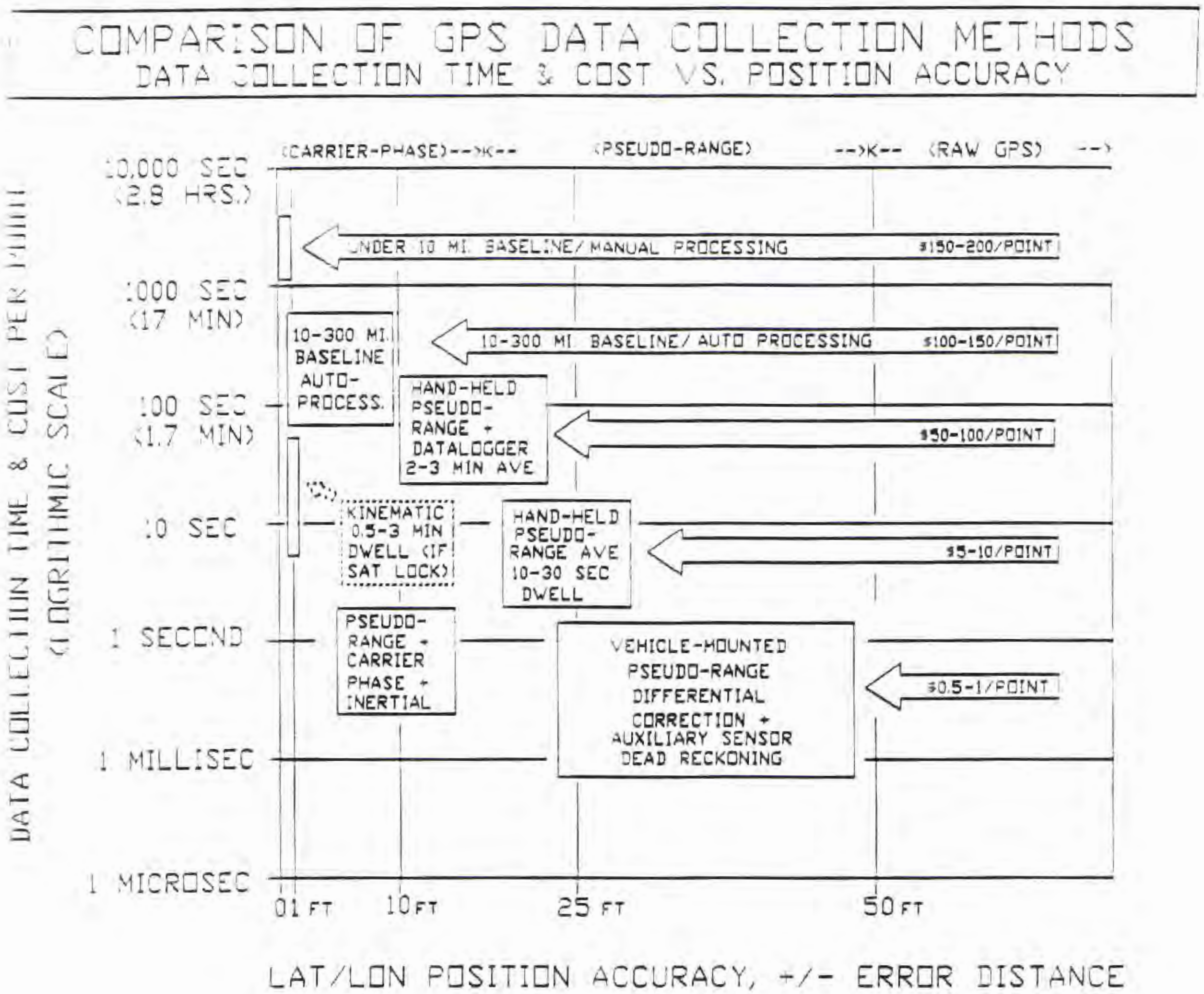



**Figure 3. Comparison of GPS Data Collection Methods**

For the stationary survey-quality categories, GPS costs per data point are generally accepted as a meaningful cost comparison technique, but are heavily influenced by major variables such as monument construction and documentation costs.

Kinematic techniques that generally depend on continuous visibility of GPS satellites are closely related to surveying applications and use surveying-quality GPS equipment. These techniques are being used for precision location tasks such as positioning off-shore oil drilling rigs, but they have only a limited application for highway attribute location tasks unless the highways have no over/underpasses and are in open terrain. New innovations in GPS kinematic surveying technology were developing rapidly during the performance period of this contract promising many new surveying applications for DOT's.

A study conducted by The Ohio State University Center for Mapping Multi-State GPS/Imaging/GIS Project achieved repeatable positioning accuracies of +/- 5 feet during its demonstration tests. For that research program two surveying-quality GPS receivers were used in a sophisticated and high-cost system implementation. The system concentrated on developing highly accurate GPS/LOGMILE road alignment track and used only a limited Hotkey-type touch screen data entry technique, so cost per mile or cost per point projections for collecting typical highway attribute data with the system would not be meaningful.

For the other mobile categories that generally use one-solution-per-second navigation receivers, the cost per point is much more dependent on the data entry technique used for identifying highway attributes than on the cost of collecting the GPS coordinates for the point.

GPS-related data entry techniques in use today range from visual observation of handheld GPS receiver readouts and manual notes on a clipboard to fully automated computer entry of attribute descriptions complete with GPS tags. The "Eyeball and Clipboard" manual techniques can capture 2-3 attribute descriptions and locations per minute during a sustained inventory. In contrast, NMC's patented Voice Data Entry System (VDES) is now capable of capturing a variety of attribute data at sustained rates approaching 10 features per minute.

In addition, most GPS inventory system approaches suitable for use by SDDOT have both the capabilities to record attribute data at user-selected feature points and the capability to record continuous vehicle track coordinates. So a cost per point comparison does not show the incremental value of also producing the road alignment track between attribute points.

GPS equipment technology and data collection capabilities have been going through a rapid evolution during the past year that is continuing to accelerate as we approach the satellite launch completion date in 1993.

As you can see from this wide range of variables, only a gross comparison between the costs of the different GPS surveying techniques and GPS highway attribute location techniques is possible. Cost per mile comparisons for these kinds of systems seem to be more representative, so a sub-task effort has been initiated to try to catalog some representative cost per mile data.

### *INVENTORY DATA COLLECTION COST PER MILE COMPARISONS*

In NMC's data collection experience with "standard GPS" windshield surveys during the Desert Storm period (when Selective Availability was turned off), average costs of $25 per mile were demonstrated with accuracies in the +/- 50 foot range. Today, with selective availability turned on, using differential correction techniques under the same conditions improves the accuracy to the +/- 35 foot range, but increases the average cost to the $35 per mile range due to the added cost of operating the additional GPS Base Station equipment and post processing software.

To try to put some perspective on these costs, a comparison chart (Figure 4) of cost per mile was made for various types of inventory data collection based on telephone inputs from inventory personnel in several State DOT's. This chart and the GPS Cost/Accuracy chart described above were circulated for comment to the State DOT's who participated in the Task 3 GPS/GIS Questionnaire survey. There does not seem to be much of this kind of planning or reference information readily available within the DOT's we were able to contact. Six States responded with information that was used to update the charts as shown in this report.

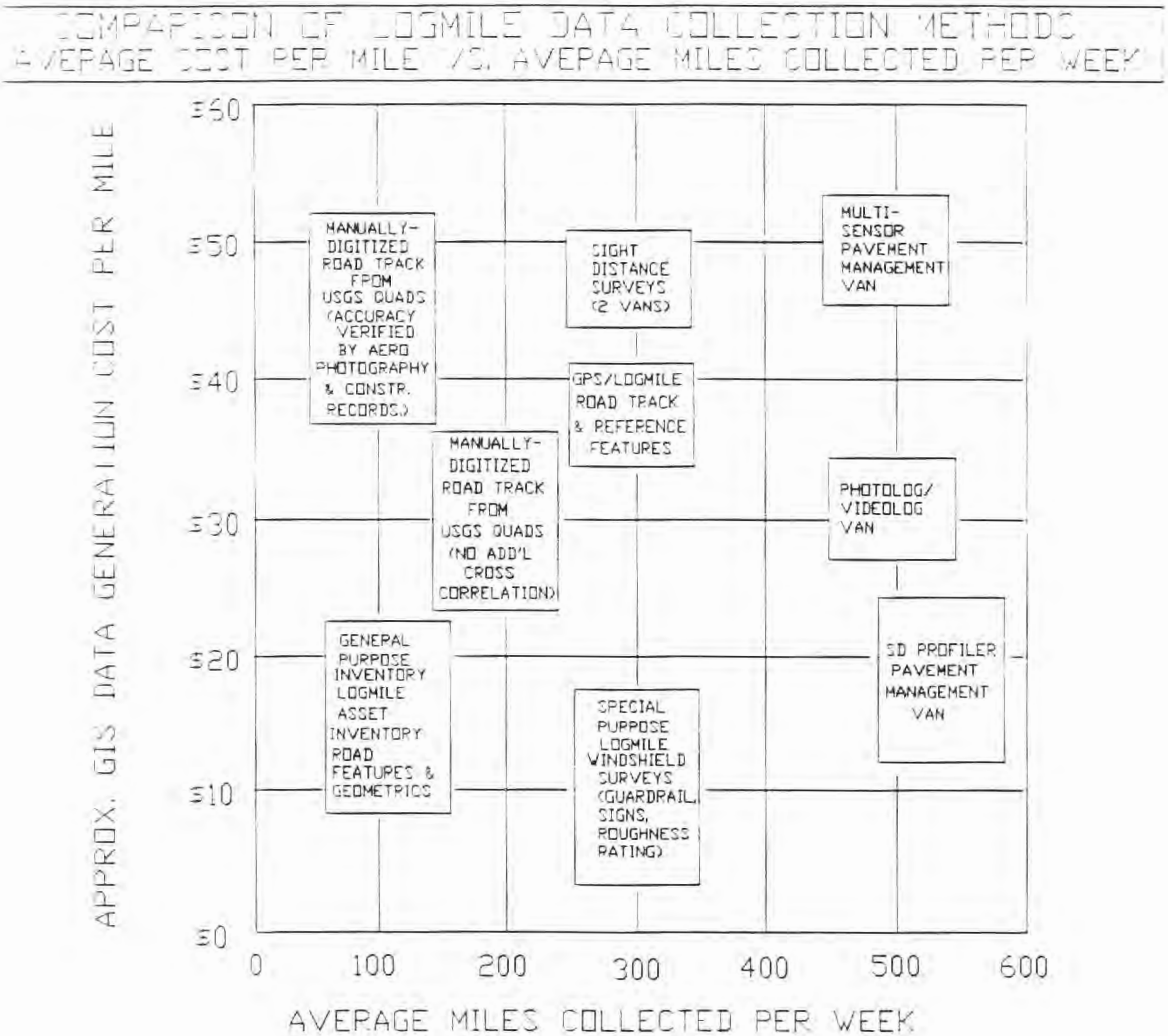



**Figure 4. Inventory Cost Comparisons**

While this analysis was only preliminary, clearly there is a significant difference in the cost of the different classes of highway attribute data collection and processing. It is also clear that it costs significantly more to collect attribute data with a GPS-based data collection system than with the elapsed distance MRM-based system currently used by SDDOT. This analysis should continue to be refined and updated by SDDOT to help provide a better decision-making environment for potential SDDOT GPS/GIS applications.

# TASK 3. PREPARE A SUMMARY OF GPS/GIS DOT APPLICATIONS

This section of the report presents a summary of the responses to the GPS/GIS questionnaire that was sent by Jim Jenssen, Director, Division of Planning, to the Planning Division Directors or their equivalents in the other 49 State DOT's.

A total of 38 States responded with completed questionnaires. As mentioned earlier, a follow-up mailer was sent in July to all questionnaire respondents to solicit information on inventory data collection costs. Six States responded with data that was used in the cost-per-mile estimates for the data collection categories shown in TASK 2.

The questionnaire responses were divided into four categories:

1. Computer-Based Inventory Systems
2. Computer-Based Mapping Systems
3. Geographic Information Systems
4. GPS Applications

Figures 5-8 show the distribution of responses for each of these categories and the observations of the research team.

1. Computer-Based Inventory Systems

Figure 5 shows the distribution by State of responses to questions aimed at identifying the types of Highway Attribute Inventory Systems in use today. Almost all responding States employ a mainframe data system similar in function to SDDOT's RES database. Most States use this system to manage the Federally-mandated standard categories of Roadway Features, Bridges, Road Condition or Pavement Management, Traffic and Accident data. Surprisingly, a noticeable portion of these States do not apparently maintain computerized inventories of the Road Geometry Attributes of their highways.

Over 80% of the States also maintain distributed database capability, either on Work Stations, PC's or both.Almost two-thirds of the States maintain some form of Highway Attribute inventory database on their complete public road network, with the remaining third focused only on their State-maintained system.

Not surprisingly, Logmile distance within State, County or Control Segments is the de facto standard for location of Highway Attributes. Several of the States reported using a combination of methods, but only four indicated using South Dakota's MRM-type of signpost reference system exclusively.

The positioning accuracies reported for Attribute location can be somewhat ambiguous. We asked the question "What is your accuracy **specification** for attribute location?", when what we should have asked is "What is the accuracy of your Attribute **database**?". For example, Vermont reports a placement specification of 0.1 mile, but one of their pavement management managers believes that this data is accurate to .001 mile. On the other hand, Tennessee collects field data to .001 mile accuracy and then rounds to the nearest .01 mile because the inventory record structure only allows two decimal places. From follow up telephone conversations we concluded that most States use Distance Measuring Instruments with 0.001 mile specification precision and believe that their attribute databases have an overall accuracy within 0.01 mile at the time of update.

About half of the States use pavement management sensor-based vehicles, and about two-thirds are using photo/video logging vans.

## COMPUTER-BASED HIGHWAY ATTRIBUTE INVENTORY SYSTEMS

| States | AK | AL | AR | CA | CO | CT | FL | GA | IA | IL | IN | KS | KY | MA | MD | ME | MI | MN | MO | MS | MT | NE | NV | NY | OK | OR | PA | SC | SD | TN | TX | VA | VT | WA | WI | WV | WY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1) Where are inventory data files stored? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mainframe | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Workstation | | Y | Y | | | | | | | Y | | | Y | | Y | | Y | Y | | Y | Y | | | | | Y | | Y | | | | | | Y | | | Y |
| PC-Based | Y | | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | | | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | Y | Y | | | Y | | | Y |
| 2) What assets are inventoried? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Road Geometry | Y | | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | | | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | Y | Y | | | Y | | | Y |
| Road Condition | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y |
| Roadway Features | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | | Y | Y |
| Bridge Condition | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y |
| Off-road Features | | Y | | | Y | Y | Y | | | | | | | | | | Y | Y | | Y | | Y | | | | Y | | | | Y | | | Y | Y | | | Y |
| Traffic Statistics | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | Y | | Y | Y |
| Accident Locations | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | | Y | Y | Y | Y | Y | Y | | Y | Y |
| 3) Inventory all public roads? | Y | Y | Y | Y | Y | | | Y | Y | Y | Y | | Y | Y | Y | Y | | Y | | Y | Y | Y | | Y | Y | Y | | | Y | Y | Y | | Y | | | | |
| 4) Inventory state controlled roads? | Y | | | Y | | Y | | | | | | Y | Y | | | | Y | Y | Y | | | | Y | | Y | Y | Y | | | | Y | Y | | Y | Y | Y | Y |
| 5) What inventory feature location is used? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Logmile distance within State/County Boundries | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | | | Y | Y | Y | Y | | Y | | Y | | | Y | Y | Y | | | | Y | | Y | Y |
| Logmile distance within road control segment | | | | | Y | | | | | | | Y | | | | | Y | Y | | | Y | | | Y | | Y | | | | | Y | | Y | Y | | | |
| Offset distance from known reference markers | | | | | | | | | | | Y | | | | Y | | | Y | | | | Y | | | | | Y | | Y | | Y | Y | | | Y | | |
| 6) Accuracy requirement for feature placement? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Y | | | | |
| 0.01 | Y | Y | Y | | Y | Y | | Y | Y | | Y | | | Y | Y | Y | | Y | | | | Y | | Y | Y | Y | Y | Y | | Y | | Y | | Y | Y | Y | Y |
| 0.001 | | | | Y | | | Y | | | Y | | Y | Y | | | | | | Y | Y | Y | | Y | | | | | | Y | | Y | | | | | | |
| 7) Operate automated road condition vehicles? | Y | | | | | Y | Y | | Y | Y | | Y | Y | Y | | Y | Y | Y | Y | | Y | Y | Y | | | | | Y | Y | Y | Y | | | | Y | | Y |
| 8) Operate a photolog system? | Y | Y | | | | Y | Y | Y | Y | | Y | Y | | | Y | | Y | Y | | | Y | Y | Y | Y | Y | Y | | | Y | Y | | | Y | Y | Y | Y | Y |
| 9) Other automated data acquisition systems? | Y | | | Y | Y | Y | | | Y | | | | Y | Y | | Y | Y | Y | | Y | | | Y | | | Y | Y | | | Y | | | | Y | Y | | |
| States | AK | AL | AR | CA | CO | CT | FL | GA | IA | IL | IN | KS | KY | MA | MD | ME | MI | MN | MO | MS | MT | NE | NV | NY | OK | OR | PA | SC | SD | TN | TX | VA | VT | WA | WI | WV | WY |

Figure 5. Computer-Based Highway Attribute Inventory Systems

## 2. Computer-Based Mapping Systems

Computer-based cartography is used by 90% of the responding States, as shown in Figure 6. Manually digitizing from Quads, manually digitizing from existing maps, and using NGS Digital Line Graph (DLG) files or the equivalent U.S. Census Bureau TIGER files seem to be about equally popular sources for data.

Sources used do not necessarily correspond with map accuracy standards, however. For example, Texas has recently established a Quad-based map accuracy of +/- 40 feet as part of their new GIS Standard, but it is generally acknowledged that most of the source data currently in use is based on DLG accuracies of +/- 150 feet. We expect that as GIS implementation progresses, computerized map accuracy standards will have to be tightened to match the basic accuracies of the Attribute databases they must support.

Almost all of the responding States who have implemented computerized mapping are responsible for mapping all roads in their State, but some certainly do it faster than others. The reported map update frequencies show a 10:1 range, with no observable pattern.

### COMPUTER-BASED MAPPING SYSTEMS

| States | AK | AL | AR | CA | CO | CT | FL | GA | IA | IL | IN | KS | KY | MA | MD | ME | MI | MN | MO | MS | MT | NE | NV | NY | OK | OR | PA | SC | SD | TN | TX | VA | VT | WA | WI | WV | WY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Have you implemented computer-based mapping? | Y | Y | Y | Y | Y | Y | Y | | Y | | Y | Y | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | Y | | Y | Y | Y | | Y |
| (2) How do you create your base-maps? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| USGS 7.5 minute Quads | | Y | Y | Y | Y | | Y | | Y | | | Y | Y | | Y | | Y | Y | | Y | | Y | | Y | Y | Y | Y | Y | | Y | Y | | | Y | | | |
| Other existing maps | | | | Y | Y | Y | Y | | Y | | | Y | | | | | | Y | Y | | | Y | Y | Y | Y | | | | | | Y | | Y | Y | Y | | |
| In-house map scanning | | Y | | | | | | | | | | Y | | | | | | | | Y | | Y | | | Y | | | Y | | | | | | Y | Y | | |
| Purchase digitized maps | | | | | Y | | | | | | | Y | | | | | | | | | | | | | | | | Y | | | | | | | | | |
| Digital Line Graphs | Y | | | | | Y | Y | | | | | Y | | Y | | | | | Y | Y | | Y | | Y | | Y | | | Y | | | | | Y | Y | | |
| Tiger Files | | | | | Y | Y | | | | | Y | Y | | | | | | | | | | | | | Y | | | | | | | | | Y | Y | | |
| (3) Which road set do you map? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| All public roads | Y | Y | Y | Y | Y | | Y | Y | Y | | Y | Y | | Y | Y | Y | | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y | | Y | | | | Y |
| State controlled roads | Y | | | | | Y | | | | | | Y | | | | | | | | | | | | | | | | | | | | Y | | Y | Y | | |
| (4) What is your map update frequency (yrs)? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| State Maps | 10 | .5 | 10 | .5 | 1 | * | 2 | 1 | 1 | | 1 | 2 | 1 | | .5 | 5 | | 1 | 2 | 1 | | 1 | 5 | 10 | .5 | 1 | 2 | 1 | .5 | 2 | 1 | 1 | * | * | 2 | 1 | 1 |
| County Maps | | 6 | 10 | 1 | 1 | | 3 | 5 | 1 | | 3 | 7 | 1 | | 1 | 5 | | 1 | 5 | 8 | | 5 | 10 | | 7 | 20 | 5 | 2 | 4 | 10 | 1 | 2 | 5 | 2 | 2 | 2 | 7 |
| Local Maps | 10 | | 10 | | 1 | * | | 5 | 1 | | 3 | * | * | 4 | 1 | 5 | | 1 | 5 | 8 | | 5 | | 10 | 7 | 5 | * | 1 | 3 | 10 | * | | 1 | | 2 | * | 7 |
| * = as needed | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| (5) What is your map accuracy standard? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DLG/Tiger (+/- 150 ft) | | | | | Y | | | | | | Y | Y | | | | | | | Y | Y | | | | | | Y | | | Y | | | | | | Y | | |
| USGS Quad (+/- 50 ft) | | Y | Y | | | Y | Y | Y | | | Y | Y | Y | | | Y | Y | Y | | | Y | Y | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | Y | | Y | |
| States | AK | AL | AR | CA | CO | CT | FL | GA | IA | IL | IN | KS | KY | MA | MD | ME | MI | MN | MO | MS | MT | NE | NV | NY | OK | OR | PA | SC | SD | TN | TX | VA | VT | WA | WI | WV | WY |

Figure 6. Computer-Based Mapping Systems

## 3. Geographic Information Systems

The section of Questionnaire responses related to Geographic Information Systems is shown in Figure 7. About two-thirds of the responding States indicated they are either planning to or are in the process of implementing a GIS.

Except for Pavement Management, there is less emphasis on implementing Highway Attribute applications then we had anticipated. (That is probably because they do not know yet how easy it will be to access their existing Attribute database after they have a GPS/LOGMILE Skeleton Network!)

Intergraph, Arc Info and EDS/GDS provide most of the GIS equipment and software reported to be currently in use, with Intergraph a 2:1 favorite. Our questionnaire did not specifically query the current use of PC-based desktop GIS systems, but the rapid advances being made in Windows-type GIS equipment and software technology will almost certainly be a strong influence on future GIS application selections.

The map data sources for GIS applications are essentially the same as were shown for computer-generated cartographic maps in the previous section of questionnaire responses, with the comments already noted.

### GEOGRAPHIC INFORMATION SYSTEMS

| States | AK | AL | AR | CA | CO | CT | FL | GA | IA | IL | IN | KS | KY | MA | MD | ME | MI | MN | MO | MS | MT | NE | NV | NY | OK | OR | PA | SC | SD | TN | TX | VA | VT | WA | WI | WV | WY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Have you or are you implementing a GIS? | Y | | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | | Y | Y | Y | | Y | | Y | Y | | Y | Y | Y | | | Y | | Y | | | Y | Y | | |
| (2) What are your primary GIS applications? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pavement Management | | | Y | Y | Y | | | Y | | | Y | | | | Y | | | | Y | | Y | Y | | | Y | | | | | | | | | | Y | | |
| Traffic Analyses | | | Y | | Y | | | | | | Y | | | | | Y | Y | | Y | | | | | | | | | | | | | | | | | | |
| Bridges | | | Y | | Y | | | | | Y | Y | | | | | | | | Y | | Y | Y | | | | | | | | | | | | Y | | | |
| Accident Analyses | | | Y | | Y | | | | | | Y | Y | | | | | Y | | Y | | | | | | | | | | | | | | | Y | Y | | |
| Other Applications | Y | | Y | Y | Y | Y | Y | | Y | Y | Y | Y | Y | | Y | Y | Y | | Y | | Y | Y | | Y | Y | Y | | | Y | | Y | | | Y | Y | | |
| (3) What type of GIS software are you using? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Intergraph | | | Y | | | Y | | | Y | | | Y | Y | | Y | | | | | | Y | Y | | | Y | | | | Y | | Y | | | Y | | | |
| ARC/INFO | | | | Y | Y | | | | | | | | | | | | | | Y | | | | | Y | | | | | | | | | | | Y | | |
| EDS/GDS | Y | | | | | | Y | | | | Y | | | | | Y | | | | | | | | | | | | | | | | | | | | | |
| Developed in-house | | | | | | | | | | Y | | | | | | | | | | | | | | | | Y | | | | | | | | | | | |
| (4) How are you creating your graphics files? | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| USGS 7.5 minute Quads | | | Y | | Y | | Y | | | | | | Y | | Y | Y | Y | | | | | | | | Y | Y | Y | | | | Y | | | Y | | | |
| Other existing maps | | | | Y | Y | | | | | Y | | | | | | | | | | | Y | | | Y | Y | | | | | | Y | | | Y | | | |
| In-house map scanning | | | | | | | | | | Y | | | | | | | | | | | | Y | | | Y | | | | | | | | | Y | | | |
| Purchase digitized maps | | | | Y | Y | Y | | | | | | | | | | Y | | | | | | | | | Y | | | | | | | | | | | | |
| Digital Line Graphs | Y | | | Y | | | Y | | | | | Y | | | | Y | | | Y | | | | | | | Y | | | Y | | | | | Y | Y | | |
| Tiger Files | | | | | | Y | | | | | Y | | | | | Y | | | | | | | | | Y | | Y | | | | | | | Y | Y | | |
| States | AK | AL | AR | CA | CO | CT | FL | GA | IA | IL | IN | KS | KY | MA | MD | ME | MI | MN | MO | MS | MT | NE | NV | NY | OK | OR | PA | SC | SD | TN | TX | VA | VT | WA | WI | WV | WY |

Figure 7. Geographic Information Systems

4. GPS Applications

Figure 8 (opposite page) summarizes the responses to the GPS application portion of the Questionnaire. Two-thirds of the responding States have had some experience with GPS applications. Most of that experience, however, has been in GPS Surveying applications.

One of the main objectives of this section of the questionnaire was to find out what lessons other States have learned in applying GPS technology to the location of Highway Attributes. Unfortunately, the answer so far seems to be "Not Much Yet." Most are in an evaluation mode similar to SDDOT.

Telephone follow-ups to the questionnaire were made with GPS/Inventory contacts in AK, CT, IA, ID, KY, MI, MS, MT, NE, PA, TN, TX and VT. Each of these States has conducted GPS evaluation programs during the past two years or is planning a pilot project during 1993.

The only State contacted with any production experience in GPS/Inventory data collection is Tennessee, who was the pioneer in this field using "pre-Selective Availability" GPS technology developed by Rockwell in 1987-88. Within the current Department of Defense (DOD) environment of controlled GPS accuracy degradation, that technology is no longer viable, and Tennessee is preparing to upgrade their GPS data collection to an inertially aided ***ROADMAPPER***-type differential GPS system.

Montana, Idaho, Connecticut and Pennsylvania have conducted unsatisfactory evaluations of pure GPS-based data collection systems, and several have initiated in-house development of inertially-aided systems to "fill the gaps". During 1992 Alaska was evaluating several similar un-aided GPS data collection systems, but the results were not available at the time of this report. Texas has evaluated a development concept similar to the one used in the OSU/Center For Mapping Project that uses Survey-quality GPS receivers. Vermont, Mississippi and Nebraska are planning GPS data collection pilot projects for implementation in 1993. None of the States we contacted, except Tennessee, have developed production implementation plans yet.

# GLOBAL POSITIONING APPLICATIONS

| States | AK | AL | AR | CA | CO | CT | FL | GA | IA | IL | IN | KS | KY | MA | MD | ME | MI | MN | MO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Have you had experience with GPS? | Y | Y | Y | Y | Y | Y | Y | Y | Y | | | Y | Y | Y | | Y | | Y | Y |
| (2) Do you use GPS for: | | | | | | | | | | | | | | | | | | | |
| Establishing networks? | Y | Y | | | Y | Y | Y | | | | | Y | | Y | | | | Y | Y |
| Project survey? | Y | Y | Y | | Y | Y | | Y | Y | | | Y | | Y | | Y | | Y | |
| Other survey? | | | | | Y | | | | | | | | | Y | | | | Y | |
| Planning inventory? | Y | | | | Y | Y | | | | | | | Y | | | | | | |
| Other applications? | Y | | | | Y | Y | | | | | | | | | | | | Y | |
| (3) Have you used GPS service companies for: | | | | | | | | | | | | | | | | | | | |
| Establishing control networks? | Y | | | | | Y | Y | | | | | Y | | Y | | | | Y | Y |
| Other applications? | Y | Y | | | Y | | | | | | | | | | | Y | | | |
| (4) Are you planning the use of GPS for: | | | | | | | | | | | | | | | | | | | |
| Computer-based mapping? | | Y | Y | | Y | Y | Y | Y | | | Y | | Y | | | | Y | Y | |
| Inventory applications? | Y | | Y | | Y | Y | Y | Y | | | Y | | Y | | | | Y | Y | |
| Precision survey? | | | Y | | Y | Y | Y | Y | | | Y | Y | Y | Y | | | Y | Y | |
| Other uses? | Y | | | Y | | | Y | | | Y | | | | | | | | Y | |

| States | MS | MT | NE | NV | NY | OK | OR | PA | SC | SD | TN | TX | VA | VT | WA | WI | WV | WY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Have you had experience with GPS? | | Y | | Y | Y | | Y | Y | | Y | Y | Y | Y | | Y | Y | | Y |
| (2) Do you use GPS for: | | | | | | | | | | | | | | | | | | |
| Establishing networks? | | Y | | | Y | | Y | Y | | | Y | Y | Y | | Y | Y | | Y |
| Project survey? | | Y | | | | | Y | Y | | | Y | Y | Y | | Y | Y | | Y |
| Other survey? | | | | Y | | | | Y | | | | | Y | | Y | Y | | Y |
| Planning inventory? | | Y | | Y | | | | | | Y | Y | | | | | | | |
| Other applications? | | Y | | Y | | | | | | | | | | | | | | |
| (3) Have you used GPS service companies for: | | | | | | | | | | | | | | | | | | |
| Establishing control networks? | | | | | Y | | Y | Y | | | | | Y | | | Y | | Y |
| Other applications? | | | | | | | Y | Y | | Y | Y | | | | | Y | | |
| (4) Are you planning the use of GPS for: | | | | | | | | | | | | | | | | | | |
| Computer-based mapping? | Y | Y | Y | Y | | | Y | Y | | | Y | Y | Y | | Y | Y | | Y |
| Inventory applications? | Y | Y | Y | Y | | | | Y | | Y | Y | Y | Y | | Y | Y | | Y |
| Precision survey? | Y | Y | | | Y | | Y | Y | | | Y | Y | Y | | Y | Y | | Y |
| Other uses? | | Y | | | Y | | | | | Y | | | | | Y | Y | Y | Y |

Figure 8. GPS Applications

## TASK 4. CONDUCT SDDOT GPS/GIS APPLICATION REQUIREMENTS ANALYSIS

### I. *Requirements Summary*

This research project is structured on the basic premise that the benefits which GPS and GIS implementation offer will yield significant improvements to the planning and decision-making needs of SDDOT. The Requirements Analyses conducted under this TASK 4 of the contract by Bill Beanland have been aimed at identifying the requirements that must be met for this premise to be valid.

### II. *Project 92-05 Requirements Statement*

Project 92-05, "Location of Highway Attributes by Global Positioning", is one of three research projects conducted by SDDOT which aim at applying this new location technology to the formidable task of providing responsive information support for managers facing continuous and ever-growing change in the regulatory and other mandates to which they must respond. The RFP for this project describes the intent of the DOT as follows:

"Problem Description: The locations of Mileage Reference Markers on the state's highway system are not well known. Errors in measurement and documentation, errors have introduced inaccuracies in mileage reference markers' location, typically of some fraction of a mile. Although these errors might seem small, they frustrate various inventory operations. For example, sign inventories can show signs in the wrong locations and in the wrong order because the signs were referenced to erroneously located mileage reference markers. In at least one region, the sign inventory has been suspended until mileage reference marker errors are resolved.

The Department of Transportation also has a need to become familiar with Global Positioning System (GPS) technology. GPS technology is maturing, and promises to economically solve many problems associated with determining locations. One problem is referencing data over time. In a recent report "Historical Database Feasibility Study" it was emphasized that an (x,y,z) coordinate system is necessary to reference data over time, in other words, for historical data bases. Our current data base system consists of an Intergraph Computer Aided Design (CAD) system and a Roadway Environment System (RES).

Many DOT activities gather vast quantities of data on highway attributes, rapidly. GPS provides an opportunity to provide very accurate location data along with other data attributes. Some of the activities that may benefit from GPS are engineering surveying, secondary roads, road profiler, non-state trunk road inventory, mapping and video logger. A pilot GPS study is needed to give the Department experience in GPS equipment and utilization of the data."

## *III. Response to RFP 92-05*

RFP 92-05 calls for the enunciation of new concepts in the position or "place" location of transportation assets and other data useful to the Department, and for the proof of these concepts in GPS demonstrations conducted in a designated test area in Aberdeen for existing SDDOT applications. This portion of the project report addresses the requirement for these new methods in both the near and long terms.

## *IV. Research Method*

Broadly, the research reported here followed the classical approach to systems analysis: "Find out what the user wants, determine the data needed to produce what the user wants, then define the system which will most efficiently encompass all of the information functions needed to produce what the user wants from the defined set of raw data."

RFP 92-05 does not, except by implication, address a total system requirement. It seeks to determine, instead, the benefits that accrue from having existing data (of which RES is a subset) augmented with standard and accurate time and place references.

GPS is a part of one information subsystem, data acquisition, which must be combined with other subsystems that create and maintain databases, process information, and create output. Although evidently in today's information technology, the use of GPS would be greatly enhanced if it became an adjunct to a relational data base operating in a functionally distributed system architecture, that larger view of the "system" requirement is not addressed here. The focus here has been on GPS, itself, and those things that would impact its use by SDDOT. But with that caveat, a real effort has been made to address this "requirement" in the most comprehensive fashion that the scope of this contract will allow.

Information for this report was accumulated from the following sources:

1. Interviews with SDDOT personnel
2. Interviews with geodesists, surveyors, military personnel, land managers and other GIS and GPS users with specialized views of GPS use in civil applications
3. Review of a very broad range of secondary material
4. Direct experience with the GPS field activities in May and July of 1992
5. Field experience in and documentation of other GPS/GIS development activities during the past 6 years.

1. SDDOT Personnel Interviews

A number of recorded interviews were conducted in Pierre and in Aberdeen, the majority with DOT personnel. Persons from other state agencies with an interest in a state-wide geographic information system were also interviewed. Other interviews were conducted by telephone. Many other SDDOT persons contributed to this report in informal, unrecorded conversations. The following is a list of the "formal" interviews that have been conducted and used for reference during the conduct of this Requirements Analysis Task:

The following interviews were conducted with South Dakota personnel during our May and July trips to Pierre:

A. Requirements from the Headquarters Perspective

Dean Schofield, Deputy Secretary
Jim Jenssen, Director of Planning
Ben Orsbon, Engineering Supervisor
Dean Hyde, Transportation Office Engineer
Ken Marks, Senior Engineer
Rudy Persaud, Analyst
Jerry Jacobson, Exempt Professional
Dave Huft, Transportation Office Engineer
Daris Ormesher, Project Engineer
Gay Rhoades, Director of Finance
Wally Larsen, Chief Engineer
John Thune, Director of Railroads
Al Yocom, Systems and Program Manager

B. Requirements from the Regional Perspective

Larry Afdahl, Region Engineer
Norm Humphrey, Operations Engineer
Alan Petrich, Area Maintenance Coordinator
Doug Feickert, Senior Trans. Technician

C. Requirements from the State GIS Perspective

Ron Woodburn, Chairman, State GIS Committee
Kevin Dalstad, South Dakota State University
Jim Hill, Budget Director
Jim Douglas, Information Systems Director

D. Requirements Related to South Dakota Geodetic Reference Standard

1. Wes Odom, NGS Coordinator in South Dakota

2. Gary DeJong, Engineering Supervisor
3. Bob Thielan, Project Engineer, Survey
4. Frank Schaefbauer, Chief Cartographer

E. Extracts from SDDOT planning documents and related reports

1. South Dakota Historical Database Study, Re/Spec, Inc., Jan 91
2. South Dakota Information Systems Plan, Deloitte Touche, Sept 91
3. South Dakota DOT Strategic Plan, 1992, 1993

In most cases, interviews were done in a one-on-one manner. The group interview – essentially a listening session with a panel of carefully selected persons to which a carefully selected set of questions is asked – is a primary tool used by systems analysts. This method of information gathering is extremely useful where there is a need to arrive at a consensus opinion on the adequacies and deficiencies of a system or technology with which all participants are completely familiar. The group session is much less useful in cases where an entirely new (to the group) technology or an entirely new information concept is being evaluated. Past experience with groups has demonstrated that if an analyst attempts to introduce a new concept and, at the same time, get opinions on the usefulness of this new concept, he usually overruns the attention span of his audience before he begins to get information that is of value to his research, if he gets anything at all. When he gets back to his office and listens to his recording, the voice he hears most often is his own.

Elapsed-distance place reference systems have been in general use in transportation agencies since the early 1930's and a group of highway people can be a very effective forum for providing a consensus on the pros and cons of this method of locating highway attributes. But two of the characteristics of GPS – three dimensional place definition and the time tag – are, for most transportation people, entirely new concepts. Raising either of these in a group session almost always results in only blank stares. This fact coupled with a desire to address various specific aspects of the Department's need with persons with in depth knowledge of that particular part of DOT activity led to the choice of the one-on-one session as the preferred mode of information gathering.

For someone whose prior knowledge of South Dakota had been derived from a limited number of telephone conversations and one day visit to Pierre during the Multi-state project, the interviews became a source of invaluable facts and perspectives on the information needs of the Department. Perhaps most important, they did conclusively show that while DOT managers have a broad latitude in how they manage, what they manage on a day to day basis is something that is generally mandated by forces external to the DOT: (1) the United States Department of Transportation (USDOT), Environmental Protection Agency (EPA), Office of Management and Budget (OMB), the Congress and other federal institutions; (2) the Governor of South Dakota, the State Legislature, South Dakota State Agencies: and, (3) informally, the citizens of the State through their demands for information and actions on roads and other matters within the Department's jurisdiction.

2. Interviews with other GIS and GPS users

GPS technology and the geodesy on which the use of GPS is based are both going through their own rapid evolutions. As of October 1992, the work period for this task, 14 (out of 21) operational Block II GPS Satellites were in orbit. Five Block I (R&D) satellites still usable for a total of 21 operational spacecraft. As the system gets closer to full operation, there is an ever increasing rate of investment in the development of new receivers, new techniques for acquiring GPS data, and in the implementation of High Accuracy Reference Networks for the control of GPS usage. A larger and larger number of end users are gaining direct GPS experience using low cost, pseudo-range receivers. At the other end of the hardware spectrum, new high accuracy, dual frequency receivers are beginning to appear on the market.

Keeping up with the leading edge of GPS use is a full time job and with no intent of achieving that end, interviews have been conducted with surveyors, GIS implementors, geodesists, and others in the GPS community in order to validate the conclusions in this report. Most of this has been done in the District of Columbia and in adjacent Maryland and Virginia. A special effort was made to interact with the Federal Geographic Data Committee, the inter-agency organization that has been charged by the Office of Management and Budget with the task of coordinating federal use of digital spatial data.

En route to Pierre in July, a half-day visit was made to the Kentucky Transportation Cabinet in Frankfort. The Kentucky transportation agency is in the very initial stages of using GPS for road alignment data acquisition and this visit provided a better understanding of their field equipment and processing methods. On the return from Pierre visits were made to the Council of State Governments (the publisher of "State Geographic Information Activities Compendium"); to the City of Lexington, who recently implemented a GPS control network; and to GRW Aerial Surveys, a Lexington engineering company who performed the surveys that produced the city's control net.

3. Review of Materials From Secondary Sources

Secondary materials -- many in number and widely varied in content -- have been reviewed as a part of this project effort. Included here are a range of documents from:

1. SDDOT and South Dakota Department of Environment and Natural Resources (SDDENR)
2. The Intermodal Surface Transportation Efficiency Act and proposed rule makings associated with that act
3. Federal Regulations pertaining to highways
4. A variety of documents from the National Geodetic Survey, National Geographic Control Committee and other sources describing geodetic standards and methods
5. The general press (in particular, the Wall Street Journal, the New York Times and the Washington Post) for information on the rapidly changing computer industry.

## *V. Management System Requirements*

In the context of our Project Objectives, this broad and divergent range of user inputs has been analyzed to assess the present and future requirements for GPS-related applications. Although GPS has been our primary focus, it is important to keep in perspective that GPS technology is only one small part of one of the system elements, data collection, that must be linked together to achieve cost-effective management and decision-making capabilities.

The System Requirements chart shown in Figure 9 summarizes the key requirements resulting from these analyses that will be necessary for a successful GPS/GIS implementation within SDDOT. Details of the work accomplished to support each of these conclusions is contained in the subsections that follow the chart.

*ESSENTIAL GPS/GIS SYSTEM REQUIREMENTS*

1. Provide Responsive Decision Support
2. Demonstrate Accurate Output
3. Provide Near Term Return On Research Investments
4. Achieve Implementation Without Undue Delay Or Chaos
5. Provide Ability To Incorporate New Information Technology
6. Cause No Disruption Of Operations
7. Provide Capability For Graphic Displays And Thematic Maps
8. Allow User-Defined Geographic Domain Of Output
9. Demonstrate Correlation Between Graphic And Alphanumeric Data
10. Provide Access To All Data In The Department
11. Provide Growth Capability For Three-Dimensional Data
12. Maintain Elapsed Distance Over The Ground Reference System
13. Provide Capability For Historical Data Analysis
14. Provide Flexibility To Incorporate New Data Requirements
15. Provide Flexibility To Respond To New Management Methods And Mandates

**FIGURE 9. GPS/GIS Requirements Summary**

SDDOT's prime requirement for improved information systems was succinctly put by Dean Schofield during an interview on May 22, 1992:

> "One thing that I think probably could be of tremendous value to us here for an information system – and part of it may be the way we are trained and the way that we operate – but there are only so many hours and so much time in a day. If you spend all eight or ten hours of that in dealing with and responding to questions or that sort of thing, you don't then spend any time thinking about the future of the Department, where you are going, where you should be a year

from now or two years from now or five years from now. So I think that if you have a good information system that is able to provide you with the information that you need to make decisions – it's up to you to make that decision – but you should be able to make it faster and then be able to get on to other things that are important as far as the Department is concerned. The people who are doing all the work and all the effort deserve some direction on where the Department is going so that they can plan their work and their efforts. If I don't give the division some direction on where we want to go, they can respond with everything that is happening in their division. Each office can respond with everything that is happening in the office. But are those responses really towards the point where the Department wants to go or where they want to be someplace down the road. I've thought about that a lot and I think that's something that we haven't done very well that we need to improve upon. I guess a good information system would help us do that....From my perspective, I think that we've touched about everything. I probably need to reemphasize – because I've not had the time or the availability of resources to do this thing about thinking in the future. That the area that I see lacking in this position. That's very important. "

Expanding on the comment above, Mr. Schofield defined "future of the Department" to include things like multi-modal operation, better understanding of the transportation of agricultural products, enhancing the movement of freight on the South Dakota's interstates, tracking of trucks and cargoes, hazardous materials tracking, rail and truck interactions, short haul trucking patterns, grain elevator impacts on transportation, railroad traffic, railroad safety, regulation, the implications of the Intermodal Surface Transportation Efficiency Act, bus service, changing demographics and an aging state population, environmentalism and the environmental impact process, and others. In response to a question about deficiencies in the current information system, he replied, " I haven't thought about this as much as I should, but the main thing is that I would like to be able to respond faster."

The implications for the data acquisition needed to address this very basic requirement is obvious. In the broad sense, quick turn around in an information system demands more current and more accurate data files. For GPS based data acquisition, there is a requirement for data that defines the current situation in all of the environments enumerated by Mr. Schofield. Specifically, there is a requirement for a close coordination and very efficient execution of all aspects of data acquisition – mission scheduling, mission planning, control selection, base station operation, mission execution, raw data editing, GPS processing, and post-processed data archiving. There is also a requirement that the data acquisition be done in a manner that will not impose constraints on the remaining steps in the information process – including the linking to existing log mile defined files. Enhancement and rapid completion of the database, processing, and end product generation functions, although outside the scope of this project, are also a requirement.

This also implies that the costs, personnel requirements, and long and short term reliability of GPS based subsystems be compatible with the State's need to do simultaneous data acquisition in all DOT regions. To meet Mr. Schofield's requirements, GPS data acquisition should be possible in any weather condition in which other DOT activities are underway.

2. Assure Usable Accuracy Of Output Data

The South Dakota DOT defines "place" in a number of different ways. One of these is the surveyed site of a Mileage Reference Marker functioning as a node in a link/node system. Location is defined in certain RES files as the displacement (in miles and parts of a mile) from a Mileage Reference Marker. A third definition of place is "mileage" that is the elapsed distance from an arbitrary starting point. In one case, the record file (Planning) contains a "length of segment" that is determined to a thousandth of a mile. Table 1 summarizes the current RES accuracy standards.

## RES Accuracy Standards

| File | MRM (mi) | Length or Displacement (mi) | Mileage (mi) |
|---|---|---|---|
| Traffic Inventory Master File | .01 | .001 | NA |
| Roadway Features Inventory Master File | .01 | .001 | NA |
| Intersection Inventory Master File | .01 | .001 | NA |
| Sufficiency Inventory Master File | | | |
| START | .01 | .001 | NA |
| END | .01 | .001 | NA |
| DRS Inventory Master File | .01 | .001 | NA |
| Maintenance Inventory Master File | .01 | .001 | NA |
| Mileage Reference Marker Master File | .01 | NA | .001 |
| Highway Planning Inventory File | | | |
| START | .01 | .001 | NA |
| END | .01 | .001 | NA |
| LENGTH | NA | .001 | NA |

**Table 1. RES Accuracy Standards**

Bridges with structure numbers are located by coordinates to an accuracy of a tenth of a minute (+/-500-600 feet) for both latitude and longitude in addition to the MRM-tags in the Roadway Feature file. Railroad crossings are unique in that they are located by county, town, and highway/street/location.

Non-system roads are related by log mile segments to a place reference grid based on South Dakota township lines. Attributes for these roads cannot be determined without visual reference to the reference grid.

Project 92-05 was begun partially because of an accuracy problem in Mileage Reference Marker system. Norman Humphrey of the Aberdeen region described the difficulty that he had encountered, "You probably are well aware that we've had some problems with our mile post system. There were some inaccuracies in it that destroyed the data, really. We were using data that we thought was good but it wasn't. The way that our system is set up, they had the ability to shuffle data and you really can't get back to where you started from with it." Mr. Humphrey described accuracy as a three part process including the acquisition of the raw data, the encoding of the data, and the manipulation of the data in a program: "Really, you have three functions. You have the data – raw data – which is paramount to anything. If the encoding isn't accurate – and nobody verifies it anymore. It's all single point of entry and you have to do it right. There is no verification process, basically, that I am aware of, anymore. And then there is the person who determines how to manipulate the data to present it."

Mr. Schofield's comment here is direct and unambiguous: "I think that having the data as current as possible and as accurate as possible is important. And having it easy to get to is important." "Accuracy " of new data describing transportation attributes, is a combination of the datum used, the precision of the measuring tool, skill and attention in acquiring raw data, and quality control in the entry of raw data. As Mr. Humphrey points out, even good data can be made into bad information if it is improperly processed. The phrase, "current as possible and as accurate as possible" is a requirement that has to be met and demonstrated before GPS can come into general use. It's also a validation of the premise that the demand for accuracy in geographic location is limited not by real user need but by the limitations and costs of available location technology. Each improvement in accuracy opens completely new uses of geographic data and geographic information systems.

3. Assure Correlation Between Graphic And Alphanumeric Data

There is a critically important requirement that the alphanumeric GIS files match their graphic counterparts. Ideally, this is an exact congruency that would allow a display of exactly what is in the non-graphic file. The user should have the ability to toggle back and forth between alphanumeric and graphic versions of the file and see the same thing.

4. Maintain MRM/Elapsed Distance Reference System

Distance over the ground (also known by such various terms as mileage, log mile, and elapsed distance) is an essential definition of place for location of highway attributes. Unlike aircraft or marine navigation, which allows straight-line travel to a set of latitude/longitude coordinates, DOT's "navigate" to their destination by driving wherever the road goes and locate their assets by measuring some form of elapsed distance from a State Line, County Line or displacement from a Mileage Reference Marker whose elapsed distance is known. This "real-world" correlation allows communications among highway people, highway users and all other classes of people. GPS receivers can establish the X-Y-Z coordinates necessary for GIS applications, but there is a very basic requirement that GPS data acquisition methods also include the capability for accurately defining over-the-ground distance. Elapsed distance is the essential link which allows graphics-enabling coordinates to be transferred to RES and other files which are MRM defined.

The elapsed distance method was mandated as a requirement for state highway agencies in the early 1930's and now is in universal use through out the country. The Stewart Warner Surveying Odometer set the technical standards for inventory and was in general use until the appearance of the electronic odometer in the 1970's. Much of the original inventory was done with precision measured in hundredths of a mile and the early fixed record databases allowed two decimal digits for mileage precision. This tended to freeze the standard and even though the electronic odometer could measure to a thousandth of a mile, the record system could not accommodate that extra digit. In the real world, however, for safety reasons, most inventory is done from a vehicle moving at traffic speed. There are very few experienced inventory people who will claim that they can consistently enter data at five-foot accuracy while in motion. In RES files (see above) displacements from MRMs are determined to .001 miles.

The requirement for elapsed distance, as a consequence, has at least two implications for GPS data acquisition. In a sense, the South Dakota system of MRM, displacement and mileage is self editing. As a consequence, road alignment inventories, for example, of US 12 and SD37 should intersect in Groton with a mileage of 207.179 on US12 and a mileage of 157.478 on SD37. (From Mileage Reference Marker Listing for the Aberdeen Region, 6/10/91) This requirement for matching mileages has to be considered in the operational procedures for GPS road alignment inventory.

In addition, nothing in near term GPS methods and procedures should preclude the use of entirely different non-odometer methods for acquiring and using much more accurate over the ground distance.

5. Provide Capability For Graphic Displays And Thematic Maps

More specifically, there is a requirement that GPS data enhance the quality of thematic map presentation by accurately representing highway attributes as they are on the ground, and in particular, where they are in relation to other attributes. There is also a requirement that the use of GIS techniques achieve significant improvement in the responsiveness of the system to management requests for new thematic displays. GPS implementation should be done with the intent to minimize as far as is possible, the State's need for new data and the presentation of that new data in system-generated thematic maps.

There are many near-term "interface-like" implications in this requirement. There are longer term implications like, for example, the need for mobile communications to GPS platforms so they – like existing PCs and workstations – can have on-line access to the other portions of the total system.

6. Cause No Disruption Of Operations

As information systems become bigger, more firmly entrenched in day to day operations, and, sometimes, less responsive to the changing needs of their users, they tend to become a potential single point total failure, "bet your business", kind of element in an institution's activity. Users are now so dependent on the computer that major disruption in its operation are unthinkable.

There is an absolute requirement that the implementation of GPS data acquisition methods not create a disruption in the orderly operation of the existing system. Two areas where this requirement might first manifest itself are in adding geographic coordinates to the fixed structure of the RES files and to the county mapping effort now being done on SDDOT's Intergraph workstation. In South Dakota, ideally, it should impose no requirement for new programming for the mainframe system.

7. Provide Near Term Return On Research Investments

As demonstrated by the success of its Road Profiler and video logger projects, the South Dakota DOT has been a major contributor to the advancement of the information sciences in transportation applications. Hardware, software, communications, and data base needs have been evaluated in a number of formal and informal studies by the DOT's staff and by outside organizations. The DOT is also a participant in planning for a new, state-wide geographic information system. GPS is not a new subject in the SDDOT.

It is probably fair to say that senior managers of the Department believe strongly that new information technologies such as GPS should be completely validated, but with that done, implementation of these new technologies should proceed to implementation in an expeditious fashion. There is a real requirement that GPS data acquisition, once proven, be moved into an operational mode. Only then can the benefits from the GPS data become routinely available to all the Department's information system users.

8. Achieve Implementation Without Undue Delay Or Chaos

Influenced, perhaps, by past experience, the Department also has an absolute requirement that any comprehensive implementation of GPS be done in a systematic, orderly, and non-chaotic fashion. There is a requirement for an implementation plan which accurately reflects not only the Department's overall approach to the use of GPS, but the technical, logistical, personnel and institutional barriers which could impede the orderly implementation of GPS-based data acquisition.

9. Provide Access To All Data In The Department

There is a requirement that the graphic display method eventually encompass all of the data acquired by the Department. Among other things, this will eliminate the need for a "manual GIS" in which Magic Marker defined data is applied to hard copy maps to create a thematic presentation. As in many other departments of transportation, the "manual GIS" is widely used in SDDOT. Access to all data would, for example, allow a regional traffic planner investigating the need for new control signals in the vicinity of a school quick access to the traffic, alignment, crossing, signs and signals and other needed data in an automatically produced thematic display. It would also allow safety managers access to accident records in context – surface, traffic, frequency of accidents, signs, etc. Access to all data allows policy decision makers the option to consider all variables in arriving at their judgments.

Automated thematic maps require that data elements be defined with geographic coordinates so they can be computer generated from a Geographic Information System instead of manually generated by the current "Magic Marker" system. The clear implication here is that there is a requirement that the GPS method for establishing X-Y-Z coordinates be applied to all inventoried attributes.

FHWA's "Place Defined Features, Federal Regulations Pertaining to Highways" enumerates approximately three thousand different things with place and time dimensions that the Federal Highway Administration has said must be managed by state transportation agencies. If anything, this is a conservative estimate of the data acquisition task since it does not include any new requirement flowing from new ISTEA rules, or from regulatory requirements of other agencies, or from requirements which the Department imposes on itself.

The paragraph above may unintentionally leave the impression that there is a massive new data acquisition task facing DOT's. The fact is that SDDOT is one big data acquisition machine where almost all of the people in the Department spend at least some part of each day acquiring data. Much of what is called for in federal regulations is data that the Department is already getting, although a significant part of it may not be included in any automated database.

The longer range implications for GPS-defined attribute acquisition are profound, however. GPS eventually will be used to locate things that are not on the road, (bicycle paths, railroad alignment and bridges,); things that are above the road (clearances, pollution plumes); things that are below the road (flood plains, drainages); and things that are abstract in nature (zoning limits, city boundaries).

10. Provide Capability For Historical Data Analysis

Part of the power of GIS as an information assimilating tool stems from its ability to display different classes of data in a given geographic domain in "overlays." Given the existence of archival data, the same technique can be used to impart a historical perspective to the decision process. There is a requirement in the SDDOT for historical data, and particularly for historical data reflecting highway condition.

In the current state of GIS technology related to Highway Attributes, most time tags for the historical perspective can be determined from built-in coputer clocks - the uses for GPS time tags with microsecond precision have not been developed yet.

However, the GPS time tag is a potentially valuable operational new data element. The near term implementation of GPS data acquisition techniques should be done with the intent of retaining the utility of the time tag for historical and other purposes. Conversely, nothing in the near term implementation should have the effect of inhibiting the widest use of the time tag in future applications.

11. Allow User-Defined Geographic Domain Of Output

Equitable application of the Department's resources is a pressing, and every day task for SDDOT managers. Priority for a particular proposed project is determined by relating it to all other needs in the State. The decision tool – really, the bible – now used is the annual "Highway Needs Analysis and Project Analysis Report." The use of GPS to facilitate the production of a graphic, rapid response version of the Needs report for senior managers would be one of the most productive of all near term uses of this new technology. A fundamental requirement here is that users have the option to define any geographic domain – from state wide to project level or smaller – as the area to be covered in the displays which the system will create. The Needs Report works because it allows the decision maker to look (although manually) at a particular project in the context of similar projects throughout the whole state.

One thing clearly evident here is that "everything has to fit" regardless of the areas that is displayed. The Needs-like graphic output should be a model for the near term use of GPS data acquisition and every effort should be made to use the

capability inherent in GPS of accurately displaying geographic domains without regard to scale. Obviously, to achieve that end, there are things that have to be done in the non-data acquisition portions of the total system which address the movement of files, database creation, management and use, data analysis, and display creation. These are not addressed in this research. It is incumbent on GPS implementors, however, to assure that nothing done in data acquisition will inhibit an efficient interface with these other systems functions.

12. Provide Ability To Incorporate New Information Technology

Like many people in many other institutions, there are SDDOT information users who have felt, on occasion, that they were being managed rather than served by the computer system. Part of this may have been due to institutional causes, but a very large part of it probably was due to real technical limitations. There is a requirement that GPS implementation be done in such a way that when advances in GPS - or in the various elements of the automated system which it serves - become available, these advances can be brought into use in an orderly and expeditious fashion.

This implies a need to understand, among other things, the structural arrangement of the system, the nature of intra-system interfaces, and the specific information functions which will be performed by a GPS data acquisition sub-system. To paraphrase the good advice of Al Yocom, it probably also means that "GPS should be kept at least five layers away from the machine."

13. Provide Growth Capability For Three-Dimensional Data

As indicated above, highway assets in South Dakota exist on, and above and below the highway in a natural three dimensional matrix. Since Thomas Jefferson's time when large area surveys began in the United States, users of spatial data have been severely constrained by the technical limitations in the way place location was measured and by the technical limitations of cartography where space was portrayed in two dimensions. The underlying principles of modern geodesy, with its separate systems of horizontal and vertical control, are not all that different from those which guided Ferdinand Hassler in 1816 when the country's first geodetic survey was begun. Geographic Information Systems which would serve transportation users have a requirement for GPS place determination where "Z" accurately determines elevation or, in lay terms, "where the water will go."

14. Provide Flexibility To Incorporate New Data Requirements

Even a brief glance at the description of new management required by ISTEA or the newly mandated Bureau of Transportation Statistics will convince most observers that the database content of transportation geographic information systems is in a constant state of change. The Bureau of Transportation Statistics will be responsible for, "Compiling, analyzing, and publishing a comprehensive set of transportation statistics to provide timely summaries and total (including industry wide aggregates and multiyear averages) of transportation-related information..." (Title VI, Public Law 102-240) The law further charges the new agency ensuring that data acquisition be done in such a way as to "maximize the ability to compare data from different regions and for different time periods."

There is a requirement that the implementation of GPS acquisition methods be done in a manner that will allow routine modification of the inventory process so that new forms of data, including new forms of data acquired by sensors and other automatic data acquisition devices, can be added to the database.

15. Provide Flexibility To Respond To New Management Methods And Mandates

Given the changing state of the economy and the environment, the changing nature of Federal/State relations, demographic changes in South Dakota, and other factors, it would probably be naive to assume that the charter of the DOT – either de jure or de facto– and the management style of the DOT will not, themselves, undergo change that must be reflected in the Department's information system. Some already evident symptoms of this include a 28% reduction in staff over the last ten years, the retirement of the Interstate generation of senior managers and the institutional memory that goes with them, and a growing reliance on consultants to perform functions previously done with in-house staff are all evidence of that change.

A GPS acquisition subsystem – and the information system which it serves – should be designed and implemented in such a way that changes in management charter and style can be accommodated with the minimum disruption.

## *VI. Data Requirements*

Several approaches were used in attempting to define a representative list of the types of data which have to be accommodated in GPS data acquisition. The first of these was to extract from the various database studies done for SDDOT and from the Department's 92/93 strategic plan and from other documents provided by SDDOT those highway attributes with place or time descriptors. This was followed by a similar review of the transcripts of interviews in Pierre and Aberdeen. The list which resulted from this was an impressive reflection of what the SDDOT information system now handles but in order to get a better look at what it might be called on to handle in the future the review of ISTEA, the rule making processes spawned by ISTEA, and the file of federal regulations currently pertaining to highways was undertaken.

The intent here was not to produce a definitive list of the attributes that need time and place references but rather to produce a representative list from which the scope and variety of highway attributes could be inferred. For a number of reasons, the Current Federal Regulations Pertaining to Highways became the primary source for this part of the research. Although quite large (>2,000,000 bytes) the data was available in digital format and with 72 different sections covering, presumably, every aspect of highways, it had to be seen as comprehensive. In addition – and this was discovered after the data reduction process was well under way – it provided a real opportunity to look at the overlap of attributes in various regulations. The specific word "Construction" appeared in 42 of the 72 regulatory parts.

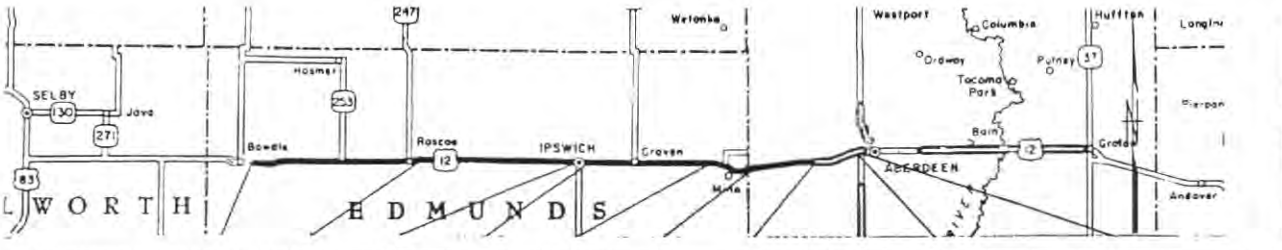
The data reduction method was straightforward. A judgment was made that words – generally nouns and the noun form of verbs – that describe things, events, or activities – are also descriptive of highway attributes which require time and place tags. In this context, a thing is, for example, a bridge, a highway, a bridge pier, a shoulder, etc. An event included items such as accident, or flood. An activity was the term applied to construction, evaluation, maintenance, etc. A word processor program was used to build an index of all these. The index was then scanned to eliminate duplicates such as "road" and "roads" in a single file and the result was then added to the continuing index of all files. When all CFR parts had been indexed and combined into one data set, this was sorted by feature name, manually scanned again for obvious errors and then printed.

Using the index logic described above, 13 of the regulatory parts had in excess of 100 different kinds of attributes with an implicit need for place and/or time references. CFR650.92 (Bridges, Structures and Hydraulics) with 425 references and CFR750.92 (Highway Beautification) with 423 were the hands-down winners.

# *TASK 5. PREPARE GPS/GIS APPLICATION RECOMMENDATIONS*

One of the primary recommendations resulting from the Requirements Analysis task was "The use of GPS to facilitate the production of a graphic, rapid response version of the Needs report, for senior managers would be one of the most productive of all near term uses of this new technology."

Figure 10 is a copy of a representative page from the "1992 Highway Needs Analysis and Project Analysis Report". This sample is one of the pages of tabular data applicable to our project's US Highway 12 test area near Aberdeen. This data summarizes the final result of the project planning and prioritization effort, but it represents the tip of an analytical iceberg that goes on during the annual planning process.




| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | EBL | WBL | EBL | WBL |
| BEGINNING MRM | 233.36 | 248.18 | 262.60 | 263.34 | 274.00 | 278.32 | 284.09 | 284.09 | 288.94 | 288.94 |
| MRM DISPLACEMENT | 0.000 | 0.018 | 0.000 | 0.265 | 0.973 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| LENGTH | 14.915 | 14.394 | 1.003 | 11.302 | 3.412 | 5.475 | 4.768 | 4.768 | 0.068 | 0.068 |
| YEAR BUILT | 1958 | 1952 | 1977 | 1974 | 1970 | 1971 | 1971 | 1971 | 1971 | 1971 |
| YEAR LAST SURFACED | 1985 | 1980 | 1977 | 1974 | 1971 | 1971 | 1971 | 1971 | 1971 | 1971 |
| YEAR LAST SEALED | 1989 | 1985 | | | | | | | | |
| PSR EQUIVALENT | 3.85 | 3.33 | 3.13 | 3.84 | 4.10 | 4.35 | 4.31 | 4.32 | 3.94 | 4.07 |
| CURRENT ADT | 1495 | 1659 | 1746 | 2061 | 2100 | 2181 | 1951 | 1944 | 5520 | 4370 |
| NUMBER OF TRUCKS | 250 | 221 | 248 | 293 | 298 | 310 | 252 | 251 | 408 | 323 |
| ROADBED LAYERS 1 | 58-BU-46 - 5.0 | 52-BU-43 - 2.0 | 77-BL-44 - 4.0 | 74-BL-46 - 4.0 | 71-BL-30 - 4.0 | 71-BL-30 - 4.0 | 71-BL-30 - 4.0 | 71-BL-30 - 4.0 | 71-BL-30 - 4.0 | 71-BL-30 - 4.0 |
| 2 | 58-AF-42 - 1.5 | 53-BU-43 - 4.0 | 77-CP-44 - 7.0 | 74-CP-24 - 7.0 | 71-CP-24 - 7.0 | 71-CP-24 - 7.0 | 71-CP-24 - 7.0 | 71-CP-24 - 7.0 | 71-CP-24 - 7.0 | 71-CP-24 - 7.0 |
| 3 | 58-AF-40 - 1.5 | 53-AF-24 - 1.5 | | | 71-BU- 4.0- 9.5$ | 71-BU-22 4.0- 9.5$ | 71-BU-16 4.0- 9.5$ | 71-BU-16 4.0- 9.5$ | 71-BU-16 4.0- 9.5$ | 71-BU-16 4.0- 9.5$ |
| 4 | 74-AE-24 - 1.5 | 61-AF-43 - 1.5 | | | 71-AE-20 - 1.5$ | 71-AE-20 - 1.5$ | 71-AE-14 - 1.5$ | 71-AE-14 - 1.5$ | 71-AE-14 - 1.5$ | 71-AE-14 - 1.5$ |
| 5 | 82 SND SEAL | 61-AF-24 - 1.5 | | | 89 PAVE RES | 89 PAVE RES | 89 PAVE RES | 89 PAVE RES | | |
| 6 | 85-AD-14 - 1.5$ | 69 CHP SEAL | | | 90 SHLDR IM | 90 SHLDR IM | 90 SHLDR IM | 90 SHLDR IM | | |
| 7 | 85-AD-30 - 2.0 | 80-AD-40 - 1.0 | | | | | | | | |
| 8 | 87 CHP SEAL | 80-AD-24 - 1.5 | | | | | | | | |
| 9 | | 85 SND SEAL | | | | | | | | |
| 10 | | | | | | | | | | |
| SURFACE - ROAD WIDTH | 30-38 | 24-40 | 44-48 | 24-46 | 24-44 | 24-44 | 24-38 | 24-38 | 24-39 | 24-38 |
| SURFACE TYPE | BIT-MAT | BIT-MAT | PCC | PCC | PCC | PCC | PCC | PCC | PCC | PCC |
| SHOULDER TYPE | BIT-MAT | BIT-MAT | C-G | PCC | BIT-MAT | BIT-MAT | BIT-MAT | BIT-MAT | BIT-MAT | BIT-MAT |
| ROW WIDTH | 200 | 200 | 66 | 200 | 200 | 250 | 100 | 176 | 50 | 33 |
| SUFFICIENCY RATING: | | | | | | | | | | |
| CONDITION - SAFETY | 34- 28 | 29- 30 | 20- 30 | 31- 30 | 33- 30 | 33- 30 | 33- 30 | 33- 30 | 30- 30 | 33- 30 |
| SERVICE - NET RATING | 28-090 | 27-086 | 22-081 | 27-084 | 28-091 | 29-092 | 29-092 | 29-092 | 26-086 | 27-090 |
| SURFACE INDICATOR | 085 | 070 | 065 | 075 | 079 | 082 | 082 | 082 | 076 | 082 |
| AVERAGE ROUGHOMETER | 3.99 | 4.05 | 2.39 | 3.59 | 3.96 | 4.39 | 4.25 | 4.29 | 0.00 | 3.57 |
| AVERAGE STRENGTH | 3.79 | 3.16 | 4.08 | 3.88 | 3.94 | 3.96 | 4.04 | 4.06 | 3.70 | 3.96 |
| SKID TESTS: | | | | | | | | | | |
| 0 TO 20 - 21 TO 30 | 0- 1 | 0- 1 | 0- 1 | 0- 1 | 0- 0 | 0- 0 | 0- 3 | 0- 5 | 0- 0 | 0- 0 |
| 31 TO 40 - 41 + | 5-13 | 2-12 | 1- 0 | 5- 6 | 1- 5 | 0- 7 | 10- 0 | 6- 0 | 0- 0 | 0- 0 |
| RUTTING: SEVEREST | 0.5 | 0.5 | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 | 0.1 | 0.0 | 0.0 |
| X > 0.25" - X > 0.50" | 1- | 78- | - | - | - | - | - | - | - | - |
| X > 0.75" - X > 1.00" | - | - | - | - | - | - | - | - | - | - |
| X > 1.25" - X > 1.50" | - | - | - | - | - | - | - | - | - | - |
| NUMBER OF STRUCTURES | 0 | 1 | 0 | 2 | 1 | 1 | 1 | 1 | 0 | 0 |
| FHWA RATING 1- 2 | - | 58- | - | 80- 91 | 89- | 90- | 95- | 95- | - | - |
| 3- 4 | - | - | - | - | - | - | - | - | - | - |
| 5- 6 | - | - | - | - | - | - | - | - | - | - |
| 7- 8 | - | - | - | - | - | - | - | - | - | - |
| 9-10 | - | - | - | - | - | - | - | - | - | - |
| MAINTENANCE COSTS(100) | | | | | | | | | | |
| ROADWAY SURFACE | 3 | 1.0 | 1.0 | 2 | 1.3 | 6 | 9 | 9 | 0 | 0 |
| STRUCTURE | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| CONTRACT MAINT. | 3.6 | 0 | 4.0 | 2.4 | 3.2 | 6 | 3 | 3 | 0 | 0 |
| TOTAL | 5.0 | 1.9 | 6.9 | 3.6 | 6.3 | 2.6 | 2.0 | 2.0 | 0 | 0 |
| ACCIDENTS: RATE | .92 | 1.95 | 4.12 | 1.59 | 1.92 | 1.71 | 1.31 | 1.01 | .00 | .00 |
| NO. OF FATAL-INJURY | 0- 3 | 0- 5 | 0- 1 | 1- 3 | 0- 2 | 1- 1 | 0- 3 | 0- 2 | 0- 0 | 0- 0 |
| NO. OF PROP. DAMAGE | 13 | 38 | 5 | 20 | 9 | 9 | 6 | 5 | 0 | 0 |

HIGHWAY 012
BEGIN MRM 233.36
END MRM 288.94
MAP NUMBER-04

SOUTH DAKOTA DEPARTMENT OF TRANSPORTATION
PROJECT ANALYSIS REPORT
DATE: 02/24/92

PAGE NUMBER 18

HIGHWAY 012
BEGIN MRM 233.36
END MRM 288.94

**Figure 10. Sample Data From Annual Highway Needs Report**

The following list is a partial itemization of highway attribute information from the SDDOT's Roadway Environment System that is used in the preparatory analyses:

1. Plans, Contracts, C.C.O's, Legislative Action:
   - Route Length
   - Year Built
   - Last Year Surfaced
   - Last Year Sealed
   - Roadbed Layers
   - Surface – Width and Type
   - Shoulder Type
   - Right-of-Way Width
   - Number of Structures and Rating

2. Traffic
   - Current ADT
   - Number of Trucks

3. Roadway Profile
   - Profiler – ROUGHOMETER Surface Roughness Measurement

4. Roadway Rutting
   - Rut Depth Measurement

5. Roadway Sufficiency Rating

   Subjective Visual Evaluation:
   - Condition
   - Surface
   - Safety
   - Net Rating

6. Pavement Deflection
   - DYNAFLECT Average Strength Measurement

7. Pavement Skid Resistance
   - Skid Test Slippery Condition Measurement

Tagging this data with geographic coordinates will pave the way for the computer generation of Thematic Maps to make the comparative analyses more accurate, complete and timely.

The following is a partial list of color-coded thematic maps and their legends taken from past management presentations that were generated manually during past Needs Analysis planning tasks:

1. Overview State Highway Map showing:
   - Interstate – 678 miles
   - High Volume Arterial – 2256 miles
   - Low Volume Principal Arterial – 279 miles
   - Minor Arterial – 3288 miles
   - State Secondary – 1409 miles

2. Reconstruction and Resurfacing under Contract
   - (Prior 10 year history)
   - Resurfacing Projects
   - Grading and Surfacing Projects

3. Annual Average Daily Traffic Flow
   - 0 - 400
   - 401 - 1000
   - 1001 - 3000
   - 3001 - AND OVER

4. State Highways With Minimal Width
   - Roadway Widths less than 26 feet - 1296 miles
   - Roadway Widths of 26 - 28 feet - 1068 miles

5. Federal-Aid Highway System
   - Interstate System
   - Federal-Aid Primary System
   - Federal-Aid Secondary System (State)

6/7/8/9. Next 5 Years: Project Plans versus Needs

(6. High Volume Arterial/
7. Low Volume Arterial/
8. Minor Arterial/
9. State Secondary)

Resurfacing

- Current Project Plans
- Unplanned Needs

Grading and Surfacing

Current Project Plans

Unplanned Needs

10. State Preferential Truck Network

Preferred Routes Which Meet Design Standards

Preferred Routes Which Do Not Meet Design Standards

This is the kind of decision-making information that can be much more easily generated automatically by processing the RES data through the GIS. The GIS demonstrations conducted under Task 8 are designed to illustrate this process.

## *TASK 6. DEMONSTRATE GPS FOR ENGINEERING SURVEY QUALITY USE*

### *A. Procedures of Collection of the Field Data*

During the period May 19-21, 1992, two Trimble 4000 survey receivers and software were used to demonstrate static engineering-quality position locating procedures. The primary objective of this task was to provide accurate base station antenna locations in Pierre and Aberdeen. These locations were later utilized to differentially correct the road alignment and inventory GPS data that was collected by the ***ROADMAPPER*** van.

To achieve centimeter accuracy with GPS, certain control requirements must be maintained. These include true leveling of the antenna, accurate measurement of antenna height, and proper placement centered directly over the National Geodetic Survey (NGS) monument. The level that these controls were adhered established the level of repeatable accuracy in the sub-meter levels. To achieve sub-meter accuracy, two survey receivers must be collecting data from the same satellites, simultaneously. Desired satellite geometry is evenly spaced across the horizon with a minimum of 3 satellites visible. The data files from both locations are then post-processed against each other using Trimble's Trimvec software package. If all statistical and technical criteria are met by these two files, confidence in results is achieved. If the criteria are not met following exhaustion of processing techniques, the survey must be repeated.

Throughout this test period, high wind conditions persisted so sandbags were utilized as tripod anchors for both the Pierre and Aberdeen base station locations, which made the desire for a permanent antenna mount be provided by SDDOT on their rooftops. It was generally agreed upon that these locations were within 2-4 inches of the selected points, despite the difficulty caused by the wind on our field-expedient plumb bob.

With the help of the local NGS representative, a Class A GPS surveyed NGS monument was located approximately 2.4 miles from the SDDOT building in Pierre. This NGS monument identified as "Hyde" was used as the primary reference location for our base station surveys.

### *Pierre Base Station Survey*

On May 19, one of the survey receivers was positioned on the roof of the Pierre DOT building, while the other receiver was positioned over the Hyde monument. Data was collected simultaneously over both locations for a period of 61 minutes. This was done to accurately locate the position of the Pierre DOT rooftop base station. The decision to translocate a base station on the roof was to enable the surveying instrument to collect data without the need for additional security for the instruments. This was the first step in a type of "leap-frog" process to move the base station locations closer to the field test area to assure the best accuracy for the mapping project in the Aberdeen area. The baseline length has a direct relationship with accuracy of the solution. The longer the baseline, the less accurate the results. The basic accuracy of the corrected, post-processed data is approximately +/- 2 cm + 2 parts per million (ppm) times the length of the baseline. Thus, by reducing the baseline length, the accuracy of the results will more closely approach truth.

### *Pierre Base Station Verification Test*

On May 19, the Pierre rooftop receiver was programmed to collect data throughout the night, while the second receiver was positioned over an NGS monument located at the Gettysburg Airport enroute to the Aberdeen test area. This Third Order NGS Monument is called "Gettysburg". Data was collected for approximately one hour at this location to collect comparison data for the Pierre base station. The two solutions from Gettysburg and Hyde would be compared against each other to determine the strength of the solution for the Pierre base station, and demonstrate repeatable accuracy.

Upon arrival at the Aberdeen DOT building, the receiver was positioned on the rooftop to act as the Aberdeen base station. Data was collected overnight to be processed against the data file collected overnight at Pierre. The Aberdeen base station was to be used to correct the roadtrack alignment data.

### *Aberdeen Base Station Survey*

On May 20, the Aberdeen and Pierre receivers were pre-programmed to begin collecting data simultaneously when it was estimated the roadtrack data collection run would begin. Both receivers collected data for approximately 4 hours. These files were to be redundant files for comparison tests and to ensure a base station file was available in case problems arose at either of the base stations.

### *Surveyor Data Post-Processing Overview*

The method of post-processing GPS surveyor data files are automatically post-processed using Trimble's Trimvec processing software package. This package contains two primary programs from which accurate sub-meter solutions can be achieved. These programs use similar algorithms in determining solutions with one basic difference: the number of simultaneous data files being processed against each other. The Trimble Single-Baseline Processor (SBP) is limited to process only two stations' data with a limited size of each data file. The Trimble Multiple-Baseline Processor (MBP) can process more than two stations' data simultaneously with no limit on file size. Both processors will produce essentially the same solution. According to Trimble Technical Support, the Single-Baseline Processor is being phased-out due to its limitations and the MBP's ability to do all the SBP can do and more. Both processors were utilized in post-processing the data sets from South Dakota with similar, repeatable results.

The steps involved in survey quality measurements are the same in both processors. The data files are loaded, the parameters for the processor are programmed, and the results are reviewed by the operator to determine the quality and strength of the solution. The criteria for these measurements is derived from the standards established by NGS for GPS surveyed points. If the results do not meet this criteria, dependent upon the required level of accuracy, the data may be manually processed. Manual processing consists of independently manipulating parameters and adjusting factors to compensate for inferior satellite data, ionospheric effect, or poor satellite geometry. Manual processing can not make bad data acceptable. It can only make the software's job easier by a knowledgeable user deciphering the statistical analysis and guiding the program to the usable data, while ignoring the bad data.

## *SECOND DATA COLLECTION TRIP TO SOUTH DAKOTA JULY 20 - 22*

### *PIERRE BASE STATION RE-SURVEY*

On July 20, we positioned one antenna on the rooftop at the Pierre DOT building and the other over the Hyde NGS monument to demonstrate the repeatable accuracy of GPS survey equipment. Data was collected for approximately 4 hours at both locations. The objective of this survey was to compute one more location for the Pierre base station. The ultimate objective in conventional and GPS surveying is to find, from three separate solutions, an average solution to gain a high measure of confidence. This method enables one to gain confidence in the results or identifies potential problem areas. Both antennas were placed as close as possible to their previous locations to eliminate any error due to placement.

### *PIERRE BASE STATION VERIFICATION TEST*

On July 21, another Third Order NGS monument was located near Holabird, SD, approximately 35 miles from Pierre. This location was used to survey the Pierre base station location from another separate NGS monument. This was also a point which had a much longer baseline distance than from Hyde. This is a good location to demonstrate the effects of a longer baseline on accuracy, and to provide another location for the Pierre base station. Data was collected at both stations for approximately two hours.

### *PIERRE AREA ROADTRACK ALIGNMENT DATA COLLECTION, FIRST RUN*

During the program review with the Technical Review Committee, it was decided that a data collection run would be undertaken in the immediate vicinity of Pierre. This was decided to demonstrate the capabilities of the ***ROADMAPPER*** (tm) system in a completely different geographical environment. In contrast to the Highway 12 test area, the Pierre area provided an urban environment, with trees and buildings which would inhibit reception of the GPS signal at times. It is during these times that inertial aiding data is required in order to permit the accurate mapping to continue. The surveyor at the Pierre base station was to be utilized to differentially correct this roadtrack alignment. Data was collected for approximately five hours at the base station during which the roadtrack alignment data was collected.

### *PIERRE AREA ROADTRACK ALIGNMENT DATA COLLECTION, SECOND RUN*

On July 22, another data collection run was made on approximately the same route in the Pierre area to demonstrate the ***ROADMAPPER*** techniques and capabilities to Mr. Rudy Persaud. During this run, a surveyor was located at Hyde, and recorded data simultaneously with the Pierre base station. This purpose for this was two-fold: one, to differentially correct the roadtrack for comparison from both locations to demonstrate repeatability, and two, to re-survey the Pierre base station from Hyde for the third separate solution for that location. Data was collected at both locations for approximately four hours.

### *PIERRE BASE STATION VERIFICATION TEST*

Following the completion of the roadtrack collection, both receivers were downloaded and the Pierre station was restarted. The other receiver was removed from the Hyde monument and taken to the Gettysburg Third Order NGS monument located approximately 50 miles from the Pierre base station. The objective of this survey was to get another set of data from a longer baseline NGS monument from which to compare the results. We collected data at both locations for approximately one and half hours.

### *SURVEY POST-PROCESSING OVERVIEW*

All of the data was post-processed using the Trimvec Basic Revision E software package. The Multiple Baseline Processor was utilized for differential correction of all surveys. NGS published coordinates were used for all monument locations involved in the surveys.

## COORDINATE CORRECTION

An apparent 22 meter elevation discrepency was identified in the long baseline surveys in the first two Quarterly Reports. After review with NGS, we determined that the problem was caused by our incorrect interpretation of NGS published coordinates. The geoid separation was calculated on data which had already taken this into account. All exhibits in this final report have been updated with corrected and reprocessed coordinates.

## *SURVEYED COORDINATES EXHIBITS*

### COORDINATES FOR PIERRE BASE STATION-HYDE NGS

| | SOLUTION #1 HYDE NGS | SOLUTION #2 HYDE NGS | SOLUTION #3 HYDE NGS | AVG. OF 3 HYDE NGS SOLUTIONS |
|---|---|---|---|---|
| LATITUDE | 44 22 04.11953 | 44 22 04.11852 | 44 22 04.11877 | 44 22 04.11894 |
| LONGITUDE | 100 20 35.39529 | 100 20 35.39539 | 100 20 35.39575 | 100 20 35.395477 |
| ALTITUDE (m) | 442.091 | 442.179 | 442.178 | 442.149267 |
| SLOPE DISTANCE (m) | 3192.3228 | 3192.3413 | 3192.3428 | 3192.335633 |

**The above exhibit presents** the surveyed coordinates for the Pierre base station as located from the Hyde NGS monument. (1) The first three columns are the coordinates for the three independent surveys on different days. (2) The fourth column is the average solution for the first three columns.

### PIERRE BASE STATION DELTAS FROM AVG. SOLUTION

| | AVG. OF 3 HYDE NGS SOLUTIONS | SOLUTION #1 DELTA (m) | SOLUTION #2 DELTA (m) | SOLUTION #3 DELTA (m) |
|---|---|---|---|---|
| LATITUDE | 44 22 04.11894 | 0.018211 | 0.012964 | 0.005247 |
| LONGITUDE | 100 20 35.395477 | 0.004128 | 0.00192 | 0.006026 |
| ALTITUDE (m) | 442.149267 | 0.058267 | 0.029733 | 0.028733 |
| SLOPE DISTANCE (m) | 3192.335633 | 0.012833 | 0.005667 | 0.007167 |

**The above exhibit presents** the computed deltas of each separate solution from the averaged solution for the Pierre Base Station as computed from the Hyde NGS monument. Very good correlation is demonstrated by these deltas representing the repeatability of accuracy which is achievable by GPS.

## COORDINATES FOR PIERRE BASE STATION-CROSS CHECKS

| | SOLUTION #1 GETTYSBURG NGS | SOLUTION #2 GETTYSBURG NGS | SOLUTION #3 HOLABIRD NGS | AVG. OF 3 HYDE NGS SOLUTIONS |
|---|---|---|---|---|
| LATITUDE | 44 22 04.11309 | 44 22 04.11290 | 44 22 04.11135 | 44 22 04.11894 |
| LONGITUDE | 100 20 35.41503 | 100 20 35.41046 | 100 20 35.40628 | 100 20 35 .395477 |
| ALTITUDE (m) | 442.081 | 442.3444 | 442.381 | 442.149267 |
| SLOPE DISTANCE (m) | 75561.7482 | 75561.6733 | 56889.0864 | 3192.335633 |

**The above exhibit presents** the surveyed coordinates for the Pierre Base Station as located from various NGS monument locations other than Hyde. (1) The first two columns present the solutions for the coordinates for the Pierre Base Station as surveyed from the Gettysburg NGS Third Order monument during two separate surveys. (2) The third column presents the solution as surveyed from the Holabird NGS Third Order monument.

## CROSS CHECK DELTAS FROM PIERRE AVERAGED SOLUTION

| | AVG. OF 3 HYDE NGS SOLUTIONS | GETTYSBURG #1 DELTA (m) | GETTYSBURG #2 DELTA (m) | HOLABIRD #3 DELTA (m) |
|---|---|---|---|---|
| LATITUDE | 44 22 04.11894 | 0.180572 | 0.186436 | 0.23428 |
| LONGITUDE | 100 20 35.395477 | 0.332256 | 0.330711 | 0.23448 |
| ALTITUDE (m) | 442.149267 | 0.068267 | 0.195133 | 0.231733 |

**The above exhibit presents** the computed deltas or each separate solution for the Pierre Base Station as computed from the Gettysburg and Holabird NGS monuments. Here we observe good correlation between latitude, longitude, and altitude for the all solutions.

### *SURVEY CONCLUSIONS*

Our conclusions from the comparisons of the May and July survey results for the Pierre and Aberdeen base stations are that both are within an acceptable margin for error for use in differentially-correcting the ***ROADMAPPER*** GPS data, which is the primary focus of this contract.

The series of tests has demonstrated accuracies and repeatability within the theoretical expectations of long-baseline GPS surveys. If subsequent tests determine that either of the base station coordinates should be adjusted, the ***ROADMAPPER*** data can be easily re-processed using the new base station coordinates.

## *SDDOT PERMANENT GPS BASE STATION COORDINATES*

During the course of the program, the Research Department sponsored the construction and installation of a permanent GPS antenna mount on the roof of the DOT building in Pierre, which hopefully will be used as the antenna location for the first SDDOT GPS Base Station. While we were in Pierre for the final program reviews during February 1993, we conducted two additional GPS surveys from the "Hyde" NGS monument to establish survey coordinates for the new Base Station antenna site. The final coordinate based upon these surveys is listed below:

# *Pierre Permanent Base Station Coordinates*

| Latitude | Longitude | Heighth Above Ellipsoid |
|---|---|---|
| 44 22 04.015885 | 100 20 35.52557 | 442.8915 meters |

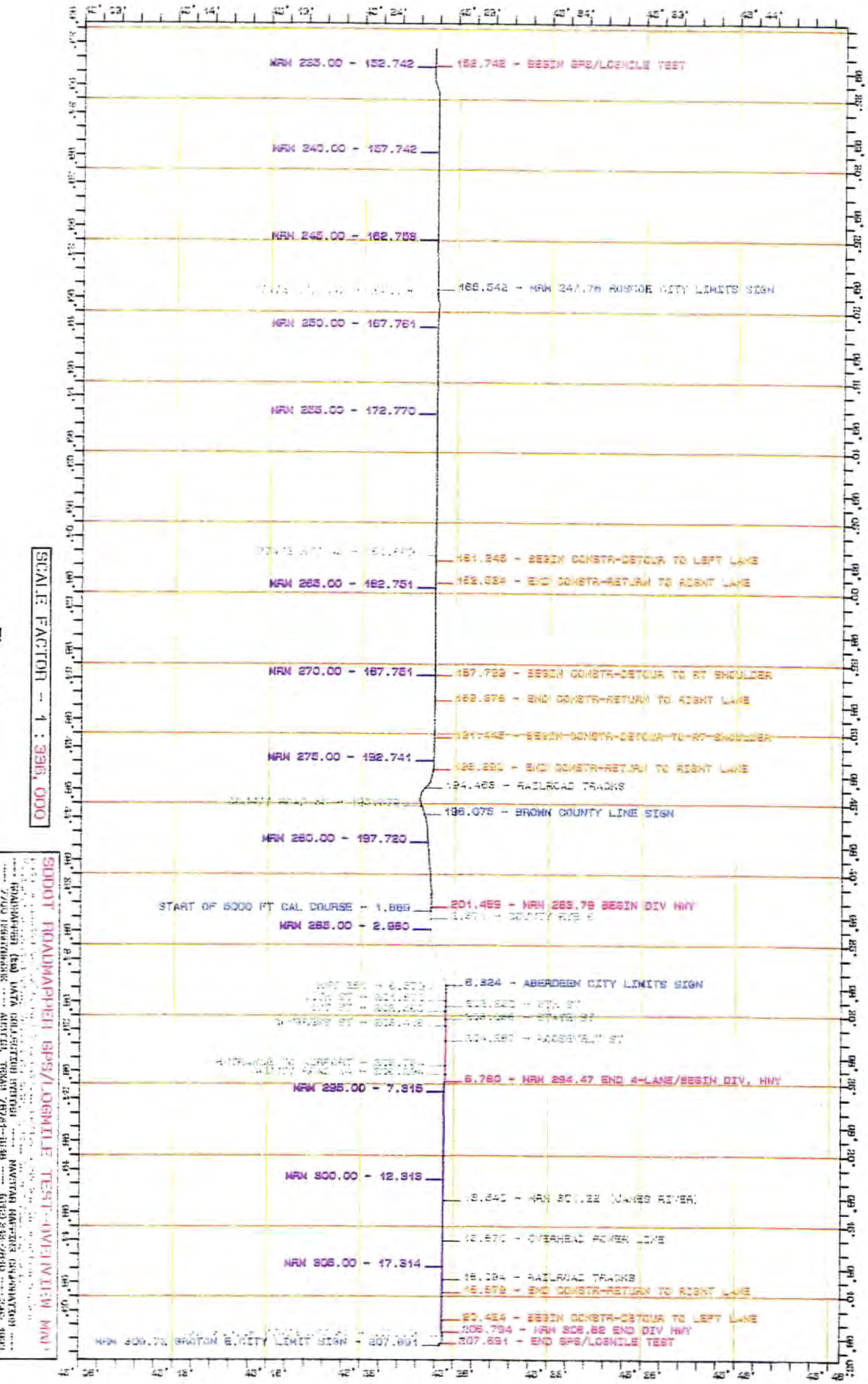

MRM 235.00 - 152.742
152.742 - BEGIN GPS/LOGMILE TEST
MRM 240.00 - 157.742
MRM 245.00 - 162.758
166.542 - MRM 247.78 ROSCOE CITY LIMITS SIGN
MRM 250.00 - 167.761
MRM 255.00 - 172.770
181.846 - BEGIN CONSTR-DETOUR TO LEFT LANE
MRM 265.00 - 182.751
182.884 - END CONSTR-RETURN TO RIGHT LANE
MRM 270.00 - 187.761
187.799 - BEGIN CONSTR-DETOUR TO RT SHOULDER
188.876 - END CONSTR-RETURN TO RIGHT LANE
MRM 275.00 - 192.741
194.468 - RAILROAD TRACKS
196.075 - BROWN COUNTY LINE SIGN
MRM 280.00 - 197.720
START OF 5000 FT CAL COURSE - 1.869
201.459 - MRM 283.79 BEGIN DIV HWY
MRM 285.00 - 2.880
6.324 - ABERDEEN CITY LIMITS SIGN
MRM 295.00 - 7.316
6.760 - MRM 294.47 END 4-LANE/BEGIN DIV. HWY
MRM 300.00 - 12.318
MRM 305.00 - 17.314
BARTON E.CITY LIMIT SIGN - 207.691
207.691 - END GPS/LOGMILE TEST
SCALE FACTOR -- 1 : 336,000
SDDOT ROADMAPPER GPS/LOGMILE TEST-OVERVIEW MAP

Figure 11

## *TASK 7. COLLECT SAMPLE HIGHWAY ROAD ALIGNMENT & INVENTORY DATA*

Field test data was collected on May 20, 1992, along US highway 12 in the Aberdeen Region to demonstrate how the ***ROADMAPPER*** (tm) data collection system is used to generate a GPS/LOGMILE skeleton road network.

GPS/LOGMILE Test Area Description

Figure 11, on the opposite page shows an overview map of the test area, generated by plotting the GPS road alignment coordinates and selected VDES features.

The test area was broken into the following segments:

Segment "12EW1e" – This is a two-lane, two-way section from MRM 235.00 (East of Bowdle) to MRM 283.79 (West of Aberdeen). The highway changes to a divided section (with median) at this point.

Segments "12E1" & "12W1" – These are the Eastbound and Westbound segments between MRM 283.79 and MRM 289.14 (West City Limits of Aberdeen).

Segment "12EW2" – At MRM 289.14, the highway changes to a four-lane street through Aberdeen and then changes back to a four-lane divided highway East of Aberdeen at MRM 294.47. Segment "12EW2e" is the Eastbound segment for this section and corresponds to the standard West-to-East inventory direction.

Segments "12E2" & "12W2" – These are the Eastbound and Westbound segments of the second section of divided highway between MRM 294.47 and MRM 308.82 (West City Limits of Groton).

Segment "12EW3" – At MRM 308.82 the highway changes back to a two-way, two-lane section through Groton. This is the final segment of the test area, which was arbitrarily terminated at MRM 309.72, the location of the Groton East City Limits Sign.

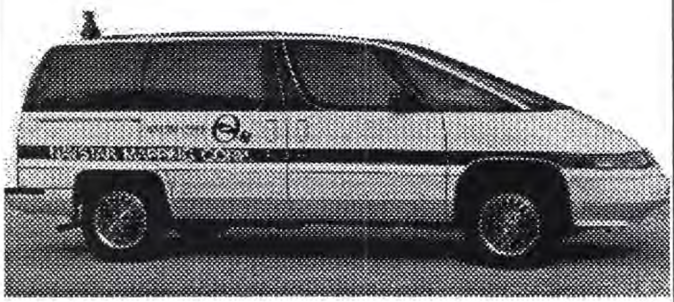
While we were collecting the GPS/LOGMILE data for this 105-mile test area, we used NMC's patented Voice Data Entry System (VDES) to capture GPS/LOGMILE coordinates for each of the Mileage Reference Marker (MRM) signpost locations. As mentioned earlier, these feature data points provide the necessary intelligence to transfer latitude/longitude/altitude coordinates from the GPS/LOGMILE skeleton road network to the MRM-referenced inventory data records.

# NAVSTAR MAPPING CORPORATION

**GPS/LOGMILE Differentially-Corrected Road Alignment Data:**
- GPS Road Track Accuracy: within +/- 25 ft. at 1 second data intervals
- GPS Feature Location Accuracy: +/- 35 ft. using 0.15 sec GPS time resolution
- GPS Gaps Filled Using Auxiliary Heading/Distance/Altitude Sensor Data
- LOGMILE Elapsed-Distance Accuracy of 0.1 % of Cumulative Distance

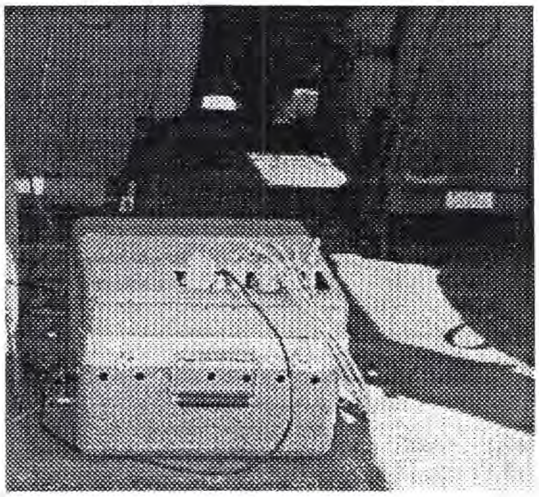
**Voice Data Entry System (Patent #5,170,164):**
- Efficient One- or Two-man Windshield Survey Data Inventories
- Automatic Location Tags - Choice of GPS or Elapsed Distance (LOGMILE) Tags
- User Options for Voice Dictation, User-Defined Hotkeys, and Keyboard Data Entry
- Custom-Designed Database Update and Edit Software

**Post-Processing Software for Mapping and GIS Applications:**
- Road Alignment Smoothing and User-Selected Data Reduction Filtering
- Re-processing Options for Database Accuracy Enrichment
- Road Alignment and Feature Data in ASCII or Custom GIS Formats



***ROADMAPPER* (tm) GPS/LOGMILE Data Collection System**

**Voice Data Entry System**



**GPS/Auxiliary Sensor Package**

The ***ROADMAPPER*** van uses GPS equipment in combination with an auxiliary sensor pachage to generate the GPS/LOGMILE road track. GPS signals are susceptable to temporary blockages along the roadway from a variety of sources such as tall buildings, overpasses, heavy foliage, or steep valleys. The auxiliary sensor package continuously generates a set of independent heading data from an inertially-stabilized heading gyro , altitude data from a barometric altimeter and elapsed distance from a wheel pulse counter. This data is used to "inertially aid" the GPS solutions by providing an alternate source of data from which geographic coordinates can be computed to fill the GPS gaps and smooth the combined road track. Use of this auxiliary data also improves the overall accuracy of the finished road track.

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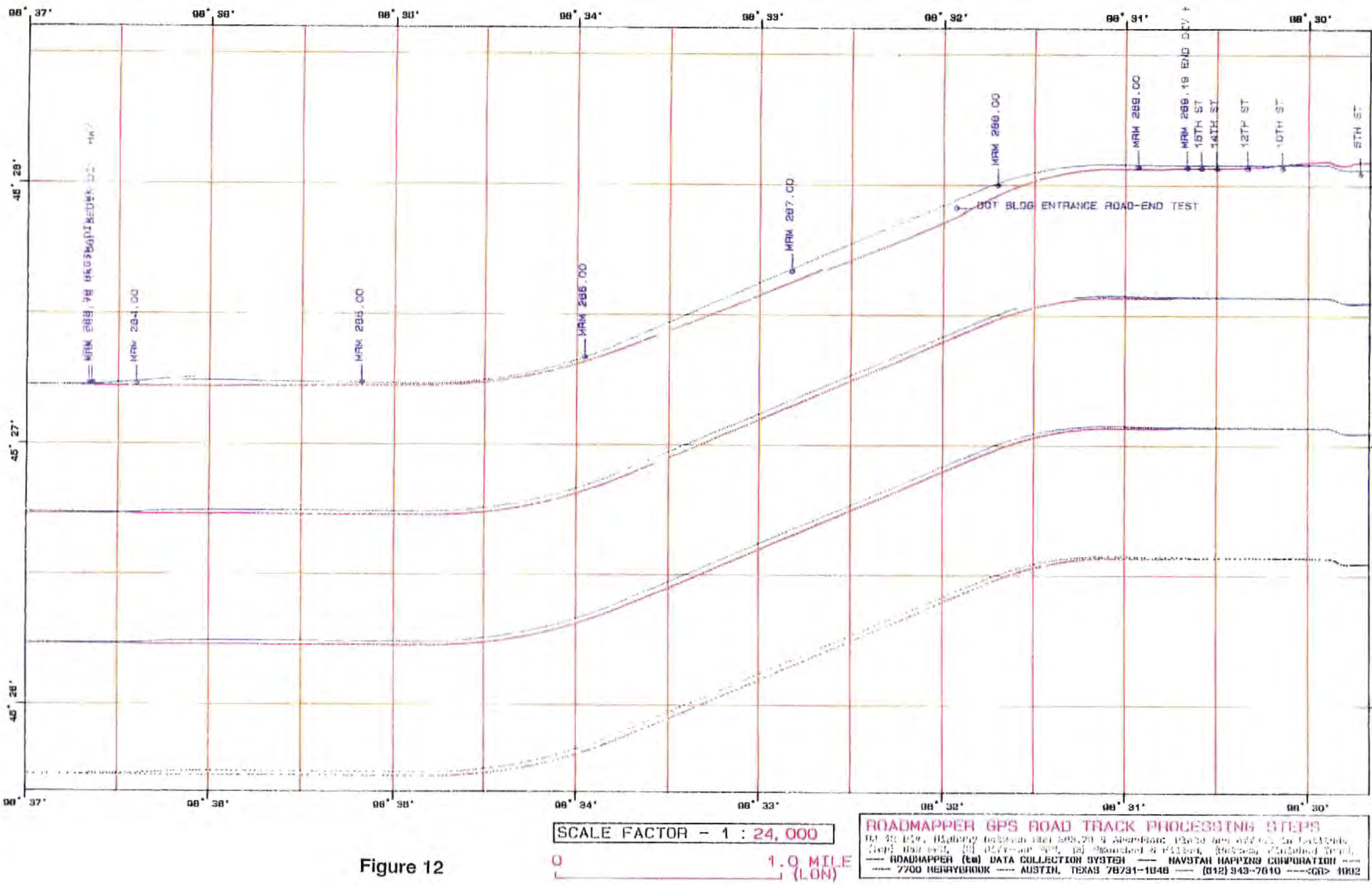


98° 37'
98° 36'
98° 35'
98° 34'
98° 33'
98° 32'
98° 31'
98° 30'
45° 28'
45° 27'
45° 26'
MRM 284.00
MRM 285.00
MRM 286.00
MRM 287.00
MRM 288.00
DOT BLDG ENTRANCE ROAD-END TEST
MRM 289.00
MRM 289.19 END DEV +
16TH ST
14TH ST
12TH ST
10TH ST
8TH ST
SCALE FACTOR - 1 : 24, 000
0
1.0 MILE (LON)
ROADMAPPER GPS ROAD TRACK PROCESSING STEPS
--- ROADMAPPER (tm) DATA COLLECTION SYSTEM --- NAVSTAR MAPPING CORPORATION ---
--- 7700 HERRYBROOK --- AUSTIN, TEXAS 78731-1048 --- (512) 343-7010 ---<GR> 1992


Figure 12

GPS/LOGMILE Skeleton Road Network Generation

For this series of tests we were simultaneously operating one of the 4000 SX GPS receivers as a Base Station from the roof of the DOT building in Pierre and the other as a Base Station from the roof of the DOT building in Aberdeen. The Trimble data was differentially-corrected twice, using each the Base Station GPS Surveyor files that will have been recorded in parallel with the field data. No significant variations were observed from preliminary comparisons between the two data sets. Surprisingly, there was a slightly higher data loss of unmatched data points from Aberdeen than from Pierre.

Calibrated LOGMILE values were then added to each of the differentially-corrected GPS records and the smooth and fill process was performed using the auxiliary sensor data.

Figure 12 shows a sample of GPS road track generation at various processing stages. Each plot shows the same road segment, a divided highway segment west of Aberdeen, with each plot offset in latitude for visual comparison. Red dots show the Eastbound lane and Blue dots show the Westbound lane.

MRM locations are plotted for visual reference. Their location circles had a radius of 25 feet plotted on the original plot scale.

The first (top) plot shows raw GPS data, and obvious accuracy problems such as apparent lane crossover on the right and data direction reversal on the left can be observed. These are typical of the signal degradation problems caused by Selective Availablity. The gaps were most likely caused by temporary signal blockage.

Most of these accuracy errors are corrected after differential correction from the Base Station as shown in the second plot. However, additional gaps are generated where there is no match between the field and Base Station data sets, and in keeping with Murphy's Law, these gaps usually occur on curves.

The third plot shows the effect of merging the GPS data with the auxiliary data from the independent heading, distance and altitude sensors. Dead-reckoning algorithms are used to fill the gaps and smooth the road track to assure that it is completely formed.

Now, after the track is known, unneeded data points can be removed. A filtering algorithm is applied which generates the fourth (bottom) plot. Dependent on the accuracy threshold selected, this process weeds out 25 - 70 percent of the data points necessary to define the skeleton road network, which has significant implications on database size for a statewide road network. For this project a +/- 5 foot track deviation was selected, which resulted in 53% of the data points being eliminated.

The final post-processing step "trims" the skeleton road alignment track into the desired segments, and tags each of the inventory features collected on the data run with latitude, longitude, altitude, and logmile values extracted from the finished road alignment data files.

### *Feature Inventory Data Collection*

The VDES was used to inventory the MRM signpost locations during this sample data collection task. Additional inventory data was also collected to demonstrate how the VDES is used for a variety of windshield survey applications.

The VDES was originally developed to serve as a stand-alone, logmile-only system that would provide a more efficient and cost effective replacement for the "DMI & Clipboard" manual techniques.

When used in combination with a GPS sensor, as in the ***ROADMAPPER*** system, the VDES can also capture GPS time tags in addition to the logmile tags at each feature location.

The accuracy and method for tagging inventory features are essentially the same for either the Logmile or the GPS time mode of operation. However, when the GPS time-tag mode is available, as was the case here, the MRM logmile "look-up" step is not needed and that step in the post-processing procedure can be bypassed.

For this demonstration the VDES was also used to inventory the location of bridges, culverts, guardrails, water line vent pipes, railroad and utility crossings, speed limit signs and road/street intersections.

Our planned data collection speed was 35 MPH to maintain approximately a 50-foot interval between the GPS raw data points. We achieved an actual average speed of 30.3 MPH and inventoried a total of 622 features during 3.6 hours of data collection. This was intentionally planned to be a medium-duty inventory demonstration because our primary objective was to capture accurate coordinates for the MRM signposts.

The test data yielded a sustained feature collection rate of about 3 features per minute, or 6 features per mile. This seemed to be about 60 percent of the capacity that the VDES could have handled with the particular Hotkey/Voice Feature configuration we were using for this demonstration.

*LOGMILE Adjustment Procedures*

We experienced MRM logmile correlation problems firsthand when comparing the logmile values of the MRM's from the ***ROADMAPPER*** data with the existing MRM logmile values from the RES file. We had encountered four construction detours during the data collection run that would account for some of the logmile variation, but it was obvious that there were still some significant discrepancies. It had previously been determined by Aberdeen Region personnel that there were errors in the MRM file and an update MRM inventory had been made. At the time of our tests, Aberdeen DOT personnel were still in the process of revising the logmile values of the MRM's on US 12. After the update was completed, Norm Humphrey provided us a printout of the new MRM logmile values for the test area that were being prepared to update the RES files. These new values provided acceptably good correlation with our data.

One of the features built into the ***ROADMAPPER*** post-processing software is the capability to scale the logmile values between the road alignment data points to match pre-surveyed or even arbitrarily defined logmile values for features. Calibration of our dual logmile sensors had been verified at both the beginning and end of our data collection run, but because of the construction detours and the fact that we did not stop at each MRM, we made the assumption that the new MRM inventory values were more accurate than the logmile values we had recorded. So we used the calibration feature to adjust all of the road alignment and feature data to generate an exact match at the type "C" MRM's and scale all ***ROADMAPPER*** data points proportionally in between. After the changes file was generated the complete re-processing operation took about 5 minutes and resulted in a new GPS/LOGMILE skeleton road network and revised feature files for the test area.

Figure 13, on the opposite page shows a sample segment of the VDES-collected test data plotted on the GPS road alignment track at approximately 1:24,000 Quad map scale. (The map shown here is a photo reduction.) This is a divided highway segment that provides the opportunity for "eyeball" comparison of the finished road track. Each feature data point is plotted at the center of a 50-foot radius circle for further comparison.

The following plotter pen color assignments were made for the feature categories to simulate GIS levels:

| | | |
|---|---|---|
| Level 1 | Black | Culverts |
| Level 2 | Red | Route Segments |
| Level 3 | Blue | Signs |
| Level 4 | Green | Road/Street Intersections |
| Level 5 | Purple | MRM signposts |
| Level 6 | Brown | Bridges & Railroad/Utility Crossings |
| Level 7 | Orange | Construction zones |
| Level 8 | Aqua | WEB water line vent pipes (none on this sample map) |

The feature files used to generate the sample plot was also imported into Intergraph MGE Work Station graphics levels for the GIS demonstrations in Task 8.

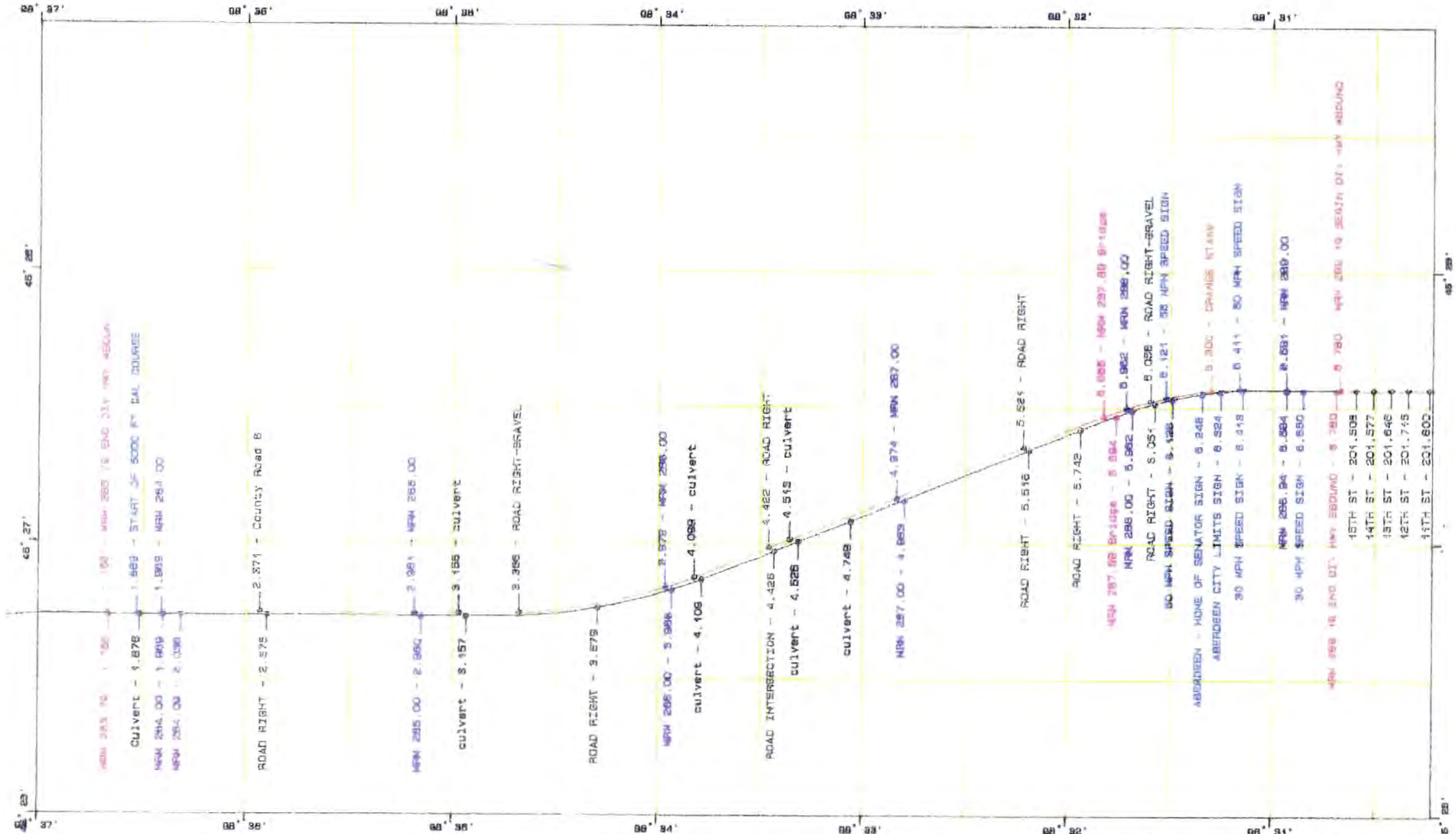



Figure 13

SCALE FACTOR — 1 : 24,000

0 1.0 MILE

SDDOT GPS/LOGMILE TEST - ROADMAPPER DATA
US 12 Divided Highway between MRM 283.79 & West Aberdeen City Limits
Features collected 08/20/92 using VDCS/GPS Time Tag Mode (Edited for clarity)
--- ROADMAPPER (tm) DATA COLLECTION SYSTEM --- NAVSTAR MAPPING CORPORATION ---
--- 7700 HERRYBROOK --- AUSTIN, TEXAS 78731-1848 --- (512) 349-7810 ---<CR> 1992

## *TASK 8. CONVERT SAMPLE GPS/LOGMILE DATA TO GIS DECISION MAPS*

The GPS/LOGMILE skeleton road network and GPS-tagged MRM signpost locations resulting from Task 7 provide two basic GIS implementation functions that are lower cost, faster and more accurate replacements for current manual operations:

1. Computer-Based Mapping

The GPS coordinates of each data point define a three-dimensional equivalent of the two-dimensional road alignment track that is generated currently in computerized mapping operations by manually digitizing from Quads, scaled aerial photos or other paper map sources.

2. Generation of GIS Tags for MRM-tagged Attribute Data

The LOGMILE distances captured with each GPS record are used as the mechanism for matching the GPS network with a variety of existing "MRM + Displacement"–based inventory records. With a non-continuous inventory location system of the type used by SDDOT, the geographic coordinate generation, or the "tagging" process must be conducted in two steps since the true logmile value is not available as a data field:

**STEP 1** The "MRM + Displacement" tag for each existing record must first be converted into an elapsed distance logmile tag. It is a simple, high-speed task to look up the logmile value of each referenced MRM, add the data record's Displacement to that value.

**STEP 2** A logmile match is then attempted for each data record by comparing against the logmile values of the records in the GPS skeleton network file. An exact match is usually not found, so a distance ratio is made between the logmile values of the two GPS road network data points that surround the logmile value of the inventory record. That ratio is then used to interpolate between the lat/lon/alt coordinates of the two GPS points to extract the inventory record's lat/lon/alt coordinates.

The accuracy of the lat/lon/alt Geographic coordinates for the MRM's and other features tagged using the Voice Data Entry System will typically be within a +/- 35 foot error circle, which includes an error allowance for both the basic precision of the differentially-corrected GPS solution, and for variations in the operator's reaction time during data entry. Because of the short distances between GPS data points, the error contribution from the distance ratioing technique is negligable.

This is an absolute position accuracy for each MRM, and is totally independent from the MRM's assigned logmile value. So, even if a new logmile value is given to an MRM during subsequent inventory updates, the latitude/longitude/altitude coordinates of the MRM will not change until the signpost is physically moved.

These GPS-tagged features can now be imported into the GIS for use in generating a variety of planning and decision maps.

GIS Demonstrations

Our data collection concepts are based on two basic facts:

1. The direct generation of GPS tags for highway attribute data costs more than twice as much as the cost of collecting the same attribute data with elapsed-distanced tags.

2. A huge database of highway attribute data with elapsed-distanced tags already exists.

Therefore an important element of this research project is to demonstrate the use of a GPS/LOGMILE skeleton road network to generate GIS data sets from existing inventory data using a methodology that is transparent to everyday SDDOT operations.

The demonstration effort of this Task was to tag and convert sample RES and other logmile-based data files for importing into an SDDOT Intergraph work station.

During the performance period of this Task, SDDOT had not purchased the Segment Management software options for the MGE work stations. So for this demonstration effort a series of custom application software programs were written in MicroSoft QuickBasic 4.5 to illustrate the process of thematic map generation.

The following MRM-based data files were tagged with Geographic coordinates using the Skeleton Road Network and imported into separate graphic layers in the Intergraph MGE environment:

1. The MRM data file 'HR45F01' was converted to a binary master reference file that was in turn used to convert the "MRM + Displacement" tags for all of the other data files to logmile tags. For the signpost-based system used by SDDOT the conversion of all data records must first be performed for the GPS/LOGMILE matching process.

2. To illustrate the GIS-tagging process for sensor-based highway attribute data collection systems, the DRS data file 'HR40F64' was converted to the following 4 separate delimited ASCII text files using another custom program:

A. 'HR40F64.RD' contains logmile-tagged records for each location at which category "W" Rut Depth data changes from one GIS layer threshhold to another.

B. 'HR40F64.DY' contains logmile-tagged records for each location at which category "X" Dynaflect data changes from one GIS layer threshhold to another.

C 'HR40F64.RM' contains logmile-tagged records for each location at which category "Y" Roughometer data changes from one GIS layer threshhold to another.

D. 'HR40F64.SK' contains logmile-tagged records for each location at which category "Z" Skid Test data changes from one GIS layer threshhold to another.

The combination Road Condition Quality/GIS Layer criteria shown in Figure 4 have been established for demonstration purposes:

| Category | Layer | Rut Depth | Dynaflect | Roughometer | Skid Test |
|---|---|---|---|---|---|
| GOOD | 3 | < 0.5 | < 1.25 | > 3.5 | > 40 |
| MARGINAL | 2 | 0.5 - 1.0 | 1.25 - 2.0 | 3.0 - 3.5 | 32 - 40 |
| POOR | 1 | > 1.0 | > 2.0 | < 3.0 | < 32 |

**Road Condition Quality Criteria (Demonstration Only)**

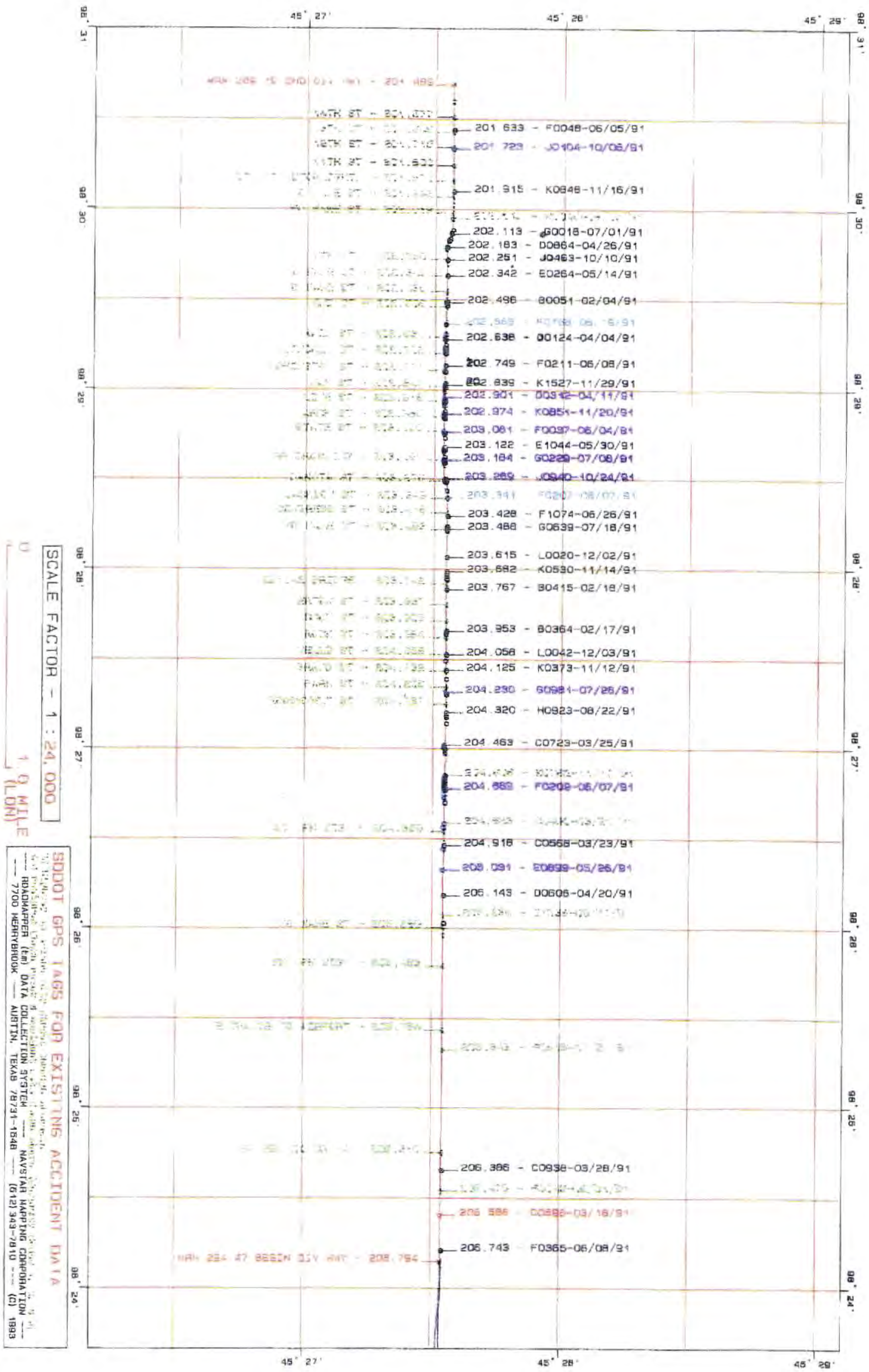
3. The current RES Feature data file 'HR40F01' was converted to the 16 separate delimited ASCII text files shown below corresponding to each of the A-P data categories and then tagged with extracted GPS coordinates. Selected data fields were then assigned to the GIS layers for demonstration purposes.

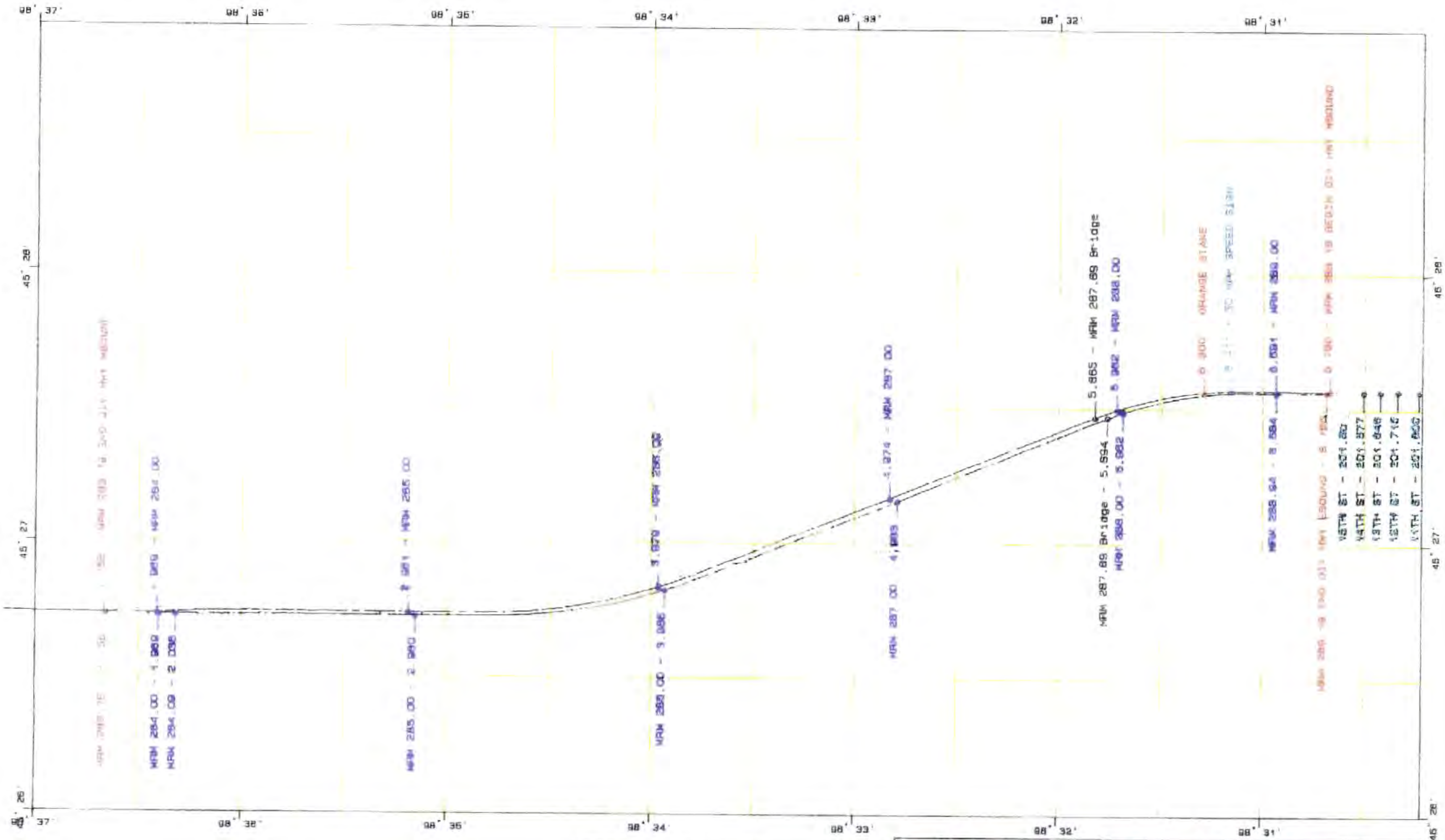
A. 'HR40F01.A' - SYSTEM AND LOCATION data
B. 'HR40F01.B' - PROJECT AND SURFACE data
C. 'HR40F01.C' - CROSS SECTION data
D. 'HR40F01.D' - ROUTE data
E. 'HR40F01.E' - GUIDERAIL data
F. 'HR40F01.F' - ROW FENCE data
G. 'HR40F01.G' - STRUCTURE data
H. 'HR40F01.H' - COMMENTS data
I. 'HR40F01.I' - ROADSIDE AREAS data
J. 'HR40F01.J' - RAILROAD SIGNAL data
K. 'HR40F01.K' - ROW WIDTH data
L. 'HR40F01.L' - HORIZONTAL ALIGNMENT data
M. 'HR40F01.M' - VERTICAL ALIGNMENT data
N. 'HR40F01.N' - ROADBED LANES LAYER data
O. 'HR40F01.O' - ROADBED SHOULDERS LAYER data
P. 'HR40F01.P' - SOIL data

4. To illustrate the GIS-tagging process for ADABAS data, an MRM-based Accident data file for a portion of the test area 'NAVSACCS' was tagged and sorted into GIS layers based on three accident severity categories.

5. To illustrate the interface with PC-based databases, Norm Humphrey provided a DBASE III Highway Sign Inventory data file maintained locally in the Aberdeen Region Office. This file had already been converted from the original logmile references to "MRM + Displacement" tags, so the GIS tagging process was exactly the same as for the RES data files.

Several representative samples of the GIS demonstration data are shown in the pen plotter outputs on the following pages.


45' 27'
45' 28'
45' 29'
98' 31'
98' 30'
98' 29'
98' 28'
98' 27'
98' 26'
98' 25'
98' 24'
201.633 - F0048-06/05/91
201.723 - J0404-10/08/91
201.915 - K0848-11/16/91
202.113 - G0018-07/01/91
202.183 - D0864-04/26/91
202.251 - J0463-10/10/91
202.342 - E0264-05/14/91
202.496 - B0051-02/04/91
202.638 - D0124-04/04/91
202.749 - F0211-06/08/91
202.839 - K1527-11/29/91
202.974 - K0851-11/20/91
203.061 - F0037-06/04/91
203.122 - E1044-05/30/91
203.184 - G0229-07/08/91
203.269 - J0940-10/24/91
203.428 - F1074-06/26/91
203.488 - G0639-07/18/91
203.615 - L0020-12/02/91
203.682 - K0530-11/14/91
203.767 - B0415-02/18/91
203.953 - B0364-02/17/91
204.056 - L0042-12/03/91
204.125 - K0373-11/12/91
204.230 - G0981-07/26/91
204.320 - H0923-08/22/91
204.463 - C0723-03/25/91
204.669 - F0202-06/07/91
204.918 - C0568-03/23/91
205.091 - E0699-05/26/91
205.143 - D0606-04/20/91
206.386 - C0938-03/28/91
206.586 - C0888-03/16/91
206.743 - F0365-06/08/91
SCALE FACTOR - 1 : 24,000
0
1.0 MILE
(LON)
SDDOT GPS TAGS FOR EXISTING ACCIDENT DATA
--- ROADMAPPER (tm) DATA COLLECTION SYSTEM --- NAVSTAR MAPPING CORPORATION ---
--- 7700 MERRYBROOK --- AUSTIN, TEXAS 78731-1848 --- (512) 343-2810 --- (C) 1993




SCALE FACTOR - 1 : 24,000

1.0 MI

SDDOT GPS/LOGMILE TEST-SAMPLE RUT DEPTH DATA
US 12 Divided Highway between MRM 283.72 & West Aberdeen City Limits
Existing RED 'Rut + Displacement' Data Tagged from GPS/LOGMILE Road Track
--- ROADMAPPER (tm) DATA COLLECTION SYSTEM --- NAVSTAR MAPPING CORPORATION ---
--- 7700 MERRYBROOK --- AUSTIN, TEXAS 78731-1548 --- (512) 343-7810 --- (C) 1993

## *TASK 9. PREPARE GPS/GIS IMPLEMENTATION RECOMMENDATIONS*

This Section presents the research team's recommendations for a GPS/GIS time-phased implementation plan for SDDOT. This plan includes recommendations for changes to SDDOT operating policies and procedures to facilitate the implementation.

### *Policy Recommendations*

The Research Team feels that SDDOT would be well served by a more complete analysis of data acquisition activity throughout the Department than could be performed within the scope of this contract. We believe that the need for improved efficiency and reduced cost of data acquisition is greater than in any other data processing activity. As a consequence, this should be a first step in attempting, for example, to respond to the Management Systems requirements in ISTEA.

Correcting the incompatibility between various information systems is certainly not a trivial undertaking. But understanding the existing cost in dollars and manpower for getting the raw data that drives these various databases is an essential first step to that objective. During the course of this research program, it was only possible to generate a rough estimate of the cost of some data collection categories. Although there was a broad consensus that most people in the Department spent some part of every day "getting data," none of the interviewees would offer an estimate of the dollar or time dimensions of this.

**Recommendation #1:** The Department should execute its own analysis to obtain at least an order of magnitude understanding of the various costs, overlaps, and inefficiencies of SDDOT data acquisition. One benefit from this is that future trade-offs in information system investments can be made on the basis of a much better understanding of where the "opportunity" really is.

In transportation agencies throughout the country, data acquisition is viewed as an entry level, last in importance, kind of task. It's usually done by summer employees or others when time allows. In fact, as Mr. Jacobson has observed, data is something without which the information system is useless and in most cases, bad data is worse than no data. In a real sense, the data acquirer performs a function that is more valuable than that of anyone else in the information production chain. There is very little that a programmer can do to make good data out of bad data; but errors in data, which frequently are invisible, can completely invalidate even the most elegant appearing computer output. This has always been true but will become more apparent as new data acquisition technologies such as GPS, direct sensing of physical characteristics, and imaging become generally used.

> **Recommendation #2:** SDDOT should review the selection, classification, training and compensation of people assigned to high technology data acquisition.

This topic was explored in some interviews during the Requirements Analysis. A number of the SDDOT interviews indicated a feeling that data collection tasks are considered as entry-level and part-time activities. With a signpost reference system, the complete database can deteriorate if the required data collection disciplines are not maintained. We believe these tasks should apply the same rigor that has traditionally been applied to the selection and quality control of construction materials.

## *GPS APPLICATION RECOMMENDATIONS*

GPS is a powerful new technology that will fundamentally change the way that computers which manage geographically distributed assets are used. But GPS is also a complex technology which is still evolving and one whose implementation, of necessity, has to be accompanied by an effective technology transfer process. The following uses for GPS are recommended to make the most cost-effective use of this new tool:

### *Road Mapping and Highway Attribute Inventory Applications*

#### 1. *State Highway System*

One - perhaps the first - non-survey positioning application of GPS was for determining the alignment of the highway, road and street system. This automated the process of creating the transportation network that, along with water, political boundaries, railroads and utilities networks make GIS an information assimilating tool.

This technology has evolved significantly over the past 7 years. The initial application concepts were essentially to extend the linear highway location methods that had been in general use since about 1930 and replace the manual process of map tracing to generate new maps. Technical feasibility was demonstrated early in the application development cycle, and it brought some new things to the table. It created a three-dimensional digital file that could be used by computers to automatically produce maps and it enabled DOT's to handle road realignments in a much easier fashion. Everyone who tried it, however, soon concluded that cartographic quality map data could not be produced consistently by relying on GPS alone due to gaps in the roadway definition caused by intermittent GPS signal blockages from various sources. So the operational mapping systems have all evolved to using auxiliary sensors to fill in the gaps in GPS data.

For highway attribute location, the technology evolved to the use of precise GPS time tags to directly locate as points along the road a wide variety of highway attributes such as bridges, culverts, geometry changes, etc. Various demonstrations have been conducted to show that GPS can be directly interfaced to automatic data acquisition devices such as video logging vans or road condition survey vehicles. As the technology continued to evolve, however, a more cost-effective method was developed. By adding a precision odometer, a GPS mapping system could include over-the-ground distance coordinates with the GPS coordinates and, by so doing, create a log mile tag that could be matched against existing odometer-defined highway attribute files. After matching coordinates had been transferred to the log mile files, maps could be automatically created from files which previously could only be displayed as listings. This method allowed the GPS mapping and highway attribute location technology to be applied simply by collecting a single set of data to define the basic road network and the location of control point features. All other data collection activities could continue without change.

This is the data collection methodology that has been demonstrated under this contract and is our recommended GPS/GIS data collection implementation recommendation for SDDOT.

> **Recommendation #3:** Aided pseudorange GPS mapping techniques should be used, under standards defined in the Highway Reference Marker Policy Manual, for acquiring the geographic coordinates of both road alignment and MRM signpost locations, with both lat/lon/alt and elapsed distance location tags, on the State-maintained highway system.

This skeleton road network should be used as both the roadway source data for SDDOT cartographic map generation operations and the master reference database from which to extract geographic coordinates for the variety of periodic MRM-based sensor and windshield survey categories of highway attribute data.

This work should be done recognizing that GPS technology will evolve. As a consequence every effort should be made to assure that future technology change can be used to advantage with the least dislocation to users and to the information system

> **Recommendation #4:** The present system of "MRM + displacement" location tags should be maintained for the variety of periodic MRM-based sensor and windshield survey categories of highway attribute data.

Direct GPS location techniques should not be used for these categories of highway attribute data collection. It is much more cost-effective and just as accurate to extract GIS geographic coordinates from the Skeleton road network established in Recommendation #3 above.

### 2. *Non-State Trunk (NST) System*

SDDOT is now in the process of manually creating digital county maps showing road alignment. In addition, ISTEA may require the extension of pavement management to all Federal Aid roads, or perhaps, a larger segment of the off-state system. Bridges and railroad crossings already have to be located to meet the requirements of other federal mandates.

There is no MRM system on NST roads in South Dakota. A master grid map with 0.1 mile segments must be visually referenced to locate the matching segment coordinates for a segment of highway attribute data. This method is cumbersome, highly error-prone, and cannot be readily implemented in GIS applications.

**Recommendation #5:** For the Non-State Trunk System , a new geographic feature-oriented, elapsed-distance reference system should first be developed to replace the current reference system for locating highway attributes. A new procedure manual, similar to Highway Reference Marker Policy Manual, should be created to define the particular nomenclatures, starting points and objects which will be used for reference.

**Recommendation #6:** After this new reference system has been defined, the manual digitizing of NST roadways should be discontinued and the GPS/LOGMILE data collection methods summarized in Recommendation 3 above should be implemented for the Non-State Trunk system as well. Again, this work should be done recognizing that GPS technology will evolve. As a consequence every effort should be made to assure that future technology change can be used to advantage with the least dislocation to users and to the information system.

### *Survey Applications*

Land surveying, by most accounts, is the most advanced civil use of GPS location methods. In High Accuracy Reference Networks, Bill Strange and John Love of the National Geodetic Survey, wrote the following description of the impact of GPS on surveying, "The surveying profession is currently in the midst of a revolution brought about by Global Positioning System measurement technology and the power of the Personal Computer. This revolution is placing into the hands of the surveyor here-to-fore unattainable capabilities. Many state, county, and private surveyors, using commercial GPS surveyors, can perform surveys extending over tens of kilometers with accuracies better than those achievable by a geodetic research organization using specialized equipment only a few years ago. Also, using their PC and commercially available software, these surveyors can now perform data reductions, coordinate transformations, and relatively large scale adjustments. In addition to providing increased capabilities, GPS and PC's have greatly reduced the cost of many types of surveys. Coincident with this increase in capability and reduction in cost, the increasing implementation of Geographic and Land Information Systems and the use of positions to define land parcel boundaries have led to increased requirements for surveying."

Surveying is suggested here as one of the first SDDOT applications of GPS because surveying is the high-value location task in the Department. In addition, surveyors, who in a short span of years have gone through the transit - theodolite - geodometer - total station evolution, have the background to quickly get productive use out of GPS and in doing so, satisfy one of the basic requirements of the Department's policy makers. The first use of GPS in surveying will, in effect, also become an empirical technology transfer process during which others in the Department will gain a direct familiarity with GPS. And finally, GPS surveying, will expand the geodetic control needed for other uses of GPS.

> **Recommendation #7:** The High Accuracy Reference Network (HARN) plan now scheduled calls for the implementation of 21 sites in South Dakota in August/September 1993. This should be vigorously pursued.

In Washington and Mississippi, a successful effort was mounted to create a consortium of users – federal, state and private – with a need for such a network. With this larger access to dollars, people and equipment, Mississippi will now install a much denser network of 61 high precision (1/1,000,000 and 1/10,000,000) sites. More importantly, the use of common methods and the common datum implicit in this network will create data in both the public and private sector that is spatially and temporally compatible.

> **Recommendation #8:** SDDOT should adopt and use NAD83 as both its standard datum GIS reference datum. It should encourage the private surveyor community with which it contracts, and other state agencies with whom it will share data, to use GPS methods. Survey data is a very important data set for a geographic information system. Technically and institutionally, GPS survey operations should become an integral part of the GIS activity. Survey data should be acquired and maintained in a way that will allow new survey methods and improved accuracy (including three dimensional accuracy) to be implemented with the minimum dislocation to users and to the total information system.

### *Location of Off-Road Attributes*

Although not included as a direct consideration in the scope this research program, a great deal has been written about the use of hand-held GPS receivers for locating off-road attributes and this is still a new dimension of GPS use. It is mentioned here because location of off-road transportation attributes is an explicit requirement for intermodal information systems. It is in this dimension of GPS use where change will probably come fastest. Among other things, this implies new platforms such as marine vehicles, off-road vehicles, rail vehicles, and aircraft. It also implies the use of directly interfaced sensors such as water quality monitors, air quality monitors and noise monitors. It very likely will get a major impetus from any process control application of GIS where there is, for example, a need to track a moving water or air plume.

**Recommendation #9:** Differentially-corrected pseudorange GPS data collection techniques should be used as the primary method for location of off-road point-feature attributes needed to satisfy both highway and intermodal requirements. These same techniques should also be strongly considered for the location of unscheduled or non-periodic on-road highway point-feature attribute data such as accident sites, where the attribute location task is a secondary consideration. The push-button convenience of GPS techniques can offset their higher cost.

## Recommended GPS/GIS Implementation Plan

To achieve a successful GPS/GIS implementation we believe that two key resources which currently do not exist should be added to the SDDOT organization structure. Doing this will have an impact on organizational structures and charters.

### *Centralized GPS Base Station Operation*

For management and control of GPS applications and reference standards, we recommend that one centralized GPS Base Station Operation be added within SDDOT. This Operation would be responsible for collecting and disseminating GPS reference data to all users within SDDOT's surveying, mapping and data inventory operations, to users in other State, County and Municipal agencies, and also to the rapidly expanding proliferation of non-government users. This should be considered as a long-term investment which will pay for itself many times over as GPS applications proliferate during the next few years.

### *Centralized GIS Management*

A centralized GIS Management function should be established and staffed to lead the development of GIS applications. This staff can evolve over the initial implementation time span, but must begin with one dedicated focal point.

Assuming that these resources can be made available and committed, we recommend a three-phase implementation program in response to the Requirements resulting from the Requirements Analysis Task 4.

If these resources cannot be made available, we recommend that the GPS/GIS implementation plan be delayed, because in our experience the implementation will fall into a low-productivity, "Muddle-Through" mode without dedicated resources and an in-house GIS Champion to push the implementation forward.

## *Phase I Implementation Plan*

The goal of this recommended plan is to reach the 80% implementation point by the end of 1994 with the completion of Phase II. The remaining 20% would evolve over the remainder of the 90's.

We recommend starting with a controlled-scope 7-month Phase I effort to be completed during 1993 that will focus on the first seven of the system implementation requirements identified under TASK 4:

***Phase I Build GPS/GIS Foundation-Demonstrate on Interstate Highway System***

1. Provide Responsive Decision Support
2. Assure Usable Accuracy Of Output Data
3. Assure Correlation Between Graphic And Alphanumeric Data
4. Maintain MRM/Elapsed Distance Reference System
5. Provide Capability For Graphic Displays And Thematic Maps
6. Cause No Disruption Of Operations
7. Provide Near-Term Return On Research Investments

This is the foundation-building phase that will validate our proposed system concepts and demonstrate the earliest possible return on your research investments. We propose to use the complete 1250 travel way miles of I90, I29 and I229 as the test bed for this foundation-building phase. In addition to serving as the best-documented and most easily verifiable class of highways, this approach will encompass the complete state-wide network for this highway class. Phase I should therefore result in a set of immediately usable GIS applications after the validation is complete.

A preliminary overview of the tasks proposed for Phase I is shown in the milestone chart in Figure 14 on the following page.

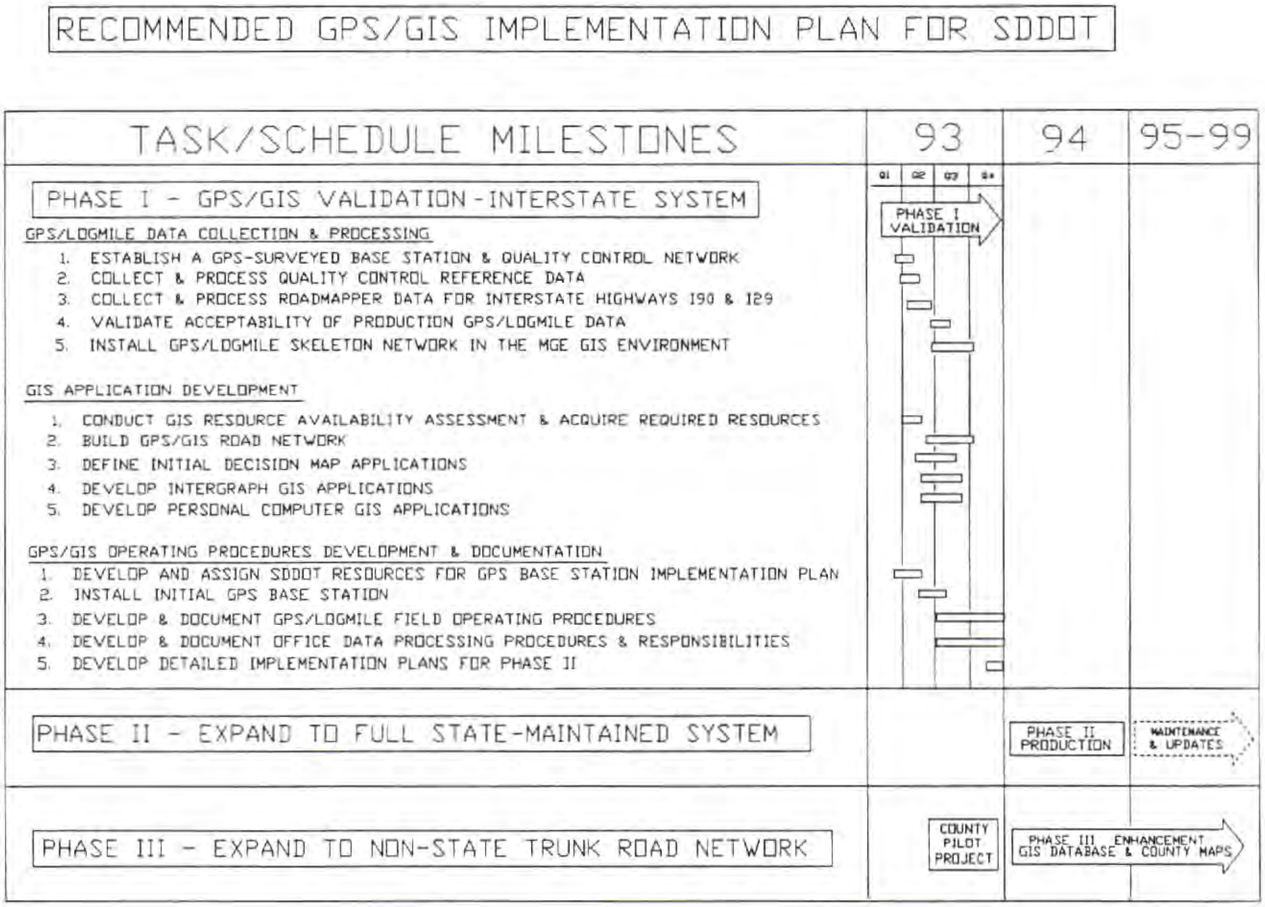



**Figure 14. Proposed GPS/GIS Implementation Plan**

As mentioned above, this plan assumes that an SDDOT implementation team will be identified and assigned to the project. This clearly is a joint effort, but our research team is prepared to assume the overall project management responsibility for this initial phase of the implementation to facilitate the technology transfer. We would expect project management responsibility to transition to the SDDOT project team through the Phase I performance period as the foundation is being established, with the members of the research team moving into individual project support roles in Phase II.

The principle tasks currently envisioned for Phase I are:

**A. GPS/LOGMILE Data Collection and Processing**

**1. Establish a GPS-surveyed Base Station and Quality Control network**

Install a permanent GPS antenna mount on the roof of the DOT building in Pierre and survey its coordinates from the Hyde NGS monument using the procedures demonstrated under Task 6 of this contract.

**2. Collect GPS Quality Control reference data**

At approximately 50-mile intervals, mark quality control check points on Interstate overpasses directly above the MRM signpost locations. Measure the vertical offset of each mark from the travel way surface below. Use GPS translocation techniques to survey the coordinates of each mark from the Pierre Base Station and then adjust the GPS altitude to compensate for the measured vertical offsets. This will yield approximately 25 surveyed checkpoints on the travel way surface for verification of the skeleton road network coordinates.

**3. Collect *ROADMAPPER* Skeleton Network data for Interstate Highways**

Use the ***ROADMAPPER*** data collection system to collect GPS/LOGMILE alignment data on both travel ways of the Interstate highway network and tag all MRM signpost locations using the techniques demonstrated under Task 7 of this contract. Adjust the measured logmile values of each MRM to match the true logmile values contained in the Master MRM mileage file. Flag any major deviations for reverification by SDDOT data inventory personnel.

**4. Validate acceptability of production GPS/LOGMILE data**

Compare the surveyed coordinates of the checkpoints from Item 2 above with the corresponding MRM coordinates from the skeleton network to verify that a +/- 35 foot accuracy level can be maintained across the State from one central Base Station in Pierre. (Accuracy deterioration beyond this level at the outer perimeters of the State would probably indicate the need for additional Base Stations to be installed across the State.)

**5. Install the GPS/LOGMILE Skeleton Network in the MGE GIS Environment**

Develop a file structure and install the post-processed GPS/LOGMILE road alignment and MRM location data into the MGE environment for use as a master reference network to import existing MRM-based highway attribute data into the GIS using the techniques demonstrated under Task 8 of this contract.

## B. GIS Application Development

**1a. Resource Assessment**

In cooperation with the SDDOT GIS Project Manager, conduct a one-month initial assessment of SDDOT resources available for GIS implementation. This assessment will determine the availability and usability of the required Intergraph hardware and software, highway inventory data, background maps. If additional resources are required, a deficiency list will be prepared for implementation decision by SDDOT.

**1b. Acquire Required Resources, if Necessary**

**2. Build GPS/GIS Road Network**

Assuming that the required resources are or can be made available, the GPS/LOGMILE data collected for the Interstate highways, background map data, and other required data will be used to build the initial GIS Master Road Network.

**3. Define Initial Decision Map Applications**

A 'target' set of GIS data requirements and specifications will be developed for generation of Planning reports and Decision Maps for the Interstate Highway System.

**4. Develop Intergraph GIS Applications** - Interface software will be written to import the required data from available SDDOT sources into the Intergraph MGE and its application software environment to generate the target cartographic maps, thematic maps and other GIS planning and decision documents.

**5. Develop Personal Computer GIS Applications** - For SDDOT users who do not have access to the MGE environment, the PC application software developed under this contract (see Section 4) will be expanded to use the techniques demonstrated under Task 8 to tag PC-based data with GPS coordinates for use with PC-based commercial desktop GIS software.

## C. GPS/GIS Operating Procedures Development and Documentation

**1a. Resource Assessment** - In cooperation with the GPS Base Station Operation Manager, prepare a recommended implementation plan for management, processing and distribution of GPS Base Station data to User organizations.

**1b. Acquire Required Resources, if Necessary**

**2. Install Initial GPS Base Station** - Install and provide training for a Survey-quality GPS Base Station receiver in Pierre. Install a PC-based data archiving system for storing Base Station reference data on a daily basis. Install a PC-based network for modem access to the Base Station reference data by users. If it is determined that additional Base Stations are required within the State, develop a time-phased implementation plan for expanding and maintaining the Base Station network.

**3. Define GPS Procedures** - Develop and document field data collection and office operating procedures for GPS/LOGMILE data collection. Modify or replace existing procedures manuals, as appropriate.

**4. Define GIS Procedures** - Develop and document operating responsibilities and procedures for maintaining and expanding the network.

### *Phase II Implementation Plan*

After validation has been achieved, Phase II would expand the Skeleton Network data collection effort during 1994 to the complete State-maintained highway system, expand the GIS database to encompass the full range of SDDOT MRM-based data records, and continue the development of GIS planning and decision-making applications.

We believe that the objectives for Phase II should shift the focus of the program to the following subset of System Requirements:

*Phase II Full Scale Implementation - Expand to Total State-Maintained Highway System*

8. Achieve Implementation Without Undue Delay Or Chaos
9. Provide Access To All Data In The Department
10. Provide Capability For Historical Data Analysis
11. Allow User-Defined Geographic Domain Of Output

We should expect the SDDOT team to assume management responsibility for the project at that end of 1993, with our research team members being prepared to individually support the project team with whatever equipment or services may be desired to continue the full-scale implementation.

Detailed tasks for Phase II have not been developed under this contract. Two basic alternatives for expanding GPS implementation to the complete State-maintained network are available to SDDOT: Either complete the remainder of the GPS/LOGMILE Skeleton Network by buying the initial set of data as a data collection service from NMC, or buy a ***ROADMAPPER***-type data collection system for SDDOT Inventory and Mapping personnel to use themselves.

The "best" alternative will depend on the internal resources available within SDDOT and the desired implementation schedule. This milestone schedule has assumed that SDDOT will opt for the earliest possible GPS/GIS implementation schedule and will choose to buy the data collection service for the initial State-maintained network implementation, then procure equipment in Phase III for update and expansion to the non-State maintained network.

If the "Do-It-Yourself" option is chosen for Phase II, allowing time for the equipment procurement cycle and personnel training will add 6-12 months to the initial implementation schedule before the complete State-maintained network can be accessed through the GIS. In either case, it is recommended that SDDOT be prepared to take over the GPS data update responsibilities for the implementation of Phase III.

## Phase III Implementation Plan

During the next two years we expect to see major advances in both GPS and GIS technologies. With proper planning, Phase III should be a seamless transition to incorporate the benefits from the predicted technology advancements and respond to the longer-range growth requirements identified under Task 4:

***Phase III Enhance Capabilities - Expand to Non-State Trunk Road Network***

12. Provide Ability To Incorporate New Information Technology
13. Provide Growth Capability For Three-Dimensional Data
14. Provide Flexibility To Incorporate New Data Requirements
15. Provide Flexibility To Respond To New Management Methods And Mandates

# *SECTION IV. PRODUCTS*

New application software has been written by NMC as part of this project to convert existing RES and other attribute data into formats that can be used with the ***ROADMAPPER*** post processing software. All of these programs have been written in MicroSoft QuickBasic 4.5 with imbedded comments and operating notes. Program source listings have been delivered separately.

Software conversion programs have been written by Frank Cooper to import the data generated using the above software into several different Intergraph-compatible formats. Those programs were used for the GIS demonstrations in Task 8 and are installed in the SDDOT MGE Work Station.

# *SECTION V. APPENDICES*

This Section of the report identifies supporting data for the Research Tasks of the contract. Much of this information has been delivered earlier in the Appendices of the First and Second Interim Reports. All Appendix material is included in a separate Appendix volume accompanying this Final Report.

Appendices are identified with a Report reference, the related Task number and a sequence Number within the Task. The following list are the Appendices with a cross-reference back to specific report pages where applicable:

| Apdx # | APPENDICES | Interim Report # |
|---|---|---|
| A1 | GPS System Overview | Proposal |
| A2-1 | Differential Positioning & Surveying - GPS World | R1-Page 6 |
| A3-1 | Sample GPS/GIS Questionnaire | R1-Page 8 |
| A3-2 | Questionnaire Responses - GPS Inventory Contacts | R2-Page 17 |
| A3-3 | Questionnaire Responses - GPS/GIS Contacts | R2-Page 17 |
| A3-4 | Questionnaire Responses - GPS Engineering Survey Contacts | R2-Page 17 |
| A4-1 | Requirements Interview: Schofield, et al | R1-Page 9 |
| A4-2 | Requirements Interview: Jenssen, et al | R1-Page 9 |
| A4-3 | Requirements Interview: Humphrey, et al | R1-Page 9 |
| A4-4 | Excerpts: SD Historical Database Study - Re/Spec, Inc. | R1-Page 10 |
| A4-5 | Excerpts: SD Information Systems Plan - Deloitte Touche | R1-Page 10 |
| A4-6 | Excerpts: SDDOT Strategic Plan for 1992 - 1993 | R1-Page 10 |
| A4-7 | Requirements Interview: Woodburn/Huft, et al | R2-Page 21 |
| A4-8 | Requirements Interview: Thielan, et al | R2-Page 22 |
| A4-9 | Excerpts: Place Defined Features, Federal Regulations re Highways | R2-Page 35 |
| A4-10 | Requirements Interview: Yocom, et al | n/a |
| A5-1 | ROADMAPPER Standard Data Formats | R2-Page 36 |
| A7-1 | GPS - Tagged Sample Feature Inventory:VDES Data Files using NMC Logmile Calibration | R1-Page 21 |
| A7-2 | GPS - Tagged Sample Feature Inventory:VDES Data Files adjusted to match SDDOT MRM Logmiles | R1-Page 22 |
| A9-1 | Excerpts from Introduction to Geodetic Networks | R2-Page 52 |