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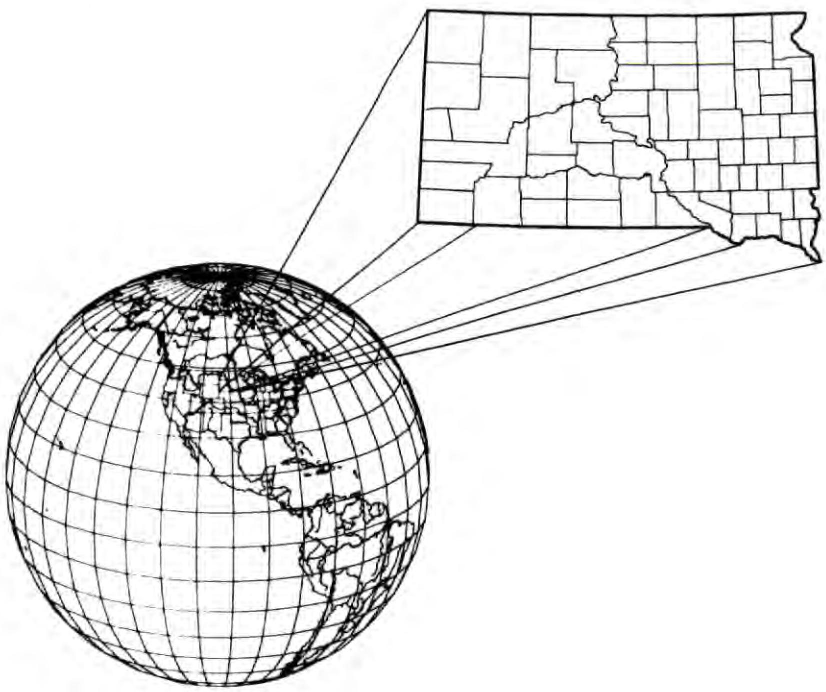

A Location Referencing System to Support Data Integration

Study SD96-04
Final Report

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May 1997

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16. Abstract

An investigation of South Dakota Department of Transportation (SDDOT) location referencing practices and procedures identified the functional requirements of and specific changes that should be implemented to establish a standard location referencing system that will address SDDOT data integration needs. Critical elements of the proposed location referencing system include a relational database to enhance data access and data management capabilities, coordinate transformation interfaces to enable integration of data from diverse referencing systems, and a time data attribute to enable historical data management.

A review of literature on recent developments in location referencing and related issues as well as a review of ongoing activities in states actively addressing location referencing issues revealed that the principal referencing method used in the transportation industry is linear. Further, the use of multiple referencing systems to support transportation management is common. Databases used to manage location-referenced data are predominantly relational, and historical data management is essential for effective transportation management. Interestingly, the states exploring the use of Geographic Information Systems (GIS) are addressing location referencing issues because of associated needs for coordinates; increased data sharing; and increased emphasis on open systems, standards, and cooperation. Management commitment/support was identified as critical to ensure success in data integration and GIS implementation efforts.

The study identified 13 discrete location referencing systems in use, provided insight on data sharing needs and uses of location-referenced data, and provided a basis for recommended changes that should be implemented to address SDDOT data integration needs. Implementation alternatives were investigated, and a recommended implementation strategy was defined. A relational DBMS was identified as the preferred DBMS based on comparative analyses of system functionality and life cycle cost and SDDOT institutional constraints. Preliminary design investigations, recommended as the first phase in the recommended implementation strategy, will resolve technical uncertainties that will have a direct impact on how the system will function and on the direction and cost of design and implementation efforts. The remaining implementation phases involve development of detailed system functional and design specifications to guide subsequent implementation of a standard location referencing system specific to SDDOT data integration needs.

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EXECUTIVE SUMMARY

PROBLEM DESCRIPTION

The current Location Referencing System (LRS) used by the South Dakota Department of Transportation (SDDOT) uses both linear and geodetic referencing methods. The primary linear method is based on the Mileage Reference Marker (MRM). MRMs are located on state trunk highways at a measured distance from the defined origin of a highway, and information on the highways is located relative to the MRMs via an MRM designation and a displacement. Although geodetic methods are primarily used for surveying on engineering projects where state law requires the use of State Plane Coordinates, the SDDOT Roadway Design and Data Inventory offices use Global Positioning Systems (GPS) for surveying and data collection on selected projects. Several other referencing methods are used to manage accident data, structure records, rural addressing, and others. These location referencing methods have a number of shortcomings that relate to either the referencing method itself or to problems associated with integrating the linear and spatial referencing technologies. More specifically:

- Data collected using one of the location referencing methods may not be usable in applications based on another method. The inability to relate and/or cross reference information results in *the effective loss of information.*
- Roadway realignments, repositioning of MRMs, highway renumbering, and transfer of ownership present significant problems with regard to maintaining a historical record of referenced locations. Without costly editing and programming, changes to the SDDOT MRM file are not concurrently propagated to MRM references in related databases, resulting in *the effective loss of information.*
- The inability of some methods to accommodate special circumstances such as coincident highways, divided highways, realignments, ramps, nonstate trunk highways, and off-road attributes results in *the effective loss of information.*
- SDDOT's current suite of location referencing methods does not efficiently support the use of a relational database for effective management of department data. The resulting data access limitations result in *the effective loss of information.*

Because of these shortcomings, integration of data that are routinely collected to support SDDOT's operations is ineffective, and the implementation of new and evolving technologies that could greatly enhance the collection, management, and use of information that is collected on South Dakota's highway network is often difficult and sometimes prevented.

To effectively address SDDOT's data integration problems, it is essential to make a clear distinction between a location referencing *method* and a location referencing *system*. The significance of each is clearly shown by the distinction provided in 1974 by the Highway Research Board:

METHOD — "... a way to identify a specific location with respect to a known point."

SYSTEM — "... the procedures that relate all locations to each other and includes techniques for storing, maintaining, and retrieving location information."

The location referencing system encompasses activities ranging from data collection through data use, including the data systems used to manage the location-referenced data.

The definition of a standard location referencing system specific to the needs of the SDDOT is the first step in addressing these deficiencies.

RESEARCH OBJECTIVES

The objectives of the current study were:

1. Define functional requirements for a standard location referencing system to support SDDOT's linear and geodetic location referencing methods used by SDDOT.
2. Recommend a standard location referencing system to satisfy the functional requirements.
3. Recommend a strategy (including hardware and software alternatives with benefits and costs) for adopting the referencing system, with consideration of SDDOT's current procedures and institutional and fiscal constraints.
4. Recommend operational procedures for using and maintaining the proposed system.

The results of SDDOT Research Project SD96-04 presented herein address each of these objectives and are intended to provide a basis for the implementation of a standard LRS that will enhance data use throughout the SDDOT and will enhance capabilities to share data with other state agencies.

RESEARCH APPROACH

Thirteen specific tasks were performed to meet the above objectives:

1. Meet with the project's technical panel to review the project scope and work plan.
2. Review and summarize literature regarding location referencing systems and related issues.

3. Identify SDDOT's and associated external agencies' current linear and geodetic referencing systems.
4. Review SDDOT's current procedures for referencing, collecting, storing, extracting, and depicting linear and geodetic data.
5. Identify functional requirements of a standard location referencing system.
6. Propose a standard location referencing system to satisfy identified functional requirements and describe necessary procedural changes.
7. Prepare and present to the technical panel an interim report defining the recommended standard location referencing system and demonstrate its use on variously referenced data supplied by SDDOT.
8. Define and evaluate alternative strategies (including hardware and software alternatives with benefits and costs) for adopting the referencing system, considering SDDOT's current procedures and institutional and fiscal constraints.
9. Recommend the preferred strategy and implementation plan for adopting the referencing system.
10. Meet with and present to the technical panel the preferred strategy for implementation of the recommended location referencing system.
11. Develop detailed operational and software procedures for establishing, using, and maintaining the recommended alternative.
12. Prepare a final report and executive summary of the literature review, research methodology, findings, conclusions, and recommendations.
13. Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

Investigations performed under Tasks 1 through 5 identified functional requirements for the desired standard location referencing system. Tasks 6 and 7 investigations provided a definition of a system that will satisfy the functional requirements and provided a basis for the development of recommendations on system implementation, use, and maintenance (Tasks 8 through 11).

GENERAL FINDINGS

An in-depth review of nearly 30 papers and reports on current developments in location referencing and related issues (the majority dated from 1993 to 1996), as well as ongoing activities in states actively addressing location referencing issues, revealed a number of notable observations related to both institutional and technical issues:

- Linear referencing will not be replaced in the near future
  - The principal referencing method used in the transportation industry is linear.
  - The use of multiple referencing systems to support transportation management is common.
- The databases being used to manage location-referenced data are predominantly relational.
- Historical data management is essential for effective transportation management.
- Significant recent advances in roadway mapping reflect the use of combined technologies
  - GPS technologies
  - Dead-reckoning technologies.
- States currently addressing location referencing issues are generally exploring Geographic Information System (GIS) capabilities
  - Coordinates are required to support GIS
  - Increased demand for data sharing
  - Increased emphasis on open systems, standards, and cooperation.
- Perceptions of location-referenced data are changing
  - Recognition of data as a "corporate" resource
  - Location-referenced data are an integrator of transportation activities.

Most significantly, the investigations revealed *unanimous concurrence that management commitment/support is critical to ensure success in data integration and GIS implementation.*

Investigations of the SDDOT location referencing practices and procedures provided considerable insight with regard to data sharing needs, interaction with other state agencies and organizations, and general uses of location-referenced data. Thirteen distinct location referencing systems were identified in use within the SDDOT:

- MRM
- Geodetic Coordinates
- Section Line Grid for Structure
- Section Line Grid for Accidents
- Station and Offset
- State Plane Coordinates With Absolute Origin

- State Plane Coordinates With Relative Origin
- Universal Transverse Mercator (UTM)
- Public Land Survey System
- South Dakota Rural Addressing Grid
- Nonstate Trunk Road Inventory System (NSTRI)
- Federal Highway Performance Monitoring System (HPMS)
- Graphical Presentations.

The HPMS link node system is used only for federal reporting requirements.

A review of current SDDOT policies and procedures revealed the following observations related to data collection and referencing, data management and access, and data use:

- <u>Data collection and referencing</u>. In general, the current data collection field procedures are sound, well documented, and well understood by the individuals who use the various location referencing systems. Many data integration needs can best be addressed through the addition of a date/time attribute for all data and enhancements in postcollection processing and management of the data, as well as the implementation of data interfaces that provide coordinate transformation capability.
- <u>Data management and access</u>. A major change in the manner in which much of SDDOT's location-referenced data are stored, managed, and retrieved will be essential to effectively address SDDOT's data integration needs. *The use of a relational database to manage SDDOT's location-referenced data is strongly recommended.*
- <u>Data use</u>. Changing patterns in data use seem to be the biggest factor driving the need for data integration. Whereas data collection efforts were originally implemented to service specific focused data needs, contemporary decision-making processes and data presentation needs are resulting in increasing needs to integrate data collected using diverse location referencing methods. Further, the high cost of data collection has resulted in increased emphasis on data sharing between state agencies, counties, and local governments.

A general observation that affects many areas of SDDOT data operations relates to procedure implementation. The interviews revealed that not all procedures were meticulously followed. Some information was not maintained because of staff reductions or a reduced perceived need for the data. Some procedures, although well written, appear to never have been implemented. Also, some new information being collected was not fully integrated into the mainframe environment because it was perceived as easier to keep on a local personal computer (PC) database. The validity of data was not clearly defined in all cases; that is, when information was no longer being maintained or additional information was being collected or the location of data changed, not everyone was aware of the change. Much of this is a communication or managerial issue. Some procedures, such as those that dictate the use of paper databases, are insufficient to allow full integration of all location-referenced data and must be changed.

RECOMMENDATIONS

The current investigations resulted in a number of specific recommendations relative to establishing a departmentwide standard location referencing system that will support SDDOT data integration needs. Five recommendations pertain to changes in current SDDOT location referencing practices that will be required to adopt the standard referencing system, system implementation, and procedure development. The final recommendation addresses several technical issues which significantly impact system planning and implementation.

Changes to Location Referencing Practices:

Five specific changes to SDDOT location referencing practices and procedures that should be implemented to address SDDOT data integration needs are recommended:

1. *Use a relational database management system (DBMS) for management of location-referenced data*
   - Enhance data management capabilities
   - Enhance data access
   - Enhance support of spatial analysis tools.
2. *Implement appropriate transformations to establish coordinate compatibility*
   - Enable integration of data from all location referencing systems in use in a common absolute coordinate system
   - Enable data transformations between all location referencing systems in use.
3. *Implement date/time as a data attribute*
   - Enable tracking of pavement conditions and maintenance activities
   - Enable historical management of road ownership
   - Enable tracking of historical changes in road realignments.
4. *Locate off-road features with one or more xy coordinates and elevations*
   - Maintain point-wise location capabilities
   - Enable integration of attributes that are best defined as spatial areas.

5. *Implement elevation as an optional data attribute*

– Enable differentiation of vertically distinct, yet laterally similar, roadways

– Enhance analysis of vertically significant features.

As indicated, each of these recommendations will provide significant enhancements to SDDOT's data management, data access, and data integration capabilities. The recommendations are presented in the order of priority. As shown in Table 1, the first three recommendations are critical to satisfy the functional requirements of the standard location referencing system and to satisfy many SDDOT data integration needs. Further enhancement of the SDDOT's overall data integration capabilities can be realized through implementation of the remaining lower priority recommendations as needed and as budgets allow.

Table 1. Criticality and Dependencies of Recommendations

Recommendation	Relative Need to Achieve Objectives	Dependency
1. Use a relational DBMS for management of location-referenced data	Critical	Independent
2. Implement appropriate data transformations to establish coordinate compatibility	Critical	Independent
3. Implement date/time as a data attribute	Critical	Independent
4. Locate off-road features with one or more *xy* coordinates and elevations	Desirable	Independent
5. Implement elevation as an optional data attribute	Desirable	Independent

Implementation Considerations:

Investigations of alternatives for adopting the proposed referencing system revealed several notable observations related to variables that will control the cost of system implementation:

- The choice of implementing a commercial database management system versus building on current data structures will significantly reduce system development costs.
- Alternative hardware/software costs do not vary significantly and will be minimal compared with system development/implementation and ongoing system maintenance costs.
- The method chosen to address data quality issues (e.g., scale, accuracy, and precision) could have a significant affect on transformation interface complexity and cost. In general, the information necessary to determine the applicability of data can be:

- Disseminated through SDDOT communications to prospective data users
- Left to the judgment of data users
- Communicated to data users through intelligent data interfaces via data attributes.

- The most significant factors that will control the implementation cost will be the time and resources needed to implement the recommended changes.

Comparative analyses of the functionality that will be realized through systems developed with identified DBMS alternatives build a strong case for deploying the standard referencing system using a relational DBMS. This is further reinforced by a comparative analysis of the life-cycle costs of the respective systems.

RE / SPEC strongly recommends that SDDOT use a relational database management system to manage location-referenced data. A client-server implementation of a relational database with appropriate coordinate transformation interfaces will provide state-of-the-art functionality, will address data access/management problems and other issues related to data integrity and consistency, and will establish a basis for integration of SDDOT location-referenced data and spatial analysis systems.

Recommended Implementation Strategy:

RE/SPEC recommends that the following phased approach be followed to implement the standard location referencing system:

Phase 1: Preliminary Design Investigations

Phase 2: Development of Detailed System Functional Specification

Phase 3: Development of Detailed System Design

Phase 4: System Development and Implementation

Phase 1 will provide critical information that will be required to develop a Detailed System Functional Specification (Phase 2) and subsequent Detailed System Design (Phase 3). Phase 4 constitutes implementation of the detailed system design to incorporate changes to current SDDOT location referencing practices and procedures that will be required to establish a data integration environment consistent with SDDOT needs.

A key consideration in the development of the above implementation strategy was a number of unresolved issues that will directly impact the development of the detailed functional and design specifications for the standard location referencing system:

- Application/data interfaces and data that will be affected.
- Data quality concerns and needs.

- Transformation interface functionality and design issues.
- Transformation implementation issues.

These are technical issues that will have a direct impact on how the system will ultimately function and on the direction and cost of design and implementation efforts. Many of these uncertainties are interrelated, and the resolution of some issues will affect the resolution of others.

Since early resolution of these issues will expedite the development of detailed system specifications, investigations to resolve these issues have been identified as Phase 1. *Although these issues could be resolved as part of Phase 2 and Phase 3 efforts, investigation of these issues is recommended before SDDOT proceeds with the development of detailed system specifications.*

6. *Investigation of unresolved technical issues is recommended before SDDOT proceeds with the development of detailed system specifications.*

The Phase 1 effort is estimated at $195,000. The combined additional support that will be required of SDDOT and South Dakota Bureau of Information and Telecommunications (SDBIT) personnel is approximately one-half (½) full-time equivalent (FTE). Project duration is estimated at 8 to 12 months. In comparison, the cost of full implementation is estimated at $1.6 to $2.1 million. In considering these estimates, it should be noted that the resulting system will reflect significant enhancements in data management and access at a cost that is less than the cost of the current system in 1997 dollars. Further, the cost of implementing these enhancements is small in comparison to the value of the location-referenced assets being managed by the SDDOT. The cost of replacing just the pavement and the bridges on the states' roadway network is estimated at $3.1 billion and $740 million, respectively.

Subsequent development of detailed functional and design specifications will provide a solid foundation for successful deployment of the standard location referencing system. Initial system implementation efforts should focus on the development of critical data transformation interfaces required to convert all information into a regular coordinate system. The capability to convert all information into a regular coordinate system (e.g., latitude and longitude) is critical for the integration of SDDOT location-referenced data for presentation purposes and should be the foremost data transformation consideration throughout the subsequent implementation project phases. The remaining transformations are less likely to be used and should be considered a lower priority to be implemented only as the need justifies.

<u>*Required Procedure Development:*</u>

Based on the review of current SDDOT procedures related to data collection and referencing, data management and access, and data use, training on current MRM policies and procedures is warranted. Additional training on MRM maintenance, specifically the unnecessary moving of MRMs, should be considered to alleviate problems associated with historical inconsistencies in MRM names.

A review of current SDDOT procedures indicated that minor changes to existing data collection and referencing procedures will be required to accommodate a date/time attribute, an optional elevation attribute, and changes in the identification of off-road features. A major review and revision of data storage, management, and retrieval procedures will be required with the implementation of the relational database management system (RDBMS), and general guidelines on data use will be required to address data integration issues related to data quality (e.g., scale, accuracy, and precision) and data history. A comprehensive training program that addresses all aspects of location referencing is essential to develop/reinforce user awareness of both old and new procedures.

7. *Review current MRM policies and other data collection policies in the context of current activities and needs and provide appropriate training for personnel.*

CONCLUSIONS

A standard location referencing system based on the current recommendations will provide significant enhancements to SDDOT's location referencing practices and procedures. The resulting contemporary environment will provide:

- System flexibility and extensibility essential to accommodate data needs that can be expected to continue to change through time.
- Historical data management capabilities that are critically needed in many transportation analysis activities.
- Coordinate compatibility essential to effectively support evolving spatial/information technologies such as GIS.
- Enhanced data access essential to support state-of-the-art desktop spatial analysis and graphical presentation tools.

A client-server implementation of the recommended relational database with appropriate transformation interfaces will provide state-of-the-art functionality, will address data access/management problems and associated issues related to data integrity and consistency, and will establish a contemporary basis for integrated use of SDDOT location-referenced data.

Although implementation of the recommended standard location referencing system is the initial step in enhancing the use of location-referenced data, the improved data access that will be provided can be expected to have a widespread impact throughout the SDDOT. The significant increase in location-referenced data that will be available for electronic access from desktop systems connected to SDDOT's network infrastructure will enable future enhancements of applications and systems used in activities that include:

- Pavement management
- Bridge management
- Maintenance activities
- Roadway alignment and inventory tracking
- Traffic analysis
- Safety analysis
- Document imaging and management
- Construction management
- Executive information systems.

In general, the enhanced environment can be expected to serve as a catalyst in the identification and application of innovative uses of location-referenced data and evolving spatial/information technologies. To temper expectations, however, it should be realized that enhancement of the applications used in these areas will be a long-term process and is not part of the initial implementation of the recommended location referencing system.

1.0 INTRODUCTION

1.1 PROBLEM DESCRIPTION

The current Location Referencing System (LRS) used by the South Dakota Department of Transportation (SDDOT) is ineffective in integrating the data that are routinely collected to support SDDOT's operations. As a result, the implementation of new and evolving technologies that could greatly enhance the location, management, and use of information that is collected on South Dakota's highway network is often difficult and sometimes prevented.

SDDOT currently uses both linear and geodetic referencing methods. The primary linear method is based on the Mileage Reference Marker (MRM). MRMs are located on state trunk highways at a measured distance from the defined origin of a highway, and information on the highways is located relative to the MRMs via an MRM designation and a displacement. Although geodetic methods are primarily used for surveying on engineering projects where state law requires the use of State Plane Coordinates, the SDDOT Roadway Design and Data Inventory offices use Global Positioning Systems (GPS) for surveying and data collection on selected projects. These location referencing methods have a number of shortcomings that relate to either the referencing method itself or to problems associated with integrating the linear and spatial referencing technologies. More specifically:

- Data collected using one of the location referencing methods may not be usable in applications based on another method. The inability to relate and/or cross reference information results in *the effective loss of information.*
- Roadway realignments, repositioning of MRMs, highway renumbering, and transfer of ownership present significant problems with regard to maintaining a historical record of referenced locations. Without costly editing and programming, changes to the SDDOT MRM file are not propagated to MRM references in related databases, resulting in *the effective loss of information.*
- The inability of some methods to accommodate special circumstances such as coincident highways, divided highways, realignments, ramps, nonstate trunk highways, and off-road attributes results in *the effective loss of information.*
- SDDOT's current suite of location referencing methods does not efficiently support the use of a relational database for effective management of department data. The resulting data access limitations result in *the effective loss of information.*

The implementation of a well-designed standard location referencing system will correct each of these deficiencies.

1.2 RESEARCH OBJECTIVES

To effectively address the deficiencies identified above, it is essential to make a clear distinction between a location referencing *method* and a location referencing *system*. The significance of each is clearly shown by the distinction provided by the American Association of State Highway and Transportation Officials [1974]:

METHOD — "... a way to identify a specific location with respect to a known point."

SYSTEM — "... the procedures that relate all locations to each other and includes techniques for storing, maintaining, and retrieving location information."

The location referencing system encompasses activities ranging from data collection through data use, including the data systems used to manage the location-referenced data.

SDDOT Research Project SD96-04, entitled *A Location Referencing System to Support Data Integration*, was initiated in mid-May 1996 to define a standard location referencing system that will support the data integration needs of the SDDOT. The four primary objectives of the study were:

1. Define functional requirements for a standard location referencing system to support SDDOT's linear and geodetic location referencing methods used by SDDOT.
2. Recommend a standard location referencing system to satisfy the functional requirements.
3. Recommend a strategy (including hardware and software alternatives with benefits and costs) for adopting the referencing system, with consideration of SDDOT's current procedures and institutional and fiscal constraints.
4. Recommend operational procedures for using and maintaining the proposed system.

From a functional standpoint, the standard location referencing system must:

- unambiguously reference locations on and off roadway networks.
- maintain compatibility with SDDOT's present linear and geodetic systems.
- allow other state agencies to use the data.
- accommodate special circumstances.

Further, the new system must support the continued use and/or development of SDDOT systems such as the Pavement Management System, the Decision Mapping project, a geographic information system, and other systems using spatial technologies.

The investigations addressing the first two objectives are intended to provide a definition of the standard system. The results of these investigations will provide a basis for review and evaluation of alternative system implementation strategies and recommendations related to operational procedures required for system use and maintenance.

1.3 RESEARCH SCOPE

The following 13 tasks were defined to meet the project objectives:

1. Meet with the project's technical panel to review the project scope and work plan.
2. Review and summarize literature regarding location referencing systems and related issues.
3. Identify SDDOT's and associated external agencies' current linear and geodetic referencing systems.
4. Review SDDOT's current procedures for referencing, collecting, storing, extracting, and depicting linear and geodetic data.
5. Identify functional requirements of a standard location referencing system.
6. Propose a standard location referencing system to satisfy identified functional requirements and describe necessary procedural changes.
7. Prepare and present to the technical panel an interim report defining the recommended standard location referencing system and demonstrate its use on variously referenced data supplied by SDDOT.
8. Define and evaluate alternative strategies (including hardware and software alternatives with benefits and costs) for adopting the referencing system, considering SDDOT's current procedures and institutional and fiscal constraints.
9. Recommend the preferred strategy and implementation plan for adopting the referencing system.
10. Meet with and present to the technical panel the preferred strategy for implementation of the recommended location referencing system.
11. Develop detailed operational and software procedures for establishing, using, and maintaining the recommended alternative.
12. Prepare a final report and executive summary of the literature review, research methodology, findings, conclusions, and recommendations.
13. Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

Tasks 1 through 7 are designed to provide a definition of the functional requirements for the desired standard location referencing system as well as a definition of a system that will satisfy the functional requirements. Tasks 8 through 13 are designed to provide definitive recommendations on system implementation, use, and maintenance.

An overview of the observations that were noted during a review of available literature concerning location referencing systems and related issues as well as a review of ongoing activities in states actively addressing location referencing issues is provided in Chapter 2.0. Descriptions of 13 distinct location referencing systems identified in use within the SDDOT and the results of a review of current SDDOT location referencing procedures are provided in Chapters 3.0 and 4.0, respectively.

Key functional requirements and critical aspects of a proposed standard location referencing system that will address SDDOT's data integration needs are presented in Chapters 5.0 and 6.0, respectively. Detailed discussions of the transformations that will be required to integrate the various referencing systems and a demonstration of the transformations that were identified as critical to SDDOT data integration needs are provided in Chapter 7.0. The results of investigations of implementation alternatives, the recommended implementation strategy, and required procedural development are detailed in Chapters 8.0 through 10.0, respectively.

Chapter 11.0 provides a summary of the project recommendations and conclusions, and a list of cited references is provided in Chapter 12.0. Appendices A through C contain a list of acronyms, maps showing Digital Line Graph coverage for South Dakota, and a list of individuals interviewed for this research project. Appendix D contains a figure that illustrates accident and structure data from Minnehaha County in the context of several location referencing systems used by SDDOT.

2.0 LITERATURE REVIEW

As a starting point in our literature review, we begin with a research publication sponsored by the American Association of State Highway and Transportation Officials (AASHTO) [1974] in cooperation with the Federal Highway Administration (FHWA). This document, which dates to 1974, states in the foreword: "All location reference *methods* are recognized to be parts of reference *systems* that include both office and field procedures intended to facilitate a variety of activities that occur in such fields as planning, safety, and maintenance." This distinction between *methods* and *systems* has been adopted in the industry.

Elaboration of SDDOT's current location referencing systems' shortcomings, as identified by SDDOT (SD96-04) are found in Lewis and Petzold [1995]. This reference depicts many of SDDOT's problems, including: alignment changes, route complexities (gaps, doglegs, split roads, cul-de-sacs, ramps), and data aggregation/disaggregation. Of particular interest to the present research effort, this source identifies the "Primary Objectives in Establishing a Standard LRS"[1] as:

- Provide an unambiguous location reference on a roadway network.
- Maintain compatibility with field milepoint measurements.
- Retain consistency with current practice to the maximum extent possible.
- Permit tracking of the "evolution" of milepoint references over time due to alignment and other modifications along the roadway.

Although these objectives were identified for a linear referencing system, they are critical to location referencing systems that integrate both linear and geodetic location referencing methods.

The remaining sources for review date no earlier than 1990, with the majority from 1995 and 1996. These sources are conference proceedings or reports of current development efforts, rather than text or reference books. For a technology area that is undergoing a rapid rate of change, even published books can provide an inaccurate assessment of the state-of-the-art.

A review of nearly 30 papers and reports on current development efforts resulted in a number of observations related to issues that are both institutional and technical in nature.

- Many of the shortcomings/problems identified in the Request for Proposal for SD96-04 are common with other Department of Transportation (DOT) offices and are not unique to SDDOT.
- Location can serve as an integrator of DOT activities.

[1] LRS in the context of this quotation stands for "Linear Referencing System." Throughout the remainder of the report, it connotates "Location Referencing System."

- Location data are best viewed as a "corporate" resource. Considerable coordination and cooperation are necessary to address data integration and data sharing needs.
- The majority of current requirements for transportation-related location data are linear in nature. Linear location referencing will not soon be replaced.
- Location data have attributes of scale, accuracy, and precision. Integration of location data must be tempered to be respectful of this reality.
- Proven and effective data collection methods and procedures should not be abandoned for the mere purpose of establishing a standard referencing system based on a single location referencing method. Tools to integrate different location referencing methods are required.
- Historical location-referenced data are required for life-cycle inventory maintenance, as well as various routine transportation analyses (e.g., pavement management, accident analysis).
- Coordinate transformation between widely used coordinate systems is proven and well documented. Integration of disparate location referencing methods can be accomplished through the use of a common coordinate system as a common denominator.
- Data sharing generally occurs between an application and a database, not between two applications. In other words, data are typically stored in a database and accessed by an application. Data are not typically moved directly from one application to another. This appears to be true across internal DOT and interagency boundaries, establishing an ideal environment for implementing data translation/transformation interfaces that are transparent to data users.
- Full-featured Geographic Information System (GIS) operates on coordinates. Linear-referenced data must be enriched to provide coordinates to support GIS activities.
- Full-featured GIS remains an unrealized goal for state DOTs. The expense of large coordinate databases and their maintenance has hindered its realization.
- Full-featured GIS requires open systems, standards, networking, and cooperation. Significant progress has been made in the last few years, but rapid change still characterizes the state-of-the-art of this technology.
- There were no state DOTs identified as having implemented a GIS that integrates all aspects of transportation management activities (e.g., administration, design, construction, maintenance, etc.). Cost is one reason this total implementation has not been completed. The current focus is in the planning area.

This review of the literature was complemented with direct contact with states that have or are currently addressing location referencing problems. In all cases, linear location referencing is the backbone of their transportation operations. Interestingly, many of the states who were actively investigating and/or pursuing location referencing issues are also either investigating the use of GIS or are in some stage of implementing GIS. The following sections provide detailed discussions of various aspects of location referencing that were noted in the review.

2.1 LOCATION REFERENCING IN RELATION TO GEOGRAPHICAL REFERENCING

Although location referencing is a specific component of the broad subject area of geographical referencing, it is useful to provide a short overview of geographical referencing. This exercise serves to place in context the practice of location referencing by identifying hypothetical queries that may be performed. These queries demonstrate the tremendous capabilities that will be available and clearly indicate that it will be geographical referencing that places the most rigorous demands on the location-referenced data.

Larson [1995] provides a brief description of the state-of-the-art in the use of location-referenced data, generalizing somewhat beyond present GIS practices. Below are listed five types of geometric queries along with examples of each.

1. Point-in-Region
   a. What is located at a certain point?
   b. What sources of data are available at a point?
2. Region
   a. What items (roadways, wetlands, cities, farms) are located in a particular region?
   b. What cities, roadways, or rivers lie in or cross the boundary of a region?
   c. What regions; i.e., counties or maintenance districts, border a region?
3. Items Within a Certain Distance
   a. What exists within a distance from a point, roadway, or region?
   b. What cities lie within a certain distance from a roadway?
   c. Where do guard rails exist along a roadway?
   d. What resources; e.g., borrow pits, lie within a certain distance from a roadway?
   e. What industrial plants lie within a certain distance from a river?
   f. What mines lie within a certain distance from a railway?
4. Path (requires a network structure to geometric points)
   a. Represents roadways, utility lines, water, or gas lines.
   b. What is the shortest route between two points?

5. Compound
    a. Combines aforementioned queries, including nongeographic data such as land ownership records and maintenance responsibilities.
    b. What are the names of the farmers affected by flooding of a certain river in certain counties?
    c. What is the fastest route to respond to a 911 call? (May include information such as speed limits, roadway conditions, traffic, etc.)

The aforementioned queries would also be time specific and the data qualified as to its scale, accuracy, and precision. Furthermore, a variety of data are assumed to reside in the database, including text, images, maps, video, etc.

The aforementioned queries have assumed that the user has a clear idea of the type of data in the database and is able to clearly state what he/she wants. A geographical information system could also accommodate "browsing" in which the information sought is unclear.

2.2 TRANSFORMATION BETWEEN DIFFERENT REFERENCING METHODS

Transformation between different referencing methods may mean:

1. A mathematical transformation between one or more coordinate systems.
2. A structural or topological transformation such as MRMs to a link-node topological model.

A mathematical transformation between one or more coordinate systems implies simply a mathematical exercise which makes routine the collection/archiving of location data in any convenient coordinate system and the subsequent use of this data in any other coordinate system. Of course, the accuracy, scale, and precision at which the data are collected will determine its utility for any particular application. The data transformation, however, is independent of these considerations. Antenucci [1993] states "The array of techniques available to accomplish transformation virtually eliminates any need to abandon data in establishing a GIS." One demonstration of this exercise is available from the "Linear Referencing Engine" [Amai, 1995]. The linear referencing engine is a software specification and demonstration of data transformation between linear referencing and absolute or datum referencing, and the reverse. What is mathematically possible, however, may still not be realized in practice for a number of reasons.

The mathematical transformation of MRM data to a cartographic reference requires:

1. One or more "anchor" points which define a datum.
2. Accurate maintenance of "as-built" roadway definitions that provide the mathematics for roadway traversal.
3. Accurate maintenance of MRMs.

Compromises in any of these will cause errors in transformations of MRM linear data into two- or three-dimensional data. Indeed, errors in Items 2 and 3 will cause cumulative errors. Of course, introduction of additional anchor points would provide means of correcting the transformation.

A study performed for the Kansas DOT [Kurt, 1993] identified widespread use of transformations between several location referencing systems using commercial and in-house software, as well as consultants. This study also reported hindrances to sharing data between agencies, including translation capabilities, planning, and infrastructure management. An identified hindrance to more widespread use of GIS was that many agencies created their maps either by digitizing or scanning existing maps. While a much less expensive alternative to data transformation, the practice of digitizing and scanning existing maps has substantial limitations as far as real-world representations are concerned.

A particular link-node specification is given by the Federal Highway Administration [1993] (i.e., the Highway Performance Monitoring System (HPMS) that dates originally to 1978). The HPMS is a nationwide inventory system that includes all of the nation's public road mileage as certified by the states' governors on an annual basis (the District of Columbia and the Commonwealth of Puerto Rico are considered to be equivalent to a state in the HPMS). Authored by the FHWA, the order is billed as "a cooperative effort with the State Highway Agencies (SHAs), local governments, and the metropolitan planning organizations (MPOs) working in partnership to assemble and report the necessary information." While support for this order is accommodated for roadway reporting in commercial software products such as **ARC/INFO** [Environmental Systems Research Institute (ESRI) Inc., 1996], the HPMS is not feature rich enough to serve as a core referencing scheme.

2.3 DATA SCALE, ACCURACY, PRECISION, AND SOURCES

Location referencing necessarily requires assessing the applicability (scale, accuracy, and precision) of the location-referenced data, whether it be linear, two-, or three-dimensional. These issues determine in what context the data may be used and the reliability of applications when using the data. Antenucci [1993] categorizes the scale as follows:

1. Large scale (1:1 to 1:500); small area of coverage; much detail; engineering applications.
2. Medium scale (1:500 to 1:2500); moderate area of coverage; moderate detail; technical planning, infrastructure management, property records application.
3. Small scale (1:2500 to ?); large area of coverage; little detail; jurisdiction mapping and resource management applications.

A publication by Vonderohe et al. [1993] suggests three different scales amenable for GIS databases:

1. 1:500,000 (precision 830 feet) for statewide planning.
2. 1:100,000 (precision 170 feet) for district-level planning and facilities management.
3. 1:12,000-1:24,000 (precision 30–40 feet) for engineering.

A fourth scale, 1:120-1:1,200 (precision 0.33–3 feet), is identified for the project level, and as such, is not routinely amenable for traditional GIS; however, the role of GIS is expanding in this area also.

Antenucci [1993] further distinguishes accuracy and precision as:

- **accuracy**: fidelity of calculated position to true position
- **precision**: fidelity of position displayed or plotted to calculated position.

Four combinations of these are possible:

1. accurate and precise
2. inaccurate but precise
3. accurate but imprecise
4. inaccurate and imprecise.

These are not absolute measures of data quality; rather, guides to determine the appropriateness of certain data for use by certain applications. Large-scale, accurate, and precise data have very limited use, not to mention extraordinarily high collection and maintenance costs. At the other end of the spectrum lies the least expensive sources of data, such as digitizing or scanning existing maps.

As reported by Kurt [1993], a hindrance to the use of more GIS features within Kansas state agencies has been location accuracy. Map creation via digitizing and scanning existing maps, while inexpensive, was one potential source of errors. Property line locations, for example, require more accurate location determinations.

Location-referenced data are the single most costly element in a GIS system, and the determination of expense in collection according to use is a judgment not likely to be supplanted by new technology. Certainly, diverse requirements for location-referenced data will require different scales, levels of accuracy, and precision. Optimum use of resources will match these requirements according to use.

Perhaps the most widespread data source for the creation of statewide base maps are the various digital products from the U.S. Geological Survey (USGS) [Juracek, 1996]. These include:

- Digital line graphs (DLGs) at scales of 1:24,000, 1:100,000, and 1:2,000,000.
- Digital orthophoto quadrangles (DOQs).
- Digital raster graphics (DRGs).

The latter are color raster versions of USGS 1:24,000, 1:100,000, and 1:250,000 scale topographic quadrangle maps produced by scanning the published quadrangle maps. DLGs provide vector information about hydrography, transportation, hypsography, boundaries, and the Public Land Survey System (PLSS). Availability of DLGs for South Dakota is indicated in Appendix B. It is observed that coverage is near complete at the 1:100,000 scale but inadequate at the 1:24,000 scale. While these data sources are convenient, they are not in keeping with the spirit of data-driven applications wherein data are maintained in lieu of maps. Furthermore, map intelligence still has to be applied; i.e., elements of the map need to have defined relationships, topology, and be able to include other descriptive attributes. The maps themselves do not provide much of this. Intelligence implies coordinating linear referencing systems (road identification, reference points, intersections, inventories, etc.) with spatial depiction (i.e., in map-amenable form). As an alternative to using USGS products, some states use GPS determination of *xy* coordinates and elevations for anchor points and software to relate these to linear reference points.

2.4 FEDERAL MANDATES

Two federal mandates or orders particularly affecting DOTs are:

- the Intermodal Surface Transportation Efficiency Act (ISTEA)
- the "Highway Performance Monitoring System" (HPMS) [Federal Highway Administration, 1993].

ISTEA suggests DOTs implement data management systems to provide assistance to the management and decision-making processes, and HPMS requires states to contribute to a nationwide inventory system of the nation's public roads. Specific database products, such as those by Oracle Corporation [1996], address or facilitate meeting the ISTEA initiatives (management of pavement, bridges, safety, congestion, public transportation facilities and equipment, intermodal transportation facilities and systems, and traffic monitoring systems).

GIS products (e.g., Environmental Systems Research Institute Inc. [1996]) provide reporting of roads in the link-node format required by the HPMS.

2.5 DATA HISTORY

An earlier SDDOT research effort (SD90-09) [Svalstad et al., 1991] identified the need for location-specific data to be readily available as a function of time. A retention of 20 years of data with ready access to 5 years of data was recommended. This would enable contemporary pavement management techniques to be employed as well as life-cycle studies of all location-referenced inventory, equipment, and resources. Historical management of data is a feature supported by contemporary database designs supporting GIS applications such as those available from Environmental Systems Research Institute Inc. [1996], MapInfo Corporation [1996], Intergraph Corporation [1996], and Graphics Data Systems Corporation [1996]. The use of a relational data model is inherent in each of these database designs.

2.6 STANDARDIZATION OF LOCATION REFERENCING METHODS

The attempts to encourage a single location referencing system or at least a single coordinate system are noteworthy. Deighton and Blake [1992] state, "To manage location referencing, a highway agency must have one, and only one, location reference system." Lee and Deighton [1995] state that "Transferring the data from one subsystem to another becomes extremely difficult if a different referencing method is adopted for each subsystem." Terry [1996] proposes the Universal Transverse Mercator (UTM) grid for a nationwide reference standard. GeoResearch, Inc. [1995], a SDDOT contractor, suggests: "A recommended uniform coordinate system for exchange would be Latitude/Longitude." This standard would allow transformation of the data to the various South Dakota UTM and State Plane zones. These recommendations are all offered by persons with hands-on experience using location referencing methods including their design and implementation. A dissenting view is offered by Scarponcini [1995]. This study involved the Minnesota DOT wherein at least 45 different definitions of "location" are used. The author explains "why a single definition of location was not possible." In general, present location referencing methods have evolved because they work and are familiar. Their principal shortcoming is that they may not relate to each other. Making this relationship is where efforts need to be concentrated, not reforming that which works and is comfortable, unless consensus is reached to adopt the changes. Mandates are not likely to work without consensus building. Witness the attempt by the federal government to transform the country to the metric system.

The proclivity towards encouraging data uniformity perhaps stems from the daunting task of using diverse data in a somewhat uniform way. This point of view is obsolete for a number of reasons. First, data transformation between coordinate systems has been shown to be routine, according to the above review. Furthermore, data sharing is likely to be between databases and applications, not between two applications. Any concerns about the speed of coordinate transformation are likewise unfounded. Computations of this nature involve little overhead when compared to the context in which they are likely to be called upon, that of image processing. The evolution of increasing computational capability will likely outpace needs associated with the implementation of full-featured GIS. The second reason discouraging the adoption of a uniform location referencing method is the eventual incorporation of metadata into the location-referenced data. This includes scanned maps, videos, aerial photography, etc. These methods will rely more on pattern recognition and other new evolving technologies and less on coordinate matching. Finally, location data are the single largest investment in a typical GIS system. Overhauling this data for the sake of data uniformity is not feasible. *More expedient is the accommodation of the variety of data, as it currently exists, through software transformation tools.*

It is worth emphasizing that the preceding review and discussion of opinions is not meant to discount the valuable and widely accepted notion of data integration through location. Rather, the restrictive interpretations of this goal are meant to be cautioned against. Reformatting or reconstruction of existing data along the lines of a "generic data model" according to, for example, Vonderohe [1995] is more farsighted. This contemporary (1994) workshop brought together 42 transportation professionals, systems developers, and academics and offers a valuable reference for a data model, though incomplete and lacking in detail, in which to reconstruct existing data and archive future data. It respects higher level operations such as those associated with GIS and network analysis and specifically identifies the need to accommodate transformations between referencing methods. It does not propose a single, best-for-all referencing method. For the purposes of error correction, however, it may be best to maintain the original data form in addition to the GIS-amenable form, where the two differ.

2.7 GIS DEMANDS ON A LOCATION REFERENCING SYSTEM

As stated above, it will be spatial analysis that places the most rigorous demands on location-referenced data. Vonderohe et al. [1993] offer a speculation into the future of GIS for transportation. It is interesting to review this vision with the benefit of the intervening 3 years.

When state DOTs were surveyed in 1991, only a few were making widespread use of GIS, though several others expressed interest. The researchers concluded that *data*, *technology*, and *institutions* represented the three primary considerations for implementation of GIS for Transportation (GIS-T). Many of the *data* shortcomings identified are the same as those identified in this study. *Technological* obsolescence, lack of trained staff, high capital costs, and frequent software changes made management reluctant to commit to GIS-T implementation. *Institutional* factors related to the need for coordination among divisions since data would be shared and therefore should be considered a "corporate resource." Generally speaking, these three broad issues are still relevant, although the use of GIS-T has become widespread, though not well coordinated or integrated. The cost has dropped precipitously with less expensive personal computer- (PC-) based systems placing pricing pressure on more expensive unix-based systems. This has encouraged experimentation with GIS-T, and at the same time, delayed the inevitable institutionwide adoption of the technologies.

The need for networking of PCs and workstations; standards for spatial databases; standards for exchange of spatial data, open systems, and a myriad of planning issues (time, staffing, training, equipment) were identified. With respect to the technology issues, networking, standards (see, for example, U.S. Department of Transportation [1995]), and open systems (eliminating the requirement to commit to a single vendor) have progressed substantially, yet competition of ideas still characterizes these areas. Planning issues have lagged due to numerous human factors related to funding, resistance to change, executive mandates, and the usual difficulties concerning consensus building. It is probably fair to characterize current state use of GIS-T as localized initiatives, demonstrating substantial benefit but as yet lacking widespread coordination and commitment.

One recommendation from Vonderohe et al. [1993] is that of a *top-down*, then *bottom-up* approach for GIS-T adoption by DOTs.

- Database design, acquisition, and development of maintenance policies and procedures should be undertaken as an organizationwide, top-down activity.
- GIS-T application development should then be undertaken on the basis of decentralized, bottom-up initiatives. GIS application development is often specific to localized analysis needs within an organization.

The Federal Highway Administration [1995] identified the lack of management focus as contributing to failure of automation efforts of the past. It further identified the lack of integration and sharing of data as partly responsible for the stalling of certain otherwise successful efforts. This publication goes on to identify the expanding roles of DOTs and the need for strategic planning. It provides tools and methods to aid in development of new capabilities while preserving existing investments. Another guide, prepared by Alliance for Transportation Research [1995], offers similar planning assistance. It is perhaps more objective, recognizing that transportation planning is ad hoc, heuristic, and highly iterative and that appropriate technologies supporting this activity will require similar characteristics. It is also ambitious, and while proposing a migration strategy, is perhaps not fully mindful of shrinking budgets and institutional inertia with respect to sweeping changes. One final reference that attempts to deal with the issues of change and integration is Petzold et al. [1996]. This is a workshop which first identifies changing needs of transportation agencies, specific issues including location referencing standards, and discusses total quality management (TQM) and reengineering approaches, as well as a concept called "technology enablers."

2.8 LOCATION REFERENCING AS A GOVERNMENT INTEGRATOR

Tom Ries of the Wisconsin Department of Transportation [Ries, 1995] discusses the notion of GIS technologies as an integrator of government activities relying on location referencing, as well as the benefits of data sharing. He discusses the notion of "intelligent base maps" and the integration of roadways, railways, and hydrography. He defines four basic categories of individuals in using location-referenced data:

1. Data producer (read, create, update privileges; fulfill requirements of data consumer).
2. Data custodian (read, create, update, delete privileges; maintenance of data over time).
3. Data broker (read privileges; form links between consumers and custodians and between custodians and producers).
4. Data consumer (read privileges; defines information and data requirements).

He identifies responsibilities and privileges of each category. Further, the multiple forms and scales in which data are collected are discussed. The apparent difficulty of GPS data as point data and the principal transportation requirement being linear data is identified. Concluding, he states that location is a suitable integrating concept but the different forms and scales of data must be accommodated. Recognizing limited resources, the importance of using existing data and building from there is emphasized.

2.9 SPECIFIC GIS/LRS STUDIES

In his study for the Kansas DOT, Cooper [1995a] conducted interviews with various units within Kansas DOT concluding:

1. Kansas DOT should view GIS as a technology and not an information system application.
2. The greatest impediment to expanding the use of GIS in Kansas DOT is its limited human resources and not the technology.
3. Kansas DOT is already using GIS technology in the Intergraph GIS environment and not only has a large investment in hardware and software, but an even larger investment in the development of skills and expertise by its staff in that computer environment.

Furthermore, he concluded that a successful adoption of GIS would require support of management in providing funding, establishing standards, and facilitating group autonomy to encourage commitment to a common goal.

Particularly noteworthy in this study is the recommendation that GIS be regarded as a technology (a tool) rather than an organizing principle. In other words, GIS is not stable and mature enough to assume the ambitious role of the organizing principle. Regarding location referencing, the study identified the reality that multiple reference methods exist and have evolved according to need and should be maintained. Still, it identified one system as the goal.

In a subsequent study for the Kansas DOT, Cooper [1995b] addressed the impact of asserting a new LRS standard on the Kansas DOT user community. The study concluded that the benefits for proceeding were "simply too beneficial to Kansas DOT from both an overall and an individual system and user viewpoint and thus warranted a concerted effort by staff to make that happen." Further, "users appeared willing to put in the extra effort to adapt to a common LRS." A postassessment of this transformation effort would be valuable.

2.10 SOUTH DAKOTA-SPECIFIC GIS/LRS/GPS STUDIES

Navstar Mapping Corporation; Time & Place Tags, Inc.; and Cooper Technology performed a study for SDDOT entitled *Location of Highway Attributes by Global Positioning* [Navstar Mapping Corporation, 1993]. The first objective of the project was a demonstration of GPS technology in the context of SDDOT's MRM practices. This was intended to make the state's linear referencing system data available to GIS. The second objective was to provide SDDOT with a GPS/GIS technology implementation plan.

The demonstration exercise used a combination of GPS coordinates and elapsed distance measurements to form one precisely defined skeleton road alignment network. While ultimately providing a successful correlation with the state's MRM data in the Roadway Environment Subsystem (RES) file, it became clear that the GPS-based data collection system costs significantly more than the elapsed distance MRM-based system currently used by SDDOT for highway attribute data.

SDDOT's most mature GIS application is a pavement management system that was implemented by Deighton Associates Limited [1994]. The system uses MRM-referenced pavement data and a digitized drawing of the state highway system for mapping. This system requires accurate pavement and MRM data, but a geographically accurate representation of the road network is not required.

GeoResearch, Inc. performed a study for SDDOT entitled *GIS Needs Assessment Study Report and Conceptual System Design* [GeoResearch, Inc., 1995]. This study views GIS as a central organizing theme, "the primary database and decision-making system within the organizations." It acknowledges the changing nature of GIS; "new standards will eventually change the methods of system implementation by imposing new requirements and guidelines on GIS system components." Furthermore, it reviews hardware and software trends; i.e., the movement toward client/server platforms and distributed processing and the use of relational databases.

2.11 DIRECT CONTACTS AT OTHER STATES

Through literature or personal reference, key persons at the Departments of Transportation in the states of Nebraska [Genrich, 1996], Tennessee [Tolar, 1996], Utah [Neeley, 1996], and Wisconsin [Duchateau, 1996] were contacted about their state's referencing practices and use of GIS. Each of these had distinct practices.

Nebraska has been identified as a pioneer in the implementation of GIS. Planning, safety, bridge inventory, and to some extent, construction, are presently integrated. The planning division is pioneering the use of GIS and makes periodic presentations to other divisions to encourage their participation. No real-time GIS, such as truck routing and intelligent transportation, is currently being implemented. The principal linear reference system, a milepoint system, is given *xy* coordinates by the GIS software and interactive adjustments are made at intersections and wherever else they are needed. County maps digitized from 1:24,000 DLGs serve as the base map. Data from both on and off system roads are included. Most Nebraska Department of Roads data are maintained on a mainframe systems with **DB2**. An **Informix** relational database is the database used for GIS. The present effort had its beginnings in 1985 and this database was standard on the hardware chosen at the time. Due to recent Nebraska legislation having to do with speed limit justification, technologies from Navstar Mapping Corporation, which include GPS-located coordinates and curve and grade determination, are beginning to be employed in the state.

Tennessee was a pioneer in the use of GPS for roadway mapping. They acquired a van with a GPS receiver in 1988 and had mapped 13,000 miles before discarding the work in favor of more reliable GPS practices beginning in 1991. The original data produced roadways with much too rough alignments; that is, the coordinates collected were not sufficiently accurate. Subsequent postprocessing of newly collected data has eliminated many of the shortcomings of these pioneering efforts. The newer GPS effort has mapped 4,000 miles. Accuracy has been found to be within 40 feet; about the same as 1:24,000 DLGs. Concerning the use of DLGs, their conclusions were that they are next to worthless, geographically speaking. TIGER files were somewhat better. GIS use for planning is presently "getting started." There is no integration of contracts and administration. While spatial data are used for GIS, linear referencing remains the standard. This past year, Tennessee has had an executive-driven goal to upgrade its information system. They are implementing a relational database management system (RDBMS), **Oracle**, in a client-server environment with a view toward GIS. Mapping is integrating GPS and elapsed distance technologies to produce database-driven map products. The objective is to provide a full-cycle physical inventory system that includes digital components in the data collection, mapping, and analysis of field collected data.

Utah is unique in that it uses **dROAD** (see also Deighton Associated Limited [1994]) for the principal location database, not just for pavement management, its original design application. Deighton Associates Limited, author of **dROAD** and associated software, was the consultant responsible for the changes [Deighton and Blake, 1992]. Utah has a linear referencing system similar to South Dakota. It uses mileage reference markers (posts) that originally represented true mileage but over time become only approximate due to the changes in alignment. Certain changes recommended by the consultant (e.g., the use of negative directions) caused confusion amongst users and resulted in a return to certain aspects of the former system. While **dROAD** serves as the principal location referencing database, it is not used departmentwide. Inventory and accidents are stored in both **ADABAS** and **Informix**; the latter being used due to shortcomings in the former. **ADABAS** is the database used for Railroad Crossings, Bridge Inventory, and Accidents at SDDOT. More widespread integration of administrative, contract, and test data has not been automated.

Wisconsin has developed a program of transformation of multiple linear referencing schemes into a neutral anchor point and link system similar to the work of Vonderohe at the University of Wisconsin [Vonderohe, 1995]. Anchor points possess *xy* coordinates and are thus amenable to spatial GIS use. This program is noteworthy in that multiple linear referencing methods have been accommodated rather than conforming to a common method [Duchateau, 1996].

Many other states, Michigan included, have had a long-standing interest and limited programs exploring the application of GIS techniques to many different aspects of transportation needs. None of the states queried have implemented a GIS that integrates all aspects of transportation management.

The cursory review of the above states' location referencing and GIS activities, presuming them to be comparatively well advanced with respect to most states, suggests full integration around location has yet to be achieved. Tennessee's assessment that GIS is just getting started, after 8 years of preparation, suggests that migration to GIS is a long-term process. Of course, many of the pitfalls Tennessee experienced can be avoided. It bears mentioning that widespread support by management was lacking in the pioneering effort. Recent executive level commitment in Tennessee has produced great strides toward realizing the spatial database goals. Without exception, linear referencing still provides the principal referencing scheme for all states interviewed. It is also a fair characterization to suggest that spatial GIS supplements linear referencing with anchor points but in no case does it attempt to replace it. It only stands to reason that road networks are linear and that linear referencing is most natural.

2.12 EMERGING TECHNOLOGY

During the summer of 1996, Navstar Mapping Corporation extended its data collection techniques to include horizontal and vertical curvature data [Lewis, 1996]. By combining GPS, distance measuring instruments, gyroscopes, and barometers, Navstar Mapping Corporation is able to determine curve beginning and ending locations as well as average degree of curvature.

This capability supplements existing capabilities of building spatially referenced road networks, associating linear referencing to them, and logging road track data. This is accomplished by van-based instruments able to collect the aforementioned data at a rate of 60–75 miles per hour (mph) on interstates, 50 mph on secondary roads, and 15–25 mph in cities. (This characterization is only approximate as the actual speed is determined by the diversity and rate of change of data.) Using software to statistically process the raw data, spatial accuracies are achieved to within ±10–15 feet. This capability will indeed play a major role in data collection/maintenance for future transportation needs. According to Lewis [1996], Tennessee is employing this latest of technologies at present.

3.0 REVIEW OF CURRENT LOCATION REFERENCING SYSTEMS/METHODS

Numerous individuals within the SDDOT and the South Dakota Bureau of Information and Telecommunications (SDBIT) were interviewed by the RE/SPEC Inc. project team to identify location referencing systems that are currently in use. These interviews, which were held in Pierre, South Dakota, on May 13 and 14 and June 27 and 28, 1996, were supplemented by follow-up telephone interviews and reviews of available written procedures for further clarification. More than 35 individuals from the state, listed in Appendix C, have contributed to RE/SPEC's understanding of current location referencing methods/systems currently in use and the particular processes that use the systems.

Individuals were also queried about the accessibility of current location-referenced data and the level of location data exchange within the SDDOT and with other state and nonstate agencies. Future objectives and needs of the SDDOT location-referenced data were also discussed. Location referencing systems in use by some of the other state, federal, and local agencies with which SDDOT shares information have been investigated. More than 20 individuals representing other agencies and private companies have also been interviewed to determine the types of location referencing systems that are currently used.

Thirteen distinct location referencing systems currently used by the SDDOT have been identified:

- MRM
- Geodetic Coordinates
- Section Line Grid for Structure
- Section Line Grid for Accidents
- Station and Offset
- State Plane Coordinates With Absolute Origin
- State Plane Coordinates With Relative Origin
- Universal Transverse Mercator (UTM)
- Public Land Survey System (PLSS)
- South Dakota Rural Addressing Grid
- Nonstate Trunk Road Inventory System (NSTRI)

- Highway Performance Monitoring System
- Graphical Presentations

A comparison of the important features of these systems is given in Table 3-1.

The remainder of this chapter provides detailed discussions of the location referencing systems that have been identified within the SDDOT and the specific processes that use these systems. Some data are currently maintained with more than one location referencing system. For example, bridges located on the state trunk system include location references with MRMs, PLSS, Geodetic, and the Section Line Grid systems. It is likely that some data which are stored with location information have not been discovered in this interview process. It is unlikely that significant additional location referencing systems exist.

3.1 HIGHWAY MILEAGE REFERENCE MARKERS

The most commonly used location referencing method within the SDDOT uses highway MRMs as defined in the SDDOT Highway Mileage Reference Marker Policy Manual, Revised January 1997 [South Dakota Department of Transportation, 1997]. This system is widely used within the SDDOT and by law enforcement agencies throughout the state. As a general rule, it appears to be relatively user friendly, understood by most who use it, well planned, and maintained through a series of procedures. The MRM system is a linear referencing system that allows identification of physical points only along currently identified roadways. Measurements are recorded to 1/1,000 of a mile or approximately 5 feet.

SDDOT selected the MRM and displacement concept to minimize maintenance since changes would only impact those MRM segments that incorporated the change. This updating of "mileages" could occur automatically. This theory collapses if the MRM (simply an identification to a geographical feature) is constantly being changed. This greatly impacts the users as their attribute data no longer have the proper MRM reference. MRM identification renaming should occur only when absolutely necessary and there should be rigid procedure to outline these changes.

The SDDOT MRM system identifies points along state trunk highways using Data Class, Highway Number and Suffix, MRM Identification (I.D.), and Displacement.

- The Data Class is one of the following:
  - State
  - County
  - City

Table 3-1. Comparisons of Identified Location Referencing Systems

System	Type: Linear, Coordinate, or Systematic	Relative Absolute	Point of Beginning	Regular Units	Resolution	Coverage
MRM	Linear	Relative	State Line	Regular	0.001 Mile	State Trunk Roads
Geodetic Coordinates	Coordinate	Absolute	Defined	Regular	0.01 Minute	State
Section Grid for Structure	Coordinate	Absolute	0,0 @ NW Extent of County	Irregular	0.1 Section	County
Section Grid for Accidents	Coordinate	Absolute	1,1 @ NW Extent of County	Irregular	0.1 or 0.01 Section	County
Station and Offset	Linear	Relative	Project Beginning	Regular	0.01 Foot	Project
State Plane Coordinates With Absolute Origin[(a)]	Coordinate	Absolute	Defined	Regular	0.01 Foot	State in Two Zones
State Plane Coordinates With Relative Origin[(a)]	Coordinate	Relative	Project Beginning	Regular	0.01 Foot	Project
UTM	Coordinate	Absolute	Defined	Regular	0.01 Foot	State in Two Zones
PLSS	Systematic	Absolute	Defined	Irregular	¼ Section	State
SD Rural Addressing Grid	Coordinate	Absolute	NW Corner of State	Irregular	1/50 Section	State
NSTRI	Linear	Relative	County Line SW	Irregular	0.01 Section	County
HPMS	Linear	Relative	State Line	Regular	0.01 Mile	State
Graphical Presentations	Coordinate	Absolute	Variable	Regular	0.5 Mile ?	State

(a) An absolute origin references the defined origin for the respective zone. A relative origin may be arbitrarily chosen for a project.

- Federal domain
- Frontage roads.

• The Highway Number is a three-digit number assigned in accord with the *SDDOT Highway Numbering Policy* and subject to the numbering hierarchy as identified in the *SDDOT Highway Mileage Reference Marker Policy Manual*. A brief summary of the hierarchy shows the following preferences:

  - Interstate routes over U.S. routes over South Dakota routes over business spurs, bypasses, truck routes, business loops, business routes, frontage roads, and service roads.
  - Even numbered over odd numbered.
  - Lower numbered over higher numbered.
  - Two exceptions are South Dakota Highways 1804 and 1806.

• The Highway Suffix is a three-place code which may include A in the first column for an Alternate Highway; E, W, N, or S in the second column to designate the direction of travel for a divided highway; and a 1, 2, 3, 4, P, B, L, or F in the third column for the First-Off Ramp, First-On Ramp, Second-Off Ramp, Second-On Ramp, Spur, Bypass or Truck Route, Business Loop or Business Route, or Frontage or Service Road.

• The MRM I.D. is a five-digit number with an assumed decimal point between the third and fourth digits. *It is important to understand that although the MRM I.D. resembles a true mileage designation, it is really a label or name for the MRM.*

• The Displacement is a five-digit number with an assumed decimal point between the second and third digits. This is the distance in thousandths of a mile from a known MRM to the point of interest.

The MRM system, which is the principal location referencing system used within the SDDOT, depends on the physical location of the MRM in the field. If the MRM is moved or removed, all references to that MRM must be altered. This may take place manually or in the once-a-year "purge" process. However, only current records are referenced, destroying historical continuity. Some of the most important databases that make use of this referencing system are described below. During the interviews, it was clear that other systems also make use of this location referencing system. Many of these other systems are not primary, may be project specific, or may be temporary in nature.

3.1.1 Roadway Environment Subsystem

The MRM system is used as the location referencing system for the RES. The RES has been identified in a previous study (SD90-09) [Svalstad et al., 1991] as the primary storage utility for the majority of the information that is collected in the course of managing South Dakota's highway system. The fact that this collection of databases continues to be one of the most important repositories of information, including location-referenced data, was reinforced many times throughout the interview process for the current project. Much of the following information describing the RES databases has been excerpted from a previous research project (SD90-09) [Svalstad et al., 1991]. During the current interview process, it was noted that a few items had changed but that the basic elements of the RES databases and their functions had not changed significantly. The *User's Manual and Coding Manual* for most of the RES database files and the Highway Planning Inventory file was also reviewed.

Ten files were previously identified as key files in the RES system. Nine of the files are master files which contain point-based information that is collected. The tenth file, identified as the Highway Planning System, contains information that is derived from the nine master files. Each of the nine master files of the RES uses MRM and displacement as the key to indexing the information in the files.

The MRM Inventory file contains all of the current mileage reference markers and the mileage location of each one. This system is implemented on the state's mainframe computer. The MRM file is used by all the other RES components to accurately locate the data coded to a highway number and MRM and to ensure that the highway number and MRM coded for certain data are actually valid. On-line screen access is available for the MRM Inventory. The MRM Inventory may also be queried and updated using standard batch job streams.

The Bridge Inventory System file is used to collect data on all aspects of each structure on the State Trunk System, County F.A.S. System, City Urban System, and Off System. In addition to using the MRM system for location-referenced data in this file, location is referenced by geodetic and PLSS systems and the location code is built into the unique structure number which is based on the Section Line Grid. This system is implemented on the state's mainframe computer using the **ADABAS** database and the **NATURAL** programming language. On-line screen access is available for this database. The Bridge Inventory System collects some data from other systems used by the SDDOT. The RES All-Data file, Project Master file, Accident file, and the highway code table provide information for the Bridge Inventory System. The Highway Planning, Maintenance Cost Inventory, RES Roadway Features, and Timesheet Teleprocessing systems obtain data from the Bridge Inventory System for their own use. Security for the Bridge Inventory System is provided by the **NATURAL** security system which is dependent on the assignment of **NATURAL** user I.D.s and passwords to anyone using the system. Access to the system is limited on a screen-by-screen basis with display and update capabilities also controlled.

The Traffic Inventory file is the RES component that is used to collect traffic data. The Traffic Inventory uses the MRM key for all of its location-referenced data. This system is implemented on the state's mainframe computer and relies in part on Panvalet data files for input. The Traffic Inventory file can be updated on-line. It may also be queried and updated using standard batch job streams.

The Sufficiency Inventory file is the RES component that is used to contain appraisal data on the adequacy of existing highways as compared to the design requirements of modern highways in the state of South Dakota. The Sufficiency Inventory uses the MRM key for all of its location-referenced data. This system is implemented on the state's mainframe computer and may be queried and updated using standard batch job streams. Some of the batch process requires input from other SDDOT systems. The Sufficiency Inventory file is inactive and will be purged in the near future.

The Dynaflect, Roughometer, and Pavement Friction Inventory file contains the results or summaries of various tests of roadway conditions. This inventory uses the MRM and Lane Code key for all of its location-referenced data. This system is implemented on the state's mainframe computer and may be queried and updated using standard batch job streams. Some of the batch process requires input from other SDDOT systems.

The Roadway Features Inventory file contains much of the information that describes each of the features along the roadways. The Roadway Features Inventory contains 15 different record types which may be divided into two specific categories. Three of the record types are point data, which describe conditions or a feature at a specific point. The point data that are stored in this inventory is:

- Structure Number
- Roadside Area Information
- Comments.

The other 12 record types contain continuous data. "When a record type is said to be 'continuous,' the data coded on a continuous record is assumed the same from one continuous record to the next continuous record of the same type, or until the end of the highway is reached. All continuous data must be coded at the beginning of every highway." Information that is stored as continuous data includes:

- Systems and Location
- Project and Surfacing
- Cross Section
- Route
- Guardrail
- Right-of-Way Fence
- Right-of-Way Width
- Horizontal Alignment
- Vertical Alignment

- Roadbed Layers
- Shoulders Layers
- Soil Type.

The Roadway Features Inventory uses the MRM key for all of its location-referenced data. When new information is being added to the Roadway Features Inventory file, data are entered on-line. The proper MRM and displacement values are stored with the new information. This system is implemented on the state's mainframe computer and may be queried and updated on-line and using standard batch job streams and on-line capabilities.

The Intersection Inventory file contains data on highway intersections in the state of South Dakota. The Intersection Inventory uses the MRM key for all of its location-referenced data. The Intersection Inventory is unique in that two "keys" are required to create an intersection. This system is implemented on the state's mainframe computer and may be queried and updated using standard batch job streams. Some of the batch processes require input from other SDDOT systems.

The Railroad Crossing Inventory file contains the descriptions of railroad crossings. This inventory uses the MRM key for only some of its location-referenced data. Data are permitted in this file without the RES key if the NSTRI key is present. This system is implemented on the state's mainframe computer and may be queried and updated using standard batch job streams. On-line access is also available for editing and querying via full-screen access.

The Maintenance Cost Inventory file accumulates all maintenance costs for each mile of roadway that is maintained in the RES MRM Inventory System and each structure maintained in the RES Bridge Inventory System. The Maintenance Cost Inventory by MRM is accumulated by fiscal year on a year-to-date basis. At the end of each fiscal year, the current year-to-date costs are saved as historical data for a period of 10 or more years. All input data for this inventory are taken from the accounting activity records. The accounting project is transposed into a valid RES highway number. The beginning milepost field is used as a starting MRM and the ending milepost field is used as a finishing MRM. All costs are prorated and charged to each mile of roadway which lies between these established points. All costs are prorated based on the mileage of the established MRM. The Maintenance Cost Inventory uses the MRM key for all of its location-referenced data. This system is implemented on the state's mainframe computer and may be queried and updated using standard batch job streams. Some of the batch process requires input from other SDDOT systems.

The Highway Planning System includes information derived from various RES databases and user-coded data in a single file. The Highway Planning System uses the MRM key for all of its location-referenced data. In addition, ties with project description numbers are provided. This system is implemented on the state's mainframe computer and may be queried and updated using standard batch job streams. Some of the batch process requires input from other

SDDOT systems. This file was used as a tool to provide a deficiency analysis for various sections of rural and/or urban highways. With this data, management determined those projects most likely in need of repair or improvement in the future, obtained a cost analysis for various levels of improvement, and projected useful life of these highway projects according to the level of improvement or repair used. The Highway Planning System has been replaced by **dRoad** and **dTims**.

3.1.2 Pavement Management System

The Pavement Management System (PMS), as it is currently implemented at the SDDOT, uses for its core data information derived from the RES databases. The PMS uses the MRM key for all of its location-referenced data in data storage and manipulation. The consultant who provided the PMS, Deighton Associates Limited, noted in the final report that "SDDOT's location reference system lacks the necessary coordination to ensure address changes are cascaded through all files simultaneously." The PMS relies on periodic "downloads" of data from the RES and other systems to create historical data. For data display, a digitized map transformed to **AutoCad** format is used. This system is implemented on a PC and uses **dBase** files for data storage.

3.1.3 Videologging System

The entire state trunk system has been videologged using a vehicle-mounted camera which provides a visual record of the roadway conditions. The videolog system was purchased and set up by Mandli Communications, Inc. The entire videolog uses the MRM system for all of its location-referenced data. This system is implemented on a Macintosh system with the video data stored on large local video disks. The video system is currently a stand-alone system that does not interact with any other part of the data collection and storage process; however, the common tie to the MRM system allows data or road conditions to be visually examined or substantiated based on MRM indexing. Because the videologging system is stand alone, all changes made elsewhere to MRMs must also be made in this system.

3.1.4 Accident Data

Accident data, as reported by all of the law enforcement agencies in the state and tribal authorities, are maintained in an **ADABAS** database on the mainframe. Although the MRM system is used for location-referencing accident data along the state trunk system, the primary system used is based on the location of the accident as measured on a county-based Section Line Grid. This system is implemented on the state's mainframe computer using the **ADABAS** database and the **NATURAL** programming language. On-line screen access is available for this database. The accident file provides information to several other systems used by the SDDOT. Persons charged with the maintenance of the accident records system reported very favorably about the performance and ease of use of the current database. The only plotting capabilities for visually showing the locations of all accidents currently available requires that the plotted overlay be moved around by hand to match different portions of the underlying county map. This is required because of the irregular sizes and shapes of the section lines that form the grid upon which the accidents are plotted.

3.1.5 Financial, Planning, and Project Management Records

The area of financial, planning, and project management records was not investigated fully by the RE/SPEC project staff. Many projects are tracked by Project Number, Project Control Number (PCNO), or Highway Number + Reporting Unit + Beginning Mileage + Ending Mileage (Maintenance Projects). In general, every project includes a tie to an MRM key at some point in the data. This may be quite exact, measured normally for the MRM key to the 1/1,000 mile, or only an approximation, to the nearest MRM. Location information may be present only within a text field in these records. This text field information is difficult to search, update, and use. Some individuals interviewed felt that project histories from conception and initial planning through construction are also difficult to track.

Location information was referred to many times in the SDDOT Data Model and Business Area Analyses, but the location referencing method or requirements were never specified. Surveys, road segments, and test locations are some of the items mentioned with regard to location.

3.1.6 Federal Highway Administration Highway Performance Monitoring System

The FHWA has the responsibility to assure that adequate highway transportation information is available to support all aspects of its functions and responsibilities. The HPMS was set up to serve the needs of the FHWA as they assess the length, use, condition, performance, and operating characteristics of the nation's highway infrastructure. The HPMS is a nationwide inventory system that includes all of the Nation's Public Road Mileage as certified by the states' governors on an annual basis. Each state is required to furnish on an annual basis all data requirements specified. The data are required to be submitted to the FWHA in a link-node format based on a Milepost system or similar to South Dakota's MRM system. HPMS records require only centerline data which is somewhat different than SDDOT's practice of defining divided highways as two separate roadways. Data for this report are produced from portions of the RES data and formatted as required for the FHWA. The data may be supplied in either a **dBase** or ASCII format. Maps are also required depicting the relationships of the described highways. Optionally, coordinates for each of the nodes in the system may also be provided, but no requirements define the type of coordinates to be used.

3.1.7 Sign Inventory

Regional offices have been charged with the responsibility of maintaining the inventory of signs within their regions. This inventory uses the MRM key for all of its location-referenced data. The Sign Inventory is currently on the PC network and is developed in **dBase**.

3.1.8 Railroad Information

Railroad information, although not a part of the state highway system, is maintained by the SDDOT in a location referencing system very similar to the MRM system used on state trunk roads. Mileposts are the key to the linear referencing system used by the railroads. Most location referencing along the railroad lines are maintained and used by the companies that own and/or use the railroad lines. Some references to location references along the railroad lines are required by the personnel of the Division of Air, Rail, and Transit. Paper maps with legal descriptions and milepost designations are the primary database for the location-referenced information.

3.2 GEODETIC COORDINATES

Geodetic coordinates may be described as "Quantities defining the horizontal position of a point on a spheroid of reference with respect to a specific geodetic data, usually expressed as latitude and longitude. These may be referred to as geodetic positions or geographic coordinates. The elevation of a point is also a geodetic coordinate and may be referred to as a height above sea level" [American Geological Institute, 1974]. Latitude may be specifically thought of as the angle between the earth's equator and the line perpendicular at a given point on the earth's surface. Longitude, similarly, is the angle between the plane of the geodetic meridian and the plane of an arbitrarily chosen prime meridian (generally the Greenwich meridian). Using the elements of latitude and longitude, one may determine position on the surface of the earth. The units used to describe latitude and longitude are typically degrees, minutes, and seconds of angle.

Geodetic coordinates, latitude and longitude, constitute a convenient method to describe points on the earth using a single method. USGS quadrangle maps and even the state highway map, as produced by SDDOT, include references to latitude and longitude. However, the method is complicated by the fact that the distances between "parallel" lines of measure are not equal. The distance, measured in linear units, between 97 degrees west longitude and 98 degrees west longitude measured at 46 degrees north latitude is not the same as the distance between 97 degrees west longitude and 98 degrees west longitude measured at 43 degrees north latitude. Also, the linear distance described by 1 degree in a north-south direction is quite different than the linear distance described by 1 degree in an east-west direction. Geodetic coordinates are one set of values that may be measured or output directly from many GPS devices. These coordinates are also routinely transformed to other standard referencing systems such as State Plane Coordinates.

Several databases within the SDDOT system were determined to include references to geodetic coordinates. Some of these databases use these coordinates as the primary location referencing key while others store the data as a secondary location reference. In some of the databases examined, geodetic information was being stored as degrees and decimal minutes with two places following the decimal point. That calculates out to a resolution of about 44 feet in the east-west direction and 60 feet in a north-south direction. In other databases, the geodetic information was stored as degrees, minutes, and seconds. One second is equal to approximately 75 feet in the east-west direction and 100 feet in the north-south direction.

3.2.1 Bridge Inventory System

The Bridge Inventory System is one of the RES components that is used to collect data on all aspects of each structure on the State Trunk System, County F.A.S. System, City Urban System, and Off System. In addition to using the MRM system for location-referencing data in this file, location is referenced by latitude/longitude, section-township-range, and the location code built into the unique structure number which is based on the location of the structure from the northernmost and westernmost points of the county. The Bridge Inventory System is an on-line system. It is being replaced by **PONTIS**, which uses an **SQL Anywhere** database system.

3.2.2 High Accuracy Reference Network

A High Accuracy Reference Network (HARN) is currently being established in South Dakota. The program, in cooperative effort with the National Geodetic Survey, will result in high accuracy benchmarks located throughout the state. These benchmarks will be primarily described in terms of geodetic coordinates. Upon establishment of the HARN, surveying and other location referencing capabilities will be greatly enhanced, particularly with regard to the application of GPS technologies.

3.2.3 Aviation Information

At least two databases found within the Division of Air, Rail, and Transit use geodetic coordinates as their primary location referencing method/system. One of these is the Aviation Hazards database. The Aviation Hazards database includes all hazards to air travel, primarily tall towers. The database is implemented on a PC with a **dBase** program. A second database, describing the airports of South Dakota, also uses geodetic coordinates as its primary location reference.

3.2.4 GPS Data Collection

Data collection currently being completed by several of the councils of local government use latitude and longitude as their primary collection referencing system. These data are typically transformed by the **GEOLINK** software of GeoResearch, Inc. into State Plane Coordinates for storage. Data are collected in North American Datum of 1983 (NAD 83). The accuracy of this work has been variously indicated as 1:100,000 scale (165 feet) to 2 meters (6 feet). SDDOT currently has no published plan for the integration of this location data into any existing database.

Currently, the location of the National Highway System (NHS) Roads are also being defined using GPS techniques. This work will also include the use of dead reckoning techniques to supplement areas and times of poor satellite reception. The specifications for this work call for delivery in **MGE/Informix** formats.

3.2.5 Decision Mapping — Intergraph

Decision Mapping is currently implemented on an Intergraph platform as well as an **ARC/INFO** platform. The base map of the state used for the Intergraph system was derived from the original digitized state map, described in Section 3.6.2, which used State Plane Coordinates with the North American Datum of 1927 (NAD 27) standard. Data are maintained within the Intergraph system as geodetic coordinates with map projections available for graphics. MRMs have been assigned spatial location coordinates using the State Plane Coordinate system. State Plane Coordinates are the primary projection system used. The Intergraph **MGE** system is capable of determining a variety of other projections. An **Informix** database maintained on an Intergraph Clipper workstation provides the data to the Intergraph system. Data are introduced to the system with ASCII files transferred from the RES on the mainframe or through the **Informix** system.

3.2.6 Other Agencies

Several other agencies both within and outside of state government use geodetic coordinates for location referencing. Game, Fish, and Parks and the Department of Agriculture are using some information in geodetic coordinates, much of it collected with GPS technology. The Department of Environment and Natural Resources currently collects some location-referenced data using GPS equipment. Some of the information that is collected includes oil and gas well locations, injection wells, nonpoint pollution data, and point sources of petroleum pollution.

The Pennington County — Rapid City Planning Department uses an Atlas system with geodetic coordinates as a referencing system. FHWA applies geodetic coordinates for their compilation of HPMS data.

3.3 SECTION LINE GRID SYSTEM — STRUCTURE INVENTORY

Every bridge within the state of South Dakota is identified by a unique eight-digit number; i.e., the Structure Number.

- The first two digits represent the county number in which the bridge is located. Bridges which are located on county lines are considered located in the county bordering to the north and/or west of the bridge's position.

- The third, fourth, and fifth digits indicate the distance in sections and tenths of a section the bridge is located east of the westernmost point in the county.
- The sixth, seventh, and eighth digits indicate the distance in sections and tenths of a section the bridge is located south of the northernmost point in the county.

The intersection of a line extending north from the westernmost point of the county and a line extending west from the northernmost point of the county is considered to be the origin and is labeled "CC000000" where CC represents the County Code. In order to adhere to the restraints of the eight-digit number, letters are used to represent distances where counties exceed 100 sections in length. "A00" represents "100.0," "B00" represents "110.0." and "C00" represents "120.0." For example, for a bridge which is located at section line 102.2, that portion of the structure number would be "A22." Structure Index Log Maps give the section line numbering sequence.

This location referencing method/system allows bridges located anywhere in the state to be uniquely referenced. The method is valid for anywhere in the state, whether located on the state trunk system or not. The resolution of this method/system is by definition limited to 1/10 of a section, or approximately 528 feet. It should be noted, however, not all sections are exactly 5,280 feet in length. The geometry of this system is further complicated by the fact that not all section lines intersect at 90 degrees. The nature of the shape of the earth requires that there are more sections in the southern part of the state than in the northern part of the state. Therefore, Structure Index Log Maps are required to confidently locate bridges based on their Structure Number.

The Structure Inventory, as was discussed above, is implemented on the state's mainframe computer and may be queried and updated on-line and using standard batch job streams. In addition, structure data are stored with the MRM system, geodetic coordinates, and PLSS. This system is implemented on the state's mainframe computer using the **ADABAS** database and the **NATURAL** programming language.

3.4 SECTION LINE GRID SYSTEM — ACCIDENT INVENTORY

The location of all accidents that are reported in the state are identified primarily by the Section Line Grid system as used for Accident Inventory. The Section Line Grid system as used for Accident Inventory is very similar to the Section Line Grid system as used for Structure Inventory discussed immediately above. Two very important differences between the two systems were identified:

1. The intersection of a line extending north from the westernmost point of the county and a line extending west from the northernmost point of the county is considered to be the origin but in the case of accident data, is labeled 1,1.
2. Reporting within urban areas is reported to the nearest 1/100 of a mile.

Assignment of coordinates in urban areas for this system is made easier and consistent by having all of the intersections in each city with a population greater than or equal to 2,500 identified by preassigned coordinate values. Therefore, to fully interpret this grid information, one must have maps with the section lines assigned coordinates and the tabulated intersection coordinates. The same problems exist in this grid system as for the previous grid system with regard to the shape of the earth and irregularities in the location of section lines. Accidents that occur on the state trunk system are also identified with MRM information.

3.5 STATIONS AND OFFSETS

Route surveying, particularly for construction purposes, is often accomplished by defining and staking the final centerline of the roadway. Technological advances in surveying equipment and practices are changing the procedures by which this is accomplished in the field. Traditional methods required surveying along the centerline, while current procedures accommodate radial surveying and other techniques which use the inherent advantages of modern surveying instruments. Stakes are typically set at full stations (100 feet) and may be set at closer intervals depending upon the terrain and other requirements. Hubs may be set at transit points, including points of intersection, points of curve, and points of tangency. Profile levels or measurements of elevation are typically measured along the centerlines with cross sections taken at each station.

Location-referenced information is typically designated as a point along the centerline located at a given station plus an offset distance (123 + 45.67 would mean 12,345.67 feet from the beginning of the project). Points off of the centerline may be designated as 123 + 45.67 – 89R which is 89 feet to the right of the centerline at 12,345.67 from the beginning of the project. Right and left is determined facing toward increasing station numbers. Right-of-way (ROW) information, information describing utilities and hydrographic information, is typically included on the resulting strip maps which are keyed to stations and offsets. Accuracy of this type of location referencing is typically presented on the strip maps to 1/100 of a foot, although the actual surveying may be completed at a higher accuracy.

All station and offset information is defined relative to a starting point and is not necessarily tied to an absolute point. It may also, however, be tied to an existing MRM or to State Plane Coordinates, if convenient. The station and offset location referencing works well for most construction purposes. Grade or relative elevation data are easily included on the stakes and are understood by those working with them. Geotechnical tests and tests of construction materials are typically noted by station and offset designations. The position of structures, culverts, ROW information, and fencing is also conveniently noted with this system.

Station and offset location referencing works well until the construction project is completed. The final roadway will then be referenced using the MRM system. Much information originally defined with stations and offsets, such as horizontal and vertical curvature, is transformed to MRM locations using a customized code within the SDDOT. Most geotechnical and construction materials test data are not currently transformed to the MRM system.

3.6 STATE PLANE COORDINATES — ABSOLUTE REFERENCE

The State Plane Coordinate systems are map projections that permit the methods of plane surveying to be extended over great distances with easily quantified corrections. At the same time, a precision approaching that of geodetic surveying is maintained. The Lambert conformal projection with two standard parallels defines a grid zone roughly 158 miles north and south. This distance bounds the limits of tolerable distortion which is a function of latitude. Since distortion is not a function of longitude, east-west extension is unlimited. Thus, the Lambert conformal projection is suited for states such as South Dakota that are of major east-to-west extent. South Dakota includes two zones for State Plane Coordinates, north and south. For the proper use of State Plane Coordinates, an elevation factor and scale factor must be included. Reference axes for each zone are such that the x and y coordinates of all points within the area will be positive. Many benchmarks in the state and all older surveying were tied to the NAD 27; however, most recent surveying is collected relative to the NAD 83. Most of the survey and planning data is reported to the 1/100 of a foot but some other applications tolerate much lower resolutions.

3.6.1 Design Projects

State law requires the use of State Plane Coordinates on engineering projects. Current design projects are being planned using State Plane Coordinates with an absolute tie to the appropriate zone. This is convenient because a design project is typically located entirely within a single zone. Surveying techniques and equipment now currently in use allow the use of State Plane Coordinates on office drawings and the convenient use of centerline staking in the field. This is accomplished because of the versatility of today's surveying instruments. Generally, NAD 83 is used for this data.

3.6.2 State Map

The state map, as maintained on the Intergraph equipment of the SDDOT cartography group, is maintained in State Plane Coordinates. Only a single zone, the South Dakota North Zone, is used. The resolution of the information stored in this system is much coarser than the resolution of the survey and planning data. The state map was originally digitized from paper USGS 1:250,000 scale maps approximately 10 years ago. The United States National Map Standards for 1:250,000 scale maps require that 90 percent of the points on the map be within about 400 feet of their true position. NAD 27 was used for this work.

3.6.3 Data Collection by the Southeast Council of Governments and First District

The data collection using GPS that is currently being completed by the Southeast Council of Governments (SECOG) and the First District with some SDDOT funding is being maintained in State Plane Coordinates. Again, only one zone is used. The resolution of this data is yet to be determined. NAD 83 is used.

3.6.4 City of Sioux Falls and Minnehaha County

The city of Sioux Falls and Minnehaha County maintain their GIS system using State Plane Coordinates. Some of this data are collected using GPS tools. The original section corners were defined or surveyed by the USGS. Some digitization from USGS 1:24,000 scale maps was also used. NAD 83 and the South Dakota South Zone are used.

3.7 STATE PLANE COORDINATES — RELATIVE REFERENCE

Until very recently, design projects had used what may be called State Plane Coordinates with a relative origin. Typically, the projects were designed on a regular grid system but the grid origin for the project was assigned an arbitrary value of 100,000 N, 100,000 E. The design projects were typically tied to absolute coordinates at one point if a benchmark was convenient. The orientation of the grid or definition of north was not always well defined. It may have been a backshot down a section line or a solar bearing. Resolution was as above, reported to 1/100 of a foot.

3.8 UTM COORDINATES

Large-scale military maps used by the United States use the UTM projection in regions away from the poles of the earth. A rectangular grid is superimposed on the military maps to assist in the location of points similar to the State Plane Coordinate system. For the UTM grid, the world is divided into 60 north-to-south zones each covering a 6-degree strip of longitude. Each zone is divided into 19 segments of 8 degrees latitude. The central meridian of each zone is assigned a value (500,000 meters). The equator is assigned a value of 0. Units of either feet or meters may be used with the UTM grid. A scale factor must be included for proper use of UTM map projections. South Dakota includes parts of two separate UTM zones.

3.8.1 County Maps

The county maps are currently maintained in UTM coordinates with feet as the unit. At the beginning of the county mapping effort, these maps were digitized from paper USGS

1:100,000 scale maps. More recent work was accomplished using DLG products with scales of 1:100,000 or less.

3.8.2 State Map as Stored on ARC/INFO

The state map that is used for Decision Mapping purposes using ESRI products is maintained in UTM coordinates with feet as the unit. The base for this work is the same as described in Section 3.6.3.

3.8.3 United States Forest Service

The United States Forest Service (USFS) uses the UTM system with meters as the unit. This is implemented on both **AutoCad** and **ARC/INFO** software. The USFS also uses Lambert conformal projections for their photo base. They use an **Oracle** database with structured query language (SQL) capabilities from **AutoCad**. For road project stakeouts, stations and offsets in feet are used. Some information included in their database has a 30-meter accuracy, which was described for most purposes as adequate. Some base map information is from digital USGS quadrangles in UTM meters.

3.9 PUBLIC LAND SURVEY SYSTEM

The Public Land Survey System had its origins in 1785 and has continued today with some variations. Early surveys made under contract were made with relatively crude instruments and often under unfavorable field conditions. The basic unit of this system is the township which is defined as 6 miles square, each containing 36 sections 1 mile square. The township is bounded by meridional and latitudinal lines and as nearly as may be 6 miles square. Because the meridians converge, it is impossible to lay out a square township by such lines, and because the township is square, not all sections can be 1 mile square even though all measurements are without error. Townships and sections have been located with respect to principal axes passing through an origin called an initial point; the north-south axis is a true meridian called the principal meridian and the east-west axis is a true parallel of latitude called the base line. The principal meridian is given a name by which all subdivisions are referred. Correction lines are located at intervals of 24, 30 or 36 miles from the principle meridian. Standard corners were established at intervals of 40 chains (66 feet each) or ½ mile. Often the lines and corners will be found in other than their theoretical locations; however, the original corners as established legally stand as the true corners.

This system was developed for the measurement and assignment of areas rather than point data. The resolution here is not very good. PLSS descriptions using section, township, and range are included in the Bridges Inventory, railroad and ROW information, and others. Borrow pits are solely located on paper files by this PLSS system.

3.10 SOUTH DAKOTA RURAL ADDRESSING GRID

The *South Dakota Rural Addressing Procedural Handbook* defines a system for any county in South Dakota that desires to have a locatable rural addressing system. The goal in building the system was to provide a simple addressing system that can be used for all addressing needs. The South Dakota Rural Addressing Grid uses baselines established on the north and west borders of the state. Each section line in South Dakota is assigned a thoroughfare number. These thoroughfare numbers are consecutive from the northern and western borders of the state. The South Dakota Rural Addressing Grid system can be used for addressing rural locations on all rural roads in South Dakota.

All east-west thoroughfares are designated streets. All north-south thoroughfares are avenues. Diagonal or meandering thoroughfares are roads. Deadend thoroughfares over 500 feet long are places. Deadend thoroughfares under 500 feet are courts. Thoroughfares which begin and end on the same thoroughfare are loops. Using this system, there will be 100 addresses per section or 50 addresses on each side of the street or avenue. Each lot is 105.6 feet wide. This system is required for any county that institutes an addressing system per Administrative Rules of South Dakota (ARSD) 50:02:03. The unit of resolution of this scheme may be considered to be approximately 105.6 feet.

Because of the curvature of the earth, the northern border of South Dakota is narrower than the southern border. Therefore, the northern border does not contain as many miles as the southern border. This causes some counties in the central or northern portions of the state to skip a street or avenue number.

3.11 NONSTATE TRUNK ROAD INVENTORY

The *Coding Manual for Rural Road and City Street Inventory* describes the methods used for locating features on the Nonstate Trunk Road Inventory. The key is Data Class (County or City), the County (two-digit identifier), Road/Street identifier (three numbers and an alpha character), the section number (five numbers designating the miles and hundredths of miles from the county line), and the section length (five numbers designating the miles and hundredths of miles of the length of the section). The resolution is 1/100 of a mile and distances are measured from the south and west county lines. Pennington County Highway Department uses this referencing system for their Features Inventory (**ROADPRO**). At least some of the data collection completed by local government organizations uses this system as its primary reference in addition to the South Dakota Rural Addressing scheme.

3.12 HIGHWAY PERFORMANCE MONITORING SYSTEM REPORTING

The HPMS is a nationwide inventory system which contains data about the nation's streets and highway systems. This database is maintained by the FHWA and relies on data furnished by the state highway agencies annually. Each state is charged with furnishing on an annual basis all data requirements for the program. The method of reporting is mandated by FHWA Order M 5600.1B, August 30, 1993. The data include information about the system's length, use, condition, performance, and operating characteristics.

The linear HPMS system is defined by two types of data. One type of data consists of nodes and includes node identification and descriptors for each node. The second type of data consists of links and include the identification of the two nodes which define the link's endpoints and descriptors for information of that link. This system of using nodes and links is used by some states as the primary system for tracking roadway information. South Dakota uses this link-node system only for reporting the required information to be used in the HPMS.

3.13 GRAPHICAL PRESENTATIONS

This category is not actually a location referencing system, but is included because of the importance of understanding how it fits in with and portrays the other location-referenced information. The primary objective of many illustrations is not to accurately portray data but to portray information in a way that items or categories may be quickly and conveniently understood. The Decision Mapping project is a prime example. The Decision Mapping illustrates roads in their relative location. Accuracy is not the primary issue. This is a situation where the final product requires a pleasant and effective appearance more than accurate locations.

Decision Mapping, as it is currently used at SDDOT, is the process of creating maps, typically at a small scale, which schematically depict one or a few conditions or values for a large area. The absolute locations of the depicted roadways are not critical; however, the relative location of roadways, so that the intersections are depicted accurately, is important.

All Decision Mapping products currently produced at SDDOT began with a paper copy of the USGS 1:250,000 maps. These paper maps were digitized by hand on an Intergraph system using only one zone of the South Dakota State Plane Coordinate system. From there, the data were transferred to either the **AutoCad** system, the **ARC/INFO** system, or another Intergraph system. Within each of these systems, attributes are assigned to the roads depicted on the map. The Decision Mapping efforts of SDDOT appear to be working well.

4.0 REVIEW OF CURRENT SOUTH DAKOTA DEPARTMENT OF TRANSPORTATION PROCEDURES

Field and office procedures are established to provide consistent and complete rules for the collection, maintenance, and use of location-referenced data. The best designed location referencing system falls short of its potential if the procedures that specify its application are not well defined or followed.

A review of SDDOT's policies and procedures for referencing, collecting, storing, extracting, and depicting linear and geodetic data was an integral part of investigations of location referencing systems in use. Established procedures and practices were discussed with various individuals throughout the project interview process. Interestingly, most of the discussions focused on the storage, retrieval, and use of data, with very little discussion on referencing, collecting, and depicting data. Numerous user's manuals and coding manuals related to the RES and other SDDOT data systems were identified and reviewed, along with key documented policies and procedures that include:

- SDDOT Highway Numbering Policy
- MRM Policy Manual
- South Dakota Rural Addressing Procedural Handbook
- City Street and Rural Road Inventory Data Collection Procedures, Requirements, and Definitions
- Portions of FHWA Order M 5600.1B, August 30, 1993.

The review of current policies and procedures revealed the following general observations related to data collection and referencing, data management and access, and data use.

- <u>Data collection and referencing</u>. In general, the current data collection field procedures are sound, well documented, and well understood by the individuals who use the various location referencing systems. Many data integration needs can best be addressed through the addition of a date/time attribute for all data, enhancements in postcollection processing and management of the data, as well as the implementation of data interfaces that provide coordinate transformation capability. Further, current procedures regarding the maintenance of MRMs must be carefully examined.
- <u>Data management and access</u>. A major change in the manner in which much of SDDOT's location-referenced data is stored, managed, and retrieved will be essential to effectively address SDDOT's data integration needs (particularly in the RES). *The implementation of a relational database is strongly recommended.* The use of a relational data model in managing SDDOT's location-referenced data would provide numerous advantages that include:

- Facilitate the cost-effective implementation of standard database interfaces to provide coordinate transformations required to integrate data collected using the various location referencing methods that are in use.
- Reduce redundancy in data management and storage, enhance support of both linear data analysis applications and spatial technologies (e.g., Decision Mapping and GIS applications), and provide enhanced ad hoc query capabilities required to support SDDOT research efforts and expanding data uses.
- Provide data management capabilities that will facilitate cost-effective management of historical data.
- Establish a data management structure that reflects the flexibility and extensibility required to accommodate SDDOT's changing data needs.

- _Data use._ Changing patterns in data use seem to be the biggest factor driving the need for data integration. Whereas data collection efforts were originally implemented to service specific focused data needs, contemporary decision-making processes and data presentation needs are resulting in increasing needs to integrate data collected using diverse location referencing methods. Further, the high cost of data collection has resulted in increased emphasis on data sharing between state agencies, counties, and local government.

A general observation that affects many areas of SDDOT data operations relates to procedure implementation. The interviews revealed that not all procedures were meticulously followed. Some information was not maintained because of staff reductions or a reduced perceived need for the data. Some procedures, although well written, appear to never have been implemented. Also, some new information being collected was not fully integrated into the mainframe environment because it was perceived as easier to keep on a local PC database. The validity of data was not clearly defined in all cases; that is, when information was no longer being maintained or additional information was being collected or the location of data changed, not everyone was aware of the change. Much of this is a communication or managerial issue. Some procedures, such as those that dictate the use of paper databases, are insufficient to allow full integration of all location-referenced data and must be changed.

The following sections provide detailed discussions of specific observations that were noted in each of the above areas during the review of SDDOT's current location referencing procedures.

4.1 DATA COLLECTION AND REFERENCING

The location referencing systems that are in place at SDDOT provide suitable information for the specific application for which that system was intended. Each system seems to be well documented, unambiguous, and well understood by those who use the system most often. In particular, the MRM system is quite robust as it is defined, with problems occurring most often when some part of the data maintenance procedures are not fully understood. Specifically, frequent and unnecessary moving or deleting and adding of MRMs presents significant problems in the maintenance of the MRM inventory. These statements are also true of the other location systems. It appears, therefore, that most current data collection procedures are essentially sound.

A review of the *SDDOT Highway Mileage Reference Marker Policy Manual* revealed that some existing procedures have not been fully implemented. Although procedures have been defined to address special circumstances such as coincident highways, divided highways, and specifically ramps on the state trunk system, they have never been implemented or procedures have not been developed to use all existing data. These procedures appear to be well thought out and should be implemented.

4.2 DATA MANAGEMENT AND ACCESS

Most of the commonly used data are implemented on the mainframe with a very extensive library of batch job streams and procedures for the storage, maintenance, and reporting of data. Many of the procedures use data from multiple databases to verify data or produce required reports. Further, the data are stored on the mainframe in a variety of formats requiring familiarity with many types of access procedures to perform queries. Some additional databases are maintained by individuals or groups on local platforms. The complexity of current interactions is exemplified in a *Descriptive Narrative of System Relationships* that was prepared by SDDOT.

A number of observations related to data management and access were noted during the interviews with SDDOT personnel.

- For some individuals interviewed, the current data implementation was considered very effective. Typically, these individuals had read, update, and query capabilities, and they were extremely familiar with the data being accessed. Typically, the individual charged with the responsibility of maintaining the specific data was comfortable with the processes.
- The concept that those who are familiar with the data should maintain specific portions of the database is widely accepted.
- Other individuals felt that a mainframe environment that requires the submission of requests to another department and a waiting period before results were received is too restrictive with regard to productive use and analysis of information. This was particularly true if the request for information was a new request that would require a greater amount of time by a programmer to create a query and format a new report. Those individuals who felt that the data were inaccessible or difficult to obtain had a

strong feeling that ready access to the data would allow them to perform their jobs better. The inaccessibility of data led some to the feeling that the SDDOT was data rich but information poor.

- Many individuals requiring access to data located using diverse location referencing methods expressed the need for a common denominator for data access. They further expressed that current data collection methods worked well, and standardization on a single location referencing method for all data was not the answer.

- Because of the very complex interrelationships between databases and accessing jobstreams, a single change in database structures or jobstream may have a wide-reaching effect because all affected jobstreams must accommodate the changes. Even with established but complex relationships between databases, individuals indicated that it was difficult to relate some things such as financial data and some materials testing data to specific locations on roadways.

- The ability to examine historical data or data from a specific time frame was cited as important. The current RES system and many other databases only maintain current information or information for a limited number of previous years. Notable exceptions to this are the limited information that is stored in the PMS, some Average Daily Traffic (ADT) information, planning information, and cost and financial information.

  Further, the ability to sample a consistent "snapshot" of the database, one that is not subject to ongoing incremental updates, was cited as important. Some sort of time label on some data may be appropriate to address this need. The addition of a time attribute will also be required to unambiguously resolve issues related to changes in ownership, highway renumbering, and highway realignment.

- Whenever a change is made to an MRM, the keys for all other databases that use the MRM "key" have to be deliberately and manually changed also. This may occur with realignments, renumberings, and changes of ownership. Slight changes in the MRM keys significantly impact the ability to perform historical comparisons which are critical for pavement management and other strategic fiscal considerations. The consultant who developed SDDOT's PMS system noted in the final report that "SDDOT's location reference system lacks the necessary coordination to ensure address changes are cascaded through all files simultaneously." This is particularly true for those cases where the location references are only text fields, not keys.

- Some individuals in the interview process acknowledged the difficulty of working with multiple location referencing systems. This was most evident when an individual with data referenced in a system other than the MRM system wanted to relate, view, or plot that data relative to the roadway network. Items specifically mentioned during the interview process were construction or preconstruction testing locations, financial and project data, and accident data.

- Location-referenced data from some of the systems can currently be related to location-referenced data in some other systems. This is demonstrated by the capabilities built into the current ESRI and Intergraph GIS systems. Methods to integrate data from some other combinations of location referencing systems need to be developed.

A common theme noted throughout the investigation was the need for data security and data integrity. The authority to update the primary or original databases must be controlled so that one cannot compromise data integrity. However, access must be easy, even for those who do not know the details of the underlying data structures.

4.3 DATA USE

Throughout the interview process, the following observations were noted with regard to trends in the use of location-referenced information.

- Many individuals expressed the need to integrate SDDOT data and data acquired external to the SDDOT.
- It was also recognized that data use will increase when this integration is achieved and the data become more readily accessible.
- At the current time, the amount of SDDOT data that is shared with other state agencies and agencies outside of the state system is fairly limited. Much of this data is currently transferred as graphical maps that are redistributed or modified slightly for other agency use. Limited data are received by the SDDOT.
- Conversations with persons outside of the SDDOT indicate that the outside systems being used will not readily accept data in the MRM format. For effective data transfer, some type of standardized absolute coordinate system is required. Most use of location-referenced data outside the SDDOT employs standard GIS tools, which require that data be available in an absolute coordinate system for integration.
- The use of GPS as data collection devices both within and outside the SDDOT will inevitably increase with time. This underscores the need to establish a location referencing system that is conveniently compatible with the absolute positioning information produced with this technology. With the full implementation of the High Accuracy Reference Network and radio-linked real time correction procedures, very precise locations will become easily attained.

- Recent requests for access to SDDOT data via the Internet have come from both within and outside of SDDOT.
- Future intelligent transportation systems, tracking management systems, and airports will require accurate coordinate location referencing.

Advances in surveying technology, GPS, GIS, and other spatial data representations; data collection and sharing among agencies; and intelligent transportation systems will all influence the future usefulness of SDDOT data.

A critical aspect of the collection, management, and use of location-referenced data that will become of increasing importance as spatial technologies continue to evolve is the recognition of existing and evolving standards. The Federal Geodetic Control Subcommittee (FGCS) of the Federal Geographic Data Committee (FGDC) "has adopted NAD 83 as the official horizontal datum for U.S. surveying and mapping activities performed or financed by the Federal Government. For further information, reference Engineer Technical Letter No. 1110-1-147, Engineering and Design Conversion to North American Datum of 1983, dated March 5, 1990." The FGCS of the FGDC has affirmed that North American Vertical Datum (NAVD) 88 shall be the official vertical reference datum for the United States. For further information, reference Engineer Technical Letter No. 1110-1-152, Conversion to the North American Vertical Datum of 1988, dated July 31, 1994.

5.0 FUNCTIONAL REQUIREMENTS OF A STANDARD LOCATION REFERENCING SYSTEM

The location referencing needs of SDDOT have been determined from the Request for Research Proposal (SD96-04) and through the interview process involving more than 35 state personnel. In addition, literature surveys helped to identify requirements for location referencing and GIS applications, as commonly perceived by the industry. The following functional requirements are a result of this investigation:

- Incorporate existing location referencing methods/systems.
- Provide transformations between existing referencing methods/systems.
- Maintain compatibility with existing SDDOT linear and geodetic analysis applications.
- Maintain a historical reference for data.
- Provide ready electronic data access.
- Provide convenient data update processes and procedures.
- Manage update access to ensure data integrity.
- Provide physical security of data via backup and archival procedures.
- Provide capability for ad hoc queries and "browsing" of available data.

A key consideration throughout the implementation of the above functional requirements will be existing and evolving standards. As noted in Chapter 4.0, standards will continue to become of increasing importance as spatial technologies continue to evolve, uses of data expand, and data sharing needs increase.

Although qualification of data with regard to scale, accuracy, and precision has not been addressed in the above functional requirements, the RE/SPEC project team recognizes their significance in data integration. The SDDOT data model report also identifies "Data Accuracy" as a problem which may affect processes. A fundamental question that remains to be resolved is: *"What role should a standard referencing system assume with regard to qualifying data?"*

In general, the information necessary to determine the applicability of data can be:

- Disseminated through SDDOT communications.
- Left to the judgment of data users.
- Communicated to data users through intelligent data interfaces via data attributes.

SDDOT management decisions will be required to address this issue.

6.0 THE STANDARD LOCATION REFERENCING SYSTEM

The critical components of a standard location referencing system that will satisfy the identified functional requirements can be categorized as follows:

- *Data collection and referencing*. Data collection and referencing practices will be sound, well documented, and understood by all personnel. These practices will:
  - Incorporate existing location referencing methods and procedures.
  - Include date/time as a data attribute.
  - Locate off-road features with one or more *xy* coordinates and elevations.
  - Accommodate an optional elevation coordinate.
- *Data management and access*. The data management environment will facilitate enhanced management of and access to location-referenced data. This will be accomplished through the following:
  - Modified data structures to accommodate temporal data attributes and location referencing transformations, as necessary.
  - Managed update practices to ensure data integrity.
  - Convenient data update procedures.
  - Physical security of data via backup and archival procedures.
  - Ready electronic data access without knowledge of data structures.
  - Capability for ad hoc queries and "browsing" of available data.
- *Data integration and use*. Data interfaces will include coordinate transformation capabilities to enhance data integration and use. These interfaces will provide:
  - Data transformations between existing referencing methods/systems, as necessary.
  - Compatibility with existing transportation analysis applications.
  - Transformation of data located using existing referencing methods and procedures into a common regular coordinate system to facilitate data integration using contemporary spatial analysis tools.

Historical management of and timely/convenient access to all location-referenced data are key characteristics of the standard location referencing system. These characteristics represent a substantial broadening of data management for SDDOT.

The implementation of coordinate transformations recognizes SDDOT's existing significant investment in location-referenced data through continued use of existing referencing methods/systems, yet positions the SDDOT to accommodate evolving spatial data collection and analysis technologies. The principal location referencing practice within the SDDOT involves the use of linear referencing; namely, MRMs. Although the use of two- or three-dimensional location referencing is currently limited, this capability would substantially increase the exploitation of location-referenced data and is expected to increase in importance through time.

7.0 LOCATION DATA TRANSFORMATIONS

An integral part of the recommended standard location referencing system is the ability to effectively integrate data maintained in one location referencing system with data maintained in other location referencing systems in use. This may be accomplished in two ways:

1. Transform data from one system to the second system.
2. Transform data from two diverse systems to a third system.

If analysis of the resulting integrated data results in new data that should be stored for future use in a form that is consistent with one of the original location referencing systems, there may be a need to transform the new data (derived in the "second" or "third" system referred to above) back into one of the original systems.

The purpose of the discussions provided in this chapter is to:

- Describe each of the transformations possible.
- Describe a common location referencing framework and identify the information and processes needed to implement critical data transformations.
- Demonstrate techniques that can be implemented to provide critical data transformations.

Implementation of transformations to and/or between the location referencing methods/systems used to locate transportation-related data is required to meet the functional requirements of the standard location referencing system. These transformations will enhance SDDOT use of all data and will be essential to meet increasing pressures for cooperative efforts between all levels of state and local government.

7.1 POSSIBLE DATA TRANSFORMATIONS

Thirteen distinct location referencing systems were identified in Chapter 3.0 (Table 3-1). The systems are categorized in Table 7-1 by system type. These categories will provide a useful framework for discussion of possible data transformations. Two systems, graphical presentations and the HPMS link-node system, are not used as primary sources of data and are not considered further.

The data transformations that are possible between the various categories of location referencing systems are identified in Table 7-2. Some of the transformations are more likely to be used than others, although theoretically, all are possible. The transformations from each of the four categories of location referencing systems to regular coordinates have been identified as critical. These transformations to regular coordinates are considered critical for several reasons:

- The transformations from each of the location referencing systems to a regular coordinate system will probably be the most commonly used.
- Transformation of the data from each of the location referencing systems to a regular coordinate system will allow all data to be effectively related to each other. (This is not true for transformations to any other category of systems.)
- The display and manipulation of data using standard spatial analysis applications/tools will require data in regular coordinates.

The transformation between linear systems has also been identified as critical because of existing needs to transform data located by station and offset to an MRM and displacement.

Table 7-1. Location Referencing System Categories

Location Referencing System Category	Location Referencing Systems
Linear	MRM Station and Offset NSTRI
Regular Coordinates	Geodetic State Plane Coordinates UTM
Irregular Grid	Grid for Structures Grid for Accidents SD Rural Addressing Grid
Public Land Survey	Public Land Survey System

7.2 TRANSFORMATION TO COMMON LOCATION REFERENCING FRAMEWORK

The standard location referencing system should be able to integrate all of the location-referenced data with no loss of information. The MRM system works well, and it is not intended that the existing linear referencing system for information that exists along roadways be replaced. Routines and procedures to transform data from each existing location referencing system to a common spatial referencing system will be required for complete integration. Effort and cost may prohibit including each of the currently used referencing systems, but the most important information may be included sooner and the least important information included when it is appropriate. Depending upon accuracy requirements and the performance and specific capabilities of the database, these coordinates may be stored or calculated as needed.

Table 7-2. Identified Potential Data Transformations

Transformation	Priority
Transformations to Regular Coordinates	
1. Regular to Regular	Critical[a,b]
2. Linear to Regular	Critical[a,b]
3. Irregular to Regular	Critical[b]
4. PLSS to Regular	Critical[b]
Transformations to Linear Systems	
1. Linear to Linear	Critical[a,b]
2. Regular to Linear	Low Priority
3. Irregular to Linear	Low Priority
4. PLSS to Linear	Low Priority
Transformations to Irregular Grid Systems	
1. Irregular to Irregular	Low Priority[a,b]
2. Regular to Irregular	Low Priority
3. Linear to Irregular	Low Priority
4. PLSS to Irregular	Low Priority
Transformations to Public Land Survey Systems	
1. Irregular to PLSS	Low Priority
2. Regular to PLSS	Low Priority
3. Linear to PLSS	Low Priority

(a) Already in place within SDDOT.

(b) Demonstrated in this report.

The most desirable choice for a common location referencing framework is geodetic coordinates, latitude and longitude, with elevation included. This common spatial location referencing system is easily convertible to other commonly used systems such as UTM and State Plane Coordinates. FHWA currently uses geodetic coordinates for the HPMS data. The geodetic system is not complicated by projections that require two State Plane Coordinate zones or two UTM zones in South Dakota. The geodetic coordinate system selected should be further defined as based on NAD 83 and the NAVD 88. The transformations should be transparent to most of the people currently collecting and processing the location-referenced data.

The identified location referencing systems may be grouped by similarities to identify the information needed to transform data from the current systems to geodetic coordinates. Table 7-3 groups similar location referencing systems and shows the information needed to be able to completely integrate the data to the geodetic coordinate system. The information that is required for complete integration is discussed in the following sections, with the exception of HPMS and Decision Mapping. The acquisition of elevation data is essentially the same for all of the systems.

Table 7-3. Information Needs for Transformation of Existing Location Referencing Systems

Location Reference System[a]	Data Needed to Define Absolute Position
Linear: MRM Station and Offset NSTRI	1. Anchor point(s). 2. Definition of orientation (north). 3. Horizontal (and vertical) curve definition.
Regular Coordinates or Grids: Geodetic State Plane — Absolute UTM State Plane — Relative	1. Definition (name) of coordinate system State Plane — relative also requires a. Anchor point(s) b. Definition of orientation (north).
Irregular Grids: Grid for Structures Grid for Accidents SD Rural Addressing Grid	1. The absolute location of each section corner (alternately, this may be thought of as the distance and orientation of a line between each adjacent pair of section corners).
Public Land Survey System	1. Specific knowledge of the system relative to the baseline.

(a) The HPMS system and Decision Mapping are not included because they are not sources of information.

7.2.1 Integration of Linear Referencing Systems

The MRM system, the Station and Offset system, and the Nonstate Trunk Road Inventory system are characterized as representing linear referencing methods. That is, they strictly reference points along a line. Software and procedures that are currently being used, part of the RES Roadway Features Inventory System, have the capability to transform station and offset information into MRM information. The NSTRI system is somewhat different in that it incorporates only the nonstate trunk roads. Three different techniques of transforming MRM information to geodetic coordinates are readily available. Each of the techniques require different information, yield different resolutions of information, and would probably have different costs to incorporate.

1. The technique that would potentially yield the most accurate information requires the horizontal and vertical curve information currently maintained in the Roadway Features file of the RES. If two anchor points or one anchor point and an orientation of the roadway is known, the curve information of the Roadway Features file should allow the spatial position of the state trunk roads to be calculated. It may be possible to calculate the positions of each MRM or perhaps even any point in between MRMs. The acquisition of anchor point information may be by survey or possibly through existing data. The accuracy of this calculation would be limited by the MRM data itself. It is not clear how well the data stored in the RES reflect actual road conditions. Alternatively, actual design information might be used but the coverage may not be adequate and the accuracy may be questionable with regard to as-built conditions.

2. Another technique which will allow the integration of MRM data into spatial data is to use the existing spatial information, as defined from the state map and GIS tools that are currently in place at SDDOT. This process has been completed on both the Intergraph system under the direction of Mr. Frank Cooper and the ESRI system under the direction of Mr. Roger Brees. The Intergraph system will currently allow the input of MRM data directly, while the ESRI system is currently using calculated miles from the road origin as input. The accuracy of this integration would be significantly less than the calculational approach since it is derived from a digitized original 1:250,000 scale USGS map and subsequent mapping of MRMs onto the linear representations of the roadways.

3. The third technique is that of measurement. The most practical way to measure roadway alignment data for the state trunk system is using GPS techniques. The combination of dynamic or kinematic GPS information with inertial data may provide relatively accurate roadway centerline information. Roadway information is currently being collected for some portions of the state trunk and nonstate trunk roadway system.

The integration of MRM system data is the most important transformation required. The MRM system is the location referencing system most commonly used within SDDOT.

7.2.2 Integration of Regular Coordinates or Grids

The location referencing systems grouped here are made up of standard, well defined, and widely used systems. Geodetic coordinates, the recommended spatial location referencing framework, is a true coordinate system while the State Plane Coordinate system and UTM systems are widely used map projections. They are all identified by regular coordinates or grids and a well identified origin. These are systems to which elevation may be easily added. Routines that transform coordinates from any one of these three systems to the others are easily obtainable and well established. Accuracies of this data are primarily a function of the original data collection technique. Scale and elevation factors must be included. Data collected in any of these systems are applicable on or off any road network.

The fourth location referencing system characterized as a regular grid is identified as State Plane Coordinates with a relative reference. As noted in Section 3.7, an arbitrary beginning point of 100,000, 100,000 was often selected for roadway design projects. This is actually more of a cartesian system and not a real map projection. Given a single anchor point and knowledge of grid north for each project, this data can be integrated.

Although these integrations are common and straightforward when using either State Plane Coordinates or UTM coordinates, the zones and correction factors must be respected for proper understanding of the accuracies and relationships of locations.

7.2.3 Integration of Irregular Grids

Three of the current location referencing systems are based upon the section lines that are nearly ubiquitous across South Dakota. These three systems are the Grid for Accidents, the Grid for Structures, and the South Dakota Rural Addressing Grid. Two of the systems use the northern and western extent of each county as the origin for that county, and one system uses baselines established on the northern and western edge of the state as the origin. Two of the systems are identical except for the definition of their origin (0,0 versus 1,1) and the resolution of measurements. Generally, the data requirements are the same to transform these systems to geodetic coordinates. Information collected using these systems is somewhat coarse, 0.1 to 0.01 mile, in resolution. The Section Grid for Accidents has the additional requirement of being compatible with all preassigned information at city intersections. These constitute the primary location referencing systems used off the state trunk system but on roadways.

The integration of these systems requires a knowledge of the location of each section corner. The curvature of the earth causes distortion of any regular grid placed on the surface of the earth. Section lines are no exception. In addition, surveying equipment and techniques in place at the time of the original Public Land Surveys, which defined the section line grids, have caused some distortion to the regular 1 mile, 5,280-foot, grid.

Three different techniques of acquiring information needed to transform irregular grid information to geodetic coordinates are available. Each of the techniques yield different resolutions of information.

1. County maps are currently maintained using UTM coordinates. County maps for the entire state are currently available. Although these maps have hand-digitized and/or DLG origins, all intersection and section line information is included. Accuracy of the information is not well defined.
2. Several areas of the state have ongoing GPS collection activities. This GPS-collected data will include the intersection or section corner information required for data transformation in those areas. It is unclear when this information will be available for all counties of the state or what the resolution of this information will be.
3. USGS maps at scales of 1:24,000 to 1 to 250,000 exist for all or most of South Dakota. Electronic versions of some of the information on these maps are also available. Using the section corners as defined on the USGS maps will provide section corners for the state but with unknown accuracy.

Whatever technique is used to assign or determine the geodetic coordinates of the section corner information, special care will be required to remain as consistent as possible with the preassigned grid values for city street intersections as assigned for accidents. As for all of the transformation processes, it may be desirable to begin with the data in hand, the county map data, or the USGS data, and incorporate more consistent and accurate data as they become available.

7.2.4 Integration of Public Land Survey System

The Public Land Survey System provides what is sometimes called the legal description and is also based on the location of section lines. This system was developed for the assignment and measurement of areas rather than point data. Consequently, the units of measure are for areas, typically acres. The system is well established and used for land ownership and the general location of points.

The information required to transform the PLSS information to geodetic coordinates is essentially the same as for the irregular grids described in the previous section. In addition, the specific knowledge of the section, township, range, and baseline labelings are needed. The three techniques described in Section 7.2.3 will provide the information needed for the integration of the Public Land Survey System.

7.3 DEMONSTRATION OF CRITICAL TRANSFORMATIONS

Examples of each of the transformations between and to regular coordinate systems are presented within the following sections. In some cases, several techniques may demonstrate similar transformations. Some of the examples are demonstrated by a computer printout(s) or a series of screen dumps of data.

In reviewing these demonstrations, keep in mind that they are provided to demonstrate transformation capabilities and techniques and not as a demonstration of the recommended implementation. Most of the transformations demonstrated in this chapter are currently being performed on a routine basis within the SDDOT. Each of these transformations can be implemented as a database interface. Because of project time and budget constraints, only those transformations that are critical or easily accomplished with tools currently available to SDDOT are demonstrated.

Based on the findings of the current study, the transformations that are not demonstrated are less likely to be used and are considered a low priority. From a theoretical standpoint, all of the transformations can be accomplished. From a practical standpoint, all location-referenced data identified in the current project can be integrated through one of the demonstrated transformations. The development of a data interface to provide these transformations may not be necessary to meet SDDOT's needs. Throughout the current investigations, the most significant driving forces for data integration that were identified related to the need to integrate data for graphical presentation and to needs associated with desired and/or planned future GIS analyses that do/will require knowledge of the relative global position of transportation-related information and/or events.

7.3.1 Demonstration of Linear System to Regular Coordinates

The transformation from a linear system to regular coordinates is currently performed within the SDDOT using several techniques. Three specific techniques will be illustrated.

The **CLM CEAL** program has built-in capabilities for transforming linear station and offset data to a local coordinate system. Figures 7-1 and 7-2 show a series of points along the Mickelson Trail with the points described in linear terms, station and offset, and in a local coordinate system. These printouts were produced by Ms. Karen Harris in the Rapid City Regional SDDOT Office. The principals are essentially the same when working with MRMs and other regular coordinate systems.

Transformations from station and offset values to coordinate values are also being done using the inherent capabilities of spreadsheet programs such as **EXCEL**. Figures 7-3 and 7-4 show the results of several transformations produced by Mr. John O'Connor of the Rapid City Area SDDOT Office.

The third example of a transformation from linear coordinates to regular coordinates is demonstrated using the Intergraph **MGE** system. Figure 7-5 shows the MRM and geodetic coordinates assigned to a single MRM, and Figure 7-6 lists the same values for a series of points on either side of the MRM displayed in Figure 7-5. These figures were produced by Mr. Frank Cooper using existing data in the SDDOT Decision Mapping program.

7.3.2 Linear System to Linear System

The transformation of construction project information located in a linear Station and Offset system to the predominant linear MRM system is routinely performed within the SDDOT. It should be noted, however, that the data maintained by SDDOT is the design information and not the as-built information.

7.3.3 Demonstration of Regular Coordinates to Regular Coordinates

The transformation of data between various types of regular coordinates is very well established. Standard transformation engines are available from the National Geodetic Survey (NGS), United States Geological Survey, as well as several commercial firms. These transformations are also included in well established GIS applications. Source code is available from both public and commercial institutions and may be used to implement database interfaces that will provide these standard transformations.

To demonstrate these standard transformations, several printouts from the program **Corpscon** are included in Figures 7-7 and 7-8. **Corpscon** was created by the U.S. Army Topographic Engineering Center based on two programs, **Nadcon** and **Vertcon**, which were created by the National Geodetic Survey (Corpscon Technical Documentation). A transformation from NAD 27

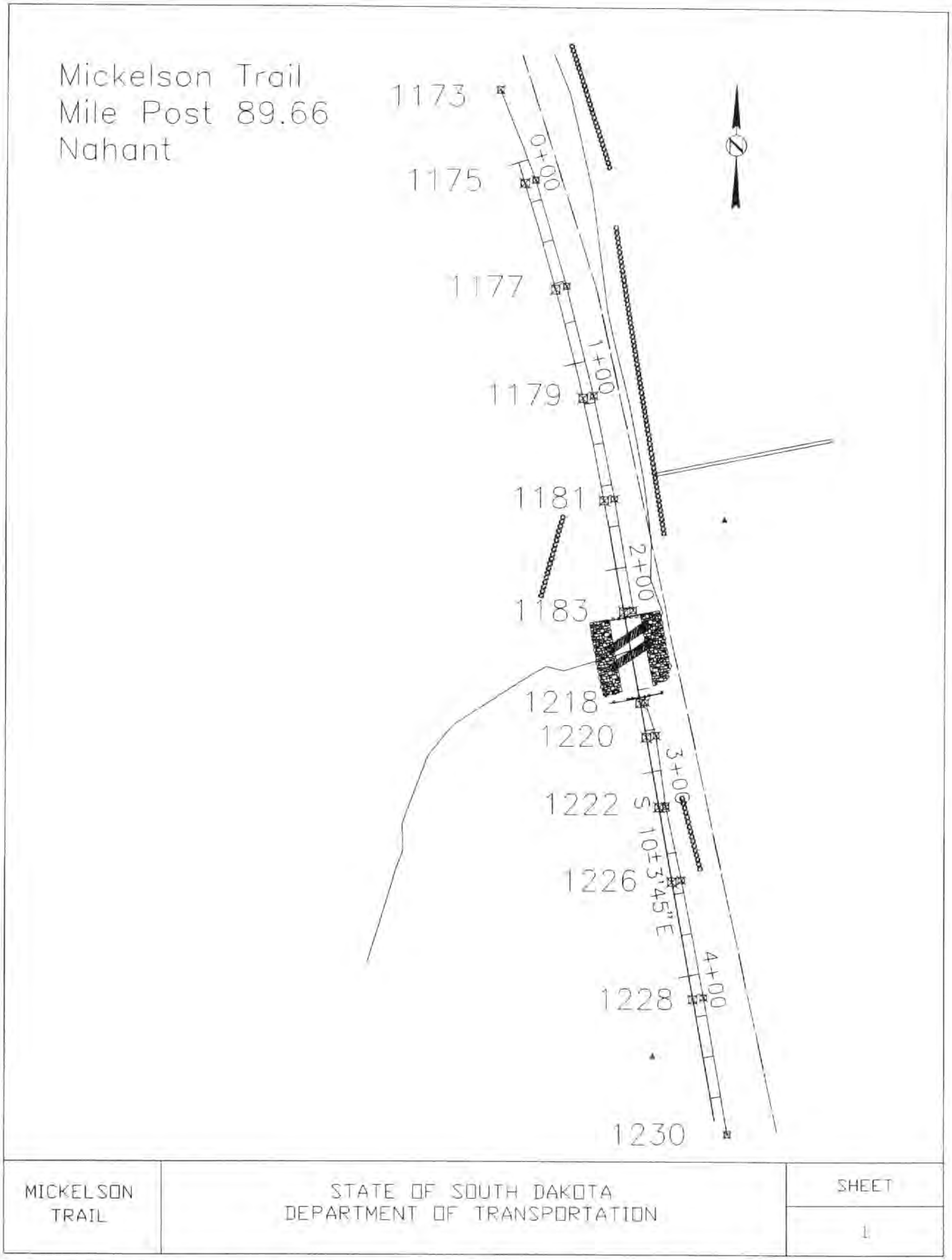

Figure 7-1. Demonstration of Linear Coordinate Transformation Using **CLM CEAL**: Stations.

```
*** ERROR - Model File DATA\471SHEND not found.
layout to a001 b200
------------------------------------------------------------------------------------
   LAYOUT POINTS FROM CHAIN A001
 TO                       OFFSET      OFFSET/TANGENT           OFFSET/PROJECTED
POINT     STATION       DISTANCE        DIRECTION                 COORDINATES
------  ------------  ----------  --------------  ------------------------------
  1173 Does not lie within tolerance distance
 1175       0+10.239       5.380L  N  72-02'11" E  N    10323.713  E      9883.107
                                   S  17-57'49" E  Z      992.498
                                                   N    10322.054  E      9877.989
 1177       0+62.810       5.487L  N  74-28'31" E  N    10273.184  E      9898.420
                                   S  15-31'29" E  Z      992.050
                                                   N    10271.716  E      9893.133
 1179       1+16.961       5.380L  N  76-59'16" E  N    10220.451  E      9911.721
                                   S  13-00'44" E  Z      991.477
                                                   N    10219.239  E      9906.478
 1181       1+67.144       5.039L  N  79-18'57" E  N    10171.063  E      9921.733
                                   S  10-41'03" E  Z      991.067
                                                   N    10170.129  E      9916.781
 1183       2+21.247       4.582L  N  79-46'15" E  N    10117.706  E      9930.936
                                   S  10-13'45" E  Z      990.316
                                                   N    10116.892  E      9926.428
set noprint
layout to a001 b700
------------------------------------------------------------------------------------
   LAYOUT POINTS FROM CHAIN A001
 TO                       OFFSET      OFFSET/TANGENT           OFFSET/PROJECTED
POINT     STATION       DISTANCE        DIRECTION                 COORDINATES
------  ------------  ----------  --------------  ------------------------------
 1218       2+66.361       2.431L  N  79-46'15" E  N    10072.927  E      9936.831
                                   S  10-13'45" E  Z      990.459
                                                   N    10072.495  E      9934.439
 1220       2+83.297       4.701L  N  79-46'15" E  N    10056.664  E      9942.073
                                   S  10-13'45" E  Z      989.747
                                                   N    10055.829  E      9937.447
 1222       3+17.577       3.330L  N  79-46'15" E  N    10022.685  E      9946.811
                                   S  10-13'45" E  Z      989.368
                                                   N    10022.094  E      9943.534
 1226       3+53.840       4.588L  N  79-46'15" E  N     9987.221  E      9954.489
                                   S  10-13'45" E  Z      989.238
                                                   N     9986.407  E      9949.974
 1228       4+11.481       5.202L  N  79-46'15" E  N     9930.606  E      9965.330
                                   S  10-13'45" E  Z      987.992
                                                   N     9929.682  E      9960.210
  1230 Does not lie within tolerance distance
gedit map 471sh
model file 471shg
gedit map 471shg
spec
pf s 471sh
sheet 471sh
index 9999 c
plot align a001
plot 1173 1175 1177 1179 1181 1183 1218 1220 1222 1226 1228
plot b200
plot b700
pf end
   IPF file closed
fin
```

Figure 7-2. Demonstration of Linear Coordinate Transformation Using **CLM CEAL**: Station and Offset to Regular Coordinates.

CONTROL	STATION		NORTH	EAST	
PT #1	998.300000		99048.650	100287.400	
PC #2	1538.777943		98647.420	100649.520	

POINT	STATION	OFFSET	NORTH	EAST	ELEVATION
#0190	1000	0	99047.39	100288.54	6426.000
#0191	1050	0	99010.27	100322.04	6423.830
#0192	1100	0	98973.15	100355.54	6421.330
#0193	1150	0	98936.03	100389.04	6418.610
#0194	1200	0	98898.92	100422.54	6415.760
#0195	1250	0	98861.80	100456.04	6412.800
#0196	1300	0	98824.68	100489.54	6409.710
#0197	1350	0	98787.56	100523.04	6406.510
#0198	1400	0	98750.44	100556.54	6403.190
#0199	1450	0	98713.33	100590.04	6399.750
#0200	1500	0	98676.21	100623.54	6396.190

Figure 7-3. Demonstration of Linear Coordinate Transformation Using **EXCEL**: Station and Offset to Regular Coordinates for Straight Road Segment.

	CURVE #2		NORTH	EAST	STATION	
	PC #2		98647.42	100649.52	1538.77	
	PI #2		98531.77	100753.91		
	PT #2				1821.89	
	Degree of Curve		21.000277			
	Radius		272.83354			
	DELTA		59.456388			
	LENGTH		283.12			
	CURVE R or L		L			
	Origin		98830.231	100852.05		
POINT	STATION	OFFSET	NORTH	EAST	ELEVATION	
#0201	1550	0	98639.24	100657.21	6392.510	
#0202	1600	0	98606.93	100695.28	6388.710	
#0203	1650	0	98582.10	100738.60	6390.370	
#0204	1700	0	98565.58	100785.72	6384.800	
#0205	1750	0	98557.93	100835.06	6386.460	
#0206	1800	0	98559.39	100884.97	6380.760	

Figure 7-4. Demonstration of Linear Coordinate Transformation Using EXCEL: Station and Offset to Regular Coordinates for Curved Road Segment.

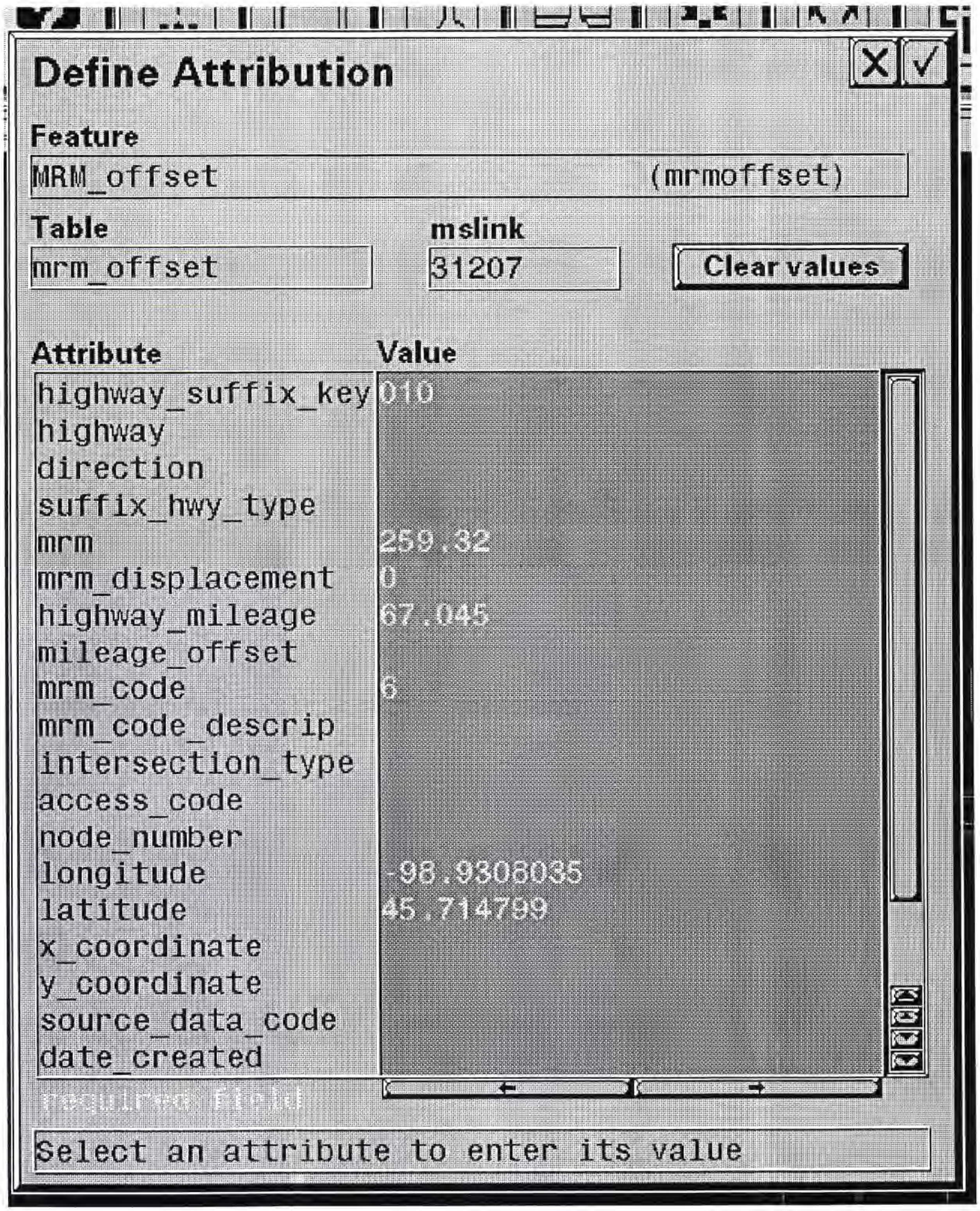

Figure 7-5. Demonstration of Linear Coordinate Transformation Using MGE: MRM to Regular Coordinates.

mslink	highway_suffix_key	mrm	mrm_code	longitude	latitude
31125	010	216.24	6	-99.8005014	45.759945
16038	010	220.24	5	-99.7171229	45.759859
31135	010	224.24	6	-99.6354333	45.759109
31151	010	225.24	6	-99.6150997	45.759723
31167	010	237.26	6	-99.3666780	45.759543
31176	010	245.62	6	-99.2013635	45.741042
31207	010	259.32	6	-98.9308035	45.714799
16130	010	269.27	5	-98.7248491	45.713979
31262	010	302.15	6	-98.1461633	45.783782
31266	010	304.16	6	-98.1056500	45.783515
16183	010	310.17	5	-97.9783612	45.783281
31292	010	321.20	6	-97.7507816	45.782841
31306	010	327.13	6	-97.6269343	45.782448
31321	010	339.39	6	-97.4098380	45.710337
31324	010	340.23	6	-97.3922051	45.710450
16246	010	349.85	5	-97.2272127	45.652236
31365	010	360.39	6	-97.0205564	45.652384
7580	010	182.37	1	-100.286623	45.889535
7599	010	193.21	4	-100.071777	45.904754
7600	010	203.22	3	-100.071291	45.759927
7727	010	279.30	4	-98.5188501	45.713127
7728	010	282.30	3	-98.5184954	45.755479
7879	010	371.58	2	-96.8333131	45.589986
23797	045	035.03	5	-98.8504120	43.499451
23842	045	071.14	5	-98.9856049	43.932540
23868	045	089.25	5	-98.9834677	44.196005
23956	045	163.63	5	-99.0313421	45.245037
23997	045	192.70	5	-98.9291959	45.588867
38837	045	081.10	6	-98.9860118	44.075939
38903	045	128.59	6	-98.9879220	44.759417
38905	045	129.59	6	-98.9878570	44.774526
38925	045	157.32	6	-99.0224355	45.152329
38929	045	159.32	6	-99.0219518	45.181343
11955	045	027.00	1	-98.8445597	43.381886
11995	045	051.61	4	-98.8519747	43.738754
11996	045	056.78	3	-98.9722782	43.729437
12079	045	111.54	4	-98.9890242	44.514881
12080	045	112.35	3	-98.9890477	44.522979
12115	045	137.71	4	-98.9874559	44.891234
12116	045	148.69	3	-99.0234003	45.026622
12163	045	177.73	4	-99.0291985	45.440839
12164	045	182.68	3	-98.9267496	45.440587
12194	045	201.99	4	-98.9308035	45.714799
12195	045	224.05	3	-99.3666780	45.759543
12210	045	236.10	2	-99.3812003	45.937964

Figure 7-6. Printout of MRM and Regular Coordinates Using **MGE**.

```
                     RE/SPEC  SDDOT
                      Demonstration              11/8/96

---------------------------------------------------------------
Original Coordinates on NAD 27 State Plane - SD South 4002, U.S. FT
Translated Coordinates on NAD 83 Geographic Coordinates
Input Vertical - NGVD 29, U.S. FT
Output Vertical - NAVD 88, U.S. FT
---------------------------------------------------------------
NAME                    INPUT                  OUTPUT

Bridge 5002+5-32+0       562818.21600 N   43 49 01.86299 N
                        2981626.83900 E  096 36 47.53544 W
Heights                        0.00000              0.89
Convergence             02 33 59.62398
Scale Factor               0.999912880
     Datum Shift(m),     Delta Lat.  =  -3.032
                         Delta Lon.  =  26.113

Bridge 5019+0-12+6       470634.94900 N   43 34 33.26573 N
                        2883741.70400 E  096 59 52.11307 W
Heights                        0.00000              0.98
Convergence             02 18 04.49270
Scale Factor               0.999907148
     Datum Shift(m),     Delta Lat.  =  -2.477
                         Delta Lon.  =  26.943

Bridge 5010+0-14+1       518571.16800 N   43 42 24.01808 N
                        2889584.64700 E  096 58 06.42295 W
Heights                        0.00000              0.96
Convergence             02 19 17.40439
Scale Factor               0.999908058
     Datum Shift(m),     Delta Lat.  =  -2.630
                         Delta Lon.  =  26.923

Bridge 5013+0-14+6       502741.52200 N   43 39 46.48450 N
                        2892863.48300 E  096 57 30.57297 W
Heights                        0.00000              0.97
Convergence             02 19 42.13417
Scale Factor               0.999907176
     Datum Shift(m),     Delta Lat.  =  -2.601
                         Delta Lon.  =  26.897

Bridge 5016+0-15+2       487142.16400 N   43 37 10.97611 N
                        2896745.69600 E  096 56 46.45116 W
Heights                        0.00000              0.97
Convergence             02 20 12.57023
Scale Factor               0.999906875
     Datum Shift(m),     Delta Lat.  =  -2.577
                         Delta Lon.  =  26.869

---------------------------------------------------------------
U.S. Army Topo. Engineering Center, CORPSCON BETA V4.0, Page 1 of 99
```

Figure 7-7. Demonstration of Regular Coordinate Transformations Using **Corpscon**: State Plane Coordinates to Geographic Coordinates.

```
                    RE/SPEC  SDDOT
                    Demonstration              11/8/96

----------------------------------------------------------------
Original Coordinates on NAD 27 State Plane - SD South 4002, U.S. FT
Translated Coordinates on NAD 83 UTM Zone 0014, U.S. FT
Input Vertical - NGVD 29, U.S. FT
Output Vertical - NAVD 88, U.S. FT
----------------------------------------------------------------
NAME                     INPUT                 OUTPUT

Bridge 5002+5-32+0       562818.21600 N  15926271.01984 N
                        2981626.83900 E   2270166.71734 E
Heights                       0.00000               0.89
Convergence             02 33 59.62398    01 39 10.88633
Scale Factor                0.999912880       1.000053190
     Grid Shift(US Ft), Delta North = 562818.216
                        Delta East  = 2981626.839
     Datum Shift(m),    Delta Lat.  =  -3.032
                        Delta Lon.  =  26.113

Bridge 5019+0-12+6       470634.94900 N  15835660.69103 N
                        2883741.70400 E   2170811.06663 E
Heights                       0.00000               0.98
Convergence             02 18 04.49270    01 22 49.57725
Scale Factor                0.999907148       0.999921482
     Grid Shift(US Ft), Delta North = 470634.949
                        Delta East  = 2883741.704
     Datum Shift(m),    Delta Lat.  =  -2.477
                        Delta Lon.  =  26.943

Bridge 5010+0-14+1       518571.16800 N  15883497.88463 N
                        2889584.64700 E   2177421.99792 E
Heights                       0.00000               0.96
Convergence             02 19 17.40439    01 24 14.55594
Scale Factor                0.999908058       0.999929537
     Grid Shift(US Ft), Delta North = 518571.168
                        Delta East  = 2889584.647
     Datum Shift(m),    Delta Lat.  =  -2.630
                        Delta Lon.  =  26.923

Bridge 5013+0-14+6       502741.52200 N  15867617.28799 N
                        2892863.48300 E   2180446.94434 E
Heights                       0.00000               0.97
Convergence             02 19 42.13417    01 24 35.28527
Scale Factor                0.999907176       0.999933263
     Grid Shift(US Ft), Delta North = 502741.522
                        Delta East  = 2892863.483
     Datum Shift(m),    Delta Lat.  =  -2.601
                        Delta Lon.  =  26.897

----------------------------------------------------------------
U.S. Army Topo. Engineering Center, CORPSCON BETA V4.0, Page 1 of 119
```

Figure 7-8. Demonstration of Regular Coordinate Transformations Using **Corpscon**: State Plane Coordinates to UTM Coordinates.

South Dakota South Zone State Plane Coordinates to NAD 83 geographic coordinates is shown in Figure 7-7. A transformation from NAD 27 South Dakota South Zone State Plane Coordinates to NAD 83 UTM Zone 14 is shown in Figure 7-8. These printouts were produced at RE/SPEC using the **Corpscon** program.

SDDOT's Intergraph **MGE** system is also capable of transforming information from State Plane Coordinates to geodetic coordinates. Figure 7-9 demonstrates that data may be stored with geodetic coordinates, latitude and longitude, as well as State Plane Coordinates. This figure was produced by Mr. Frank Cooper using existing data in the SDDOT Decision Mapping program.

7.3.4 Demonstration of Irregular Grid System to Regular Coordinates

Although most of the transformations demonstrated in this chapter are currently being performed on a routine basis within the SDDOT, the transformation from an irregular grid system to regular coordinates is one transformation that is not currently being accomplished within SDDOT. This transformation is successfully demonstrated using available data defining road centerlines in Minnehaha County, county accident data, county structure information, and a limited amount of programming.

The information required to transform irregular grid system data to regular coordinates was discussed in Section 7.2.3 and listed in Table 7-3. To demonstrate this transformation, it was necessary to acquire data describing every section corner within the example area in terms of regular coordinates. Minnehaha County was able to provide a centerline drawing of the roads for the entire county in State Plane Coordinates. From this centerline drawing, intersections (assumed to be very nearly section corners) were extracted and placed in a database. In the database, one-to-one relationships were established with each section corner defined in State Plane Coordinates, the Accident Grid Coordinates, and the Structure Grid Coordinates. Public Land Survey information was also included.

Accident data for 1995 rural Minnehaha County accidents were obtained from the Accidents Records group of the SDDOT. Structure information for Minnehaha County was obtained from the Bridge Design group of the SDDOT. Plate I found in Appendix D combines accident data and structure data on a map which includes State Plane Coordinates, UTM coordinates, geodetic coordinates, accident coordinates, structure coordinates, South Dakota Rural Addressing Grid coordinates, and PLSS information. This figure represents eight of the thirteen identified referencing systems used by SDDOT. Two of the five unrepresented systems are not used as data, and the remaining three are linear systems which could also be represented on this map. Figure 7-10 shows the State Plane Coordinates for a portion of the bridges. Plate I is a preliminary map of Minnehaha County showing accident and bridge locations for most of the county. Both the section corner data and the calculations behind these transformation can be improved for a more thorough and more exact implementation of this transformation.

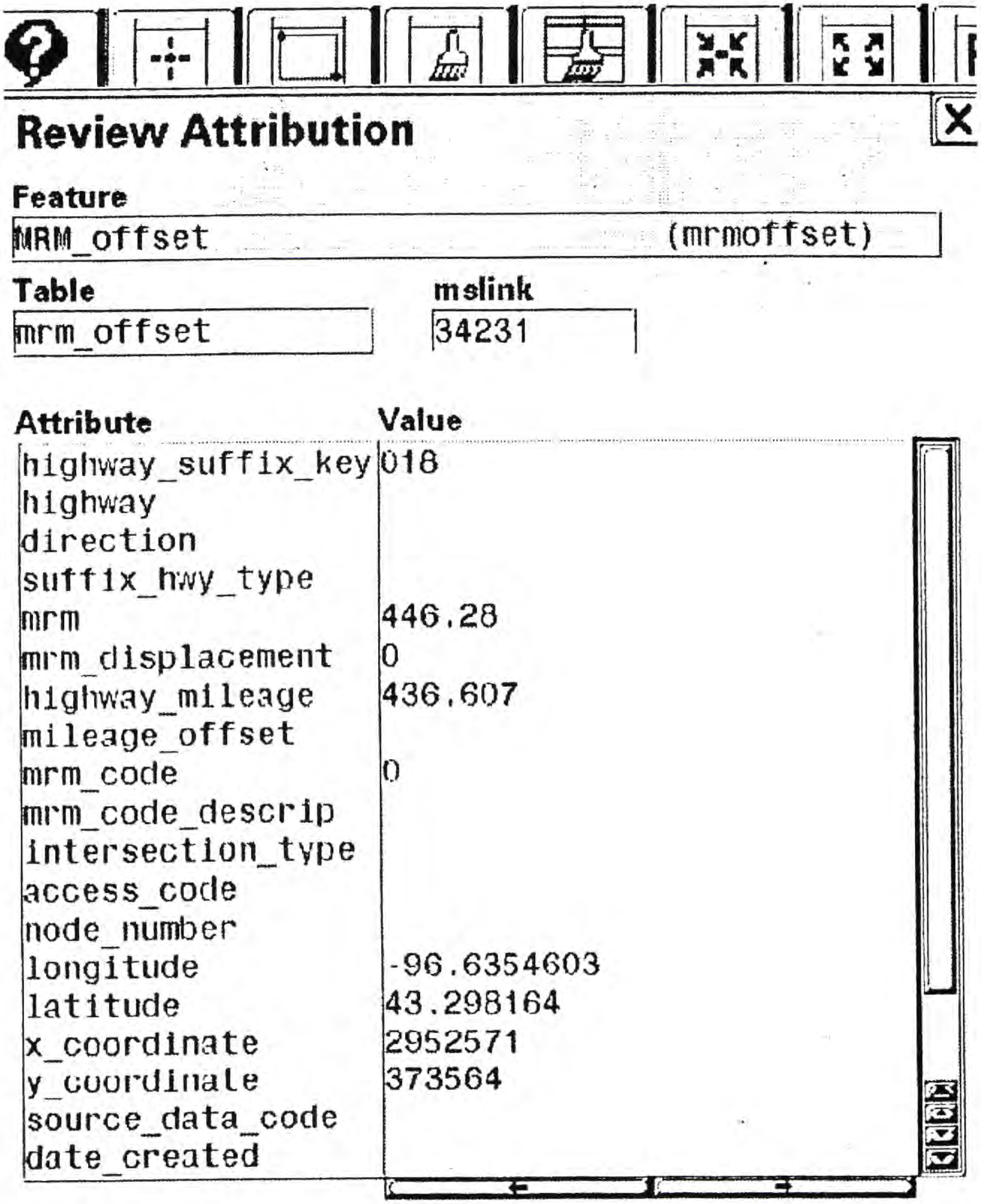

Figure 7-9. Demonstration of Regular Coordinate Transformation Using **MGE:** Geodetic Coordinates to State Plane Coordinates.

State Plane Coordinates		Bridge Coordinates	
Easting	Northing	Easting	Northing
2981626.839	562818.216	2+ 5	32+ 0
2883741.704	470634.949	19+ 0	12+ 6
2889584.647	518571.168	10+ 0	14+ 1
2892863.483	502741.522	13+ 0	14+ 6
2896745.696	487142.164	16+ 0	15+ 2
2925281.332	493634.969	15+ 0	20+ 6
2886108.864	555296.386	3+ 0	13+ 9
2990051.809	491154.265	16+ 0	32+ 9
2964543.377	494999.315	15+ 1	28+ 1
2901354.612	466035.598	20+ 0	15+ 9
2990374.281	491986.645	15+ 9	33+ 0
2970977.516	469835.873	19+ 9	29+ 0
2931051.902	525169.767	9+ 1	22+ 0
2908003.940	519234.338	10+ 0	17+ 6
2915369.703	551525.921	4+ 0	19+ 2
2938459.841	499519.803	14+ 0	23+ 2
2933116.099	485591.324	16+ 6	22+ 1
2932183.243	457910.642	21+ 8	21+ 7
2928177.320	467979.003	19+ 9	21+ 0
2928219.192	467434.506	20+ 0	21+ 0
2922955.022	485192.582	16+ 6	20+ 0
2891058.337	460273.519	21+ 0	13+ 9
2880742.765	489092.643	15+ 5	12+ 2
2894517.913	510868.512	11+ 5	15+ 0
2821704.107	452080.750	22+ 0	0+ 7
2912653.874	535292.418	7+ 0	18+ 6
2925688.147	504174.150	13+ 0	20+ 8
2923408.994	488333.938	16+ 0	20+ 1
2963237.524	500463.287	14+ 0	27+ 9
2913780.732	468856.222	19+ 6	18+ 3
2919079.035	446359.861	23+ 9	19+ 1
2958486.237	455609.289	22+ 4	26+ 6
2974248.993	467719.212	20+ 3	29+ 7
2918613.021	485963.270	16+ 4	19+ 3
2826839.744	494426.035	14+ 1	2+ 0
2832142.857	490368.817	14+ 9	3+ 0
2843084.781	482848.500	16+ 4	5+ 0
2876761.492	483636.826	16+ 5	11+ 4
2879393.293	483636.826	16+ 5	11+ 9
2882554.695	482251.320	16+ 8	12+ 5
2881060.891	457390.979	21+ 5	12+ 0
2877814.213	484162.109	16+ 4	11+ 6
2890418.658	483752.939	16+ 6	14+ 0
2892526.556	483752.939	16+ 6	14+ 4
2894357.047	481644.901	17+ 0	14+ 7
2896745.696	484497.525	16+ 5	15+ 2
2896745.696	483968.597	16+ 6	15+ 2

Figure 7-10. Tabular Listing of State Plane Coordinates and Bridge Coordinates.

7.3.5 Demonstration of Irregular Grid to Irregular Grid

Transformations between the irregular accident grid and the irregular structure grid are trivial. The origin for the accident grid is 1,1 at the northwest corner of each county and the origin for the structure grid is 0,0 at the northwest corner of each county. As indicated in Figure 7-11, adding one to each structure grid number or subtracting one from each accident grid number will result in the grid system descriptor for the alternate system. It must be remembered, however, that the structures are located in increments of 1/10 of a section while accidents are located in increments of 1/100 of a section.

7.3.6 Demonstration of Public Land Survey System to Regular Coordinates

Applying the same section corner coordinate definitions and the information shown in Figure 7-11, the bounding coordinates for any section described in terms of the Public Land Survey System may be determined. Figure 7-12 presents a simple demonstration of how the database may be queried to determine the coordinates of a given section.

7.4 ADDITIONAL MRM-REFERENCED DATA MANAGEMENT ISSUES

In addition to the transformations between identified location referencing systems, two other data transformation/data management issues have been identified as significant:

- The transformation of data initially referenced to an MRM and the same data that must be referenced to a different MRM because of the removal or alteration of the initial MRM.
- The transformation of data referenced to an MRM on a portion of roadway that is abandoned.

Current SDDOT policy dictates that upon notification that an MRM has been removed or altered on a valid state trunk road, everyone who has data referenced to the altered MRM may change their data manually. Once each year, a "purge" process is performed to ensure that all data referenced to the deleted MRMs are "automatically" referenced to an existing MRM with a new displacement that will keep the data in its original position. No historical data regarding the deleted MRM are maintained, and all previous records that referenced the deleted MRM cannot be effectively compared. The records describing MRM positions should be retained rather than deleted. The proper procedures, which include altering MRMs only when critically required, will also help to minimize this problem.

A historical record of MRMs and data that are referenced to MRMs on an abandoned portion of roadway must also be maintained. Some roads abandoned by SDDOT later return to become SDDOT's responsibility. Preserving appropriate information may reduce the cost or eliminate the need to reinventory this portion of the road. Accident data in particular must be preserved for abandoned roads. With the implementation of roadway position data and time-referenced data, this problem also will be resolved.

State Plane Coordinates		Accidents		Structures		Public Land Survey System								
Easting (X)	Northing (Y)	X	Y	X	Y	net	ner	nes	nwt	nwr	nws	swt	swr	sws
2813537.987	0568360.051	1	1	0	0	105	52	31	105	51	36	104	51	1
2818659.428	0568570.964	2	1	1	0	105	52	32	105	52	31	104	52	6
2823888.370	0568777.757	3	1	2	0	105	52	33	105	52	32	104	52	5
2829252.591	0569013.411	4	1	3	0	105	52	34	105	52	33	104	52	4
2834507.252	0569241.078	5	1	4	0	105	52	35	105	52	34	104	52	3
2839808.741	0569469.302	6	1	5	0	105	52	36	105	52	35	104	52	2
2844914.720	0569677.946	7	1	6	0	105	51	31	105	52	36	104	52	1
2850027.171	0569901.085	8	1	7	0	105	51	32	105	51	31	104	51	6
2855354.718	0570133.619	9	1	8	0	105	51	33	105	51	32	104	51	5
2860596.694	0570362.418	10	1	9	0	105	51	34	105	51	33	104	51	4
2865845.800	0570556.369	11	1	10	0	105	51	35	105	51	34	104	51	3
2871177.612	0570776.102	12	1	11	0	105	51	36	105	51	35	104	51	2
2876480.075	0570996.845	13	1	12	0	105	50	31	105	51	36	104	51	1
2881545.572	0571192.778	14	1	13	0	105	50	32	105	50	31	104	50	6
2886801.567	0571396.207	15	1	14	0	105	50	33	105	50	32	104	50	5
2892120.471	0571626.771	16	1	15	0	105	50	34	105	50	33	104	50	4
2897405.557	0571859.696	17	1	16	0	105	50	35	105	50	34	104	50	3
2902637.052	0572081.997	18	1	17	0	105	50	36	105	50	35	104	50	2
2907809.445	0572294.344	19	1	18	0	105	49	31	105	50	36	104	50	1
2913144.437	0572523.748	20	1	19	0	105	49	32	105	49	31	104	49	6
2919322.641	0572781.304	21	1	20	0	105	49	33	105	49	32	104	49	5
2925082.956	0573047.640	22	1	21	0	105	49	34	105	49	33	104	49	4
2930369.617	0573286.692	23	1	22	0	105	49	35	105	49	34	104	49	3
2936906.077	0573619.263	24	1	23	0	105	49	36	105	49	35	104	49	2
2939591.656	0573678.107	25	1	24	0	105	48	31	105	49	36	104	49	1
2943007.661	0573666.677	26	1	25	0	105	48	32	105	48	31	104	48	6
2949014.251	0573938.638	27	1	26	0	105	48	33	105	48	32	104	48	5
2955237.056	0574279.130	28	1	27	0	105	48	34	105	48	33	104	48	4
2960545.802	0574452.511	29	1	28	0	105	48	35	105	48	34	104	48	3
2965655.947	0574619.407	30	1	29	0	105	48	36	105	48	35	104	48	2
2970932.797	0574701.699	31	1	30	0	105	47	31	105	48	36	104	48	1
2976102.349	0575065.864	32	1	31	0	105	47	32	105	47	31	104	47	6
2981754.461	0575630.674	33	1	32	0	105	47	33	105	47	32	104	47	5
2987188.997	0576147.368	34	1	33	0	105	47	34	105	47	33	104	47	4
2991625.090	0576503.180	35	1	34	0	XX	XX	XX	105	47	34	104	47	3
2813756.027	0563054.060	1	2	0	1	104	52	6	104	51	1	103	51	12
2818852.563	0563360.870	2	2	1	1	104	52	5	104	52	6	103	52	7
2824125.868	0563734.025	3	2	2	1	104	52	4	104	52	5	103	52	8
2829394.808	0563978.804	4	2	3	1	104	52	3	104	52	4	103	52	9
2834683.131	0564164.381	5	2	4	1	104	52	2	104	52	3	103	52	10
2839980.019	0564351.726	6	2	5	1	104	52	1	104	52	2	103	52	11
2845232.041	0564450.048	7	2	6	1	104	51	6	104	52	1	103	52	12
2850229.602	0564740.466	8	2	7	1	104	51	5	104	51	6	103	51	7
2855521.883	0564938.742	9	2	8	1	104	51	4	104	51	5	103	51	8

Figure 7-11. Tabular Listing of State Plane Coordinates and PLSS Information With Accident and Structure Coordinates.

```
SECTION  32
TOWNSHIP 101
RANGE    49

THE SW CORNER OF THE SECTION IS  2918625.13, 445829.99
THE SE CORNER OF THE SECTION IS  2925118.74, 446126.22
THE NW CORNER OF THE SECTION IS  2916966.75, 482832.19
THE NE CORNER OF THE SECTION IS  2922923.05, 483098.34


SECTION  12
TOWNSHIP 103
RANGE    48

THE SW CORNER OF THE SECTION IS  2967759.93, 532555.20
THE SE CORNER OF THE SECTION IS  2973060.99, 532518.53
THE NW CORNER OF THE SECTION IS  2965909.26, 569337.70
THE NE CORNER OF THE SECTION IS  2971156.77, 569503.02
```

Figure 7-12. Demonstration of Transformation From Public Land Survey System to State Plane Coordinates.

8.0 IMPLEMENTATION STRATEGIES/ALTERNATIVES

The functional requirements for a standard location referencing system that will support SDDOT's data integration needs have been defined and a standard location referencing system that will satisfy the functional requirements has been identified. The first step in defining a system implementation strategy is consideration of critical system component implementation alternatives to define definitive recommendations that will ensure successful system development and deployment.

Investigation of these alternatives resulted in a number of specific implementation recommendations related to:

- Data collection and referencing
- Data management and access
- Data integration and use.

Table 8-1 summarizes each of the recommendations based on their implementation priority. The criticality of each recommendation with regard to achieving the desired system functionality is indicated, along with the dependencies of each of the recommendations.

Table 8-1. Criticality and Dependencies of Recommendations

Recommendation	Relative Need to Achieve Objectives	Dependency
1. Use a relational DBMS for management of location-referenced data	Critical	Independent
2. Implement appropriate data transformations to establish coordinate compatibility	Critical	Independent
3. Implement time as a data attribute	Critical	Independent
4. Locate off-road features with one or more $xy(z)$ coordinates	Desirable	Independent
5. Implement elevation as an optional data attribute	Desirable	Independent

As indicated, implementation of three of the recommendations will be critical to realize data integration objectives. The remaining two can be delayed and implemented in a progressive manner to further enhance data integration capabilities as funds become available. As indicated in Table 8-1, each of the recommendations can be implemented independently; that is, without the implementation of any of the others. A potential need for future inclusion of the nonstate trunk roads in the MRM system in response to trends toward cooperative management by state and local agencies was identified but is not included as a recommendation at this time.

The following sections provide in-depth discussions of various implementation alternatives, including cost comparisons and comparative analyses. In reviewing the alternatives, it is important to note that the selection of specific software and hardware is beyond the scope of this study.

8.1 DATA COLLECTION AND REFERENCING

Investigation of specific data collection procedures was not a part of this study. An in-depth review of SDDOT's field collected roadway data and data collection methods is being performed under a concurrent research project (SD96-03). Throughout the interview process, however, investigations revealed that in general the current data collection field procedures are sound, well documented, and well understood by the individuals who use the various location referencing systems. Although the 13 location referencing methods identified in use are quite diverse, they all seem to perform the purpose for which they were intended. Some additions/changes to data collection and referencing procedures with regard to maintaining date/time, elevation, and off-road features are included as recommendations.

8.1.1 Existing Location Referencing Methods and Procedures

Each of the identified location referencing systems currently in use at the SDDOT exists to satisfy specific needs within the department. Original data are currently stored using many of these location referencing systems. It is possible to include data from each of these location referencing systems in the standard system. At this time, there is not a need to make significant changes in the existing location referencing methods and procedures, and data from each system should be incorporated into the standard system.

8.1.2 Date/Time as a Data Attribute

At the present time, there is very little information maintained within the SDDOT that does not represent current conditions. Exceptions to this are the average daily traffic reports for a very limited number of years and the annual snapshots of data as stored in the Pavement Management System. The interview process revealed a need to examine more historical data than are currently available. A previous study (SD90-09) [Svalstad et al., 1991] identified numerous potential uses of historical data, in addition to the then current, primary use for pavement management. It recommended a 20-year retention policy and a 5-year on-line policy for all data in the Highway Planning Inventory file. The recommendations made in this previous study remain pertinent. The use of historical data includes many aspects of the SDDOT and is not limited to pavement management.

Each independent piece of data must be maintained with a date/time attribute. This attribute is required to enable temporal tracking of pavement conditions, historical management of road ownership, and tracking of historical changes in road realignments. This will also facilitate the more timely updating of data to the database while allowing consistent data sets to be used throughout the department.

The inclusion of a date/time attribute can be accomplished through temporal dynamic segmentation whereby only the time when a piece of data is changed is recorded or through the implementation of an activation time and a deactivation time. Records which were at any time valid will be maintained for a defined retention time. It is probably sufficient to have this time recorded with a resolution of 1 day.

Conclusion: A date/time attribute for location-referenced data will be essential to enable historical data management, a key functional requirement of the identified standard location referencing system.

Recommendation: Implement date/time as a data attribute for all location-referenced data.

8.1.3 Location of Off-Road Features

Much of the information currently maintained at the SDDOT describes data located along state trunk roads which may be conveniently referenced with the MRMs. A certain amount of current information, however, is not located along any roadway and is not conveniently referenced. It is likely that the need to locate off-road features will increase.

For data not associated with a road, spatial location referencing is the obvious choice. Geographically "small" attributes may be located with a single *xy* coordinate and elevation. Geographically "large" attributes should be located by outlining a polygon. Implementation of the practice of defining off-road attributes as either points or polygons will facilitate the use of desktop spatial queries and will provide direct support for spatial analysis tools. With the addition of coordinate transformations, many off-road features will be easy to include in graphical presentations, required analyses, and general transportation network queries.

Although no specific cost/benefit analysis was completed for this recommendation, the costs associated with required changes to the database to accommodate coordinates and/or coordinate transformations are discussed in Section 8.2.5. The benefits will be significant as more spatial areas are identified and may be included.

Conclusion: Although a relatively low priority recommendation, off-road features should be accommodated in the database.

Recommendation: Locate off-road features with one or more *xy* coordinates and elevations.

8.1.4 Elevation as a Data Attribute

Elevation is currently maintained as an attribute to data in only a few places within the SDDOT. The maintenance of elevation data would remove ambiguities associated with referencing multilevel interchanges and some slope or vertical curve situations. In a previous study (SD90-09), Svalstad et al. [1991] recommended that elevation be maintained for RES data.

Although current needs for the elevation coordinate are limited, the relative cost to implement this data attribute will be minimized if it is done in conjunction with any major upgrade of the current database to establish *xy* coordinate compatibility. It is not expected that this data attribute would be quickly populated, but may be done so as information becomes available. Null entries can be used to define attributes for which an elevation is not deemed necessary to minimize initial data storage requirements. The benefits associated with the availability of elevation will become more significant as more elevations are defined and included as data attributes.

Conclusion: The addition of elevation as an optional data attribute should be considered a low priority recommendation. Because of the current limited need for elevation, implementation of the elevation attribute alone is not justifiable. The attribute should be implemented in conjunction with system modifications to establish xy coordinate compatibility.

Recommendation: Implement elevation as an optional attribute for location-referenced data.

8.1.5 Minor Procedural Changes

Interstate Ramps:

Although not a primary concern at this time, the current policy regarding the posting of MRMs on interstate ramps needs to be reexamined to determine if this is a problem. Historically, ramps have been field labeled but this policy was reversed. Although the unique identification of these ramps may be required for detailed mapping at some point in time, the identification of interstate interchanges may not warrant the effort.

MRM Management:

The field procedures related to the placement, relocation, removal, and identification of MRMs are critical to the effective use of most of the data collected by the SDDOT. Although periodic verification of the MRM inventory is required by the *MRM Policy Manual*, unnecessary moving of MRMs is causing problems and can often result in the loss of information. An extensive effort, much of it manual, is required to update the MRM inventory and all other files in which changes must be incorporated. If the update is not timely, information is incorrect or lost. Further, the moving of an MRM often results in a permanent loss of historical information.

All personnel should be apprised that the change in the position of an MRM has significant ramifications with regard to historical consistency. If at all possible, the name should be retained and only the physical location updated to minimize the potential loss of information. Further, the *MRM Policy Manual* should be updated to clearly state that MRMs should only be moved if the resulting benefits outweigh this significant additional effort.

Conclusion: MRMs are currently the foundation of SDDOT's linear referencing system. Because of the linear nature of transportation-related information, the importance of MRMs will not diminish in the foreseeable future. Policies regarding MRMs need to be examined in the context of current activities and needs. In the event that the MRM policies are revised and/or the MRM manual is updated, training in the revised policies must be provided for critical personnel.

Recommendation: Review current MRM policies and other data collection policies in the context of current activities and needs and provide appropriate training for personnel.

8.1.6 Statewide Uniform MRM Referencing

Several location referencing systems rely on the irregular grids formed by section lines. The systems that rely on section lines are:

- Section Grids for Structures and Accidents
- South Dakota Rural Addressing
- Nonstate Trunk Inventory (NSTRI)
- Public Land Survey System.

Some of the coordinate systems are county specific, and all are somewhat cumbersome because of the irregular nature of the PLSS on which they are based. With the exception of the NSTRI, the two-dimensional coordinate systems used for these referencing systems lack the network structure necessary for unambiguous location referencing, particularly in an automated fashion. For this reason, if network definition is desired for the nonstate trunk roads, road and road inventories, accidents, etc., can be brought into the state MRM referencing system. This sentiment is further echoed by the FGDC Ground Transportation Subcommittee [Federal Geographic Data Committee, 1994], which recommends abandoning county-based referencing in favor of state-based referencing. This change would have a number of benefits:

- The present referencing method is highly manual, both with respect to encoding field data for digital entry and for decoding the digital data for the purposes of sending someone to a specific location in the field. The MRM system avoids this manual processing.
- The network structure afforded by the MRM system would assist in a variety of routing needs such as construction, truck routing, accident avoidance, E-911, etc.
- The entire road network of the state, cities excepted, is brought into a common referencing system.

Clear similarities in road identification procedures and county-based E-911 investments to identify all intersections provide a sound basis for consideration of this change without imposing current MRM posting requirements delineated in the MRM Policy Manual on the nonstate trunk roads. The number of MRMs for nonstate trunk roads need not be as frequent as are presently maintained for state trunk roads. The minimum requirement would be MRMs at intersections.

Conclusion: Considering SDDOT's current responsibilities for managing the NSTRI, consolidation of the state and nonstate trunk systems is not recommended at this time. Increasing pressure for increased government efficiencies through shared or consolidated services at multiple levels of government (e.g., state and county), however, could result in a future need to integrate the state trunk and nonstate trunk roads into one network to realize expected operational efficiencies.

8.2 DATA MANAGEMENT AND ACCESS

Consideration of data management and access alternatives available to implement the standard location referencing system focused on several key aspects of data management:

- Database management system alternatives
- Database hardware platform alternatives
- Database management utilities and procedures.

The results of these investigations indicate that the single biggest decision/alternative that will ultimately affect the cost of establishing a viable standard LRS is the decision whether to build on the data management structure currently in place versus implementing a commercial database management system. This decision will have a significant impact on implementation costs and, just as importantly, future flexibilities and costs associated with ongoing system maintenance.

Replacement of the Virtual Sequential Access Mode (VSAM) data structures in which a significant portion of SDDOT's location-referenced data is maintained will be essential to provide the flexibility and extensibility necessary to support SDDOT's current and future data *management and data access needs; needs that can be expected to change as information management and use technologies continue to evolve.* Further, near-term savings that may be realized through an implementation of the standard location referencing system based on ADABAS will be offset by the cost of recoding that will be required to implement any future major structural change to the database schema. Based on the current investigations, *RE/SPEC strongly recommends that SDDOT use a relational database management system (DBMS) for management of location-referenced data.*

In considering this recommendation, it is worth noting that SDDOT's previous *Historical Database Feasibility Study*, SD90-09 [Svalstad et al., 1991], recommended the implementation of a distributed relational database to support SDDOT's data and computational requirements. The merits of using a relational database to manage roadway data were further extolled in a paper on *Integrating Roadway Data in a Corporate Database* [Deighton and Ruck, 1990]. The recommendations put forth in these two publications remain pertinent today.

Investigations of DBMS software and hardware platform alternatives clearly indicate that the capital costs of implementing a PC/workstation to midrange-based data management environment are not expected to vary significantly between most alternatives, are significantly less than the recurring costs associated with a mainframe-based solution, and will be minimal compared to total system implementation costs. The IBM mainframe environment is heavily oriented toward routine transaction processing and severely limits DBMS options to address the management of nonroutine access to engineering data such as the location-referenced data used within the SDDOT.

8.2.1 Types of Database Management Systems Available

In considering the most appropriate DBMS to support the standard location referencing system, it is worthy to note that there are three approaches (data models) used in available DBMSs:

- Relational
- Network
- Hierarchical.

The current data management system is a combination of ADABAS (a network model DBMS) and structured files managed by custom COBOL software. Both hierarchical and network database models rely on the use of permanent internal pointers to relate records to each other. The process of inserting, updating, and deleting records using these types of databases requires synchronization of the points, a process that can be cumbersome. Relational databases are distinct from these others in that they rely on the actual attribute values to link records. A fourth approach, sequential, was excluded from further consideration because of anticipated performance problems since the entire database must be scanned for each query.

The various approaches can best be compared by evaluating them with regard to ease of use and performance.

8.2.1.1 Ease of Use

With regard to ease of use, the relational approach is superior to the network and hierarchical approaches. The relational approach is based on a single concept, the relation. Relational algebra and calculus provide powerful and succinct notation which carry over well to the actual relational query languages. Repeating a quote that was used previously by Svalstad et al. [1991]:

> *"the network model requires our understanding of both record types and links, and their interrelationships. The implementation of many-to-many relationships and relationships on three or more entity sets is not straightforward,... Similarly, the hierarchical model requires understanding the use of pointers (virtual record types) and has the same problems as the network model regarding the representation of relationships that are more complex than many-to-one relationships between two entity sets."* [Ullman, 1981, pp. 168-169].

Historical data entities have a many-to-one relationship to the point in space that they are describing. Considering the multiple entity sets for which historical data must be stored, the resulting relationships would produce a system of undue complexity if the network or hierarchical approach were used.

8.2.1.2 Performance

From a performance standpoint, early implementations of the network and hierarchical approaches outperformed the early implementations of the relational approach, especially for queries for which a database had been specifically designed. The performance differences have diminished, however, with improvements in the relational models and the advent of query optimizers that greatly improve query performance. Further, SDDOT data access patterns can be expected to change with enhanced access to available data and as a result of the continued evolution of information technologies.

8.2.1.3 Preferred DBMS Type

The explicit linking of related entities in the network and hierarchical approaches causes any change in the structure definition to have a major impact on both the data already stored and the software accessing the data. Considering the anticipated long-term use of the DBMS, it would be preferable to use a relational DBMS with a standard query language such as the ANSI standard structured query language, SQL. Further, the implementation should be a client/server configuration to minimize the required network bandwidth.

Conclusion: The relational approach for DBMSs is preferable since it provides much more flexibility and extensibility than the network or hierarchical approaches and is easier to use.

Recommendation: Use a relational DBMS for management of location-referenced data.

8.2.2 Specific Database Management System Options

Replacement of the VSAM data structures currently used in the management of a significant portion of SDDOT's location-referenced data is essential to achieve the functionality inherent in the proposed standard location referencing system. Although anything is possible, modification of the existing system to enable historical data management alone would be a monumental effort. Further, the resulting system would still lack the flexibility and extensibility that is needed to support SDDOT's changing data needs.

Based on current institutional and financial constraints, the leading DBMS candidates to support the data management functions of the standard location referencing system are **ADABAS** on the IBM mainframe and Microsoft **SQL/Server** on a Windows NT platform. Although **DB2** is an excellent candidate for implementation, the cost of statewide replacement of **ADABAS** with **DB2** would be prohibitive. Additionally, the standard location referencing system by itself will not provide sufficient justification to implement and maintain a second major database on the state's mainframe. Microsoft **SQL/Server** has been designated as the state's relational database standard by SDBIT and is currently being used to develop client/server database applications within the SDDOT.

Further discussions of the identified DBMS alternatives are provided in the following sections.

8.2.2.1 The Existing Data Management System

The current system that is used to manage SDDOT's location-referenced data is in essence a custom DBMS that is a combination of **ADABAS** (a network model DBMS) and structured VSAM files that are manipulated through custom software written in **COBOL**. As indicated in Table 8-2, the system reflects a number of inherent weaknesses related to ease of maintenance and ease of use. Although the system is a very effective implementation of the data requirements and user functionalities specified in the original system specification which was developed in the early 1970s, changing data requirements and functionalities are very difficult to implement. Either new file types must be introduced with corresponding software to manipulate them, or existing file structures must be modified and all software that access these files must be modified to handle the new structure.

Any cost-effective modifications that could be implemented on the current system will not address current limitations on user data access. A user query that requires correlation of data attributes that reside in distinct files requires the development of special software that scans the distinct files and extracts data according to the specified correlation. This restriction on user's access to location-referenced data is unacceptable with regard to servicing current and future user data access needs.

Table 8-2. Major Weaknesses of Current Data Management System

Characteristic	Major Weaknesses
Ease of Maintenance	• Underlying data structure is not easily modified. • Modification of access patterns requires knowledge of file structures and content. • Restoration of data is cumbersome. • Portability restricted by machine dependent software.
Ease of User Access	• Access is batch oriented and effectively inflexible. • Retrieval of nonroutine data requires interface code development. • Access to data from multiple files requires interface code.

Conclusion: This existing custom software solution is not acceptable due to its lack of flexibility and extensibility and inherent data access limitations. Although a custom DBMS could be developed to provide the desired flexibility, data access would still be cumbersome and the effort required would not be cost effective in comparison to implementation of a commercially-available DBMS. Any new DBMS will require a major redesign of the data structures.

8.2.2.2 ADABAS on the IBM Mainframe

ADABAS is considered as a DBMS option because it is currently available on the IBM mainframe. Although Software AG has an SQL-based interface to **ADABAS** that provides a relational look and feel to the user, it is a DBMS based on the network approach for storage and retrieval of information. As such, the DBMS still reflects the inherent inflexibility of the network approach. Further, **ADABAS** does not support the major spatial systems in use at the SDDOT. Limited third party DBMS access tools function against **ADABAS** and the primary access tool is Software AG's **NATURAL** interface.

*Conclusion: Although **ADABAS** may be the least expensive DBMS solution in the near term because of the state's familiarity with **NATURAL**, the savings would be offset by the need for recoding to accommodate future structural changes to the database schema that can be expected as SDDOT's data needs change.*

8.2.2.3 Relational DBMS Alternatives

The DBMS will be the primary repository for SDDOT's location-referenced data, providing original data to SDDOT's spatial systems as well as a variety of other numerous applications. For maximum utility, the DBMS should support many applications, including the more popular GIS packages, and should be compatible with as many of the operating systems installed at SDDOT as possible (*Windows NT*, *Unix*, and *IBM MVS*, in particular).

Table 8-3 summarizes the "advertised" interoperability between various contemporary GIS and relational DBMS software packages. Some of these compatibilities are direct; that is, without any additional bridging software or gateways to establish the interoperability. Some are indirect, requiring the use of intermediate products to achieve interoperability. **ADABAS D** is relatively new and its support is limited, as indicated in Table 8-3. The database products included in this discussion are industry leaders in this area. Although many niche database products are on the market, these industry leaders were considered to ensure accessibility to most SDDOT applications. Many of the database products included in this summary were originally developed for the *Unix* platform or another specific platform, but most are currently available on multiple platforms.

Table 8-3. GIS/RDBMS Software Interoperability

	ARC/INFO[a]	Intergraph GIS Office[b]	MapInfo Professional[c]
ADABAS D			
DB2	•	•	•
Informix	•	•	•
Ingress	•	•	•
Oracle	•	•	•
SQL/Server	•	•	•
Sybase	•	•	•

(a) Environmental Systems Research Institute Inc. [1996]

(b) Intergraph Corporation [1996]

(c) MapInfo Corporation [1996]

As indicated, substantial interoperability exists amongst the various software packages investigated. With present emphasis on open computing, SQL capabilities, and open database standards (ODBC), this is likely to increase. The DBMS packages, therefore, cannot be distinguished solely on this criterion.

With one exception, cost is also not a significant differentiator between software packages. As indicated in the following database product overviews, the cost of PC/workstation/mini-based packages is significantly less than the recurring cost of a mainframe-based solution.

Database Product Overviews:

The following database product overviews are taken primarily from product literature. Pricing is approximate due to each publisher's accommodation of institutional clients requiring multiple seats. Also, most of the products are available in component form and with an increasing array of add-ons. Although Microsoft **Access** is not deemed robust enough to be a viable consideration as the primary DBMS to support the system, it is included in this discussion because of its potential as a front end to other contemporary relational databases.

ADABAS D is relational database management software for open systems and is available on *Unix* and *Windows NT* operating systems. Note that it is different from **ADABAS**, the DBMS presently resident on the IBM mainframe. **ADABAS** is not a relational database although access tools are available to make it appear as one. **ADABAS D** is an advanced, distributed DBMS offering seamless multimachine access across a network.

Pricing: $2,500/server and $150/user for both *Unix* and *Windows NT*.

DB2 is a relational database management system for distributed client-server computing on the IBM *MVS*, *Unix* (*AIX*), and *Windows NT* operating systems. It is designed for large databases, is scalable, and includes support for multimedia and Web connectivity. **DB2** supports many of the standards for relational databases, distributed processing, and connectivity.

Pricing: $4,765/month on IBM mainframe (group 40), $1,595 per server and $369 per user on *AIX* (IBM unix), and $1,399 per server and $349 per user on *Windows NT*.

Informix is a relational database management system for distributed client-server computing on *Unix* or *Windows NT* operating systems. It is designed for large databases, is scalable, including support for multi- and parallel-processing computer architectures. **Informix** supports access to the Web and Internet, as well as internal intranets. A comprehensive fourth-generation application development and production environment supports application development needs. **Informix** is the platform strongly preferred by Intergraph technical personnel and is used by the Nebraska Department of Transportation.

Pricing: $500/developer, $250/user for "standard engine" product.

Ingres is a relational database management system for distributed client-server computing across multiple operating systems. While not operational on IBM systems running *MVS*, "gateways" are optional to access **DB2** on these machines. It supports large-scale databases and provides an SQL engine with full multithreaded/multi-CPU support capable of providing access to thousands of concurrent users. More recently, **Ingres** development has not kept pace with more aggressive database developers.

Pricing: $1,600 per developer on *Windows NT* and $4,000 per developer on *Unix* for both platforms, $1,000 per concurrent user.

Oracle is a relational database management system for distributed client-server computing on *Unix*, *Windows NT*, and *OS/2* operating systems. It is designed for large databases and uses fourth-generation features for development and access. **Oracle** appears to have a larger market share than the other databases investigated and has been very aggressive in implementing innovative technology in its products. **Oracle** products are used by the DOTs in states that include Minnesota, North Dakota, Wisconsin, Kansas, Missouri, Arizona, and Tennessee.

Pricing: $1,475 for five concurrent users, $1,995 for one developer.

SQL/Server by Microsoft is a relational database management system designed specifically for distributed client-server computing for the *Windows NT* operating system. As such, a variety of tools are available for assuring data consistency and integrity amidst simultaneous, multiuser access. It has been designed to send and receive information via the Internet or internal intranets. Microsoft **SQL/Server** has been designated as the state's relational database standard by the SDBIT and is currently being used to develop client/server database applications within the SDDOT.

Pricing: SQL6.5 costs $1,399 for 5 users with other pricing strategies for 10, 25, 50, 100, 250+ users. Additional pricing strategies include server/user pricing.

Sybase is a relational database management system for distributed client-server computing across multiple operating systems. It is designed for extensive connectivity including the Internet. It is designed for large databases and uses the fourth-generation computer language, SQL. **Sybase OmniConnect** can provide connectivity to many other databases, including **ADABAS** and VSAM files. **Sybase** is used by the Colorado Department of Transportation.

Pricing: $4,000 for server/development license plus $795/concurrent user on *Unix* and *IBM*, $1,000 for server/development license plus $195/concurrent user on *Windows NT*.

Access by Microsoft is a relational database management software for the *Windows 95* and *NT* operating systems. It offers tools for transforming flat-files into relational databases. As part of the **Microsoft Office** (**Word, Excel, PowerPoint, Schedule, Access**) family of programs, interoperability is broad, including extensibility to **Microsoft BackOffice** server software. **Microsoft Access Developer's Toolkit** provides tools to create, manage, and distribute Microsoft **Access** applications. Also available, free of charge, are **Microsoft Access Upsizing Tools for Windows 95**, assisting the migration from **Access** to Microsoft **SQL Server**.

Pricing: Less than $100/user for institutional users requiring multiple seats.

Pricing for most of the various RDBMS products listed is comparatively low. **DB2** for *MVS* is available for a significant monthly fee. One cannot be recommended over the others based on pricing alone. As they are all relational databases, flexibility as to host operating systems and interoperability with spatial analysis software remains as the principal distinguishing features. **SQL/Server** from Microsoft resides exclusively on *Windows NT* which could limit its use as a comprehensive DBMS for interdepartmental use. **ADABAS D, DB2, Informix, Ingres, Oracle, Sybase** are all available on *Unix* and *Windows NT*. **DB2** is also available on *IBM MVS*. With the exception of **ADABAS D**, all the RDBMS/GIS interoperability is excellent. Although Microsoft **Access** is not deemed robust enough to be a viable consideration as the primary DBMS, it is included because of its potential as a front end to other contemporary relational databases.

Currently, **ADABAS** is on the IBM mainframe running the *MVS* operating system and the Microsoft products **SQL/Server, Foxpro**, and **Access** on the *Windows NT*, *Windows 95*, *Windows 3.11* and/or *DOS* operating systems are the standard database products for the state of South Dakota. In addition, SDDOT uses **dBase** and **Informix** for specific applications. This brief review of the most popular relational databases shows that **DB2, Informix, Ingres, Oracle**, and **Sybase** should each be considered for the principal DBMS. **Informix, Oracle**, and **Sybase** seem to be the DBMS of choice of other Departments of Transportation. **DB2, Informix, Oracle**, and **SQL/Server** seem to be the most aggressive in supplying tools for internet and intranet support. **SQL/Server** has been selected as the state relational DBMS standard although it is currently supported only on Windows NT.

Conclusion: Based on institutional constraints, the leading RDBMS candidate to support the standard location referencing system is Microsoft ***SQL/Server***. *Microsoft* ***SQL/Server*** *has been designated as the state's relational database standard by the SDBIT and is currently being used to develop client/server database applications within the SDDOT. The fact, however, that* ***SQL/Server*** *is currently only available on the Windows NT platform should not be overlooked.*

8.2.3 Database Hardware Platform Alternatives

Computer hardware can be distinguished largely according to operating system. Three general categories of hardware and operating systems are appropriate for consideration.

- PCs/workstations/servers running *Windows NT*.
- Workstations/servers running *Unix*.
- The current IBM mainframe running *IBM MVS*.

It should be noted that substantial differences exist between some *Unix* operating systems. Executable programs that run on one *Unix* system may not run on another.

In general, computer hardware may be selected by identifying which operating systems are able to host the software of interest. This is principally an issue for host database management software since many applications (including spatial analysis applications such as GIS) are able to access data in a client-server mode, regardless of operating system.

As indicated in Table 8-4, the *Windows NT* operating system will host all the RDBMS programs investigated. *Unix* will host the RDBMS programs **DB2**, **Informix**, **Ingres**, **Oracle**, and **Sybase**. As mentioned previously, however, *Unix* operating systems vary substantially so not all *Unix* workstations will support the DBMS as Table 8-4 suggests. *IBM MVS*, currently on the IBM mainframe, will only host **DB2**.

Table 8-4. Operating System/RDBMS Software Interoperability

	Windows NT	Unix	IBM MVS
ADABAS D	•	•	
DB2	•	•	•
Informix	•	•	
Ingres	•	•	
Oracle	•	•	
SQL/Server	•		
Sybase	•	•	

Historically, the principal domain of engineering workstations was characterized by high-end, three-dimensional graphics and a computational advantage over personal computers of approximately 2 to 100. Both of these areas of distinction are shrinking. Computational speeds of high-end personal computers now compete with engineering workstations. Hardware-driven graphics add-ons for personal computers have also narrowed the graphics advantage. Combining these observations with the software pricing advantages sometimes available for the personal computers, the overall price and functionality favors the high-end personal computer over the engineering workstation for database and application servers. For a large-scale database server, however, the workstation or mini may be preferred over the personal computer due to more disk hardware flexibility and capacity. The IBM mainframe is a candidate for the server because of its current existence and its potential use in a client/server database configuration.

All of the hardware platforms considered are in use at SDDOT. The IBM 3090 mainframe has long been the platform for many database applications, including the RES files. Workstations running *Unix* have supported many of the design and cartography functions within the department. Personal computers have been common on the desktop and are gaining acceptance in the server area because of price/performance advantages and the success of

Windows NT. The *Windows NT* environment is a relatively new platform, but is rapidly gaining acceptance and has been established as one of the state standards.

Conclusion: The selection of hardware platform and operating system is largely an institutional choice; however, the versatility of hardware, growing popularity, and cost effectiveness of software on the Windows NT platform makes it the most desirable candidate when compared to a mainframe or unix platform.

8.2.4 DBMS Management Utilities and Procedures

Although procedures to ensure data integrity and security are presently in place for the current mainframe-based data management system, control of some nonmainframe-based data systems that exist within the SDDOT is questionable. All utilities and procedures for managing SDDOT's location-referenced data will require careful review and revision to reflect any data management system enhancements that are implemented to support the standard location referencing system. The utilities and procedures that will be required to maintain the historical consistency of the data are a classic example. All data updates should be made as they are realized, with data extraction available at any historical time.

With the implementation of the recommended relational DBMS with an ANSI standard SQL interface, data access will become intuitive and routine, requiring little appreciation for how the DBMS is structured or how it operates. This flexibility, however, will result in a significant increase in the number of data users and will introduce more opportunities for error if data integrity and security policies are not enforced through well-implemented procedures.

Although the specifics of the policies and procedures that are required to ensure data integrity and security will depend on the specific DBMS that is implemented, data management and access policies and procedures that are implemented should result in and/or reflect the following:

- *Controlled database structure changes and/or data updates*. Changes to the underlying data structures of the database as well as the data stored in the database must be controlled to ensure data integrity. Data integrity checks should be applied before committing data to the database. For spatially located data, a map generation exercise included as an integral step in an update would identify many errors related to location. Particular attention must be paid to data that are not historical and which may result in existing data being overwritten. The designated database administrator and data custodian(s) will have appropriate write and update privileges and responsibilities.
- *Well-planned database backup, archive, and recovery procedures*. These procedures must be well-planned to prevent inadvertent and/or deliberate loss of data or, in some situations, access to data that should not be disclosed indiscriminately or without qualification. Although malicious use of location-referenced data is not a major concern,

effective data backup, archive, and recovery processes are extremely important to ensure data security in case of hardware failure and/or disaster situations.

- *Timely database updates.* Database updates must be timely to support historical data management.
- *Automated database updates.* Database updates should be automated to the maximum extent possible.
- *Controlled data access.* General data users will have read-only data access.
- *Reduced data redundancy.* By making the data more accessible to more users, there will be less or no need to download portions of the master database into smaller, local, temporary data files. This will reduce the redundancy and minimize data inconsistencies by providing everyone with access to the same data.

A key consideration in establishing these policies and procedures must be database privilege assignments. These privilege assignments should be maintained by the DBMS and managed by the database administrator.

With regard to data utility, managed logs of database queries would provide valuable information related to data use. Such monitoring of data use would allow effective management of SDDOT resources to maximize the utility of the Department's data.

Conclusion: Changes to database data structures must be controlled, updates to the database must be controlled, and general user access must be controlled. Further, scheduled backups and well-planned archives of the database will be essential for effective use of the standard location referencing system. Implementation of these data management policies and procedures is considered to be an integral part of implementation of the DBMS.

8.2.5 Comparative Analysis of System Implementation Costs

A good indication of the cost/benefit of various implementation alternatives can be determined from a comparative analyses of the cost and functionality of critical component alternatives. The most critical component of the standard location referencing system with regard to achieving the desired functionality is the DBMS upon which the system is implemented. As indicated in Table 8-5, three DBMS alternatives have been identified:

- The current custom data management system that is comprised of managed VSAM files and limited use of **ADABAS**.
- **ADABAS**, the network DBMS that is currently resident on the state's IBM mainframe.
- **SQL/Server**, the state's relational DBMS standard currently installed on the network.

Comparison of the inherent flexibility of the DBMS data structures and data access capabilities gives a good indication of the functionality that will be inherent in the systems developed with each of the DBMS alternatives. Subsequent comparison of the relative cost of each of the steps required to implement the respective systems provides a good indication of the relative life-cycle costs of the respective systems.

Table 8-5. Comparison of Functionality/Cost of DBMS Alternatives

DMBS Alternatives	Functionality	Relative Hardware/Software Capital Costs	Relative Implementation Cost
Current System (VSAM Files + **ADABAS**)	*Poor* • Lacks Flexibility • Restricts Access	Very Low[a]	Very High[b,c]
Software AG (**ADABAS**)	*Good* • Lacks Flexibility • Enhanced Access	Very Low[a]	High[c]
Microsoft (**SQL/Server**)	*Excellent* • Flexible/Extensible • Enhanced Access	Low	High[c]

(a) IBM Mainframe, **ADABAS**, and **SQL/Server** are already in place.

(b) Will require design and implementation of functionalities inherent in a commercially-available DBMS.

(c) Will require redesign of underlying data structures.

As indicated in Table 8-5, it will be very difficult and expensive to satisfy the identified functional requirements of the standard location referencing system using the current VSAM data structures. Extensive development of routine DBMS capabilities that are available in **ADABAS** and **SQL/Server** would be required to implement the current recommendations and achieve the desired functionality. In all likelihood, a system developed in this environment will not satisfy the desired system functional requirements because of cost constraints.

The costs of implementing **ADABAS** and **SQL/Server** are expected to be very similar, with both alternatives providing a distinct cost advantage over the use of VSAM data structures. Efficiencies that may be realized in the **ADABAS** environment because of SDBIT's previous experience with the **NATURAL** language are expected to be offset by the increased complexity of the **ADABAS** network model, particularly with regard to implementing historical data management. Capital expenditures for all three alternatives will be low in comparison to labor costs associated with implementation.

A similar comparative analysis of the relative life-cycle costs of the various alternative implementation strategies (e.g., combination, network, or relational approach) leads to similar conclusions on the desirability of the network or relational data models over a VSAM-based implementation (see Table 8-6). Further, the inherent inflexibility of the VSAM structures will continue to severely hinder future efforts to enhance SDDOT data use.

Table 8-6. Comparative Cost of Standard Referencing System Life Cycle

Implementation Phases	General Data Model/DBMS		
	Combination Current System (VSAM Files + ADABAS)	*Network* ADABAS (Software AG)	*Relational* SQL/Server (Microsoft)
1. Preliminary Design Investigations	Medium[a]	Medium[a]	Medium[a]
2. Development of Detailed System Functional Specification	High[b]	Low[c,d]	Medium
3. Development of Detailed System Design	High[b,c]	High[c,d]	Medium[e]
4. System Development and Implementation	Very High[b,c]	High[c,d]	High[e]
5. Ongoing System Maintenance and Development	High[b,c]	Medium[c]	Low

(a) Preliminary design investigations will address design and implementation issues pertinent to all data models.

(b) Development/modification of system functional and design specifications and subsequent implementation efforts must/may address functional capabilities inherent in commercially-available DBMSs.

(c) Increased complexity of data structures.

(d) Experience/knowledge of NATURAL programming language will expedite efforts.

(e) Learning curve associated with development tools.

The most significant cost difference between using ADABAS and SQL/Server is the projected lower ongoing maintenance costs of SQL/Server because of its inherent flexibility and extensibility (see Table 8-5). Although the total costs through initial system implementation are projected to be comparable, future changes that can be expected as SDDOT's data needs change will be more difficult to implement with ADABAS because of the inflexibility of the underlying data structures. Note that the cost of preliminary design investigations that will be essential to address unresolved technical issues related to system interface functionality, design, and implementation will be the same for all three systems and are not dependent upon the DBMS selected to support the standard referencing system.

Conclusion: Careful consideration of the functionality that will be realized through systems developed with each of the DBMS alternatives (Table 8-5) and the comparative life-cycle costs of the respective systems (Table 8-6) builds a strong case for deploying the standard location referencing system using the established relational DBMS standard, SQL/Server. A standard location referencing system that reflects a distributed client/server system configuration built upon SQL/Server will provide the greatest enhancements in data management and data access capabilities for the dollars spent.

8.3 DATA INTEGRATION AND USE

Three additional issues warrant further consideration in reviewing overall coordinate transformations and resulting data integration capabilities. These relate specifically to the utility of the data that will be available.

There is only one general recommendation which results from the discussions in the three following sections. Two sections describe issues which will need to be addressed in the design and implementation of the standard system.

Several important issues warrant further consideration in reviewing overall coordinate transformations and resulting data integration capabilities. These relate specifically to the utility of the data that will be available.

8.3.1 Data Transformations

The standard location referencing system should be able to integrate all of the location-referenced data with no loss of information. Routines and procedures to transform data from each existing location referencing system to a common spatial referencing system have been provided in Chapter 7.0. Effort and cost may prohibit including each of the currently used referencing systems, but the most important information may be included sooner and the least important information included when it is appropriate.

This study has determined that the most desirable choice for a common location referencing framework is geodetic coordinates, latitude and longitude, with elevation included. Latitude and longitude offer the least ambiguous regular coordinate solution for use as a primary data integration system. The geodetic coordinate system selected should be further defined as based on NAD 83 and NAVD 88. The transformations should be transparent to most of the people currently collecting and processing the location-referenced data.

The 13 location referencing systems that were identified as being in use by the SDDOT were categorized in Chapter 7.0 into four categories for the purpose of defining the information needed to convert the data into the geodetic coordinates. Subsequently, 15 coordinate transformations were identified to accommodate full integration of all categories of location referencing systems (Table 7-2). Two location referencing systems, HPMS and graphical presentations, were eliminated from further consideration since they are not primary sources of data.

Although all of the transformations identified in Table 7-2 are theoretically possible, the development of data interfaces to provide all these transformations may not be necessary to satisfy SDDOT's data integration needs. Some of the transformations are more likely to be used than others. Throughout the current investigations, the most significant driving forces for data integration that were identified related to the need to integrate data for graphical presentation and to support GIS analyses that require knowledge of the relative global position of transportation-related information.

Based on the current findings, the transformations from each of the four categories of location referencing systems to regular coordinates have been identified as critical. The transformation between linear systems has also been identified as critical because of existing needs to convert data located by Station and Offset to an MRM and displacement. The integration of MRM system data is the most important transformation required. The MRM system is the location referencing system most commonly used within SDDOT.

Conclusion: The capability to convert all information into a regular coordinate system is critical for the integration of all SDDOT location-referenced data. The initial implementation efforts should focus on the development of these critical data transformation interfaces. Further, latitude and longitude offer the least ambiguous regular coordinate solution for use as a primary data integration system.

Recommendation: Implement appropriate data transformations to establish coordinate compatibility.

8.3.2 Data Quality

Several aspects of data quality must be considered throughout the process of data integration:

- It is likely that the numerical accuracy of all transformation processes will be more accurate than the initial location data upon which the transformation processes will operate.
- Combining two data sources will only produce information which is of equal or lesser accuracy than the original data.

The end user of all location-referenced data should be aware of the limits and accuracies of information being used.

Transformation methods should be appropriate to the use of data. Projects that cover relatively small areas may use transformations that are not appropriate for projects that span very large areas. This refers specifically to the use of State Plane Coordinates and UTM coordinates that require corrections of unit distances depending upon the position of the data within a zone.

Currently, Decision Mapping produces maps at the scales of 1" = 15 miles (1:950,400) and 1" = 30 miles (1:1,900,800). These scales are typically used to depict data for the entire state. United States National Map Accuracy Standards indicate that horizontal accuracy for maps published at scales of 1:20,000 or larger should maintain 90 percent or more of all well-defined points within 1/30 of an inch. For the map scales used by Decision Mapping, this means that well-defined points on the maps should be within 0.5 to 1 mile.

Conclusion: The desired accuracy for all data must be defined with procedural verification of accuracy. Also, the role of the DBMS data transformation interfaces with regard to data quality (e.g., accuracy, precision, and scale) must be defined. Investigations beyond the scope, budget, and schedule constraints of the current project are required to resolve this issue.

8.3.3 Coordinate Storage Versus Coordinate Calculation

Geodetic coordinates could be stored as a complement of some or all original data or geodetic coordinates could be calculated as needed. Ongoing definition of desired products of data integration should help to determine the appropriate method that should be used. In any case, the original information which describes an attribute location should be maintained in the original form.

Maps are typically drawn with straight line segments between points (MRMs) defined by coordinates. MRMs occur at least every mile and usually more frequently. With these standards in mind, it is clear that using the coordinates for MRMs alone would be more than sufficient to provide data for current decision mapping products. As the scale of maps get smaller, a point is reached where it is no longer effective to use only MRMs and connecting straight line segments. The ability to calculate coordinates at intermediate locations must be maintained as a process that may be run at any time to calculate intermediate points as needed. As different map products are needed, additional evaluations will be required.

For purposes of illustrating divided highways and some other relationships, some points on the maps are necessarily and intentionally altered. It may be advisable to store actual coordinates in the database for calculations of features such as proximity. Also, it may be appropriate to store map-drawing coordinates so points in close proximity to each other may be clearly seen on a large-scale map.

Conclusion: The specifics of coordinate transformations and storage is, in part, dependent upon objectives related to data accuracy and system configurations. Investigations beyond the scope, budget, and schedule constraints of the current project are required to resolve this issue.

9.0 RECOMMENDED IMPLEMENTATION STRATEGY

RE/SPEC recommends that the following phased approach be followed in implementing the standard location referencing system:

Phase 1: Preliminary Design Investigations

Phase 2: Development of Detailed System Functional Specification

Phase 3: Development of Detailed System Design

Phase 4: System Development and Implementation

Phase 1 will address unresolved technical issues providing information that will be required to develop the detailed system functional specification (Phase 2) and detailed system design (Phase 3). Phase 4 will involve implementation of the detailed system design to incorporate changes to current SDDOT location referencing practices and procedures that will be required to establish a data integration environment consistent with SDDOT needs.

A key consideration in the development of the above implementation strategy was a number of unresolved issues that will directly impact the development of the detailed functional and design specifications of the standard location referencing system. Many of these uncertainties are interrelated, and the resolution of some issues will affect the resolution of others. Since early resolution of these issues will expedite the development of detailed system specifications, investigations to resolve these issues have been identified as Phase 1.

Although these issues could be resolved as part of Phase 2 and Phase 3 efforts, investigation of these issues is recommended before SDDOT proceeds with the development of detailed system specifications.

Recommendation: Investigation of unresolved technical issues is recommended before SDDOT proceeds with the development of detailed system specifications.

Although there are numerous uncertainties that may have a significant impact on system implementation costs, the cost of full implementation of the standard location referencing system is estimated at $1.6 to $2.1 million. In considering this estimate, it should be noted that the resulting system will reflect significant enhancements in data management and access at a cost that is less than the cost of the current system in 1997 dollars. Further, the cost of implementing these enhancements is small in comparison to the value of the location-referenced assets being managed by the SDDOT. The cost of replacing just the pavement and the bridges on the states' roadway network is estimated at $3.1 billion and $740 million, respectively.

Further discussion of each of the implementation phases is provided in the following sections.

9.1 PHASE 1: PRELIMINARY DESIGN INVESTIGATIONS

Although the project team has provided specific recommendations regarding the implementation of the standard referencing system, certain aspects are not fully resolved. Prior to the complete development of detailed functional and design specifications, it will be necessary to resolve unanswered questions and uncertainties related to:

- Application/data interfaces and data that will be affected.
- Data quality concerns and needs.
- Transformation interface functionality and design issues.
- Transformation implementation issues.

As indicated in the following overviews of each of these concerns, they are technical issues that will have a direct impact on how the system will ultimately function and consequently on the direction and cost of subsequent system design and implementation efforts. Further, the knowledge gained through these investigations will provide a basis for the development of refined system implementation resource projections for budgeting purposes.

The Phase 1 effort is estimated at $195,000. The combined additional support that will be required of SDDOT and SDBIT personnel is approximately one-half (½) full-time equivalent (FTE). Project duration is estimated at 8 to 12 months.

Application/Data Interfaces and Data That Will Be Affected:

This study has clearly identified a comprehensive suite of location referencing systems that are currently in use at the SDDOT and generally where the information located with each referencing system is stored and used. Additional detailed information is necessary, however, to proceed effectively with the definition of detailed functional and design specifications.

- The storage location and data formats (data structures) of all location-referenced data to be included in the standard referencing system must be identified in detail.
- Existing application/system/data interactions and associated interfaces must be clearly identified.

Although details on data structures for a significant portion of the SDDOT's location-referenced data is well documented, this information needs to be confirmed to ensure that it is up to date and expanded to include data that are managed by separate functional areas within the SDDOT. In essence, details on all the data that will be integrated through the standard referencing system needs to be pulled together.

Further, interviews during the current study identified that at least 130 documented applications/systems currently interact with the data. It is anticipated that additional undocumented applications/systems exist and must be considered. In order to prepare a detailed functional specification for the standard location referencing system, each of the applications/systems that interact with location-referenced data must be identified. Interactions between systems and interfaces and processes that link and use location-referenced data must be identified to ensure that system/process interfaces that will be impacted through implementation of the standard location referencing system are appropriately reflected in the detailed functional and design specifications. Although an in-depth review of the SDDOT data model and subsequent business area analysis results was beyond the scope of this study, a preliminary review of these results indicates that coordination with these activities is an essential aspect of this effort. It is important to note that the current study addressed the technical aspects of integrating the location-referenced data collected by the SDDOT using various location referencing methods. The current study did not address SDDOT business processes and data at the level of these previous and ongoing internal investigations. RE/SPEC envisions that SDDOT and SDBIT personnel involved in the development of the data model and business area analyses will play a significant role in identifying the application/data interfaces that will be impacted by the standard referencing system and the specific data and information that will be included in the referencing system.

This investigation will provide a comprehensive compilation of systems, files, and data structures to be considered in Phases 2 and 3 and will facilitate the design and development of an effective system that meets SDDOT's data integration needs.

Data Quality Issues and Needs:

The need for awareness of the scale, accuracy, and precision of location-referenced data will become of increased importance as data collected for diverse purposes are made readily available to the general data user community through enhanced data access and integration capabilities. Currently, statewide decision maps are the most common application of GIS-type location-referenced data. Decision mapping, at the scale it is currently practiced, does not require survey-level (0.01 foot) accuracy. Further, it is unlikely that meaningful survey-level accuracies can be collected and maintained for much of the location-referenced data currently maintained.

It is currently unclear, however, whether or not there is justification to maintain data in better than decision mapping accuracy. A significant amount of data is being collected using GPS technology. The accuracy of this data is not well defined nor has its appropriateness for incorporation into the mainstream of SDDOT information been thoroughly investigated. Additionally, roadway geometrics have been identified as a possible source for data that would potentially yield quite accurate data (though perhaps not survey-level accuracy). Investigation of its use will be pursued as it could have a significant impact on the amount of coordinate information that will have to be maintained to spatially locate information along the linear roadway network.

This investigation would explore the need, within the context of the identified applications/systems and processes, to maintain data more accurate than that required for decision mapping. It would also investigate the feasibility of using collected GPS data and roadway geometrics to define MRM positions and the roadway path between MRMs. Additionally, this task will investigate the results of mixing data of two differing accuracies and the techniques needed to inform the users of the data sources and accuracies (metadata).

Transformation Interface Functionality and Design Issues:

This study identified the need for coordinate transformations as one of the key functional requirements of a standard location referencing system. Ideally, these transformations will be an integral part of the database interface, with all transformations performed as part of a data query. Further details will be necessary to define the functionality and design the transformation interfaces.

There are a number of unresolved questions related to the intelligence that should be built into transformation interfaces that should be explored:

- Should the interface return all data requests in a default absolute coordinate system with users provided the capability of overriding the default?
- Are bidirectional coordinate transformations between existing referencing systems required?
- What is the required accuracy for the transformations?
- What role should the database interface have in flagging data quality or controlling how data of disparate quality is used?
- What data attributes or metadata will be required to implement desired interface intelligence?

In general, users of location-referenced data should not be required to be familiar with details of data collection and storage for each of the location referencing systems. At a minimum, however, users should probably be made aware of the limitations and appropriateness of data they are retrieving for use. As data become increasingly accessible, these issues will become even more significant. Transformations performed as part of a data query should be transparent to the user, yet the transformation interfaces should provide appropriate information (metadata) to minimize the potential for the data user to misuse or wrongly apply data.

The transformations that are developed to support the location referencing system must be efficient and appropriate for their intended use. Although the foremost need for data integration was to integrate data for graphical presentation, decisions on the accuracy at which the various types of data will be maintained will directly impact the required transformation accuracy and associated design. Further, the results of this investigation will depend on and/or affect the resolution of some of the data accuracy issues. If only decision mapping accuracies are required, determination of roadway data position based on MRMs alone would be sufficient. If, however, more accurate roadway location information is desired, it will be important to understand how that roadway information is best obtained. Again, the integration of GPS and/or potential use of roadway geometrics should be a part of this investigation.

The purpose of this investigation is to provide guidelines for the functional definition and design of the transformation interfaces required to appropriately and efficiently supply the necessary information and appropriate metadata to data consumers.

Transformation Implementation Issues:

It has been demonstrated that all of the transformations identified as critical in Chapter 8.0 can be accomplished. The specific information needed to perform those transformations has also been identified and several alternatives were discussed for some of the transformations which yielded varying accuracies of information. Some of the transformations (although not critical transformations) require very little information to complete. An example of this is the transformation between various systems based on the irregular section lines. Within a county, it is quite simple to transform locations from the accident grid to the structure grid.

The critical conversion from an irregular grid to a regular coordinate system, however, requires that each section corner be identified by regular coordinates. Depending again upon the accuracy desired, the relative cost for obtaining the necessary section corner coordinates can be quite variable. If one chooses to use PLSS information from the 1:100,000 DLG maps currently available, the cost will be relatively low. Accuracy of these points may be on the order of 250 to 300 feet. The GPS roadway mapping effort currently in progress may eventually provide many, but not all, of the section corners with improved accuracy.

The transformation of all location-referenced data to a common regular grid coordinate system has been identified as critical and the most commonly used transformation. Although the data needed to perform these transformations has been identified, further investigation is required to define the best approach to obtaining the required information, to refine associated cost estimates, and to establish implementation priorities.

As a part of the investigation of the various transformations, it will be most beneficial to explore the capabilities of the various transformations using some portion of existing SDDOT location-referenced data (possibly a two-county area) to help define and verify implementation methodologies and hypotheses. Exploration of the needs and capabilities of the transformations and the quality of current data will help quantify system limitations and refine implementation cost estimates.

The purpose of this investigation is to develop and verify transformation implementation methodologies.

On-Site Technology Investigations:

On-site reviews of location referencing practices in states where location information has been effectively integrated should be an integral part of the preliminary investigations discussed above. Considerable insight can be gained through on-site demonstrations and discussions with personnel involved with location referencing in states that have made significant advances in data integration; both with regard to "what works" and with regard to problems and pitfalls that were encountered (information that is often not included in industry publications).

9.2 PHASE 2: DEVELOPMENT OF DETAILED SYSTEM FUNCTIONAL SPECIFICATION

Careful consideration of the results of current investigations, the results of the preliminary design investigations performed in Phase 1, the results of pertinent previous SDDOT research efforts, and the results of ongoing SDDOT data modeling activities will provide a basis for the development of a detailed system functional specification. The specification will address in detail the functionality that will be reflected in each of the critical system components:

- The data management system that will support the standard location referencing system.
- Data interfaces to provide user access to data acquired using diverse location referencing systems.

Careful consideration of the manner in which required coordinate transformation capabilities are to be implemented is essential to minimize current and future impacts on analysis applications and system users.

The deliverable for Phase 2 will be a detailed system functional specification. The detailed design should be reviewed and approved by SDDOT management before development of the detailed design of the system proceeds.

9.3 PHASE 3: DEVELOPMENT OF DETAILED SYSTEM DESIGN

The detailed system design will define all location referencing system components and will guide subsequent system development and implementation efforts. The specification, which will be developed based on the detailed system functional specification, will identify all required hardware and software, as well as required system development tools and standards, and will provide detailed designs of critical system components:

- Network enhancements that may be required to enhance data access.
- A database to support data management activities.

- Database interfaces to provide user access to data acquired using diverse location referencing systems.

Although the need for significant enhancements to the SDDOT network was not identified during the current investigations, significant changes to SDDOT data structures will be required to provide the desired data access and data management capabilities.

Design details for the database that will be used to manage the location-referenced data will be a critical part of the design specification. A detailed design of the underlying data structures will be developed, and all functional requirements defined in the detailed functional specification will be implemented through detailed definitions of all database interfaces and supporting management utilities. All data structures and database interfaces, including the critical coordinate transformation interfaces, will be defined to the level of detail necessary for development of the system.

Key factors that will influence the level of effort required to develop the detailed design include:

- Results of preliminary design investigations (Phase 1).
- Functional requirements defined in Phase 2.

The deliverable for Phase 3 will be a detailed design specification. The detailed design should be reviewed and approved by SDDOT management before the system development and implementation proceeds.

9.4 PHASE 4: SYSTEM DEVELOPMENT AND IMPLEMENTATION

The final phase of the project will effectively involve implementation of changes to SDDOT's location referencing practices and procedures identified in the current investigations and confirmed or modified through subsequent design and planning efforts. Activities will include:

- Procurement of all required hardware and software.
- Development of coordinate transformations.
- Development of database structures and database interfaces.
- Modification of analysis/data presentation applications.
- Data conversion/integration.
- Modification/development of supporting procedures.
- System demonstration/acceptance testing.

Required user and system documentation will be developed and training classes will be held to facilitate a smooth transition to the new system. The primary resource in the development of the user documentation will be the detailed functional specification. The primary resource in the development of the system documentation will be the detailed design specification.

Modifications to SDDOT location referencing practices and procedures should be developed and implemented in parallel with existing practices and procedures to minimize the impact on SDDOT operations and to facilitate a smooth transition to the new system.

10.0 LOCATION REFERENCING SYSTEM PROCEDURES

Operational procedures are essential to provide complete and consistent guidelines for the collection, maintenance, and use of location-referenced data. An in-depth review of current SDDOT procedures within the framework of existing location referencing systems and current needs and goals is provided in Chapter 4.0. The intent of this chapter is to provide further guidance on procedural changes that will be required to support the standard location referencing system.

The following discussions address changes to operational procedures that will be required to maintain and use the standard location referencing system. More specifically, these procedures relate to three general areas:

- Data collection and referencing
- Data management and access
- Data use.

Specifics of many of these procedures (particularly software procedures) will be dependent upon future implementation decisions.

The following discussions provide an overview of changes that have been identified to correct deficiencies in the current system and changes that will be required to maintain and use the recommended standard location referencing system.

10.1 DATA COLLECTION AND REFERENCING

In general, the current data collection field procedures are sound, well documented, and well understood by the individuals who use the various location referencing systems. Investigations, however, identified areas in both current data collection activities that require clarification and/or modification and procedural changes that will be required as a result of implementation of the standard location referencing system.

10.1.1 Clarification/Modification of Current Procedures

Current investigations revealed that existing procedures are not fully implemented or require clarification in the following areas:

- Guardrail management
- MRM management.

The existing procedure guiding the maintenance of guardrail data in the RES is no longer followed because of staff reductions or a reduced perception of the need for the data. Interestingly, maintenance of this data has been reinitiated in another area within SDDOT.

The field procedures related to the placement, relocation, removal, and identification of MRMs are critical to the effective use of most of the data collected by the SDDOT. Although periodic verification of the MRM inventory is required by the *MRM Policy Manual*, unnecessary moving of MRMs is causing problems and can often result in the loss of information. An extensive effort, much of it manual, is required to update the MRM inventory and all other files in which changes must be incorporated. If the update is not timely, information is incorrect or lost. Further, the renaming of an MRM often results in a permanent loss of historical information.

All personnel should be apprised that the change in the position of an MRM has significant ramifications with regard to historical consistency. If at all possible, the name should be retained and only the physical location updated to minimize the potential loss of information. Further, the *MRM Policy Manual* should be updated to clearly state that MRMs should only be renamed if the resulting benefits outweigh this significant additional effort.

10.1.2 Procedural Changes Related to Standard Location Referencing System

Investigations leading to the definition of the standard location referencing system identified required procedural changes related to the following:

- Implementation of date/time data attribute.
- Location of off-road features.
- Implementation of elevation data attribute.
- Identification of interstate ramps.
- Use of multiple referencing systems.

These changes will be required to accommodate changes in referencing practices.

Definition of Date/Time Data Attribute. One of the recommendations that was identified as critical to achieving the objectives of the standard location referencing system was the implementation of a date/time attribute for all data. Currently, some data include a time attribute (e.g., the installation date of an MRM). Updated procedures should require the date that data elements change. In the event that a data item ceases to exist, the effective date for this must also be recorded.

Location of Off-Road Features. The location of off-road features is currently accomplished by identifying a point (e.g., the offset from a station) or a generalized area (e.g., a PLSS description). The acceptance and use of GPS techniques will allow a more accurate and complete description of off-road areas to be defined. Procedures will need to be updated to accommodate the following guidelines for locating off-road features.

- Geographically "small" attributes should be located with a single *xy* coordinate and elevation.
- Geographically "large" attributes should be located by outlining a polygon. Optionally, "large" attributes can be located by specifying the centroid of the area.

Inclusion of Elevation Data Attribute. Another recommendation, although not identified as critical, was the inclusion of an elevation attribute where it is appropriate. This is an attribute that may easily be accommodated in a RDBMS, but should not necessarily be a priority to populate. When the collection of elevation data is warranted, data collection procedures should be modified appropriately.

Identification of Interstate Ramps. Interstate ramp identifications are not included in the SDDOT MRM system although provisions for MRM placement on ramps have been defined. For completeness, the interstate ramps should be included. The third column of the highway suffix may be used as described or slightly modified to include all interstate ramps. An even-numbered over odd-numbered hierarchy should be adopted for interstate interchange ramps as part of the procedure update.

Use of Multiple Referencing Systems. With the implementation of the standard location referencing system and its associated user-transparent coordinate transformation capabilities, it is anticipated that individual projects will include data from multiple referencing systems or a choice of referencing systems. Some procedures may have to be updated to accommodate the use of multiple referencing systems.

10.2 DATA MANAGEMENT AND ACCESS

Although many general aspects of data management will remain the same, implementation of an RDBMS will require the development/modification of policies, procedures, and processes related to database management. Data security and integrity must be a key consideration throughout the development of database interfaces, as well as user and system utilities and associated procedures. Appropriate access controls must be implemented and enforced. Further, all system management activities should be audited.

Procedures will be developed by the respective data custodians and a database coordinator during system implementation to incorporate specific data needs and systemwide standards related to:

- Data input and updates
- Data management
- Data retrieval.

The specifics of these operations and associated procedures are software dependent and will depend on future SDDOT decisions related to the database platform (e.g., RDBMS, hardware platform) and database design (e.g., client-server approach and centralized versus distributed configuration).

10.2.1 Data Input and Updates

A significant portion of the location-referenced data is currently collected using computers. Automation of data uploads to the RDBMS should be maximized to the extent possible to minimize errors and facilitate timely and efficient maintenance of data.

Procedures to guide both interactive and batch loading and updating of field-collected data will have to be developed. These procedures must accommodate uploads that cannot be automated and facilitate/enable timely database feedback associated with error correction.

10.2.2 Data Management

The implementation of an RDBMS will have an impact on a number of aspects of database administration:

- Historical data management
- Data archive, restoration, and purge.

Maintenance of SDDOT's MRM inventory maintenance will be one area in which significant efficiencies will be realized. MRM changes will be managed in one location without the need to propagate changes throughout a significant number of files or tables.

Historical Data Management. The implementation of a date/time data attribute will have a significant impact on all aspects of data management and access. The date/time attribute will:

- Enable timely data updates to make current data more readily available.
- Enable retrieval of transportation data with historical consistency.
- Enable historical tracking of road ownership, road realignment, roadway conditions, highway renumbering, as well as changes in MRM positions.

In general, the ability to retrieve a snapshot of the state's transportation data at any given time will eliminate the need to manage data to minimize undesirable impacts on the data view that users will see with a database query.

It is important to note, however, that further investigation of the most appropriate method to identify historical changes is warranted. Historical data management clearly requires both the date at which a data item becomes effective and the date at which it becomes obsolete. The use of temporal dynamic segmentation to eliminate the need to record two times to denote activation and deactivation of data elements should be explored.

Data Archive, Restoration, and Purge. Data that are no longer needed will be archived to an appropriate off-line storage medium and subsequently purged from the database to minimize system storage requirements and to improve database server performance. Archived data will be available for restoration to the system should access to the information become necessary. Appropriate procedures must be developed to ensure that these processes can be performed in a timely and trouble-free manner.

The most noticeable change that will be readily apparent is that data archive and purge processes will be based on data retention policies consistent with SDDOT needs versus current periodic schedules (e.g., annually).

10.2.3 Data Retrieval

Data access methods and procedures will change significantly with the implementation of an RDBMS. The enhanced query capabilities that will be provided by the RDBMS will minimize the need for SDBIT development of utilities and processes for nonroutine data access. Ad hoc query capabilities will enable data access for relatively untrained management and staff who are unsure of the specifics of data structures.

User-transparent location referencing system transformations will change the methods by which people request data and will enable individuals to query the system based on a familiar referencing system and access/retrieve data that was originally collected and stored in some other referencing system.

Procedures will have to be developed to guide users in the use of the enhanced data interface. Further, procedures may be implemented to track data access to ensure that data most often accessed is afforded commensurate attention with regard to data collection and maintenance.

10.3 DATA USE

Most of the current data use procedures relate to job streams or processes that move data from one database to another or combine data from several databases to produce a specific report. Established/documented procedures and policies related to the general use of location-referenced data are noticeably absent. Procedure development/modification will be required to replicate these routine procedures and to provide general guidance on use of the data that will be readily accessible through the capabilities of the new RDBMS.

As data integration capabilities are enhanced, SDDOT can expect a dramatic increase in data use. Enhanced data access and user-transparent location referencing system transformations will enable users to more easily, or for the first time, examine data that were originally collected and maintained in diverse location referencing systems. In recognition of this, procedural guidance and/or policies will be required in two specific areas:

- Data quality (i.e., data scale, accuracy, and precision).
- Use of historical data.

Preliminary investigations will be required to address the data quality issue.

10.3.1 Data Quality

Although the significance of data qualification in data integration (e.g., with regard to scale, accuracy, and precision) was recognized in the current study, a fundamental question remains to be resolved: *"What role should a standard referencing system assume with regard to qualifying data?"*

Several options are available to address the data quality issue. Information necessary to determine the applicability of data can be:

- Disseminated through DOT communications.
- Left to the judgment of data users.
- Communicated to data users through intelligent data interfaces via data attributes.

Appropriate policies and/or procedures will be required with each of these options.

As data become more readily available and usable by standard spatial referencing applications, defined methods/procedures will be required to govern the export of SDDOT data to other state agencies, other governmental agencies, and the general public. Through sharing of the data, the SDDOT assumes the inherent responsibility of providing the appropriate metadata to ensure that users external to the SDDOT are apprised of the quality issues related to the SDDOT data.

10.3.2 Use of Historical Data

A significant enhancement that will be realized through implementation of the standard location referencing system will be the capability of a data user to view a "snapshot" of the transportation system at any point in time. The time period over which on-line data access will be available will be limited only by the constraints imposed by established on-line data retention policies.

Although the value of maintaining a date/time data attribute will be great, procedures will have to be developed to ensure users specify and use the data that reflects the time period of interest. Appropriate procedures or guidelines will be required to guide users in selecting/specifying the point in time for which they wish the data to be valid.

11.0 RECOMMENDATIONS AND CONCLUSIONS

The current investigations resulted in a number of specific recommendations and conclusions relative to establishing a departmentwide standard location referencing system that will support SDDOT data integration needs.

11.1 RECOMMENDATIONS

Seven specific actions are recommended to establish an effective data integration environment within the SDDOT. Five recommendations pertain to changes in current SDDOT location referencing practices that will be required to adopt a standard referencing system. The sixth recommendation addressees resolution of technical issues that will significantly impact system planning and implementation. The final recommendation addresses procedural changes that should be implemented and training that should be considered.

Changes to Location Referencing Practices:

Five specific changes to SDDOT location referencing practices and procedures that should be implemented to address SDDOT data integration needs are recommended:

1. *Use a relational DBMS for management of location-referenced data*
   - Enhance data management capabilities
   - Enhance data access
   - Enhance support of spatial analysis tools.
2. *Implement appropriate transformations to establish coordinate compatibility*
   - Enable integration of data from all location referencing systems in use in a common absolute coordinate system
   - Enable data transformations between all location referencing systems in use.
3. *Implement date/time as a data attribute*
   - Enable tracking of pavement conditions and maintenance activities
   - Enable historical management of road ownership
   - Enable tracking of historical changes in road realignments.
4. *Locate off-road features with one or more xy coordinates and elevations*
   - Maintain point-wise location capabilities
   - Enable integration of attributes that are best defined as spatial areas.

5. *Implement elevation as an optional data attribute*

   – Enable differentiation of vertically distinct, yet laterally similar, roadways

   – Enhance analysis of vertically significant features.

As indicated, each of these recommendations will provide significant enhancements to SDDOT's data management, data access, and data integration capabilities. The recommendations are presented in the order of priority.

Implementation Considerations:

Investigations of alternatives for adopting the proposed referencing system revealed several notable observations related to variables that will control the cost of system implementation:

- The choice of implementing a commercial database management system versus building on current data structures will significantly reduce system development costs.
- Alternative hardware/software costs do not vary significantly and will be minimal compared with system development/implementation and ongoing system maintenance costs.
- The method chosen to address data quality issues (e.g., scale, accuracy, and precision) could have a significant affect on transformation interface complexity and cost. In general, the information necessary to determine the applicability of data can be:
  – Disseminated through SDDOT communications to prospective data users
  – Left to the judgment of data users
  – Communicated to data users through intelligent data interfaces via data attributes.
- The most significant factors that will control the implementation cost will be the time and resources needed to implement the recommended changes.

Comparative analyses of the functionality that will be realized through systems developed with identified DBMS alternatives build a strong case for deploying the standard referencing system using the established relational DBMS standard. This is further reinforced by a comparative analysis of the life-cycle costs of the respective systems.

RE / SPEC strongly recommends that SDDOT use a relational database management system to manage location-referenced data. A client-server implementation of a relational database with appropriate coordinate transformation interfaces will provide state-of-the-art functionality, will address data access/management problems and other issues related to data integrity and consistency, and will establish a basis for integration of SDDOT location-referenced data and spatial analysis systems.

Recommended Implementation Strategy:

RE/SPEC recommends that the following phased approach be followed to implement the standard location referencing system:

Phase 1: Preliminary Design Investigations

Phase 2: Development of Detailed System Functional Specification

Phase 3: Development of Detailed System Design

Phase 4: System Development and Implementation

Phase 1 will provide the critical information that will be required to develop a Detailed System Functional Specification (Phase 2) and subsequent Detailed System Design (Phase 3). Phase 4 constitutes implementation of the detailed system design to incorporate changes to current SDDOT location referencing practices and procedures that will be required to establish a data integration environment consistent with SDDOT needs.

A key consideration in the development of the above implementation strategy was a number of unresolved issues that will directly impact the development of the detailed functional and design specifications for the standard location referencing system:

- Application/data interfaces and data that will be affected.
- Data quality concerns and needs.
- Transformation interface functionality and design issues.
- Transformation implementation issues.

These are technical issues that will have a direct impact on how the system will ultimately function and on the direction and cost of design and implementation efforts. Many of these uncertainties are interrelated, and the resolution of some issues will affect the resolution of others.

Since early resolution of these issues will expedite the development of detailed system specifications, investigations to resolve these issues have been identified as Phase 1. *Although these issues could be resolved as part of Phase 2 and Phase 3 efforts, investigation of these issues is recommended before SDDOT proceeds with the development of detailed system specifications.*

6. *Investigation of unresolved technical issues is recommended before SDDOT proceeds with the development of detailed system specifications.*

The Phase 1 effort is estimated at $195,000. The combined additional support that will be required of SDDOT and SDBIT personnel is approximately one-half (½) full-time equivalent (FTE). Project duration is estimated at 8 to 12 months. In comparison, the cost of full implementation is estimated at $1.6 to $2.1 million. In considering these estimates, it should be noted that the resulting system will reflect significant enhancements in data management and access at a cost that is less than the cost of the current system in 1997 dollars. Further, the cost of implementing these enhancements is small in comparison to the value of the location-referenced assets being managed by the SDDOT. The cost of replacing just the pavement and the bridges on the states' roadway network is estimated at $3.1 billion and $740 million, respectively.

Subsequent development of detailed functional and design specifications will provide a solid foundation for successful deployment of the standard location referencing system. Initial system implementation efforts should focus on the development of critical data transformation interfaces required to convert all information into a regular coordinate system. The capability to convert all information into a regular coordinate system (e.g., latitude and longitude) is critical for the integration of SDDOT location-referenced data for presentation purposes and should be the foremost data transformation consideration throughout the subsequent implementation project phases. The remaining transformations are less likely to be used and should be considered a lower priority to be implemented only as the need justifies.

Required Procedure Development:

Based on the review of current SDDOT procedures related to data collection and referencing, data management and access, and data use, training on current MRM policies and procedures is warranted. Additional training on MRM maintenance, specifically the unnecessary moving of MRMs, should be considered to alleviate problems associated with historical inconsistencies in MRM names.

A review of current SDDOT procedures indicated that minor changes to existing data collection and referencing procedures will be required to accommodate a date/time attribute, an optional elevation attribute, and changes in the identification of off-road features. A major review and revision of data storage, management, and retrieval procedures will be required with the implementation of the RDBMS, and general guidelines on data use will be required to address data integration issues related to data quality (e.g., scale, accuracy, and precision) and data history. A comprehensive training program that addresses all aspects of location referencing is essential to develop/reinforce user awareness of both old and new procedures.

7. *Review current MRM policies and other data collection policies in the context of current activities and needs and provide appropriate training for personnel.*

11.2 CONCLUSIONS

A standard location referencing system based on the current recommendations will provide significant enhancements to SDDOT's location referencing practices and procedures. The resulting contemporary environment will provide:

- System flexibility and extensibility essential to accommodate data needs that can be expected to continue to change through time.
- Historical data management capabilities that are critically needed in many transportation analysis activities.
- Coordinate compatibility essential to effectively support evolving spatial/information technologies such as GIS.
- Enhanced data access essential to support state-of-the-art desktop spatial analysis and graphical presentation tools.

A client-server implementation of the recommended relational database with appropriate transformation interfaces will provide state-of-the-art functionality, will address data access/management problems and associated issues related to data integrity and consistency, and will establish a contemporary basis for integrated use of SDDOT location-referenced data.

Although implementation of the recommended standard location referencing system is the initial step in enhancing the use of location-referenced data, the improved data access that will be provided can be expected to have a widespread impact throughout the SDDOT. The significant increase in location-referenced data that will be available for electronic access from desktop systems connected to SDDOT's network infrastructure will enable future enhancements of applications and systems used in activities that include:

- Pavement management
- Bridge management
- Maintenance activities
- Roadway alignment and inventory tracking
- Traffic analysis
- Safety analysis
- Document imaging and management
- Construction management
- Executive information systems.

In general, the enhanced environment can be expected to serve as a catalyst in the identification and application of innovative uses of location-referenced data and evolving spatial/information technologies. To temper expectations, however, it should be realized that enhancement of the applications used in these areas will be a long-term process and is not part of the initial implementation of the recommended location referencing system.

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APPENDIX A

DEFINITIONS AND ACRONYMS

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DEFINITIONS AND ACRONYMS

ADT	Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ARSD	Administrative Rules of South Dakota
DBMS	Database Management System
DLG	Digital Line Graph
DOQ	Digital Orthophoto Quadrangle
DOT	Department of Transportation
DRG	Digital Raster Graphic
ESRI	Environmental Systems Research Institute Inc.
FGCS	Federal Geographic Control Subcommittee
FGDC	Federal Geographic Data Committee
FHWA	Federal Highway Administration
FTE	Full-Time Equivalent
GIS	Geographic Information System
GIS-T	GIS for Transportation
GPS	Global Positioning System
HARN	High Accuracy Reference Network
HPMS	Highway Performance Monitoring System
I.D.	Identification
ISTEA	Intermodal Surface Transportation Efficiency Act
LRS	Location Referencing System
mph	Miles Per Hour
MPO	Metropolitan Planning Organization
MRM	Mileage Reference Marker
NAD 27	North American Datum of 1927
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988

NGS	National Geodetic Survey
NHS	National Highway System
NSTRI	Nonstate Trunk Road Inventory
ODBC	Open Database Compliant
PC	Personal Computer
PCNO	Project Control Number
PLSS	Public Land Survey System
PMS	Pavement Management System
RDBMS	Relational Database Management System
RES	Roadway Environment Subsystem
ROW	Right of Way
SDBIT	South Dakota Bureau of Information and Telecommunications
SDDOT	South Dakota Department of Transportation
SECOG	Southeast Council of Governments
SHA	State Highway Agency
SQL	Structured Query Language
TQM	Total Quality Management
USFS	United States Forest Service
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VSAM	Virtual Sequential Access Mode

APPENDIX B

CURRENT DIGITAL LINE GRAPH FOR SOUTH DAKOTA

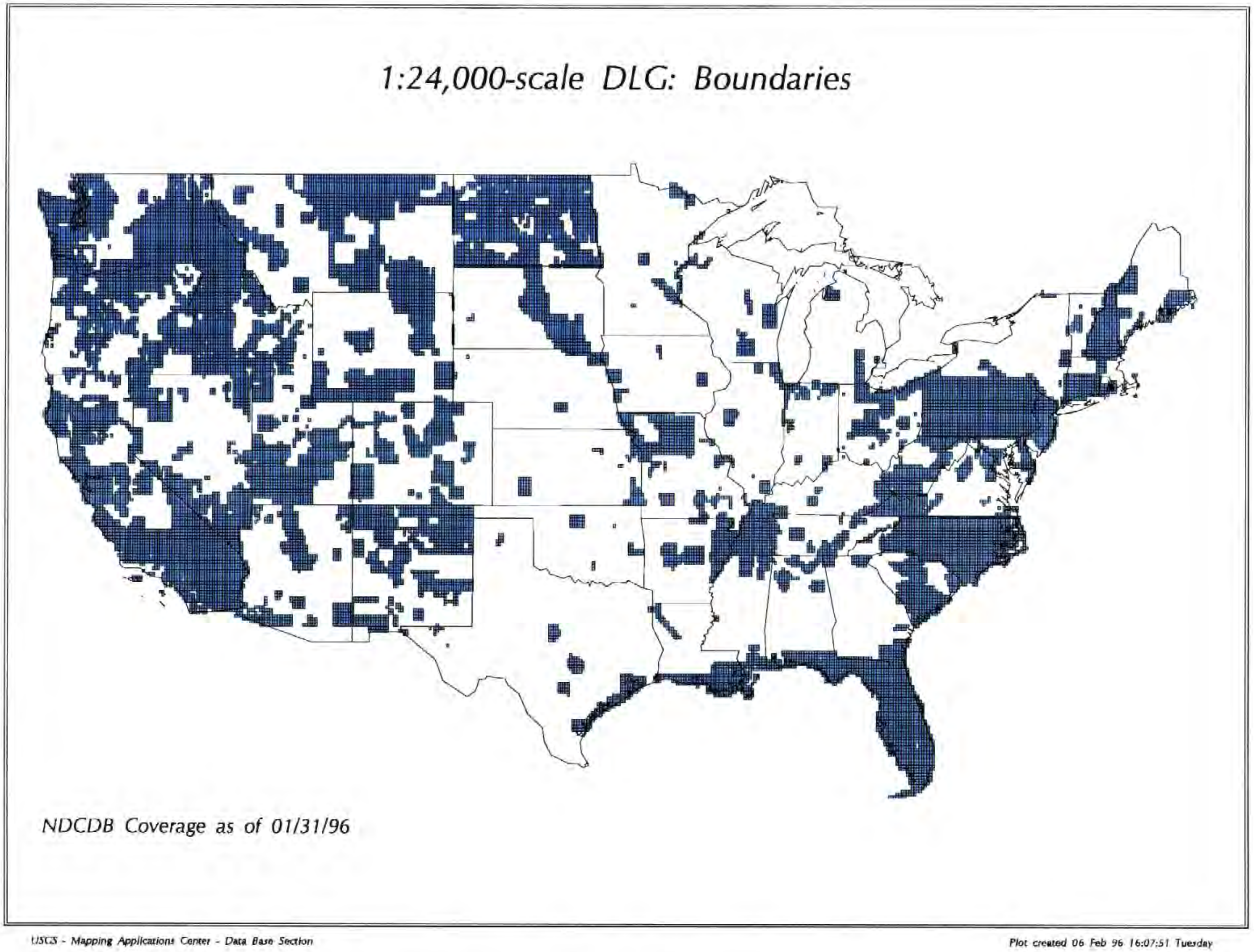

Figure B-1. 1:24,000-Scale Digital Line Graph: Boundaries.

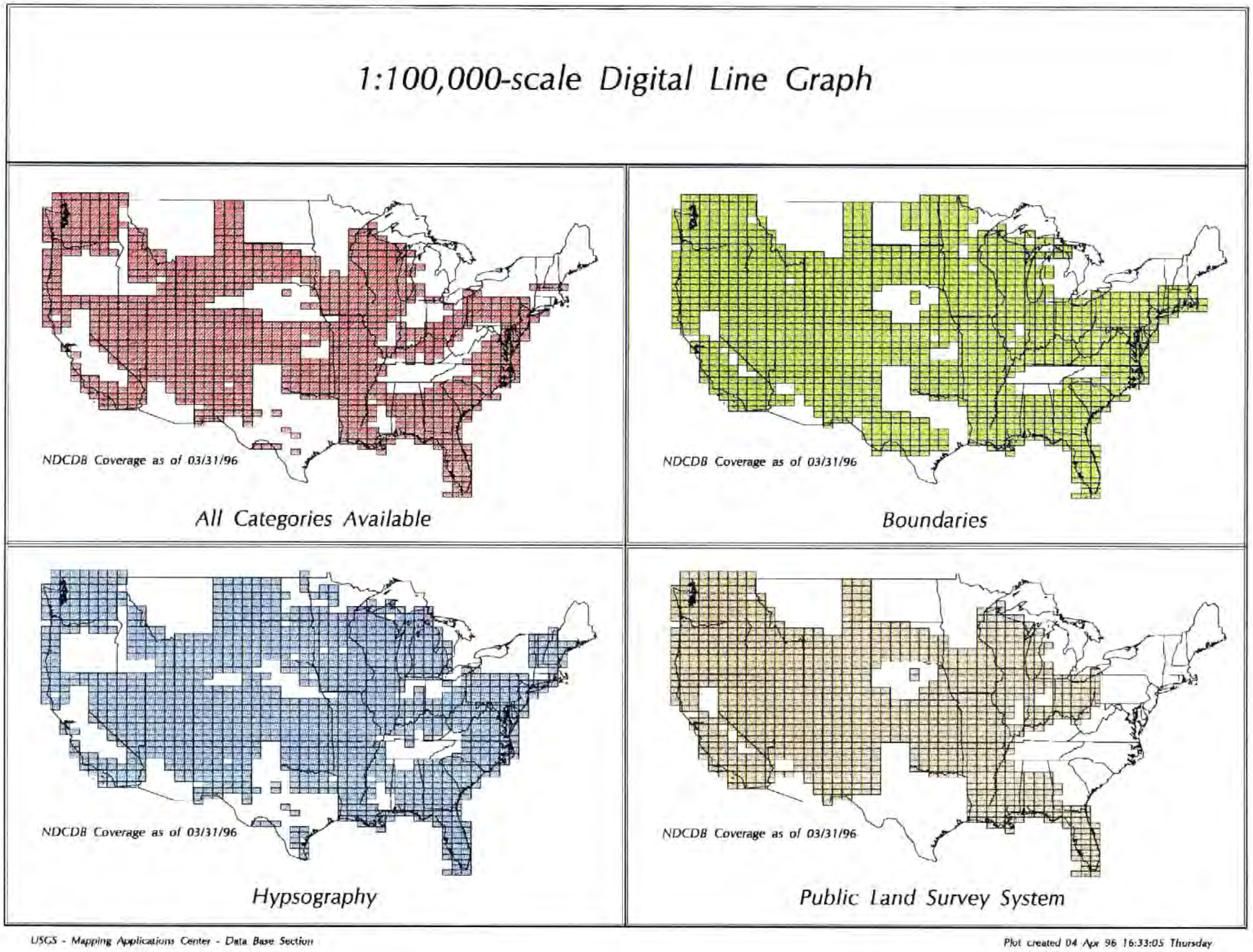

Figure B-2. 1:100,000-Scale Digital Line Graph.

APPENDIX C

INDIVIDUALS INTERVIEWED AS A PART OF SD96-04

APPENDIX C

INDIVIDUALS INTERVIEWED AS A PART OF SD96-04

The following individuals from SDDOT and SDBIT were either interviewed or participated in a discussion of the problem as a part of the project technical panel:

Tim Bjorneberg	SDDOT
Roger Brees	SDBIT
Orville Charlson	SDDOT
Tim Cowman	SDDENR
Nanette Daily	SDDOT
Larry Dean	SDDOT
Terry Erikson	SDDOT
Joel Gengler	SDDOT
Steve Gramm	SDDOT
Karen Harris	SDDOT
Duane Heermann	SDDOT
David Huft	SDDOT
Norm Humphrey	SDDOT
Jerry Jacobsen	SDBIT
Brent Johnson	SDDOT
Dennis Johnson	SDDOT
Michael Jordon	SDDOT
Will Komes	SDDOT
Ken Marks	SDDOT
Charles McFarling	SDDOT
Micheal McNamara	SDBIT
Creighton Miller	SDDOT
Wayne Nelson	SDDOT
Curtis Nessan	SDDOT

John O'Connor	SDDOT
Daris Ormesher	SDDOT
Rudy Persaud	SDDOT
Linda Peterson	SDBIT
Evelyn Putzier	SDDOT
Dale Russell	SDDOT
Frank Schaefbauer	SDDOT
Larry Schoenhard	SDDOT
Todd Seaman	SDDOT
Chan Singh	SDDOT
David Voeltz	SDDOT
Dennis Winters	SDBIT
Ron Woodburn	SDBIT
Mike Young	SDDOT

In addition, the following personnel from other agencies were contacted and interviewed with regard to location referencing systems currently in place and data sharing needs that they anticipate or would find useful.

Bill Anderson	Pennington County Highway Department
Sherry Bauer	USFS
Tom Croymans	BIA
Jack Dozzi	Horizons, Inc.
Darren Eddleman	Minnehaha County
Ryan Hartley	First District Association of Local Governments
Steve Hasenohrl	SD Forestry
Patsy Horton	Pennington County — Rapid City Planning Department
Dave Greenlee	EROS Data Center
Pam Johnson	United States Forest Service
Rick Kirschenmann	Rushmore Electric Power Cooperative
Jeff Manley	Black Hills Power and Light
Mike McMahon	Western Pennington County Flood Management
Kelli Neu	SECOG

Linda Peterson	Pennington County Department of Equalization
Roger Petzold	FHWA
Darlene Pickkola	Lawrence County
Maribeth Price	SDSM&T
Pam Sides	Planning District III
Luanne Thouson	Pennington County Department of Equalization
Steve Van Aartsen	City of Sioux Falls
Ronald Wencl	USGS
Rusty Wilder	USFS

APPENDIX D

DEMONSTRATION OF SDDOT LINEAR REFERENCING SYSTEMS, MINNEHAHA COUNTY, SOUTH DAKOTA

Demonstration of Accident Data and Structure Data on a Base Map Showing:
• State Plane Coordinates
• UTM Coordinates
• Geodetic Coordinates
• Accident Grid
• Structure Grid
• SD Rural Addressing Grid
• Public Land Survey Information
LEGEND
ACCIDENT LOCATION
STRUCTURE LOCATION
SECTION CORNER
GEODETIC COORDINATES NAD 83
UTM COORDINATES NAD 83 FEET
SD RURAL ADDRESSING GRID COORDINATES
SCALE (MILES)
0 1 2 3
(STATE PLANE COORDINATE SYSTEM)
NOTES:
1) Roadway centerline data from Minnehaha County in State Plane Coordinates, South Zone.
2) 1995 accident data for rural Minnehaha County from Accident Records, SDDOT.
3) Structure data from Bridge Design, SDDOT.
4) Geodetic coordinates and UTM coordinates calculated using corpscon.
STRUCTURE GRID
ACCIDENT GRID
SOUTH DAKOTA ADDRESSING GRID COORDINATES
NORTHING (FEET) STATE PLANE COORDINATE SYSTEM SOUTH ZONE
EASTING (FEET) STATE PLANE COORDINATE SYSTEM SOUTH ZONE
R 52 W
R 51 W
R 50 W
R 49 W
R 48 W
R 47 W
T 104 N
T 103 N
T 102 N
T 101 N
RE/SPEC INC.
3824 JET DRIVE
P.O. BOX 725
RAPID CITY, SD
57709
PH. (605) 394-6400
4775 INDIAN SCHOOL RD., NE
SUITE 300
ALBUQUERQUE, NM
87110
PH. (505) 268-0040
DRAFTSMAN
DATE
MAY 1997
CHK'D
DATE
DIV. APVD.
DATE
Q.A. APVD.
DATE
TITLE
Demonstration of SDDOT Location Referencing Systems Minnehaha County, South Dakota
DRWG. NO. RSI-464-96-003