HISTORICAL DATABASE FEASIBILITY STUDY

Topical Report RSI–0383

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prepared for

South Dakota Department of Transportation
Research Program, Room B-116
700 Broadway Avenue East
Pierre, SD 57501–2586

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RE/SPEC Inc.
RESEARCH / SPECIALISTS

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PROBLEM STATEMENT

The current central database that is used in the management of South Dakota's pavement system is nonhistorical and primarily reflects the current status of South Dakota's highway system. The lack of historical information is detrimental to the South Dakota Department of Transportation's (SDDOT) pavement management program in several regards.

- Current estimates of pavement life, life cycle costs, and revenue needs by the SDDOT may not always reflect true past performance and cost and can be time-consuming and costly to prepare.
- The SDDOT is prevented from using more advanced pavement management techniques.
- The SDDOT is prevented from quantitatively analyzing new pavement management techniques that are available and determining whether more advanced techniques are needed.

Convenient access to historical information would correct each of these deficiencies.

The evaluation of the feasibility of implementing a historical database for use in SDDOT's pavement management program is the first step in addressing these deficiencies.

RESEARCH OBJECTIVES

The four primary objectives of the study were

1. To identify potential pavement management uses of a historical database relative to pavement management.
2. To recommend specific data items and retention times needed.
3. To develop a conceptual design for a historical database, preferably consistent with existing SDDOT data.
4. To estimate costs of implementing the design, including computer hardware and software, data conversion, and database maintenance.

Identification of the potential uses of the data is essential to design, develop, and implement a historical database that is functional and addresses South Dakota's current and projected pavement management needs. Since the intended uses of historical data inherently dictate minimum database content and interface requirements, their identification is essential to ensure compatibility with current and projected pavement management methods. A conceptual design that has the flexibility and extensibility to accommodate current and projected SDDOT data storage and access requirements is essential to estimate the costs associated with implementing a historical database.

The *Historical Database Feasibility Study* presented herein addresses each of these objectives and is intended to provide a basis for SDDOT's decision on whether to implement a historical database. If feasible, the conceptual design is intended to provide the foundation for development of the database.

RESEARCH APPROACH

Seven specific tasks were performed to meet the above objectives:

1. Review literature concerning historical statewide transportation databases.
2. Investigate representative historical databases, including the Federal Highway Administration's Highway Performance Monitoring System for applicability to South Dakota's needs.
3. Interview SDDOT personnel to determine how the existing RES database is organized and used.
4. Analyze the existing database's strengths and weaknesses.
5. Develop a conceptual design for a historical database.
6. Identify technical problems associated with a historical database and recommend their solution.
7. Estimate costs of developing, implementing, and maintaining a historical database.

Tasks 1 through 4 were designed to provide objective and knowledgeable recommendations on historical data uses, data types and associated retention times, and database management system functional features that should be considered in the SDDOT pavement management program. Tasks 5 and 6 were designed to provide a conceptual design for a historical database and associated database management system that is specific to South Dakota's current and projected pavement management needs and to identify potential problems that may be encountered in the implementation of the conceptual design along with proposed solutions to the problems. Task 7 was designed to provide an estimate of the costs associated with implementing the conceptual design.

CONCLUSIONS AND RECOMMENDATIONS

A review of the current Roadway Environmental Subsystem (RES) database and nine representative historical statewide transportation databases identified a number of potential uses of historical data. Although the current primary use of historical data is in the development of pavement performance curves, several states are realizing the cost benefits provided by historically based pavement management. The preservation actions identified by Arizona's historically based pavement management system resulted in decreased preservation expenditures of $14,000,000 during the first year of operation.

The majority of the required pavement performance data is currently being collected by SDDOT during its annual pavement appraisals. Data items identified for addition to the RES database include additional soil properties and lane identification, as well as design, as-built, and construction information.

It is recommended that SDDOT immediately adopt a 20-year retention policy for all RES pavement performance related data items with 5 years of data maintained on line. All data items not related to pavement performance should be reviewed for retention. It is further recommended that this policy include all data in the Highway Planning Inventory file. The 5-year on-line retention time is the nominal time being used for pavement predictions and is the minimum time that is being used to generate pavement performance curves. The data should be archived for a total of 20 years for verification of pavement performance.

Direct implementation of either an existing statewide transportation database or the Federal Highway Administration's Highway Performance Monitoring System is not recommended. To achieve the database flexibility and extensibility required by the SDDOT, RE/SPEC Inc. recommends a distributed relational database design that will provide a basis for SDDOT's data and computational requirements into the next century. The design is a client-server configuration with the database server process (IBM's DB2 Relational Database Management System) and the actual data residing on South Dakota's IBM 3090 mainframe. Distributed access to the data will be provided via client processes active on the mainframe, a gateway serving personal computers functioning as X-terminals, or workstations. All distributed hardware will be connected to the IBM 3090 via a standard protocol such as TCP/IP on an Ethernet network. The database server will receive all requests for data, perform the required query against the database, and return the requested data to the user via the client processes.

The relational database management system and client-server approach will provide state-of-the-art functionality, address issues related to data integrity and consistency, and provide a basis for future extension to a truly distributed database environment that integrates geographic information system and mapping databases and systems such as ROAD-VIEW.

1.0 INTRODUCTION

Convenient access to historical data is essential to the South Dakota Department of Transportation (SDDOT) in estimating pavement life, life cycle costs, and revenue needs. These data are required to provide a basis for selecting appropriate maintenance and construction strategies and for the evaluation of the effectiveness of selected strategies. Ideally, the allocation of funds should be based upon data collected during regularly scheduled surveys that identify use and pavement data such as traffic levels, wheel loads, and associated pavement distress (type and severity), as well as repair and improvement history. With this information available, pavement design, construction, and repair can be performed in a logical and structured manner based on past experience and pavement life cycle costs.

The current central database that is used in the management of South Dakota's pavement system is nonhistorical and primarily reflects the current status of South Dakota's highway system. The lack of historical information is detrimental to SDDOT's pavement management program in several regards.

- Current estimates of pavement life, life cycle costs, and revenue needs by the SDDOT may not always reflect true past performance and cost and can be time-consuming and costly to prepare.
- Without historical data, the SDDOT is prevented from using more advanced pavement management techniques.
- Without historical data, the SDDOT is prevented from quantitatively analyzing new pavement management techniques that are available and determining whether more advanced techniques are needed.

Convenient access to historical information will correct each of these deficiencies.

1.1 OBJECTIVES

As the first step towards addressing the above deficiencies, the current *Historical Database Feasibility Study* was initiated to evaluate the feasibility of implementing a historical database for use in SDDOT's pavement management program. The four primary objectives of the study were

1. To identify potential pavement management uses of a historical database relative to pavement management.
2. To recommend specific data items and retention times needed.
3. To develop a conceptual design for a historical database, preferably consistent with existing SDDOT data.

4. To estimate costs of implementing the design, including computer hardware and software, data conversion, and database maintenance.

Identification of the potential uses of the data is essential to design, develop, and implement a historical database that is functional and addresses South Dakota's current and projected pavement management needs. Since the intended uses of historical data inherently dictate minimum database content and interface requirements, their identification is essential to ensure compatibility with current and projected pavement management methods.

Consideration of this key design information will ensure the development of a historical database that provides flexibility with regard to pavement evaluation techniques that can be used and is characterized by well-designed user interfaces that are compatible with the potential uses. A conceptual design is essential to provide a basis for estimating the costs associated with implementing a historical database and to provide a foundation for subsequent development and implementation of such a database. The conceptual design should reflect system features that will enhance system operation and accommodate both current and projected data storage and access requirements.

The results of the investigations addressing each of these objectives is intended to provide a basis for SDDOT's decision on whether to implement a historical database. If feasible, the conceptual design is intended to provide the foundation for the system.

1.2 SCOPE

The following seven specific tasks were performed to meet the above objectives:

1. Review literature concerning historical statewide transportation databases.
2. Investigate representative historical databases, including the federal Highway Administration's Highway Pavement Monitoring System (HPMS) for applicability to South Dakota's needs.
3. Interview SDDOT personnel to determine how the existing RES database is organized and used.
4. Analyze the existing database's strengths and weaknesses.
5. Develop a conceptual design for a historical database.
6. Identify technical problems associated with a historical database and recommend their solution.
7. Estimate costs of developing, implementing, and maintaining a historical database.

As shown in Figure 1-1, these tasks were designed to provide the following:

- *Database design requirements.* Tasks 1 through 4 were designed to provide objective and knowledgeable recommendations on the historical data uses, data types and associated retention times, and database management system functional features that should be considered in the SDDOT pavement management program.

- *Conceptual database design.* Tasks 5 and 6 were designed to provide a conceptual design for a historical database and associated database management system that is specific to South Dakota's current and projected pavement management needs and to identify potential problems that may be encountered in the implementation of the conceptual design along with proposed solutions to mitigate the problems.

- *Projected implementation costs.* Task 7 was designed to provide an estimate of the costs associated with implementing the conceptual design and establishing a historically based pavement management system.

An overview of the general observations that were noted during a review of available historical statewide transportation literature is provided in Chapter 2. Nine states that are in the process of developing historically based pavement management systems are identified along with the analytical approaches to pavement analysis that they are employing. Results of investigations of the historical databases used by these nine states with regard to historical data uses, types of historical data and the length of time they are being retained by each state, and the potential for direct implementation by the SDDOT are presented in Chapter 3.

The identified organization and uses of the current RES database and the results of an evaluation of the current RES database with regard to the functionality and content that will be required to support a historically based pavement management system are provided in Chapters 4 and 5, respectively. A conceptual database design that will provide the desired functionality and flexibility throughout and beyond the development of a historically based pavement management system is presented in Chapter 6, and an estimate of the cost of implementing the conceptual design is provided in Chapter 7.

RE/SPEC's conclusions and recommendations regarding the addition of historical capability to South Dakota's transportation database (the RES) are summarized in Chapter 8. Supporting information about the organization of the master RES database files and the Highway Planning Inventory file is provided in Appendix A. A Glossary defining much of the terminology used in the discussion of the conceptual design is included in Appendix B for reference.

A major finding of the study relates to the relationship between the RES database master files and another key file around which the majority of SDDOT's pavement management system is centered; namely, the Highway Planning Inventory

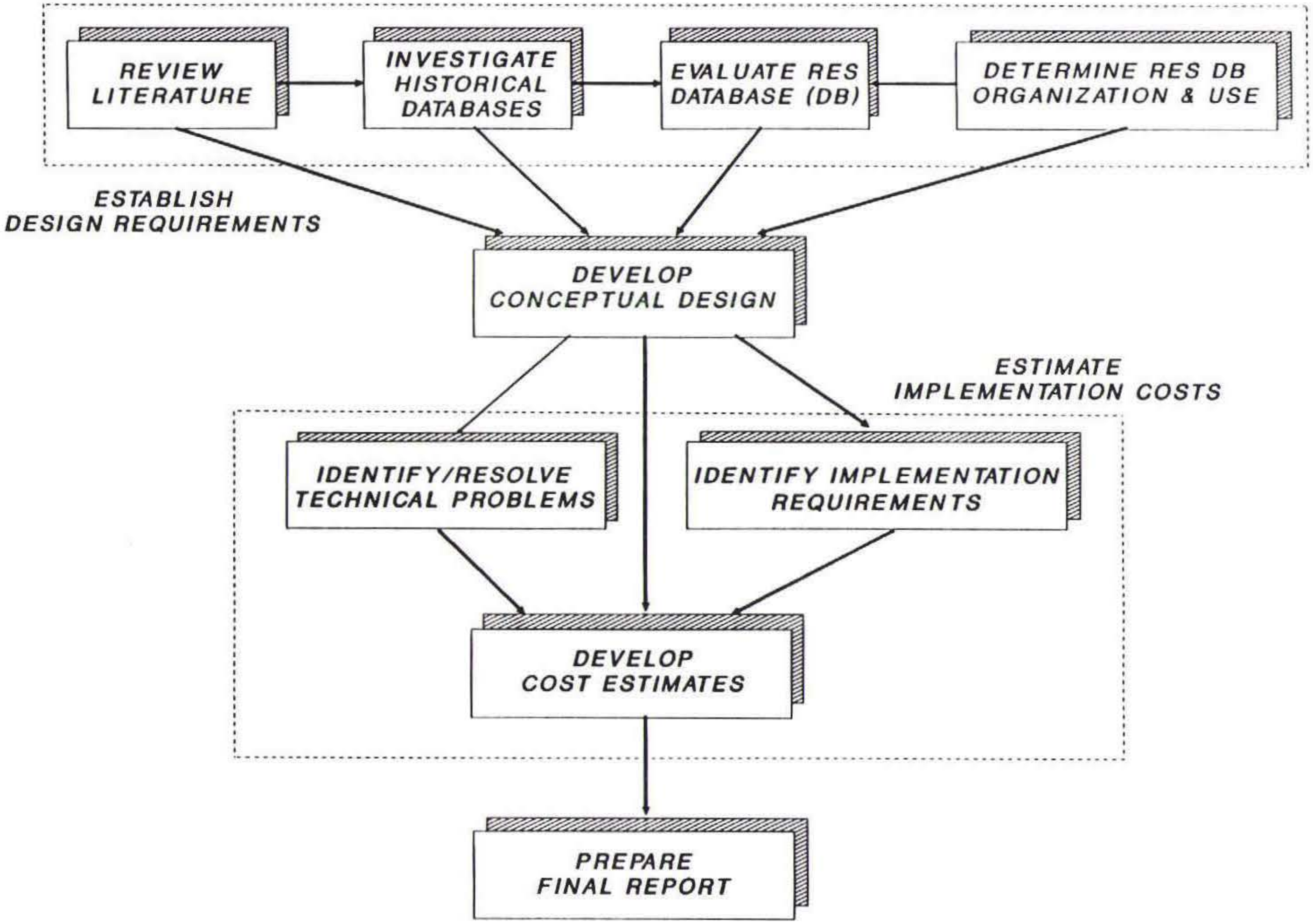

Figure 1-1. Feasibility Study Flowchart.

file. Whereas the master files contain point-based information that is collected on a periodic basis, the Highway Planning Inventory file contains consolidated roadway segment information that is derived from the RES master files and various auxiliary supporting files.

Although the focus of the current study was the RES database, the integrated nature of the database and the pavement management system dictated further expansion of the scope of the study to include the Highway Planning Inventory file. Even though considerable attention was focused on this key file, the budget constraints of the current study did not allow a comprehensive investigation of analysis software interfaces with the Highway Planning Inventory file.

2.0 REVIEW OF HISTORICAL STATEWIDE DATABASE LITERATURE

Similar to the design of any system, the design of a database application is driven by its use. The current investigations clearly indicate that the Roadway Environmental Subsystem (RES) database is the primary storage utility for the majority of the information that is collected in the course of managing South Dakota's highway system and is an integral part of South Dakota's pavement management. Although the objective of this study is not to design a historically based pavement management system, it is clear that the requirements imposed by the pavement management system directly influence the design of the database system. Since the pavement management system inherently dictates minimum database requirements related to both functionality and content, consideration of functional features that would increase the efficiency of pavement management activities was considered an integral part of the review of existing historical databases that support historically based pavement management systems.

Information was collected on the pavement management systems and associated historical transportation databases of fifteen state highway departments, as well as the Federal Highway Administration's Highway Performance Monitoring System. A review of this information revealed the following general findings.

- All fifteen states that were identified in the literature and/or contacted directly have pavement management systems in place that make use of information that is collected annually on a statewide basis. The data are used to determine the present condition of their highway networks and to subsequently rank and schedule maintenance/rehabilitation (M/R) projects that are within their fiscal constraints. Historical information is not needed to prioritize M/R efforts on an annual basis.
- Nine of the fifteen states are developing pavement management systems that make use of historical information that includes more than 1 year's data. The current focus is on the development of pavement performance curves. The use of historical data in the optimization of M/R activities is limited.
- The analytical approaches being used to predict the future state of a highway system can be categorized as either regression analysis or Markovian probability analysis [Benjamin and Cornell, 1970; Dougherty, 1990]. A third approach that is being considered for application to prediction of pavement performance is Bayesian decision theory [Parker, 1990]. In contrast to Markovian theory, which is based on the assumption that the process being modeled is a random process, Bayesian theory assumes some systematic or probabilistic flow in transition from one condition state to another. Whereas the Markovian probability matrix is appropriate for an instant in time but may be different

for another point in time, the Bayesian probabilities for each step in a process are assigned based on rational evaluations, information, and qualitative data that may be available.

- None of the states contacted are implementing the Federal Highway Administration Performance Monitoring System (HPMS).
- Many of the highway department personnel that were contacted believe that pavement management systems will eventually all be GIS-based systems, but felt that the cost of implementing such a system is not justifiable at the current time.
- The implementation of a database that would support the implementation of a GIS-based system in the future would provide significant long-term cost benefits. RE/SPEC's recommended change in the RES index key will address this.

The nine states that were identified for further investigation of their historical database with regard to applicability to South Dakota's needs were: Arizona, Colorado, Kansas, Minnesota, Nebraska, North Dakota, South Carolina, Washington, and Wisconsin.

Although only one state, Wisconsin, was identified as using a Geographic Information System (GIS) in its pavement management system, it was interesting to note that the city of Albuquerque, New Mexico, has been using a GIS-based PMS for the past 4 years with great success, but does not include any performance curves or use historical information [Wahl, 1990].

The states that were contacted but eliminated from further investigation because they do not use historical data in their pavement management systems were Alabama, Montana, Nevada, New Mexico, Utah, and Wyoming. The Alabama Highway Department [Turner et al., 1986] utilizes engineers' experience to develop programs that correlate pavement service ratings with different types of distress. These correlations are then used to calculate M/R strategies using actual pavement distress data. This approach is very subjective because there is no correlation of quantifiable data to support the engineer's decision. New Mexico performed a similar effort in the development of an artificial intelligence system for pavement design [Luecke, 1990]. Although New Mexico's PMS database presently contains 3 years of data on distress and roughness [Cogland, 1990], no performance curves have been developed using this data. Similarly, Montana and Nevada do not presently have a historically based PMS [Wright, 1990; Bosch, 1990]. Utah [Blake, 1990] is currently reviewing systems available for PMS and pavement performance prediction. Wyoming is planning to develop performance curves over the next 5 years and presently retains the previous 3 years data in the PMS database [Adkins, 1990].

Finally, it should be noted that investigation of alternate and new approaches to monitoring and predicting pavement performance is an on-going effort by the Long Term Pavement Performance (LTPP) program within the Strategic Highway

Research Program (SHRP). Progress in this program should be closely monitored for new developments and recommendations.

3.0 INVESTIGATION OF REPRESENTATIVE HISTORICAL DATABASES

Nine statewide historical transportation databases that were identified as supporting historically based pavement management systems (Table 3-1) were investigated. The Highway Performance Monitoring System (HPMS) was included in this investigation because of its use by the U.S. Department of Transportation, Federal Highway Administration, to evaluate the interstate network system. As shown in Table 3-1, the analytical approaches used in the pavement management systems that eight of the historical databases support are either regression analysis or Markovian probability analysis applied at the network level. The ninth system is GIS based. No states were identified as having implemented the HPMS.

Investigation of these databases revealed a variety of findings related to potential uses of historical data, to the type and retention time of data that is being retained, and to the potential for direct implementation by the SDDOT. Current uses of historical information include:

- All states are using historical data to evaluate pavement performance.
- There is limited use of historical data to optimize M/R expenditures at the network level.

Although the predominant use of historical information at this time is in the evaluation of pavement performance, there are a number of historical data uses that can be considered as a historically based PMS matures.

- Evaluation of M/R strategies/policies to identify the best M/R strategy for a given pavement condition.
- Validation of design policies and procedures to optimize design practices.
- Evaluation of innovative materials to identify optimum M/R and construction materials.
- Evaluation of construction techniques to optimize construction methods.
- Investigation of seasonal variations of falling weight deflectometer data to minimize negative affects of freeze/thaw cycles on pavements through identification of improved materials, designs, and construction methods.

Ready access to historical data is essential to the development and use of each of these pavement management activities. The demonstrated performance of pavements through time (life curves) provides the basis for the development/validation of

Table 3-1. Statewide Historical Pavement Management (PM) Systems Investigated

State	PM System		Database System			Reference
	Analytical Approach	Level Applied	Hardware (Database/Access)	Software	Data Retention (Years)[a]	
Arizona	Markov	Network	Mainframe	Custom	7	Goladi & Kulkarni, 1982
Colorado	Markov	Network	Mainframe	Custom	7	CDH, 1985; Millet,1990
Kansas	Markov	Network	Mainframe/WS	INGRES	5	Clark, 1990
Minnesota	Regression	Network	Mainframe/PC	FOCUS	5 (20)[b]	Hill, 1990
Nebraska	Markov+Regression	Network	Mainframe	Custom	5 (20)	Wedner, 1990
North Dakota	Regression	Network	PC/PC	dROAD	5 (20)	Deighton, 1990; ERES Consultants, 1990; Horner, 1990
South Carolina	Regression	Network	Mainframe/PC	Custom & FoxPro	5 (20)	Cambell, 1990; PMS, Inc., 1989
Washington	Markov+Regression	Network	Mainframe/PC	ADABAS & Basic	5 (20)	Jackson, 1990
Wisconsin	GIS	Network	Mainframe/WS	ARCinfo	Unknown	Fletcher & Ries, 1989; Reis & Fletcher, 1990; Solberg, 1990; WDOT, 1990

(*a*) Nominal age of data retained and used on-line.

(*b*) Nominal maximum age of retained data if different than on-line retention.

predictive capabilities to project the future condition of a highway system based on its present condition. Pavement deterioration as a function of time can be correlated with various pavement performance-related variables to identify the appropriate independent parameter(s) that should be used to predict pavement deterioration. The historical information further provides an objective basis for the evaluation of the effect of pavement design, construction, and maintenance practices on pavement performance. Comparison of the deterioration of pavements that reflect differing design practices, construction methods, or maintenance actions provides an effective means of identifying cost-effective department practices/policies. When integrated, these capabilities provide an effective means of optimizing the allocation of department funds to either maximize the miles of highway that can be maintained in acceptable condition for a fixed cost or to minimize the cost of maintaining a fixed percentage of the highway system in acceptable condition.

Arizona is a good example of a state that is realizing the cost benefits of a historically based pavement management system that utilizes some of the historical data uses identified above. During the first year of use, the preservation actions identified by Arizona's historically based PMS resulted in decreased preservation expenditures of $14,000,000. There were two reasons for the cost reduction:

- A pavement management approach involving costly corrective preservation actions was replaced by an approach that is based on less costly preventive maintenance.
- Conservative preservation actions were replaced with less conservative but more cost-effective preservation measures.

Although it might be possible for SDDOT to simulate history by considering the present condition of various highway projects of various ages, caution should be exercised in doing so. Improper grouping of the projects to eliminate performance differences due to variations in variables that affect pavement performance could lead to poor and/or inaccurate correlations. Further, categorization of projects could result in too few data points to provide a meaningful correlation. By collecting and analyzing data for a pavement segment or group over time, the reliability of the data can be better established, and outliers or anomalies in the data can be identified for further investigation.

Further consideration of the analyses that are being performed indicates the following with regard to the functionality of user/application interfaces.

- Pavement performance investigations require extensive database queries.
- Graphics capability is becoming a requirement in the analysis environment.
- The widespread interest in the movement of PMS toward GIS-based systems warrants consideration in any changes to South Dakota's RES database.

There were no notable differences in the type of data being retained by states adopting regression-based versus Markovian-based PMS. In general, the types of historical data that are being used in pavement management activities include:

- Pavement roughness measurements
- Pavement strength measurements
- Pavement condition measurement
- Traffic volume
- Annual maintenance information.

Measurements of roughness, strength, and condition are the minimum data items required to define pavement performance and are typically obtained at periodic intervals through respective measurements using a profilometer or a device such as a Mays ride meter, measurements of deflection or pavement stiffness using a falling weight deflectometer (FWD) or a Dynaflect, and through inventories that quantify the types and amount of pavement distress. Traffic volume and maintenance information are additional data items that are used in the prediction of pavement performance and in the optimization of M/R expenditures.

As indicated in Table 3-1, nine states are retaining this information on line for a minimum of 5 years while some states (Minnesota, Nebraska, North Dakota, South Carolina, and Washington) have nominally 20 years of retained data. It should be noted, however, that the states only use 3–5 years of data in their pavement management activities. In all cases, construction data is retained from the time of initial construction.

The current investigations revealed that the utility of historical information is still being investigated, and there is no current standardization of specific data items being used in pavement management activities by the states investigated. Each state highway department has included in its pavement management system unique (but comparable) data items that it believes accurately represents the performance of the state's pavements. Further, discrimination of data retention times is currently limited to on- versus off-line retention time.

None of the systems investigated were deemed to be appropriate for direct implementation by the SDDOT. Most of the systems investigated maintain a minimum of information, merely that information which is used in their pavement management system. Although these stream-lined systems are attractive in the storage and performance arenas, they cannot be directly implemented by the SDDOT because there is a considerable amount of information in the RES that is required to maintain current functionality and is required as a matter of historical record. Further, SDDOT desires to experiment with different approaches to pavement management and the data requirements must be flexible. We recommend an integrated approach which addresses both the descriptive data needs as well as the analysis data needs.

One of the systems investigated is PC-based. The major problems with the entirely PC-based, stand-alone systems are as follows:

1. The massive amounts of data required in the SDDOT effort are better suited to mainframe management and backup procedures.

2. Data integrity issues are introduced when multiple copies of a database are distributed among various users. These physically disjoint databases may become inconsistent and resulting analyses may be unreliable.

3. The memory and extended memory management on the x86 architecture is extremely poor. This results in sluggish performance in the handling of large amounts of data as well as in the screen management required for a reasonable user interface.

In addition to the entirely PC-based system, there are several systems which consist of a database on a mainframe accessed via microcomputers (PC's and workstations). However, they do not make use of networked, distributed database access. They retrieve information from the mainframe database and download it to the microcomputer to perform analyses. This can have the following adverse effects:

1. Modifications to the data performed on the microcomputer may produce analysis results which are inconsistent with the data on the mainframe.

2. Since microcomputer backups are typically the responsibility of the user of that microcomputer, the ability to reproduce analysis results will depend on the user maintaining historical backups of his data and/or uploading his analysis data to the mainframe.

The HPMS is not recommended for direct implementation by SDDOT for two specific reasons.

- The efforts associated with customizing the HPMS to meet South Dakota's needs would be comparable with the implementation of a more useful system.
- The HPMS's capabilities with regard to optimizing M/R strategies is limited.

Further discussions on each of the historical pavement management systems and supporting historical database are provided in Sections 3.1 through 3.9. Further discussion of the Federal Highway Administration's Highway Performance Monitoring System (HPMS) is provided in Section 3.10.

3.1 ARIZONA

Arizona has developed a pavement management system that makes use of a "constrained Markov decision process that captures the dynamic and probabilistic aspects of the pavement management problem" [Goladi and Kulkarni, 1982].

Goladi and Kulkarni state that the PMS saved approximately $14 million dollars to maintain the 7,400-mile network with a net expenditure of $32 million dollars. The model's condition states were divided into three levels of cracking, three levels of roughness, three levels of the change in the amount of cracking from the previous year, and five levels of the index to first crack. The statewide network was divided into 9 categories using average daily traffic and a regional environmental factor based on elevation and rainfall. The index to first crack is defined by Goladi and Kulkarni as "the average number of years to the initiation of the first crack following a given preservation action." The index is a means to quantify the durability of alternative repair methods. One repair method may result in a restored pavement section that may have 5 years to first crack whereas an alternate method may result in a restored pavement section that may have only 3 years to first crack. The database system used in Arizona was reported to be a custom system and to contain only that information used in the pavement management model used. This approach is not directly applicable to South Dakota because a custom system is typically difficult to modify and the information base does not satisfy the data requirements outlined above.

Arizona is realizing the cost benefits of a historically based pavement management system. The system, which was implemented in May 1980, has changed Arizona's pavement management decision process from a subjective non-quantitative method to a modern system that integrates managerial policy decisions and engineering inputs through an optimization system. During the first year of use, the preservation actions identified by Arizona's historically based PMS resulted in decreased preservation expenditures of $14,000,000. Although $46,000,000 had been budgeted to keep Arizona's 7,400-mile network in acceptable condition based on previous pavement management practices, the Arizona Department of Transportation was able to achieve the same standard at a cost of $32,000,000 because of the following:

- Prior to implementation of the system, the tendency had been to allow roads to deteriorate to a rather poor condition before a costly corrective preservation action was taken to restore the road to an acceptable condition. The historically based PMS recommends less substantial preventative actions before the road deteriorates to a really poor condition. As stated by Goladi and Kulkarni, "Analysis shows that less substantial but slightly more frequent measures not only keep the roads in good condition most of the time, but are overall less costly: they prevent the road to reach really bad conditions needing the costlier corrective measures."

- Before implementation of the system, corrective actions were too conservative and it was not uncommon to resurface a road with 5 inches of asphalt. The assumption had been that the thicker the asphalt layer, the longer it would take for the road to deteriorate below acceptable standards. While the basic assumption was correct, the prediction model developed from the states' historical data showed that the time it takes for a road to deteriorate is not proportional to the asphalt layer thickness and that there is no significant difference between the rate of deterioration of a road resurfaced with 3 inches of asphalt and a road resurfaced with 5 inches of asphalt. Whereas it was not uncommon previously to resurface a road with 5 inches of asphalt, the policies recommended by the historically based system are less conservative and a recommendation for 3 inches of overlay is rather rare and is only reserved for the worst conditions.

3.2 COLORADO

Colorado has adopted the Arizona DOT's Markovian based system because of its success in Arizona and began development of the required information by using the subjective approach of interviewing the pavement engineers to collect their professional judgements on the M/R strategies [CDH, 1985]. Recent discussions with DOT personnel [Millet, 1990] indicate that a more objective and quantifiable approach is being developed as data on the pavements are collected and analyzed. Both Arizona and Colorado use roughness and cracking in their performance models. Since the Colorado approach is the same as that of Arizona, we do not recommend it for the reasons outlined above.

3.3 KANSAS

Another state PMS that is similar to the Arizona system is that of Kansas [Clark, 1990]. The PMS is a Markov-based model that predicts pavement performance based on condition survey data on cracking. Forty-six alternative M/R actions are combined with approximately 20 pavement types and traffic categories resulting in a 216×216-square matrix that is updated annually with new data. A main planning database is currently accessed using UNIFY but is in the process of being converted to use INGRES. An Intergraph workstation is used as a file server to access the main planning database and perform most of the functions required by the PMS. The database contains all three principle types of data including raw crack data and maintenance costs. The main planning file or database resides on a mainframe. Files are downloaded to minicomputers for analysis, and new files are uploaded to the mainframe where optimization programs are used to analyze the highway network. Reports are subsequently generated from downloaded files on minicomputers. Presently there are 5 years of data in the historical database. This system is one of the examples of the mainframe to microcomputer download of information for analysis. We do not recommend such a system due to the problems outlined in the introduction to this chapter. In short, there are data integrity and analysis result consistency and reliability problems inherent in this approach.

3.4 MINNESOTA

Discussions with Minnesota Department of Transportation personnel [Hill, 1990] revealed that their PMS contains distress and ride quality data since 1967. A regression-based model that defines 36 performance curves that are based on three traffic levels, three subgrade strengths, and four pavement surface types is used in their system. All three types of data are collected and used by Minnesota to develop regression equations that are used to predict pavement performance. The PMS is capable of either prioritizing M/R strategies based on level of funding constraints or maximizing benefits of M/R efforts on the network level but does not optimize with respect to alternatives for a particular pavement. Their pavement management system was developed 5 years ago, and pavement performance curves are due to be reviewed and updated in the near future. The data are stored on a mainframe computer, but are downloaded to microcomputers for analysis and model development. This is another example of the mainframe data downloaded to microcomputer for analysis system scenarios which we do not recommend for integrity, consistency, and reliability reasons.

3.5 NEBRASKA

Nebraska utilized regression analysis to develop performance curves using the Nebraska Service Index (NSI) correlated with age, but recognized an increased variability observed as a function of age [Wedner, 1990; Wedner et al., 1987a; Wedner et al., 1987b]. The NSI utilizes roughness and condition data only, but deflection data is also collected. Using scatter plots of NSI versus age, three regions or phases were defined. Phase 1 was a rapid decrease in the NSI value probably due to environmental effects. Phase 2 followed Phase 1 and was defined by a relatively constant rate of change in service index with some variability in the values. Phase 3 was observed after Phase 2 to have significant random variability in index values that was associated with various types of surface treatments. Data from Phases 1 and 2 were used to develop regression equations between NSI and age. The resulting equations indicated values of the service life that correlated well with observed service lives. All files and programs reside and are used on a mainframe computer system. We do not recommend this purely mainframe approach with PC's used as terminals because it is not a proactive solution in today's highly distributed computing environment. Nebraska retains all information, some of which is 20 years old, but only uses the latest three points for prediction of performance.

3.6 NORTH DAKOTA

The North Dakota State Highway Department developed pavement performance curves based on field data from pavement sections that were grouped according to the pavement structural number and equivalent single axle wheel loads. Initial attempts to correlate field data such as the individual ratings of the types of cracking showed that the variation in the data was too great to be used to develop statistically significant regression models. A combined distress index was finally correlated with the age of the pavement. This is one of the drawbacks with adopting a regression model for development of performance curves. The variability of the data and low correlation coefficients are not conducive to high degrees of confidence in the resulting equations. Some states have worked around this shortcoming by developing performance equations for each individual pavement section.

North Dakota's PMS is a microcomputer-based, commercial software package specifically designed for pavement management [ERES Consultants, 1990; Horner, 1990]. All three types of data are retained by North Dakota for the historical database. The principle use of this data is for model development and performance evaluation/prediction. The software package, dROAD, is based on a relational database configuration [Deighton, 1990a, 1990b, 1990c] and provides the user with ready access to information in the files for ad hoc queries. Although the system has great capabilities, it appears limited for application to development of performance models. The software cannot generate plots of data items as a function of time. The literature indicates that graphical output and data manipulation or analysis is performed by other software outside of the dROAD package. In spite of this, the package should be evaluated by SDDOT for use in initial investigations of the various historically based pavement management approaches. It should be noted, however, that a microcomputer-based solution would introduce a host of data integrity issues. Any solution that RE/SPEC will recommend would integrate the advantages of microcomputer-based analysis with those of a centrally based database.

3.7 SOUTH CAROLINA

South Carolina's pavement management system [Cambell, 1990; PMS Inc., 1989] is similar to Minnesota's but uses condition survey information and roughness to develop a pavement quality index (PQI). The database is maintained on a mainframe computer and downloaded onto a microcomputer for analysis using FoxPro database management software. Performance curves were adopted from other states, but plans are to review and update the system with state-collected data. The problems associated with downloading data from the mainframe to the microcomputer for analysis have been discussed in the previous sections. We do not recommend this approach for reasons of data integrity, consistency, and reliability.

3.8 WASHINGTON

The state of Washington is perhaps the most widely known state for its early interest and development of a PMS that utilizes pavement performance curves for each individual pavement section. Condition surveys are performed every 2 years with results input to a planning database with traffic and construction information. Roughness and condition data are retained as historical information. Condition data is retained in the form of Pavement Condition Rating (PCR), the derived value obtained from individual distress measurements and types. These items may be retained in the database for ten periods. Because the condition surveys are performed every 2 years, the total retention time is 20 years. Although the PMS is used presently to prioritize only, optimization procedures are being developed. County departments are able to access this information through BASIC software programs. Presently, the PMS is a combination of the Markov chain process and regression analysis approaches [Jackson, 1990]. The Washington system is based on ADABAS with BASIC language custom interface programs. ADABAS is a network model database management system. We recommend the use of a relational database management system for reasons outlined in Chapter 6 of this document.

3.9 WISCONSIN

Of the states that were investigated in the current study, Wisconsin is the only state surveyed that utilizes a Geographic Information System (GIS) as the database for the pavement management system. Wisconsin [Fletcher and Ries, 1989; Ries and Fletcher, 1990; Solberg, 1990; WDOT, 1990] has developed and is continuing to improve its GIS database. Wisconsin's data are stored on a mainframe computer system and accessed through an Apollo workstation for analysis and display. These programs generally utilize a relational database configuration that allows ad hoc queries to be performed. Results of ad hoc queries involving time series and map-like plots are graphically displayed for initial reviews and analysis. The implementation of a historical database that uses a generic referencing system that could be updated later would appear to be a major step toward preparing for the eventual implementation of a GIS-based system. Although this system is quite attractive if the SDDOT chooses to pursue a GIS, the information gathered during this study indicates that the Wisconsin GIS does not include all of the current RES information. Hence, a GIS solution should be considered as a possible future component of this historical SDDOT database system, and the key mechanism for the current conceptual design should be constructed to maximize the ease of integration with a GIS.

Further discussions with FHWA personnel [Davidson, 1990] indicate a number of GIS-based software packages are available for PMS. These include ARCinfo, TransCAD [Simkowitz, 1990a; Simkowitz, 1990b; Caliper Corporation, 1989], and GEOSQL. These systems have two major features that are significant when relating to pavement management systems. First, these programs utilize a relational database configuration that allows ad hoc queries to be performed easily. Results of ad hoc queries involving time series and map-like plots can be graphically displayed for initial reviews and analysis. Second, a significant amount of manpower and time is required to convert the mile-reference-marker system to a more absolute referencing system. Since this is the major drawback of converting to a GIS-based system, the implementation of a historical database that uses a generic referencing system that could be updated later would appear to be a major step toward preparing for the eventual implementation of a GIS-based system.

3.10 FEDERAL HIGHWAY ADMINISTRATION

Although the Highway Performance Monitoring System (HPMS) is a complete pavement management system, it was included in the current study for investigation of possible implementation by SDDOT because of its use on the federal level. The HPMS, which is used by the U.S. Department of Transportation, Federal Highway Administration, to evaluate the interstate network system, is based on the results from the AASHO road test.

The HPMS can be used to determine the present condition of a pavement network or to predict its future condition using the AASHO Road Test equations and current and anticipated traffic growth factors. These equations, which are based on a correlation of traffic volumes (converted to 18-kip equivalent single axle loads (ESALs)) and the serviceability rating of a single pavement segment, are based on the data from one test that was performed at one location with one type of traffic. Although provisions are provided to modify the equations to account for "local variations in materials and environment" [FHWA, 1987], implementation by a state may require an extensive model development effort to develop equations specific to the state. Although the HPMS does not directly use historical data, historical information is used to develop the pavement deterioration rates and estimated costs of highway improvements that are used by the program.

The output of the system is a prioritization of the highway system needs and improvement mileage according to capacity-related and pavement deficiencies for urban and rural facilities and alignment deficiencies for rural facilities based on specified minimum tolerable conditions (MTC). The system is not capable of selecting alternative repair strategies having identified a deficiency, but can provide an impact analysis of delayed pavement improvements due to limited funding during a particular year.

A number of studies have examined the output of the HPMS and the validity of the AASHO Road Test data. Recent evaluations [Fwa, 1990] of the analytical form of the AASHO equations indicate that the pavement performance curves (i.e., PSI versus time as a function of ESAL) can take on different shapes depending on the pavement structural number, pavement type, and rate of application of ESAL's.

An earlier sensitivity analysis report [FHWA, 1988] indicates that the system output is affected greatly by the present pavement condition and the current and future annual average daily traffic (AADT) and to a lesser extent, by the pavement deterioration rate. However, the deterioration rate has a greater significance when a longer analysis period is considered. The report also indicates that changes in the MTC's specified in the analyses did significantly change the system output of needs or costs of improvements and to a lesser extent the improvement mileage. The greatest change occurred with MTC for resurfacing and reconstruction.

Additional analyses of the AASHO data indicate that the equations correlate well with the road test data itself but do not "predict the damage due to mixed traffic on in-service highways," as well as other equations based on different environmental and traffic data [FHWA, 1984]. New York, however, performed a correlation study [Hartgen, 1986] between the HPMS and state results that indicated comparable distributions of pavement conditions for the same pavement section.

4.0 IDENTIFICATION OF THE CURRENT RES ORGANIZATION AND USE

The current organization and use of the RES database was identified through a review of the RES documentation provided by SDDOT and through interviews with SDDOT personnel. Ten files were identified as key files in the RES system.

1. Traffic Inventory
2. Roadway Features Inventory
3. Intersection Inventory
4. Sufficiency Inventory
5. Dynaflect, Roughometer, and Pavement Friction (DRS) Inventories
6. Maintenance Cost Inventory
7. Bridge System Inventory
8. Railroad Crossing Inventory
9. Mileage Reference Marker Inventory
10. Highway Planning Inventory

The first nine files are the master files that comprise the RES database. Each of these master files contains point-based information that is collected on a periodic basis. The additional key file, the Highway Planning Inventory file, is not categorized as a master file as its contents are derived from various data items contained in the nine RES master database files and contains information that has been consolidated to specific roadway segments.

The User's Manual and Coding Manual for each of the RES master database files and the Highway Planning Inventory file were reviewed. Additional relevant South Dakota Department of Transportation documents that were provided included the following:

- SDDOT Highway Numbering Policy
- SDDOT Highway Mileage Reference Marker Policy Manual
- South Dakota Pavement Management System [Kietzmann, 1985]
- File layouts for each of the 10 files identified above

A number of key database features were considered in the review of the current RES database organization and use.

- Internal Organization
- User Interfaces
- Data Processing Capabilities

- Maintenance and Management Procedures
- System Hardware

The key observations related to each of the above database and database management system features are summarized in Sections 4.1 through 4.5.

4.1 INTERNAL ORGANIZATION

The contents of each of the ten key files were identified from the information provided in the coding manuals and the file layouts. Various information about each data item in the files was determined, including a description of the data item, the data type and format of the item, the location of the data within the file records, and the range or limits of the data item. Brief descriptions of the data items contained in each of the nine RES master database files and the Highway Planning Inventory file are given in Tables A-1 through A-10 in Appendix A.

In addition to the contents of the RES files, the overall structure of the RES files was determined. With a few exceptions, most of the RES files are Virtual Sequential Access Mode (VSAM) files with a common index key. The index key for the files is defined as follows:

Data Class	Highway Number	MRM	Displacement

where

Data Item	Description	No. of Bytes
Data Class	Integer flag (1-4) indicating whether the highway is a state, county, city, or federal domain road.	1
Highway Number	A 3-digit highway number, and a 3-digit suffix which indicates the type of road.	6
Mileage Reference Marker	The physical mileage reference marker (MRM) for the data record coded as a 3 digit number followed by 2 decimal places.	5
Displacement	Distance from the MRM measured in thousandths of a mile.	5

Most of the RES data files are formatted files where specific data items have a fixed number of bytes and a specified byte position within a record. The RES files that are exceptions include the Bridge Inventory and the Railroad Crossing

Inventory files. These two files are ADABAS[1] files. The files are structured in a hierarchical database and a NATURAL[2] language query interface is provided.

An important factor in the organization of the RES files is that the data in all the RES database master files are keyed to a Mileage Reference Marker (MRM) plus a displacement. This provides a common data item to which all of the RES files can be linked.

Other than the common key data items, the RES files contain very little duplication of information between files. An exception to this case is the Highway Planning Inventory file. The Highway Planning Inventory is generated by data collector programs from various data items contained in the nine RES master database files.

An additional file, called the RES ALL-DATA file, is also generated from the other RES files. The ALL-DATA file is also an ADABAS file where on-line query is available to the users through the NATURAL language.

4.2 USER INTERFACES

User interface to the data is generally provided in a batch-oriented environment. Special purpose computer programs have been written to provide the user access to add new data or manipulate existing data, as well as to generate formatted output listings of the data. These batch jobs are either submitted directly by the user using special job control commands which are documented in the user's manual or through a formal request (Job Request Form) submitted to the central data processing department.

On-line screen access to data is available only for the Traffic Inventory, MRM Inventory, Bridge Inventory, Railroad Crossing Inventory, and Highway Planning Inventory files. The Bridge, Railroad, and Highway Planning Inventories are maintained as ADABAS files and on-line screen query is available through the NATURAL Language Interface.

4.3 DATA PROCESSING CAPABILITIES

For most of the RES files, a set of batch-oriented computer programs has been written to satisfy the user requirements for data manipulation and input/output of data. The User's Manuals for the RES database master files document each of these special purpose computer programs. Specifically, batch jobs provide for adding new data, editing or deleting data, creating backup copies of the files, creating special auxiliary files, or simply listing the existing data.

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[1]ADABAS is a registered trademark of Software AG Inc.

[2]NATURAL is a registered trademark of Software Ag Inc.

The available documentation for the RES files was reviewed to identify the relationship between the specific RES database master files and associated auxiliary processing jobs and auxiliary files. Input for the data processing jobs is generally provided in input records with pre-defined formats. In some cases, input records for specific jobs are created though a structure of user-generated files maintained in a PANVALET library. Some files in the PANVALET library are generated through other auxiliary processing jobs. The input files have specific names which are "hard-coded" into the computer program or specified in the control language interface for each job.

If a user has a requirement for a data operation that is outside the scope of the set of pre-written computer programs for a particular RES file, a request for writing a new computer program is sent to the data services department. This process historically requires a substantial amount of turn-around time.

4.4 MAINTENANCE AND MANAGEMENT PROCEDURES

Updates to the RES files are performed on a scheduled basis as new data become available. Some updates may be performed on an annual basis while others are updated more frequently. Data entry personnel perform these updates using the special purpose computer programs and structured input records.

Maintenance of some existing data is performed in a multi-step process. The first step checks the data and reports error messages. The user then corrects the input and re-runs the data checking phase until no errors are reported. The actual updating of the RES master file occurs in a final phase. A backup file of the previous RES file is maintained when the file is updated. Only a few of these backup copies are kept at a time before they are overwritten. These backup copies are available to restore the previous version of a file if necessary.

Archiving of ADABAS and system file data is performed on a weekly basis under the control of the central data processing department. These archives are short-term, where an old archive copy is written over during a subsequent archive within a few archive cycles.

Other file backups are performed by the users on a scheduled or as-needed basis. These file backups are maintained off-line on tape and are available to restore a file to disk if corruption of the existing disk copy occurs. Previous backup versions are maintained on a limited basis.

No protection mechanism exists for preventing unauthorized use or manipulation of data. Anyone with access to the internal structure information of a data file can gain access to the RES data file and perform an update function which may or may not be authorized. Concurrent updates of the same RES file is not a problem because the control language provides for locking a file from other user access while it is being accessed by one user for updates.

4.5 SYSTEM HARDWARE

The existing RES data files are maintained on the state's central mainframe IBM 3090 computer. The mainframe computer uses the MVS/ESA operating system environment. Individual user access is provided via personal computers (PC's) connected to the central mainframe as terminals through an IBM token-ring network or via dumb terminals. Several servers are located throughout the departments to provide a gateway to the network. Most of the individual PC's are Intel-286 IBM-compatible computers running the DOS operating system.

The central mainframe 3090 computer has many mass storage devices including fixed disk drives and removable devices. Discussions with SDDOT personnel indicate that the performance of the mainframe is sufficient both for current needs and anticipated growth.

5.0 EVALUATION OF EXISTING RES DATABASE

An overall evaluation of the existing RES file system was performed to identify its strengths and weaknesses with regard to implementing a historical database. Key factors that were considered in this evaluation included:

- The availability of data required to implement evolving historically based pavement management techniques.
- The flexibility of the current system's maintenance procedures with regard to modifying the underlying data structure and user access to the data, as well as with regard to the portability of the RES system between computer operating systems and hardware platforms.
- The ease with which the users can access data in the RES database.

As shown in Table 5-1, the evaluation revealed several key observations related to the content and functionality of the current RES database. Although the current RES database contains the majority of the data items required by a historically based pavement management system, past history on these data items is limited and the current database management system does not provide the desired functionality and flexibility that will be required to implement and maintain a historical database and subsequent historically based pavement management system.

The following Sections 5.1 through 5.3 summarize the observations that were noted with regard to each of these factors.

5.1 AVAILABILITY OF DATA

With regard to the data items that are available in the RES database, the strengths of the current system are readily apparent. The database contains a broad range of data that are complementary to the application of historically based pavement management techniques that are evolving (See Table 5-2). The data that are currently collected include such data items as annual pavement evaluations and ratings, roadway features, highway use statistics, and maintenance information; all key data items in a historically based PMS. The data are collected in a timely and organized manner; a key factor in developing and maintaining a database that will accurately reflect the current state of the road system, as well as provide a key building block for a historically based database.

Additionally, the organization of the current data is such that the transfer of existing data into a new database structure would not be a difficult process. The documentation of the current RES database provides excellent visibility of the structure and content of the current database.

Table 5-1. Evaluation of Current Roadway Environmental Subsystem (RES) Database.

Evaluation Criteria	Identified Strengths	Identified Weaknesses
Availability of Data:	• Time of field data collection is archived. • Suite of collected data is very complete. • Data duplication between RES master files is limited. • MRM system identifies number of highway lanes. • Index key based on MRM provides common link between files.	• Available data history is limited. • Soil property data is limited. • Data consistency and integrity between RES files and highway planning file is questionable. • Lane-specific data can not be stored. • Index key does not uniquely identify a given point in space over time.
Ease of Maintenance:	• Underlying data structure is well documented. • Segregation of data is well documented. • Well documented archival system is available.	• 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:	• Anticipated access patterns are reflected in RES file organization. • Retrieval for established access patterns is efficient. • Segregation of data is well documented.	• Access is batch-oriented and effectively inflexible. • Retrieval of non-routine data requires interface code development. • Access to data from multiple files requires interface code.

Table 5-2. Pavement Performance-Related Data Items Currently in RES Database

Traffic Inventory:	
TRA-DIR-DIST	Directional traffic distribution
TRA-PERC-TRUCKS	Percent truck traffic
TRA-CUR-ADT	Current average daily traffic
TRA-ADT-DATE	Date of adt measurement
Roadway Features Inventory:	
ALL DATA	All roadbed lanes layer and roadbed shoulder layer information (FEA-76 through FEA-80), and soil information (FEA-81 and 82) including soil CBR
Sufficiency Inventory:	
SUF-RATING-DATE	3 items
SUF-CONDITION	7 items
SUF-R	Rideability
SUF-UPDATE	Sufficiency rating date (3 items)
Dynaflect, Roughometer, and Skid (DRS) Inventory:	
RUT DEPTH DATA	Includes test date, lane code, and average rut depth
DYNAFLECT DATA	Includes test date, lane code, pavement temperature, pavement type, time of test, seasonal correction, deflection data for 2 sensors, and corrected deflection
ROUGHOMETER DATA	Includes test date, lane code, and average roughness index
SKID DATA	Includes test date, lane code, test speed, air temperature, and corrected and uncorrected skid numbers
Maintenance Inventory:	
MAI-FUNCTION	Function code for type of work performed
MAI-PROJ-TYPE	Project type
MAI-QUANT	Quantity amounts
MAI-LABOR-COST	Labor cost per mile
MAI-EQUIP-COST	Equipment cost per mile
MAI-MATERIAL-COST	Material cost per mile
MAI-CONTRACT-COST	Contract cost per mile

However, when considering the current system with regard to the implementation of a historical database and use of historically based pavement management techniques, a number of weaknesses are also apparent. These weaknesses relate to the availability of several key data items and the manner in which the data are currently indexed.

- The index key, which is based on Mileage Reference Marker (MRM), does not uniquely identify data items in space over time. Since MRMs are sometimes moved during highway construction projects, the current indexing scheme does not ensure accuracy/relevancy of information over time.

- The absence of lane information in some data records is a potential weakness in the content of the data. Many times data collected are unique not only to a given location along a highway, but are also unique to a given lane of the highway.

- The database does not currently contain design, as-built, or construction information such as subgrade strength, construction materials (e.g., basecourse, asphalt grade, and quality), and cost. Although design and as-built data may be the same if inspection data match the design specifications, design information typically is developed from a reduced set of data collected from the field and may not reflect actual as-built conditions along an entire pavement segment. For example, engineering judgement must be practiced to design a pavement based on reasonable and cost-effective design principles, and a pavement is typically designed for neither the weakest nor the strongest soil support conditions. Comparison of design versus actual "as-built" field-collected data would provide a means of determining whether localized sections of pavement that are performing below the average for a pavement segment are located over soils that are weaker than design subgrade strength. This information may be important to identify the "correct" performance of the pavement.

  Variation of construction material properties is another factor that contributes to variability of pavement performance. Since it is not feasible to expect that every truck load of asphalt concrete or other construction materials be inspected and certified to meet design specifications, some sections of a construction project may be at minimum or below specifications. The determination of material properties on sections of pavement that are performing poorly could identify quality control problems and may provide discriminating information that is important in grouping pavements for correlation and model verification.

- Although California Bearing Ratio (CBR) data are currently included in the RES database, additional soil information (subgrade moisture content, USCS soil classification, percent fine material, and clay content) has been identified as a potential enhancement that could provide key information critical to pavement analysis techniques and provide possible insight to be considered in future highway construction plans.

- Inconsistencies may exist between the data contained in the nine RES master database files and data contained in the Highway Planning Inventory file, a key RES output file upon which SDDOT's decisions for needed repairs and improvements are based.

- In general, the most significant weakness with regard to data availability is the fact that historical information about South Dakota's highway system is not available. Presently, only 1 year's data may be accessed through developed programs and the application of analysis techniques that require data over a period of time is either not possible because historical information is not available or is time-consuming. An exception is the maintenance cost data which is currently saved for 10 years. A critical part of the use of historical data is the availability of the data for analysis.

Because of the short time that historically based pavement management systems have been in use, it was not possible to gather sufficient information to establish a clear basis for excluding any specific pavement performance data items currently being collected by the SDDOT. The utility of historical information is still being investigated, and there is no current standard set of specific data items that has been accepted for widespread use in historically based pavement management systems. Although the types of historical data being used in pavement management activities by the states investigated do not differ significantly, each state highway department has included in its pavement management system unique (but comparable) data items that it believes accurately represents the performance of the state's pavements.

Further evaluation of the value of specific data items with respect to pavement performance models that may be adopted by the SDDOT is required before specific data items can be critically reviewed for appropriateness for a historical database specific to South Dakota.

5.2 EASE OF MAINTENANCE

The underlying data structure and the associated data management capabilities of the current RES system do not provide the extensibility and flexibility that is required to efficiently maintain a statewide transportation database that is continually changing as new data collection techniques and data analysis techniques are implemented.

- The current system does not allow for ease of modification of the underlying data structure to add new data items or to delete obsolete data items. Modifications of the underlying data structure involve code rewrites and in most cases many different programs are involved. Effectively, the current data structure is nonflexible.

- The majority of the RES database files are structured as formatted files with each data item occupying a fixed location within a defined record structure.

Access to any given data item requires knowledge of the contents of the different data files, as well as the record formats within the data files. As a result, many different programs have been written to address the data items within each record type. A functional change in user access to the underlying data currently requires the submittal of a request to write a new program to address the new user requirement. Effectively, the current user interface is nonflexible.

- Similarly, the ease with which data can be moved to another operating system environment because of software or hardware upgrades is also an important maintenance factor considering the evolving trend toward distributed databases. Porting the current RES system to a new hardware or software platform could potentially involve many different files and many different programs.

Although the current RES database was state of the art when it was implemented in the 1970's, it does not provide enhancements in data management and user access that are inherent in contemporary database structures and database management systems.

5.3 EASE OF USER ACCESS

The RES file system user interface methods were evaluated with regard to the ease with which the user can access the data in the RES database. Key considerations included the system response time to user queries, the friendliness of the user interfaces, and the ease of data access for use in analyses.

With the exception of the Bridge and Railroad Crossing Inventory files, the RES file system user access is primarily through a system of existing batch auxiliary programs that are submitted by the user. These auxiliary programs, documented in the RES System User's Manuals, provide the only user access that is currently available to these RES data files. A functional change in user access to a file currently requires submittal of a request to write a new batch program to address the new user requirement.

Access to the Bridge and Railroad Crossing Inventory files, which are structured database files, differs in that the ADABAS software environment provides a user query through the NATURAL language. While the access to the data in these files is in keeping with current fourth-generation language (4GL) technology, the file structure and access methodology is not consistent with the other RES data files and can lead to user confusion due to different training requirements.

The structure of the current RES database does not provide ready access to data items from multiple database files. The use of data analysis techniques that require cross-correlation of data items across multiple RES database files is complex and requires an in-depth knowledge of the underlying data structure.

6.0 CONCEPTUAL HISTORICAL DATABASE DESIGN

RE/SPEC Inc. recommends the development of a distributed relational database design which will provide a basis for SDDOT's data and computational requirements into the next century (See Figure 6-1). While the existing system has been taken into account, it has been our experience that a system design which leans toward industry standards provides the most flexible and lasting solution. The existing RES was a state-of-the-art system when it was implemented in the mid-1970's, but the flexibility and extensibility expected and required in today's computing environment are simply not built into the RES.

We recommend that the SDDOT IBM 3090 mainframe serve as the host machine for the DB2 RDBMS. The actual data, as well as the database server process, will reside on the 3090. The database server receives all requests for data, performs the required query against the database, and returns the data which satisfy the request to the client process. The client process could be active on the 3090, a PC, a Macintosh, or some other workstation which is connected to the 3090 via a standard protocol such as TCP/IP protocol on an Ethernet Local Area Network (LAN). This client-server approach would help to address the issues of data integrity and consistency, as well as provide a basis for an extension to a truly distributed computing and database environment in the future.

6.1 OVERVIEW OF SYSTEM REQUIREMENTS

A DBMS, network hardware and software, and application developer tools will be required for the implementation of the database design. Each of these items are available commercially.

- *DBMS.* The first software package which must be chosen is the DBMS for the server machine. We recommend the commercial package DB2[1] for two reasons:
  - DB2 is a truly relational DBMS.
  - DB2 is the recognized RDBMS of choice for the IBM mainframe environment.

  Once the server software has been selected, this narrows the choice for the software development tools for the client application.

- *Network Hardware and Software.* The server and client machines must be networked in such a way that the application software can access the database

[1] DB2 is a registered trademark of IBM Corporation.

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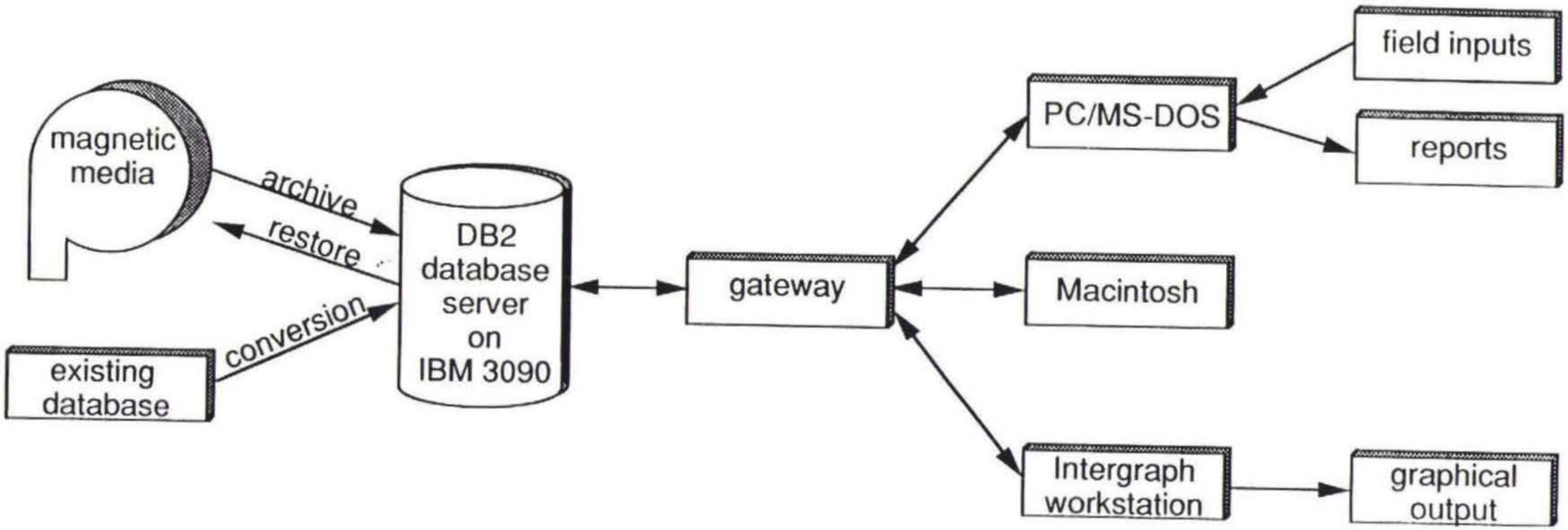

Figure 6-1. Detailed Physical Layout for Conceptual Design.

in a transparent manner; that is, as if the database server were running on the client machine.

- The network hardware should be compatible with a wide variety of system configurations to provide the connectivity required to enable generalized growth to occur in a heterogeneous computing environment. The current coverage provided by Token Ring does not provide this connectivity. The current network hardware of choice for this environment is Ethernet. This will require the purchase of an Ethernet controller for the IBM 3090 such as the Fibronics controller. This constrains the protocol selection which in turn constrains the choice of software development tools.
- Many database application software development tools work in conjunction with specialized database network software which can be installed over a specific set of protocol software. We propose the use of the TCP/IP protocol because it is the industry standard for heterogeneous computer network environments and several software development tools are available to develop applications for use across such a network.
- Each PC would also require Sun PC/NFS which includes the TCP/IP product for a forms-based application. For a windows-based application, each PC would require software to enable the existing PC's to emulate an X-terminal.

• *Application Developer Tools.* There are several criteria to be considered in the selection of software development tools.

  - These tools must be able to interface with a DB2 database transparently.
  - The software developed using these tools should be directly portable to a wide variety of possible platforms which may include IBM-compatible PC's running MS-DOS, Macintoshes, and UNIX-based workstations.
  - The tools must be integrated with database networking software which will allow access across the network to the target database on the 3090.

  Although our review of database application development tools resulted in none that entirely fulfill all of these requirements at this time, there are three options which fulfill the majority of them.

  - Information Builders Inc. provides a suite of products (FOCNET[2] and FOCUS) which provide an environment in which MS-DOS clients may access a DB2 database provided that an OS/2 machine running Extended Edition (2.1) serves as the gateway machine on the LAN. However, FOCUS is currently not available on the Macintosh and its UNIX connectivity does not yet fully support distributed applications.

[2]FOCNET and FOCUS and registered trademarks of Information Builders, Inc.

- Using the INGRES suite of products, one could develop a forms-driven application for use on the PC's, several UNIX-based machines, and VAX/VMS, but not on the Macintosh.
- Moving to the true state of the art, INGRES[3] also has a windows-based fourth generation language (Windows/4GL) which could be used on a UNIX-based host providing a gateway via Ethernet and the INGRES/NET product to DB2 on the IBM 3090. The MS-DOS PC's would function as X-terminals in such a scenario. The Windows/4GL product for the Macintosh is currently in development and is scheduled for release in mid 1991.

We recommend the use of a windows-based 4th generation language (such as INGRES Windows/4GL) to implement a custom user interface for the historical SDDOT database. This type of interface would provide the best basis for growth into the next century.

6.2 KEY ISSUES IN THE CONCEPTUAL DESIGN

Through the evaluation of SDDOT's existing database (RES), we have identified several key issues which have impacted the development of the conceptual historical database design. These are summarized in the following sections:

6.2.1 Adaptive Capability

The major limitations in the RES with respect to storage and retrieval of information are that it is very difficult to add/delete/change data attributes in the overall schema of the RES. It requires extensive knowledge of the underlying physical structure of the database and programming effort is required to extract and correlate information in a new way.

The addition of information to the RES, as well as the use of new analysis techniques on a trial basis, is inhibited. Hence, the conceptual historical database design must add flexibility and extensibility.

6.2.2 Key Index

The existing key mechanism in the RES, the MRM, has a major drawback in that it does not uniquely identify a given point in space over time. If historical data are to be integrated into SDDOT's PMS, the key mechanism must be able to handle this. In addition, the current MRM system identifies the number of lanes in a road, but it does not allow for keeping distinct data values for different lanes. This has been identified as useful information. In the current system, both underlying RES

[3]INGRES is a registered trademark of Ingres Division of ASK Corporation.

information and derived segment-based planning information are stored. Although this redundancy has not posed a storage problem, consistency problems have become apparent and storage may pose a problem as historical information accumulate. The conceptual design addresses both consistency and storage considerations.

6.2.3 Data Requirements

Elements of information have been identified that the SDDOT believes would improve their pavement management capabilities, but which are not captured in the RES. One of these is soil properties data. Design, as-built, and construction information are currently maintained by SDDOT, but not in a computer useable format. These data are considered in the current effort. Another type of information which is currently being collected via ROAD-VIEW (a Macintosh-based video imaging system), is the video catalog of the roads. An integrated solution to address all of the data needs of the department is to be chosen over the development of several islands of information which cannot be integrated. Hence, although this effort is directed at providing a historical database system, the provision for future software integration with the ROAD-VIEW database should be integrated in the functional specification and detailed design. This implies that the use of a DBMS with a standard query language interface is of utmost importance. Our investigation concentrated on historical data as it relates to pavement management systems, other uses of historical data have not been fully investigated. A thorough investigation of all potential uses of historical data should be included in the first phase of a detailed specification and design prior to implementation of a historical database system.

6.3 SYSTEM ANALYSIS

With the issues described in the previous section in mind, the conceptual design proceeded with a system analysis in which the following were investigated:

- Elements of Data
- Type of DBMS
- Specific DBMS Options

This concluded with a DBMS recommendation. Our system analysis is detailed in the following subsections.

6.3.1 Elements of Data

The data which are currently available in the RES must also be available in the new system with the added capability of keeping historical records of some of the data attributes on-line. Soil properties data are also included in the schema, as are design, construction, and as-built specifications. A way of uniquely identifying a given point in space must be included in the data schema, as well as a mapping from that key into the existing MRM structure. Several alternatives are available for that key:

- (latitude, longitude, altitude) or another (x, y, z) scheme
- A mileage metric with the far Southwest corner of the state designated as (0, 0, 0)

A simple (x, y) key would be sufficient unless two points on a given road have the same (x, y) coordinate location. The only situation that was identified where this may potentially occur is where an interstate intersection involves multilevel on/off ramps. The recommended approach includes the third coordinate to provide a design that is consistent with current trends in advancing technology.

The accuracy of the (x, y, z) coordinates is not an issue until coordinate based applications are integrated with the RES database. For the purpose of data indexing, the (x, y, z) coordinates need only be defined in sufficient detail to accurately define a unique data record. Once coordinate based applications (such as mapping systems) are integrated with the RES, the accuracy of the coordinates will be driven by the accuracy required by the applications. At the present time, SDDOT does not use altitude in any of its graphical applications and it can simply be defined globally as an arbitrary value. Ultimately, the use of a Global Positioning System (GPS) is the method of choice for defining all three coordinates.

Until GPS becomes available, it is recommended that the current (x, y) coordinate system used in SDDOT's mapping operations be used to estimate coordinates. This would allow near-term integration of the mapping system but would preclude integration of any applications requiring an elevation. Data collected based on route and MRM would be translated to the coordinate system during the data entry process.

Another major issue with respect to data entities is the handling of the Highway Planning Inventory file data. Data in the planning file are not technically part of the RES, but they are the main source of information for SDDOT planning and analyses. The planning file data are derived from the data in the actual RES. Several aspects of this issue must be addressed.

- Are the derived data to be stored explicitly in the database or should they be derived as needed. Storing derived data minimizes access time, but introduces a plethora of data integrity and consistency issues. Deriving those data as needed solves the data integrity and consistency issues, but, since the majority of the analyses are run against the derived data, the increased retrieval time is probably unacceptable.

- Data elements in the planning file have traditionally been modified within certain set tolerances for the purposes of pavement management analyses. This has produced a situation in which data used for planning purposes are not directly traceable from the data in the RES. This aspect may be addressed in several ways.
  - One approach would be to disallow any modification of derived data. In this way, all derived data would be immediately reproducible from the base data in the RES for a given time.
  - A second approach would be to allow modification within some tolerance, but to require that a record be kept of this change to the derived data which would indicate exactly which datum was changed, who made the change, the value of the change (±value), and the effective date of the change. This approach would preserve traceability as well as flexibility for the engineers.

  If the second approach is to be implemented, allowable tolerances would have to be determined for each of the data elements to be stored in the historical database system and these tolerances must be enforced by the application software or by knowledge management features in the DBMS.

6.3.2 Type of DBMS

There are three approaches (or data models) used in commercial DBMS's:

- Relational
- Network
- Hierarchical

These approaches can best be compared by evaluating them according to ease of use as well as efficiency of implementation. It should be noted that the current RES uses a mixture of ADABAS (a network model DBMS) and structured files managed by custom COBOL software.

6.3.2.1 Ease of Use

With regard to ease of use, the relational approach is indubitably 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. On the other hand, *"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].

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

6.3.2.2 Efficiency of Implementation

With regard to efficiency, the implementations of the network and hierarchical approaches outperformed the early implementations of the relational approach, especially for queries for which the database had been specifically designed. However, since 1980 many of the physical functions from those two approaches have been incorporated into the relational approach [Date, 1981]. In addition, query optimizers have been developed which greatly improve query performance. For example, if a cross correlation is desired between two distinct attributes in two different relations for a few MRMs, the straightforward relational algebra approach would be to perform the entire cross-product of the two relations involved, and then select only those for which the MRMs are equal and match the desired MRMs. The more efficient approach is to first select the attributes for the given MRMs from one relation and then join them with the attributes with matching MRMs from the other relation.

6.3.2.3 Recommended Type of DBMS

We conclude that the relational approach for DBMS's is preferable since it provides much more flexibility and extensibility than the network or hierarchical approaches and is easier to use. 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. In assessing the long-term use of the DBMS, as well as providing a component which could be easily integrated into a comprehensive pavement management system, it would be preferable to proceed with a Relational Database Management System (RDBMS) using a standard query language such as the ANSI standard structured query language, SQL.

6.3.3 Specific DBMS Options

In the current software climate, it would be more beneficial to develop a custom software interface on top of a commercially vended RDBMS. This would dramatically reduce the development and maintenance time and costs for this effort as well as provide that functionality across the South Dakota state government for other software development. The ANSI standard Structured Query Language (SQL) is available on several vended products. Although it is beyond the scope of this conceptual design to actually select such a product, we present several software options in Sections 6.3.3.1 through 6.3.3.4.

6.3.3.1 Custom DBMS

The bulk of the current RES is essentially implemented as a custom DBMS. These are VSAM files which are manipulated through custom software written in COBOL and maintained by the South Dakota Data Processing Department. The obvious benefit of this system is that it most efficiently implements those data requirements and user functionalities specified in the original system specification. However, new functionalities or data requirements are very difficult to integrate into such a system. Either new file types must be introduced with corresponding software to manipulate them, or existing file structures must be modified and all software that accesses these files must be modified to handle the new structure. In order to correlate data attributes which reside in distinct files, a special program must be written which scans the distinct files and extracts data according to the specified correlation. Any such effort is typically handled by a data processing department because of the complexity of the software required. Due to the backlog of work in most data processing departments, many engineers simply do not perform all analyses in which they are interested because of the time lag to get the requisite data.

Conclusion: The custom software solution is not acceptable due to its lack of flexibility and extensibility. Although a completely custom software DBMS could be developed which would provide the flexibility desired, the effort required would not be cost effective.

6.3.3.2 ADABAS

Although ADABAS is a DBMS based on the network approach for storage and retrieval of information, it is included in this evaluation because it is currently available on the South Dakota 3090 mainframe and several of the RES data files are currently in the ADABAS format. Software AG has introduced an SQL-based interface to ADABAS which provides a relational look and feel to the end-user, but this does not address the issues of the intrinsic inflexibility of the network approach. Another shortcoming of ADABAS is that there are very few heterogeneous DBMS access tools which function against ADABAS. In our research we only found three outside of Software AG's NATURAL proprietary access tool: On-Line Software's Ramis, Sterling Software Answer Systems Division's Micro/Answer II, and Sterling Software Dylakor Division's DYL-280 II Relational. None of these products provide access across all of the platforms of interest.

Conclusion: Although an ADABAS solution may be the least expensive approach in the near term, the savings would be offset by the need for re-coding due to any major structural change to the database schema in the future. The need to provide an application which can be easily migrated to new computer platforms, especially for engineering analysis needs, is the other major factor in the rejection of ADABAS for this proposed effort.

6.3.3.3 ORACLE

Oracle is a commercial DBMS based on the relational model and is included in this analysis because it is a well known package with many of the same functions and characteristics as DB2 and INGRES. The Oracle set of functional software packages provide a good comparison for cost as well as functionality. It was found to be close in both categories to the front runners which provides a strong indication that the packages recommended in this study are reasonable in cost and front runners in database technology. The Oracle software set is available for most of the target system platforms.

The Oracle development tools for designing and implementing user interfaces and forms are not as high a quality as in DB2 and INGRES, for example. Additionally the capability to customize code interface to the forms function and to provide custom forms is more difficult with Oracle than with DB2 or INGRES.

Conclusion: Oracle as a DBMS option must continue to be considered throughout the off-the-shelf DBMS software selection process. However, it is our experience through many database application development projects that DB2 and INGRES have the superior products from a cost-benefit point of view.

6.3.3.4 DB2

DB2 is the recognized leader in RDBMS on the IBM mainframe platform. The vast majority of the heterogeneous database access tools which provide access to an IBM mainframe operating under MVS do so via DB2 [Carl, 1990]. It is a solid relational product and many distributed database products provide gateways to DB2 so that the DB2 databases may be integrated into an overall distributed database transparently. Hence, DB2 is the natural selection for an RDBMS on the IBM mainframe. There are several alternatives for application development tools which work in conjunction with DB2 [Bochenski, 1990]. Three such options are described as follows:

- *DB2 with IBM user interface tools.* IBM offers a host of user interface and application development tools for use in conjunction with their DB2 RDBMS.

The principle advantage of using the IBM tools is that the connectivity with the IBM RDBMS (DB2) should be accomplished with a minimum of additional hardware requirements and other glitches. The principle disadvantage is that the platforms on which the IBM tools are supported are severely restricted. Even among IBM platforms, the application development tools are not uniform. That is, the tools available on MS-DOS, OS/2, and MVS vary significantly. Hence, application portability would suffer if the IBM interface tools were to be used. The application developed would not provide a general solution to the SDDOT's user interface needs.

Conclusion: We do not recommend development of the proposed SDDOT historical database application using the IBM application development tools due to portability issues.

- *DB2 with FOCUS query tools via FOCNET.* Information Builders Inc. offers a robust product set including screen- and window-based 4th generation language, distributed processing capabilities, and expert system environments (LEVEL5).

  Conclusion: Even though the MS-DOS PC connection to the IBM 3090 via an OS/2 gateway machine is currently available, there is a lack of availability of some of the connectivity desired for the entire SDDOT project. The use of FOCNET and an OS/2 gateway would satisfy the majority of the SDDOT computing needs with a minimum of network configuration changes, but would not provide the basis for a move to more general workstation use and a distributed database approach.

- *DB2 with INGRES application development tools.* Ingres Division of ASK, Inc. provides a suite of DBMS tools including screen-based 4GL (ABF), window-based 4GL (Windows/4GL), networked database manager (INGRES/NET), distributed database manager (INGRES/STAR), knowledge manager, and object manager.

  Conclusion: The INGRES tools would require a UNIX-based gateway machine for full distributed processing via the MS-DOS PC's. This would satisfy the majority of the SDDOT's current needs as well as provide the networking basis for future growth.

6.3.4 DBMS Recommendation

The first step toward implementing the conceptual historical database design would be to select an RDBMS with an SQL interface and a windows-based user interface development kit which is compatible with the RDBMS. This system should have the capability of being networked such that the users could execute a custom software interface (from IBM-compatible PC's, Macintosh Workstations, or CAD Workstations) which provides the automatic communication with a database server resident on the state's IBM 3090 mainframe. With the information gathered thus far, our recommendation is the DB2 RDBMS on the IBM 3090 and INGRES Windows/4GL and INGRES/NET on a UNIX-based gateway machine or PC/FOCUS and FOCNET on an OS/2 gateway machine. In this way, the MS-DOS PC's could access the application as X-terminals to the gateway machine and fully participate in the client/server applications.

6.4 DEFINITION OF UNDERLYING DATA STRUCTURE

There are two ways of approaching a database schema:

- Logical Schema
- Physical Schema

The logical schema addresses how the data relate to each other logically while the physical schema addresses how the data are actually stored relative to each other. The logical schema is determined by how the data are intrinsically related as well as by the definition of repeating information. For example, as described in Table A-2 of Appendix A, the Federal-aid system designated way (FEA-14A), Federal-aid system traveled way (FEA-14B), State administrative system (FEA-14C), and Special systems code (FEA-14D) are intrinsically related to each other since they comprise the Highway system code (FEA-14). An example of repeating information would be historical traffic information for a given location. Clearly, the logical schema must separate the repeating information from the constant information for a given location to minimize redundancy.

The physical schema is determined by the logical schema, physical constraints of the DBMS, and expected user access patterns. Often the DBMS constrains the number of bytes in a given row. Hence, data which logically comprise one entity may be separated due to the row size limitation. On the other hand, there may be 1,010 characters of information in a logical entity of which 10 are used frequently in the selection of data and the other 1,000 are merely stored as a matter of historical record. The physical schema should separate those into two entities for optimal access to the database.

The issues involved in defining the structure of the underlying database are as follows:

- *What Precise Types of Data Need to be Stored?*

  Although many specific data requirements have been identified, it is apparent that the data management system must have the flexibility to add and delete data attributes with (relative) ease.

- *What Are the Anticipated Access Patterns?*

The anticipated access patterns are fairly well reflected in the organization of the RES. The RES organization will be a valuable resource in the development of the physical database schema for a historical database system. However, the design must proceed with the understanding that new access patterns are likely to emerge as the user community gains ease of access to the data.

- *What Are the Relationships Among the Data?*

  The relationships among the data are also well exploited in the RES. However, these relationships must be extended to encompass historical data as well as the new data needs which have been identified.

In the following subsections we present the proposed schema and discuss it in detail.

6.4.1 E/R Diagram and Preliminary Logical Schema

The logical schema can best be presented via the construction of an entity relation diagram (E/R diagram). E/R diagrams illustrate the entity types and the logical relationships between entities. The entities model the information which is to be stored in the database. This report contains the constructed preliminary E/R diagrams. These must be further analyzed to identify all of the attributes associated with each entity and to refine the entity type definitions as necessary. For example, entity types may be split to normalize relationships among attributes and entity types may be merged to gain retrieval efficiency.

Figures 6-2 and 6-3 present our high-level E/R diagram for a historical database schema which includes all of the information currently in the RES with the added capabilities of keying on the (x,y,z) coordinate of the location and of associating a date/time stamp with each data entity. The date in the form month/day/year is probably sufficient to provide a unique time stamp for each data entity. Any additional soil information requirements would be grouped with the soil data currently handled by the RES and illustrated in Figure 6-3. The E/R diagram in Figure 6-2 incorporates the need for lane differentiation for general traffic inventory information. Figure 6-4 presents the E/R diagram for the new entities required to have on-line access to all historical specification data. In addition to these entity types, a bookkeeping entity consisting of attributes which are normally invisible to the user such as Quality Assurance (QA) information may be added. A preliminary view of the planning information is detailed in the E/R diagrams in Figure 6-5. Several issues must be addressed relative to the planning information as the first phase of the detailed design. For example, the precise mechanism for linking the RES-keys for the base data to the segment identifier for the derived planning information must be defined. It may be advisable to use automated reasoning techniques to set up triggers to maintain consistency across the entire database, both the base and the derived data.

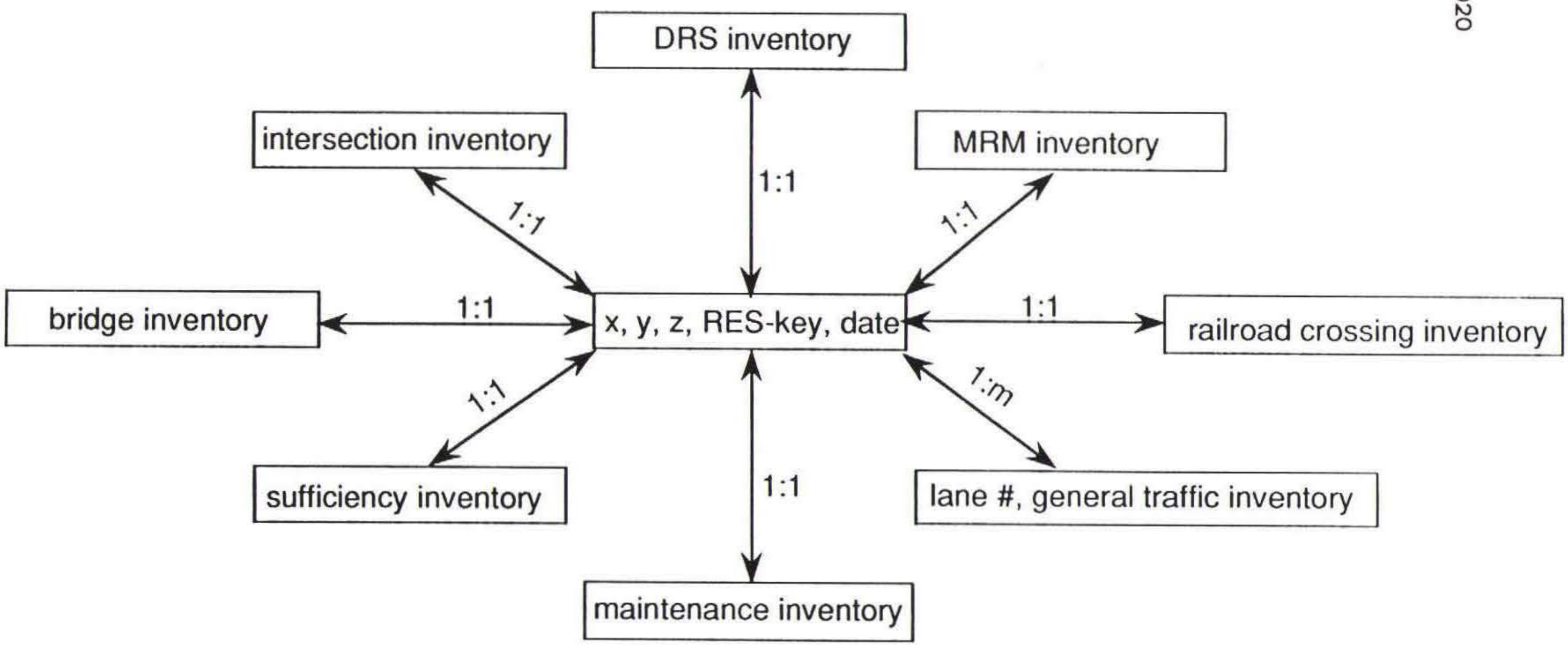

Figure 6-2. Miscellaneous Inventory Entity/Relationship Diagram.

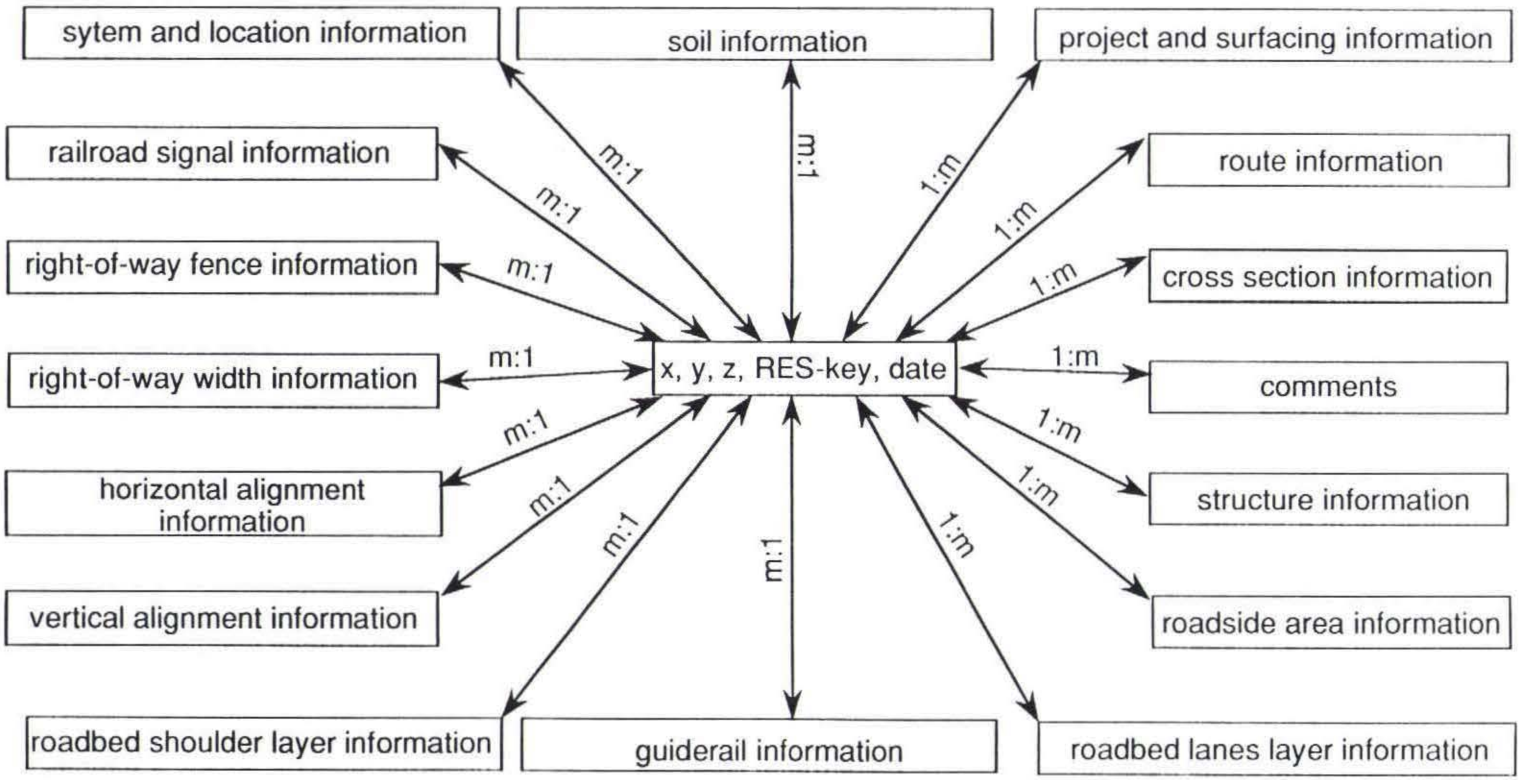

Figure 6-3. Roadway Features Inventory Entity/Relationship Diagram.

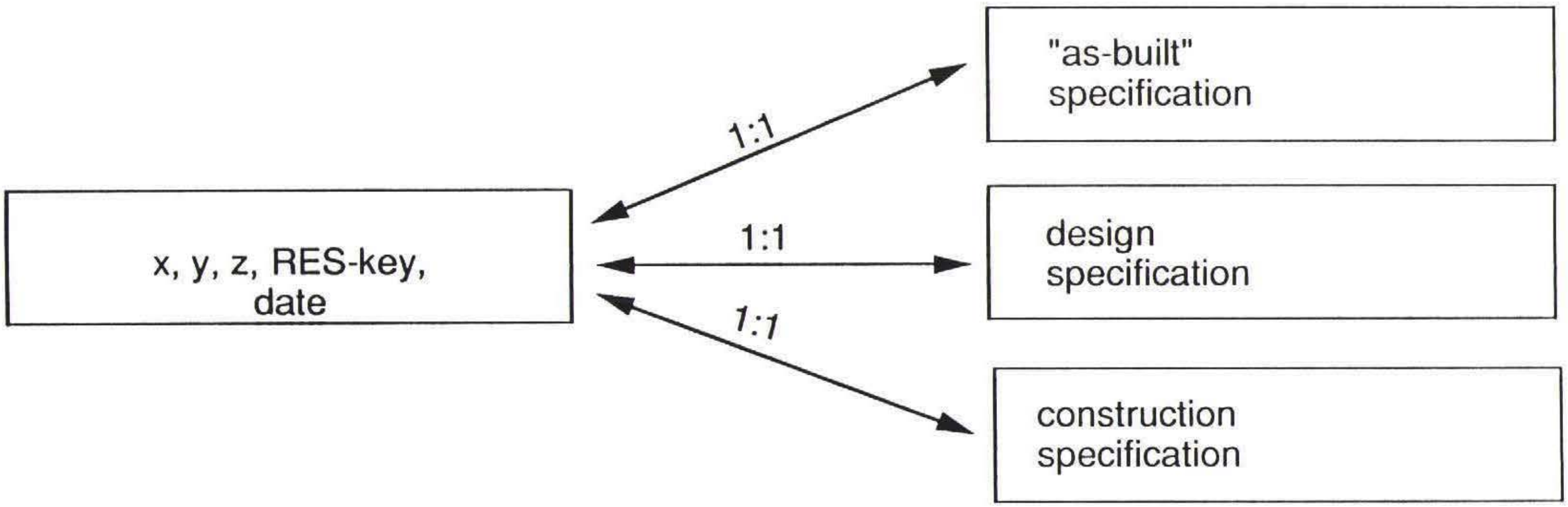

Figure 6-4. Recommended New Entities.

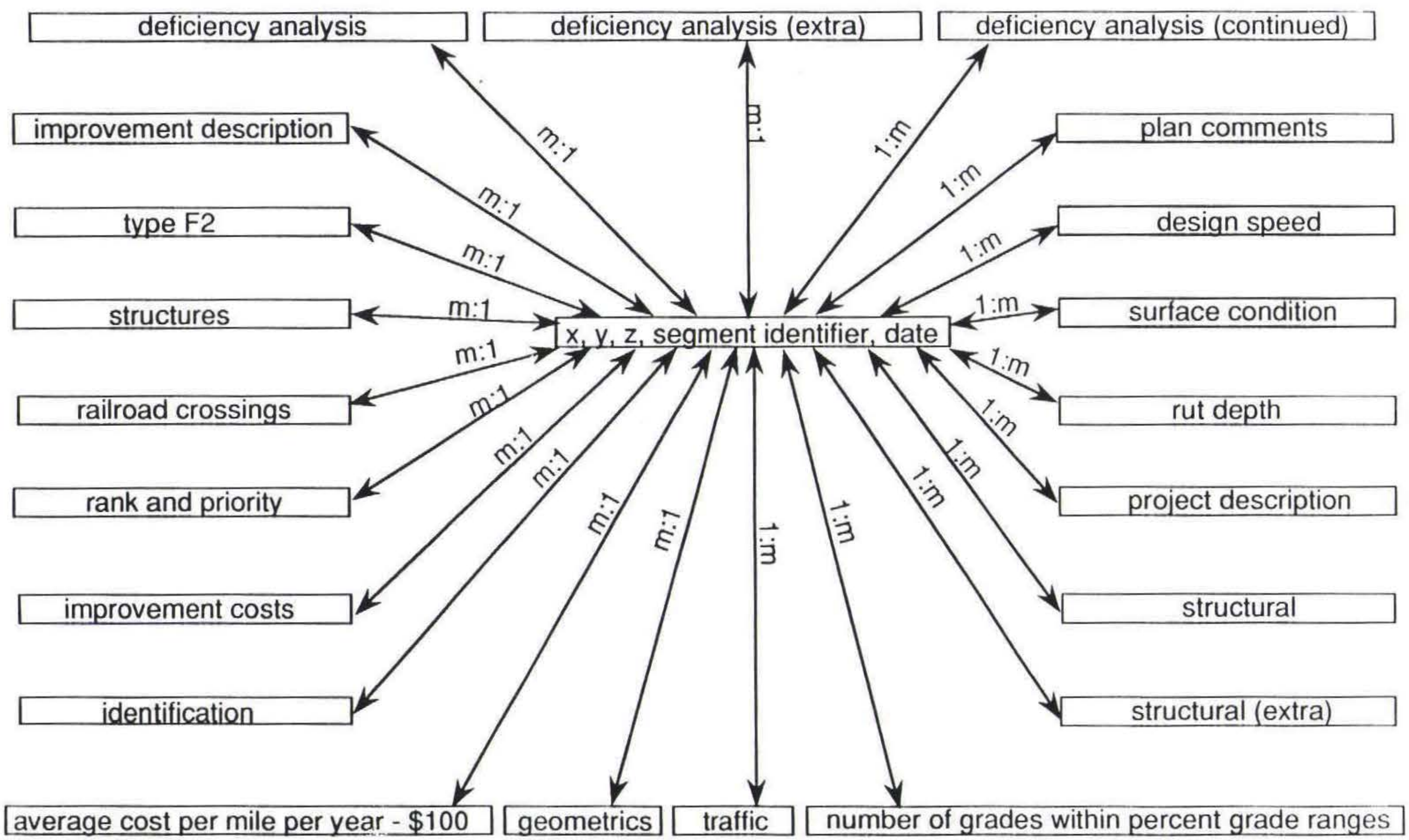

Figure 6-5. Highway Planning Inventory Entity/Relationship Diagram.

6.4.2 Logical Relationships

The E/R diagrams in Figures 6-2 through 6-5 illustrate the logical relationships between entity types. A functionality is associated with each relationship. There are three possible functionalities:

- A 1:1 (one-to-one) relationship between two entity types (say X and Y) means that each instance of the entity X is related to exactly one instance of entity Y, and vice versa.
- A 1:M (one-to-many) relationship between two entity types, X and Y, means that each instance of X is related to one or more instances of Y, and that each instance of Y is related to exactly one instance of X.
- A N:M (many-to-many) relationship between two entity types, X and Y, means that each instance of X is related to one or more instances of Y, and vice versa. There are no N:M relationships illustrated in the figures, but there are such logical relationships in this schema. For example, there may be more than one RES-keys for a given (x,y,z) location over time as well as traffic inventory information. Hence, the relationship between RES-key and traffic inventory is many-to-many.

6.4.3 Identification of Attributes and Relation Scheme Definitions

Data attributes associated with each database entry either identify the entry or provide historical information about the entry. All of the attributes currently represented in the RES must be included in the historical database schema. In addition, date and time stamps are to be associated with each entity. The RES-key is to be enhanced with an (x,y,z) coordinate location and a start date for that association. Construction specifications which are currently kept off-line are to be added in a summary form which will provide on-line access to the salient specifications while minimizing storage requirements. Using an RDBMS, it is possible to specify queries based on any stored information about an entry, whether it is considered key information or not. However, the schema will be designed and the indexing structures will be selected to optimize performance for the most common types of queries.

In Section 6.2.2, we discussed the deficiency in the current RES-key with regard to unique identification of a point in space over time. Hence, we propose an (x,y,z) coordinate key which is associated with a RES-key (based on the MRM) at a given point in time. This would provide an alternate indexing scheme whereby data can be retrieved either through a given MRM or a given (x,y,z) coordinate location. Data would continue to be collected based on the MRMs. During the initial phases of historical database development, the (x,y,z) coordinate key may contain only estimates of the actual coordinates without affecting the usefulness of the coordinate indexing scheme. In addition, this (x,y,z) coordinate key will allow the option for an easy conversion to a GIS system in the future. The inclusion of the date in the indexing scheme provides a means of storing historical information about a given location.

There are three possible values for data attribute fields.

- Some meaningful value may be assigned to the field.
- The field might not apply to a given entity. For example, soil information is not applicable to a segment of highway which consists of a bridge. Conversely, bridge information is not applicable to any portion of highway which is not a bridge.
- A null value may be assigned to a field meaning that a meaningful value could not be supplied for a particular entry. It is critical that the DBMS allow for null values. This can be illustrated by the following example. Suppose one would like to calculate the average roughness of a segment of road. If a value is not known for a given point in that segment, then it should be ignored in the average computation. However, if nulls are not handled by the DBMS, then the average computed would be based on some value for those points, perhaps 0. Although specialized code could be written to handle these cases, it would degrade performance and the resulting approach would be unnecessarily complex and counter-intuitive.

6.4.4 Physical Design

Although the details of the physical design are not visible to the ordinary user, they are critical to achieving good response time as well as efficient use of storage available. The logical schema presents the historical database as a single database, but the physical implementation may consist of several databases viewed as one through a distributed database. The primary candidate for a separate physical database is the planning information which is derived from the RES. As discussed previously, there are a plethora of issues surrounding the planning information.

- *Are the current planning data to be stored or derived on an as-needed basis?*

  It seems clear that the data must be stored to provide an acceptable response time.

- *Are modifications to the derived data which make them inconsistent with the base data to be allowed?*

  Likewise, should modifications to base data trigger a recalculation of the derived data? If the data are allowed to become inconsistent, issues of relevancy and traceability of the data must be raised. However, the planning engineers must be provided an environment in which they can work effectively.

- *Should historical records of derived data be maintained in the database or should that data be derived as needed with merely the current planning data stored on-line?*

Depending on the frequency of access to historical planning information and the resolution of the second issue, either alternative may be acceptable. (The resolution of the second issue will determine whether or not the planning information for a given point of time in the past can be derived reliably.)

There are, of course, advantages and disadvantages to both sides of these issues with related trade-offs. These issues must be resolved prior to the integration of the planning information into the physical schema.

It should be noted that long text fields should be minimized in the physical schema. Such fields are often loaded with critical information, but the information is buried in the midst of the long string. Retrievals based on partial matches of such text strings are typically slow since all of the attributes in the relation must be scanned to satisfy the query. On the other hand, if the relevant information is split into several small fields, retrievals can be specified and satisfied in an efficient manner.

Another important aspect of the physical design is the selection of primary storage structures and keys for each of the tables in the database, and secondary index storage structures and keys. These structures and keys have an enormous impact on the response time of the system to user queries. For example, suppose that the most common way of restricting queries to the database is via an MRM range. If we have a tree-structured index, such as Balanced-tree (B-tree) or Indexed Sequential Access Method (ISAM) on the MRM, then these common queries can be accomplished in logarithmic time (logarithm base m of n where n is the number of entries in the table to be searched, and m is the branching factor of tree storage structure). However, if no such index exists on the table, then a linear scan of all of the entries must be performed to find MRMs within the specified range. If n, the number of entries in the table, is small, this is of little consequence. But if n is large, the advantage of proper index structures becomes obvious.

6.4.5 Key Mechanisms in the Physical Schema

We have identified the (x,y,z) coordinate key for unique identification of a location over time, but it may not be practical to repeat the (x,y,z) key everywhere in the database for which unique location identification is required. Consider the following possible relations:

- DEFICIENCY_ANALYSIS(x, y, z, RES-key, date, deficiency analysis inventory)
- IMPROVEMENT_DESCRIPTION(x, y, z, RES-key, date, improvement description inventory)

One alternative to repeating the (x,y,z) coordinate and the date and time stamp is to associate the (x,y,z) coordinate key, the RES-key (including the MRM) and a date and time stamp with an integer surrogate key or point tag. This integer surrogate key would then be used in the repeated locations. This would be accomplished via the following types of relations:

- KEY_ASSOCIATION(x, y, z, RES-key, date, point-tag)
- DEFICIENCY_ANALYSIS(point-tag, deficiency analysis inventory)
- IMPROVEMENT_DESCRIPTION(point-tag, improvement description inventory)

It should be noted that surrogate keys would be invisible to the user with application software or DBMS views handling the link for the user.

This approach can also be used to address the technical aspects of how some data are associated with a particular point and some data are associated with a particular segment (i.e. a section of road with beginning and ending MRM). For this purpose, a relation could be set up to associate each segment to particular point locations (MRMs). Each segment tag would be defined by several point tags depending on the length of the segment. This segment to point association would be a one-to-many (1:M) relationship. For example, an arbitrary segment designation such as segment 5 could be associated with points 31 through 45. Then, the data that are associated with a segment of road would use the segment tag, and data that are associated with a given point would use the point tag. This would be accomplished via the following types of relations:

- SEGMENT_ASSOCIATION(point-tag, segment-tag)
- ROADWAY_WIDTH(segment-tag, width)
- RR_CROSSING_NUMBER(point-tag, number)

The issue of surrogate key generation must be addressed if they are to be used. In our experience, the best way to assign surrogate keys is to keep track of the highest integer key used so far as well as a free list of keys corresponding to entities which have been deleted from the database. When a new data entity is added to the database, first check the free list for available keys. If none are available on the free list, then increment the "highest so far" counter and use it. Although this scheme may introduce some problems on inserts into a table sorted on the surrogate key, its advantages outweigh its disadvantages and there are resolutions to the insertion problems. Other surrogate key schemes involve overly complex key assignment algorithms or scans of the entire KEY_ASSOCIATION relation to determine whether or not a candidate key is in use.

6.4.6 The Logical and Derived Analysis Workspace

The majority of the engineering access to the historical database would be to the derived planning information. We have discussed in previous sections the issues of storage versus as-needed derivation of the planning data. One issue that we have not addressed is the possible need for individual logical partitions of the workspace.

If modification of the derived data within certain tolerances is to be allowed, engineer Smith may modify a given value in the planning file by some factor, but engineer Jones may desire to modify that same value by another factor. In the interest of traceability of the analyses of both engineers Smith and Jones, both of their modified values must be stored. One way to handle this would be to identify an owner for each modified value in the database. Each engineer's logical view of the database would then be filtered by the application software. If the engineer owned a modified value, that is the one that he would see as the most recent value for a particular field. If the engineer did not own a modified value, then he would see the original derived value. The issue of whether one engineer may view another engineer's modified values must also be addressed.

6.5 USER AND ANALYSIS SOFTWARE INTERFACES

The recommended commercially vended software described in Section 6.3.3.4 provides elementary user access and reporting capabilities. However, in order to optimize the general user access to the database system, we recommend the development of a custom user interface based on the application development tools described in Section 6.3.3.4. There are general utilities which should be incorporated into this user interface effort which we discuss here. We illustrate a potential initial window frame for such an interface in Figure 6-6 and present its potential pull-down menus in the following discussion.

6.5.1 Inventory Input and Update Utilities

Although the majority of inventory data are collected in a manner suitable for batch loading of the data into the database, it would be appropriate to provide a window-based user interface for the database administrator (DBA) to initiate the load process. This would be especially advantageous because these loads are typically only performed once per year so a simple menu selection is preferred over expecting the DBA to remember some obscure sequence of commands.

In addition to the batch load, it would be appropriate to provide an interactive window-based utility to insert and update inventory data. Access to both the batch load and the interactive insert and update utilities must be restricted to provide appropriate levels of data security. A sample of inventory options which would be required is presented in Figure 6-7.

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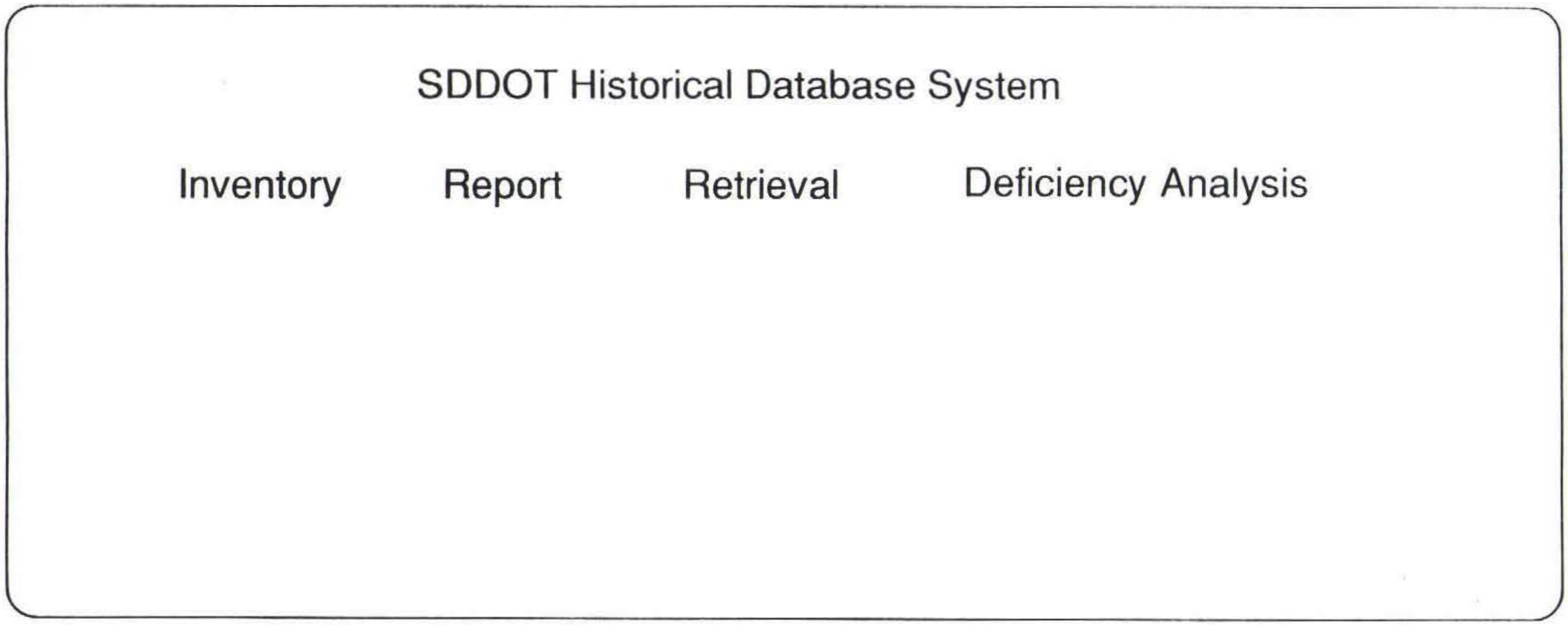

Figure 6-6. Proposed Application Startup Window.

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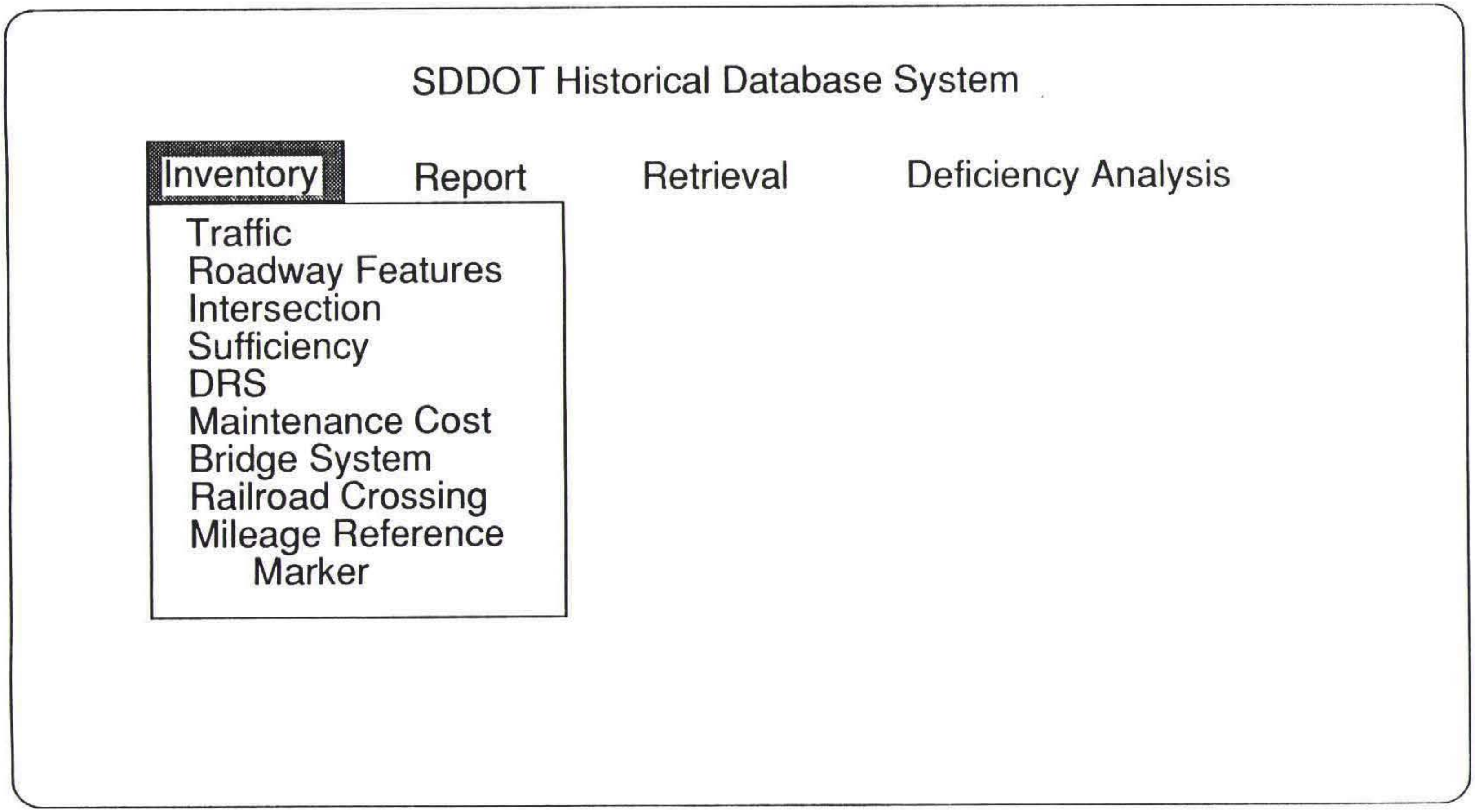

Figure 6-7. Sample Inventory Menu Options.

6.5.2 Report Generation Utilities

There are many reports which can currently be generated as part of the RES system. It is not clear if all of those reports will be necessary as users have improved on-line access to data, but it is obvious that many predefined report types will be required of this historical database system. The current RES system provides reports based on batch requests. We propose an analogous utility, but with the report criteria specified interactively via the window-based application on the client machine. The application software would then generate the batch request and submit it to the mainframe. Several potential report options are illustrated in Figure 6-8.

6.5.3 Retrieval of Data

A simple mechanism to browse the data will be provided as part of this user interface. The user will be able to specify some selection and sorting criteria. Once the request is finalized, the software would transmit the query to the DBMS, receive the set of data satisfying the query, and display it to the user. The user need not be concerned with where the data actually reside or how they are organized. All of those issues will be handled transparently by a combination of the custom software interface, the distributed and networked data management software, and the server DBMS. In addition to simple retrieval of the data, a graphical representation capability should also be integrated into this utility. Some retrieval options are presented in Figure 6-9.

6.5.4 Analysis Tools for Pavement Management

Figure 6-10 illustrates some possible analysis options which should be integrated into this user interface. The key to making the historical database a truly useful tool to the engineers in the SDDOT is to provide an integrated application environment in which they can perform their analysis tasks. Providing those tools via a user-friendly interface and providing all of the data access required to run the analyses as part of that interface would revolutionize the SDDOT pavement management. Providing on-line access to the historical data is of little value unless the analysis needs of the department are also addressed.

6.6 SUPPORTING SYSTEM UTILITIES

Several supporting system utilities must be developed for a system of this magnitude. These utilities could be provided via an interactive window-based user interface or using job control language. Since these utilities would probably not be commonly used, a more intuitive, menu-driven user interface should be developed. Here we discuss the following candidate utilities.

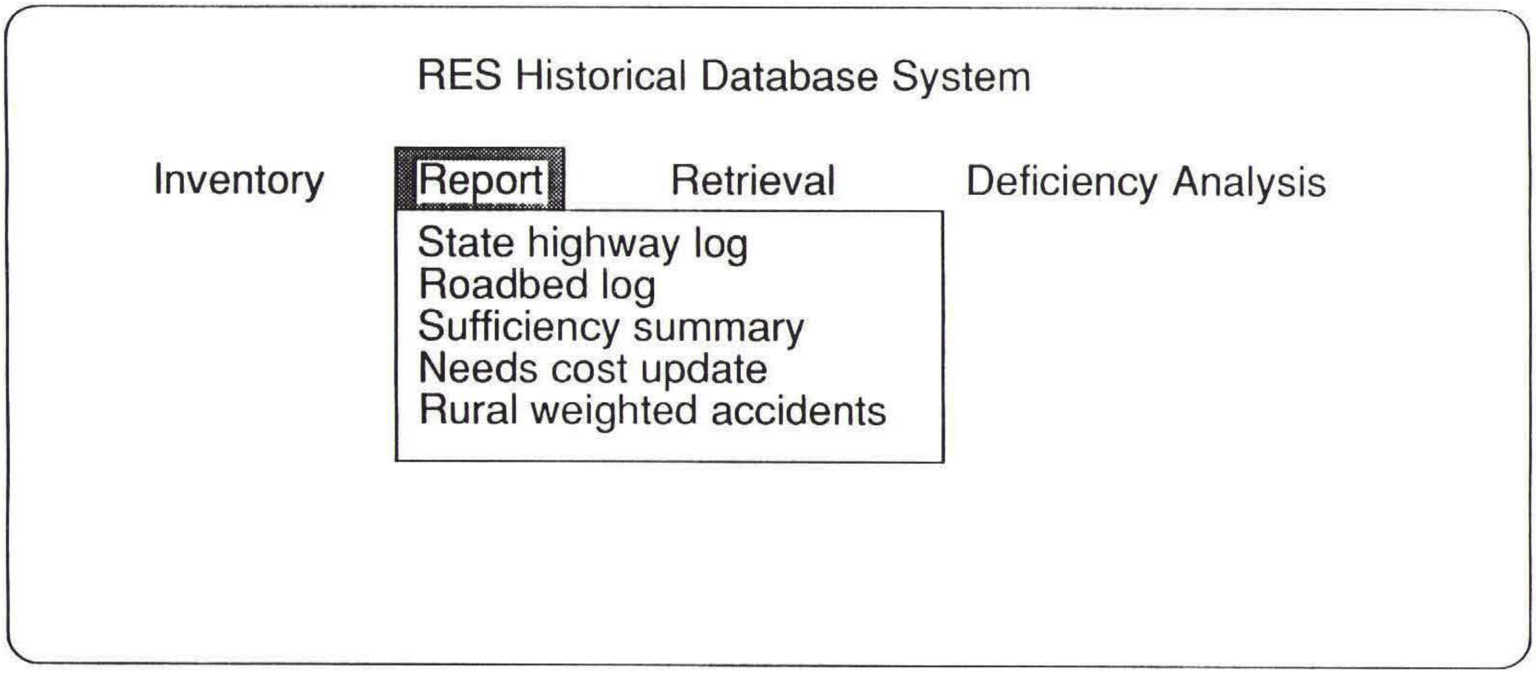

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Figure 6-8. Sample Report Menu Options.

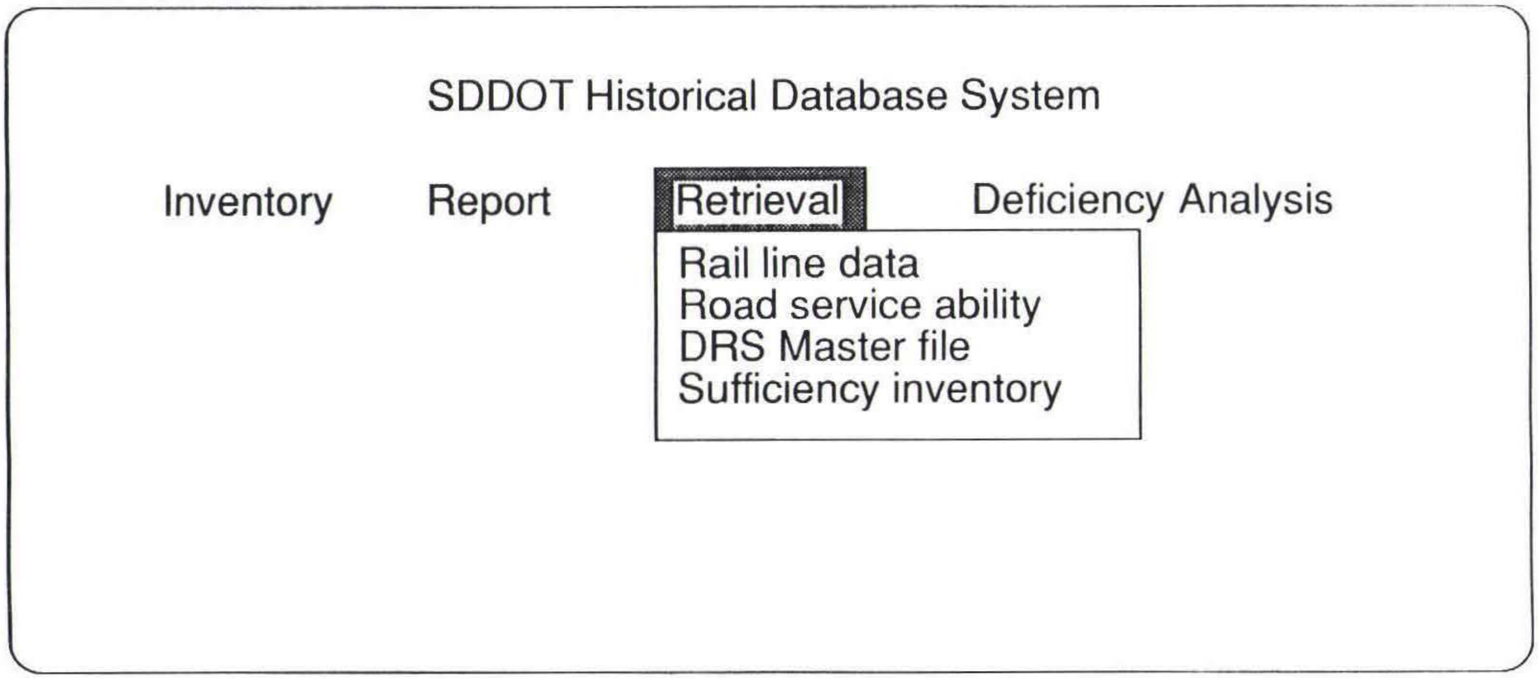

Figure 6-9. Sample Retrieval Menu Options.

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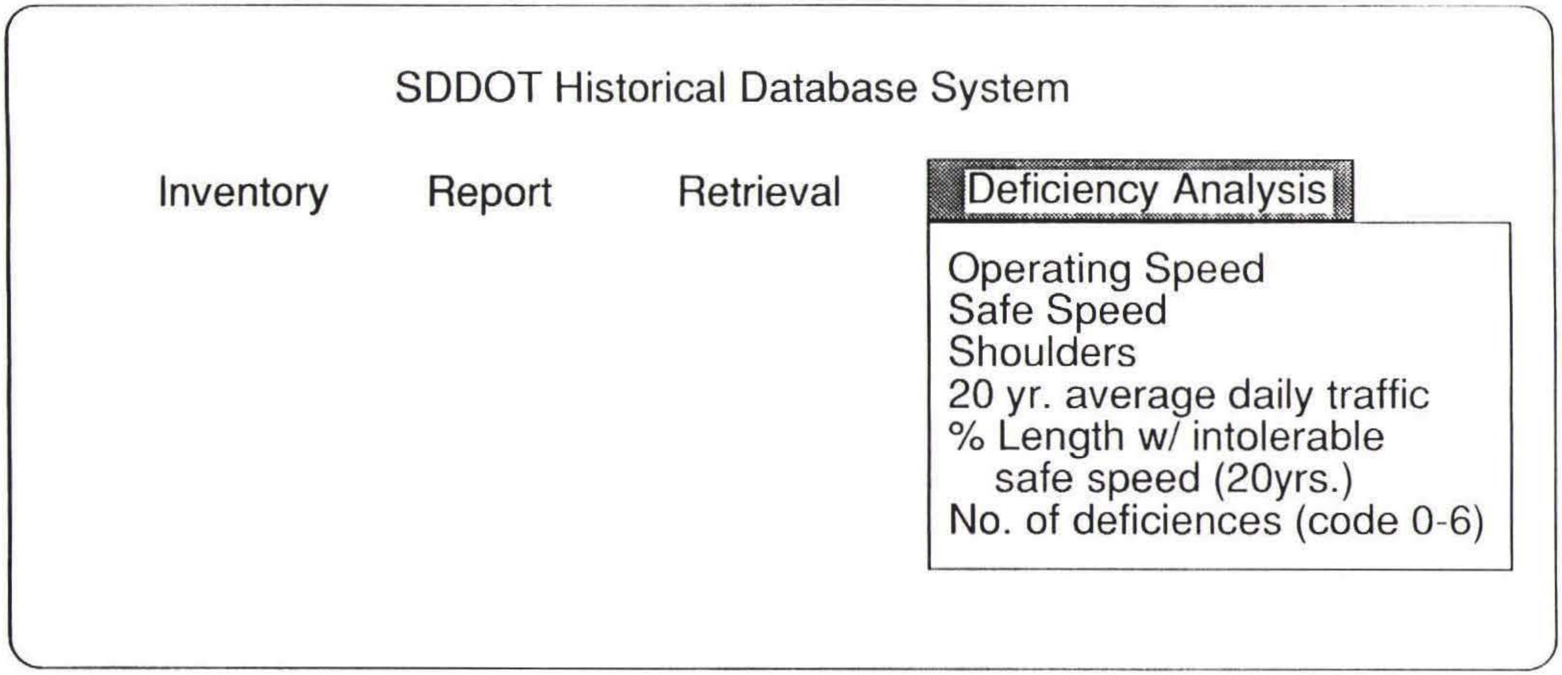


Figure 6-10. Sample Analysis Menu Options.

- Data archival utility
- Data purge utility
- Utility for restoration of archived data
- Utilities for interactive and batch loading and updating of field collected data
- Utility to generate planning file information.

6.6.1 Data Archival Utility

Historical data which are no longer in regular use should be removed from the database both to free disk space and to improve performance of the database server. These data must be archived prior to removal in such a way that a restoration utility can be automated. This means that the data must be written to a file in a specified format with all information required to uniquely identify the data. This file may in turn be stored on some mass storage device (magnetic or optical medium).

6.6.2 Data Purge Utility

Once obsolete data have been archived, they must be purged from the database to realize storage savings and performance improvements. User access to this utility must be restricted to protect data adequately. Audit trails of all such transactions must also be maintained. Any candidate commercial DBMS allows access controls and audit trails to be maintained by the DBA.

6.6.3 Utility for Restoration of Archived Data

Access to data which have been archived and purged from the database may be required at some future date. The proposed system must allow automatic restoration from the archival file once that file has been restored from the mass storage device used. This restoration process must differ from the regular load utility in that the date and time stamp on the data must be historically accurate. Such a restoration utility will maintain accessibility to the data while providing the capability to free disk space.

6.6.4 Utilities for Interactive/Batch Loading/Updating of Field Collected Data

Since the majority of the data in the RES is currently collected using computers, the capability of adding such data to the historical data management system completely automatically must be part of the system design. Interactive data loading and updating must be provided in a user-friendly manner. Again, access controls must be enforced on the loading and updating of data and audit trails must be maintained.

6.6.5 Utility to Generate Planning File Information

Once all of the current field data are loaded, the derived data in the planning file should be generated. It is expected that this utility would only be used once per year.

6.7 HARDWARE REQUIREMENTS

Our recommendation is to develop a system which will take advantage of the existing mainframe and PC hardware configuration at the SDDOT. Given the storage potential and processing capabilities of the existing IBM 3090 mainframe, and the fact that many of the DBMS operations will be off-loaded from the 3090, we anticipate a minimum of hardware purchases. Based on the discussions with the SDDOT personnel, the size of the database and the anticipated user accesses to the database would not significantly impact existing system performance. However, if the usage increases significantly more than anticipated so that performance degradation is observed, future upgrades to the existing mainframe may be necessary.

While significant hardware purchases are not anticipated, commercially-vended software purchases in the form of an RDBMS engine for the IBM mainframe, front-end application tools for the PC's, and networking capabilities that provide a transparent client-server relationship between the personal workstation clients and the mainframe database server will be required. The current configuration at the SDDOT only provides for terminal access to the IBM 3090. Hence, although the PC's have access to the mainframe, it is only as terminals via a terminal emulator package. In the current SDDOT hardware environment, any application developed to use a database on the mainframe would have to reside and be executed on the mainframe. This is basically the current situation with the RES. In order to implement a system as outlined in Figure 6-1, the following items are needed:

- An Ethernet connection to the 3090 with the corresponding TCP/IP software would provide an environment in which truly distributed computing could take place. Such a solution would not only provide a basis for this historical database application, but would also provide that basis for general distributed computing needs among the state agencies.
- A UNIX-based machine with Ethernet connectivity for use as the database gateway machine.

Although this reflects a departure from SDDOT's current gateway and networking strategy, evolving needs for fully distributed computing and distributed databases indicate that a change in the strategy should be considered.

6.8 DOCUMENTATION REQUIREMENTS

We recommend the development of two types of documentation through the process of implementing a historical database system:

- User Documentation
- System Documentation

6.8.1 User Documentation

A manual that documents the functionality of the system and any information that the user needs to be able to use the system is essential for training new users of the system. This documentation should also be provided in a computer readable/useable format so that it may be updated as new functionality is added. This document will evolve from a detailed functional specification of the system.

6.8.2 System Documentation

A manual that documents the application internals, system dependencies, maintenance requirements, etc. is essential for long-term use of the system. Such documentation should be provided in a computer readable/useable format so that it can be a "living document" which describes the actual system over time instead of the "as built" system. This document should evolve from a detailed design of the proposed system.

6.9 IDENTIFIED POTENTIAL PROBLEMS

Several potential problems, both procedural and technical, have been identified through this feasibility study. They are outlined in the following sections.

6.9.1 Procedural Problems

Procedural problems consist of those problems which result from practices and procedures in the SDDOT. Two identified procedural problems are as follows:

- *Restricted Data*

  There may be data in the SDDOT database to which access should be restricted due to its proprietary or sensitive nature. For example, there may be information about contractors such as rate structures. These data must be protected via access restrictions. Many DBMS's provide such data security tools which are put into place by the DBA.

- *Software Standards and Quality Assurance*

  Any custom software developed for the SDDOT should satisfy industry standards including modularity, transportability, documentation, ease of use and maintenance, and verification testing. Code should be written to available software standards such as SQL and C with any required non-standard operations carefully isolated and documented.

SDDOT guidelines for Quality Assurance (QA) should be incorporated into the system to the greatest possible extent. There are two types of QA issues: source and procedures. Source QA concerns itself with the integrity of the actual data, data collection and measuring, and computation of derived data. Procedural QA is concerned with the integrity of the operations performed on the data within the system, preserving the integrity of the data as it is stored, transferred, and manipulated in the system. Both issues must be addressed in the detailed design and development of a historical database and its associated user interface.

6.9.2 Technical Problems

Several potential technical problems have been identified which must be resolved as a first step in proceeding with the detailed specification, design, and implementation of a historical database system.

- *Soil Properties*

  Some soil information is currently stored in the RES, but SDDOT engineers have indicated that additional information would be helpful in their analyses. Hence, precise types of soil properties to be collected, collection procedures and schedules, and derivation procedures (from point to segment data) must be identified.

- *Derived Data*

  The issues surrounding the derived data in the planning file have been discussed in this chapter. Briefly restating the issue, derived data may be stored or derived as needed. If the data are stored, then there are consistency and integrity issues to be addressed. If they are derived ad hoc, there will be a significant delay in the most common type of data access.

- *Time Stamp Granularity*

  The granularity of time stamps on the historical data must be determined. Time stamps may be designed to be applied at the single data attribute level or at the level of groups of data attributes. It should be noted that this has an effect on the physical design. One would not want to group attributes with separate time stamps in one relation because a change to any of those attributes would require duplication of or null values for all of the other attributes not of the same time stamp grouping. This would waste storage space.

- *Highway Realignment*

  A change in the physical location of an MRM is likely to occur whenever highway alignment changes. The conceptual design takes this into account with the addition of the (x, y, z) coordinate to the indexing scheme. Some data may no longer be applicable after the realignment whereas information such as traffic counts may still be valid. Although checks could be incorporated in the retrieval process to identify alignment changes and to take appropriate action based on changes in the (x, y, z) coordinate over time, this is not a recommended practice. The engineer may or may not be aware of the realignment, and engineering judgement could be compromised. A more appropriate approach may be to identify whether an MRM has been moved and to let the engineer exercise judgement on the use of the data.

- *Highway Renumbering*

  Highway renumbering is similar to the above case except that the MRMs change and the (x, y, z) coordinates stay the same. A notable difference, however, is that the data for a highway is still appropriate for use in analyses even though the MRM has changed. Similar to a change in highway alignment, the appropriate approach may be to identify that the MRM has been changed and to let the engineer exercise judgement on the use of the data. If an engineer is doing an analysis over time and the data retrieval operation finds no more data for a given MRM, the engineer may simply continue to search for data at the given (x, y, z) coordinate. The dual indexing scheme provides a method of locating data when one or the other of the index items changes over time.

- *Transfer of Ownership*

  The transfer of ownership of a road between governmental entities poses another problem that must be addressed in implementing a historical database. When ownership is transferred from the state to another governmental entity, data collection is discontinued, and the past data is either retained on-line for use in pavement performance studies or simply archived and removed from the system. Where problems arise is when ownership subsequently reverts back to the state. If this should take place, an unavoidable gap in the historical information may exist. Including newly collected data with data acquired under previous state ownership would not be advisable unless the interim maintenance history can be established or the discontinuity can be flagged. Since the data class indicator in the MRM index will identify changes in ownership through time, the ownership changes could be flagged to allow the engineer to exercise judgement on the use of the data. An active/inactive flag may be required.

7.0 PROJECTED DATABASE IMPLEMENTATION COSTS

The estimated costs for developing, implementing, and maintaining a historical database as described in Chapter 6 is given in Table 7-1. The effort has been divided into the following three phases:

- Phase I: Development of Detailed Functional Specification and Preliminary Prototype
- Phase II: Development of Detailed Design
- Phase III: Application Development and Implementation

Table 7-1. Estimated Database Development and Implementation Costs

Cost Element	Phase I	Phase II	Phase III	Total
Labor[(a)]				
Man-years	0.75	0.6	1.20	2.55
Cost ($K)	$85	$70	$140	$295
Hardware Purchases[(b)] ($K)	—	—	$54	$54
Commercial Software ($K)				
Software Leases[(c)] ($K/yr)	—	—	$80	$80
Software Purchases[(d)] ($K)	—	—	$150	$150

(*a*) This labor estimate depends on the specific requirements of the selected system. Labor costs associated with hardware and commercial software installation are not included.

(*b*) Includes client server, Ethernet gateway, and TCP/IP boards for 20 PCs.

(*c*) DBMS.

(*d*) Includes DBMS software, development tool, client/server gateway, and network software.

The estimates provided for each of the Phases reflect the level of effort anticipated to implement a historical database that enhances the functionality of the data management interfaces provided by the current RES database and provides the enhanced data access that will be required to develop a historically based pavement management system. Although efforts to develop and implement a historically based pavement management system are not included in the current estimate, the database system will accommodate future implementation of such a system.

An estimate of the duration of each of the Phases is shown in Figure 7-1. Because of the integrated nature of the RES database and SDDOT's pavement management system, the level of effort associated with developing and implementing the historical database will be a function of future decisions by SDDOT on user/application interfaces that will be implemented in the transition to a historically based pavement management system. Although development of these interfaces is not included in the current estimate, provisions to accommodate future implementation of the interfaces would be provided.

The primary cost element considered in developing the cost of Phases I and II was labor. The primary cost elements considered in estimating the cost of Phase III were labor plus cost elements associated with the acquisition of required hardware and software. Although costs associated with maintaining the database following deployment are not given in Table 7-1, it is estimated that on-going maintenance costs will be limited to the recurring charges associated with software leases and labor costs incurred by a full-time database administrator who will perform all routine database management functions.

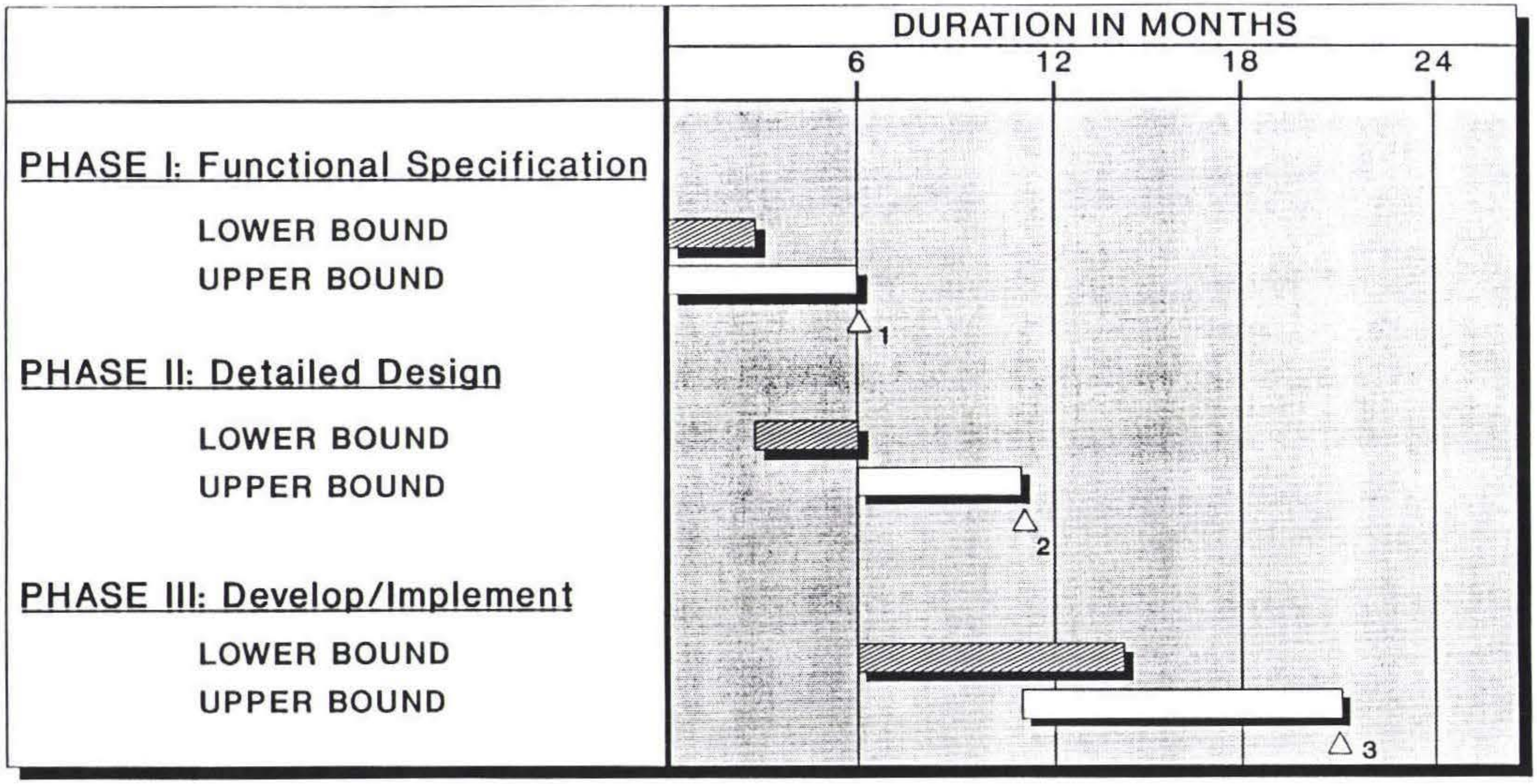
Further details on the technical efforts associated with each of the phases and the various factors that could result in deviations from the above estimates are provided in the following sections.

7.1 PHASE I: DEVELOPMENT OF DETAILED FUNCTIONAL SPECIFICATION AND PRELIMINARY PROTOTYPE

Phase I would consist of the development of a detailed specification defining the full functionality of the database application. An intermediate system prototype will be developed to provide SDDOT personnel with hands-on exposure to the "look and feel" of the system and to expedite refinement of the user interfaces. Although the prototype will not access the mainframe database, it will provide excellent visibility with regard to the functionality of the system.

The process of defining the system functionality must be done in concert with SDDOT personnel to ensure that all system interfaces and functional features are addressed. Close interaction between Systems Analysts and SDDOT Engineers will be essential during this phase because of the integrated nature of the RES database and the pavement management system. From the results of this study, it is clear that the majority of SDDOT's pavement management activities involve the Highway Planning Inventory file, a file that contains a consolidation of information contained in the nine RES master files. Although the file is not part of the RES database, it would be included in the historical database.

An estimate of the labor costs that will be incurred during Phase I is given in Table 7-1. Key factors that may influence the level of effort required to complete Phase I include the following:



Milestones:

1. Detailed Functional Specification
2. Detailed Design Document
3. Fully Implemented and Tested System With User and System Documentation.

Figure 7-1. Estimated Duration of Historical Database Development and Implementation Efforts.

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- RE/SPEC recommends that the Highway Planning Inventory file or its equivalent be integrated with the database to address data integrity issues. A detailed investigation of pavement management application software interfaces with this file was beyond the scope of the current study, and the nature and complexity of the interfaces will have a direct impact on the time required.

- The extent of the interaction that will be required between SDDOT personnel and database development personnel to define the Functional Specification will have a direct impact on the time required.

- The scope of functional features identified in the Functional Specification will impact the level of effort required to develop a preliminary prototype. Note that RE/SPEC considers a prototype essential to ensure that the desired system functionality is achieved.

The deliverables for Phase I will be a preliminary system prototype and a Detailed Functional Specification document for review and approval by SDDOT.

7.2 PHASE II: DEVELOPMENT OF DETAILED DESIGN

The Detailed Functional Specification developed in Phase I will be the basis for the development of a Detailed Design of the database application. Required hardware, required commercial DBMS and network software, and application developer tools will be selected. A detailed design of the underlying data structure will be developed, and all functional requirements detailed in the Detailed Functional Specification will be implemented through detailed definitions of database interfaces to the level of detail required for development of the system.

An estimate of the labor costs that will be incurred during Phase II is given in Table 7-1. Key factors that may influence the level of effort required to complete Phase II include the following:

- Functional features defined in Phase I

- Design methods employed

Note that the experience of personnel designing the database application is critical in preventing false starts in the design of the database logical and physical schema.

The deliverable for Phase II will be a Detailed Design document for final review and approval by SDDOT.

7.3 PHASE III: APPLICATION DEVELOPMENT AND IMPLEMENTATION

The final phase of the project will include the procurement of all required hardware, commercial software and development tools, and the development of all custom software, data conversion/integration, and demonstration/acceptance testing of the historical system. User and system documentation will be developed and user training classes will be held to facilitate a smooth transition to the new system. Note that the new system will be developed and implemented in parallel with the existing system so as not to hinder normal SDDOT operations and to facilitate a smooth transition to the new system.

The labor cost for Phase III (see Table 7-1) depends on the specific requirements of the selected system. Although the scope and complexity of the functional features and interfaces included in the system is a key factor in defining the level of effort required during Phase II, there are a number of other key contributing factors:

- Cost of the DBMS that is selected
- Cost of the development tools selected
- Cost of network integration software and hardware
- Quality of the development tools selected
- Number of major changes identified after Phase II
- Historical data available

One of the major factors that will control the effort required to develop the required interfaces for the DBMS based historical database will be the quality and functionality of the selected application development tool software. In comparison to standard programming languages similar to those used in the development of the current RES database, the higher level languages that are used in the current state-of-the-art development tool packages have reduced significantly the time required to develop a database application. It should be noted that the current estimate is based on the selection of state-of-the-art application development tools.

Further, some design changes can always be expected to evolve during the development of any software system. The impact on development and implementation efforts will depend on the number and complexity of these changes, further demonstrating the importance of the thoroughness of the efforts performed in Phases I and II.

Finally, the level of effort required to complete data conversion/integration activities is expected to increase as time passes if RE/SPEC's recommendation to begin immediate retention of all RES database information is adopted. For estimation purposes, it was assumed that this activity would commence in July 1992.

The deliverable for Phase III will include an operational historical database system and all associated user and system documentation. The user documentation will evolve from the Detailed Functional Specification. The system documentation will evolve from the Detailed Design document.

8.0 CONCLUSIONS AND RECOMMENDATIONS

A review of the current Roadway Environmental Subsystem (RES) database and nine representative historical statewide transportation databases identified a number of potential uses of historical data. Although the current primary use of historical data is in the development of pavement performance curves, several states are realizing the cost benefits associated with historically based pavement management. The preservation actions identified by Arizona's historically based PMS resulted in decreased preservation expenditures of $14,000,000 during the first year of operation.

The majority of the required pavement performance data is currently being collected by SDDOT during its annual pavement appraisals. Data items identified for addition to the RES database include additional soil properties, lane identification, design, as-built, and construction information.

It is recommended that SDDOT immediately adopt a 20-year retention policy for all RES pavement performance related data items with 5 years of data maintained on line. All data items not related to pavement performance need to be reviewed for retention. It is further recommended that this policy include all data in the Highway Planning Inventory file. The 5 year on-line retention time is the nominal time being used for pavement predictions and is the minimum time that is being used to generate pavement performance curves. The data should be archived for a total of 20 years for verification of pavement performance.

Direct implementation of either an existing statewide transportation database or the FHWA Highway Performance Monitoring System is not recommended. To achieve the database flexibility and extensibility required by the SDDOT, RE/SPEC Inc. recommends a distributed relational database design that will provide a basis for SDDOT's data and computational requirements into the next century. The design is a client-server configuration with the database server process (IBM's DB2 Relational Database Management System (RDBMS)) and the actual data residing on South Dakota's IBM 3090 mainframe. Distributed access to the data will be provided via client processes active on the mainframe, a gateway serving personal computers functioning as X-terminals, or workstations. All distributed hardware will be connected to the IBM 3090 via a standard protocol such as TCP/IP on an Ethernet Local Area Network. The database server will receive all requests for data, perform the required query against the database, and return the requested data to the user via the client processes.

The RDBMS and client-server approach will provide state-of-the-art functionality, address issues related to data integrity and consistency, and provide a basis for future extension to a truly distributed database environment that integrates GIS and mapping databases and systems such as ROAD-VIEW.

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APPENDIX A

ORGANIZATION AND CONTENT OF EXISTING RES FILES

An in-depth review of the existing RES documentation was performed to identify the organization and content of the key RES datafiles. The review was complemented with discussions with SDDOT personnel. Specific information that was identified during this review included:

- Identification of the Specific Data Items Stored in Each File.
- Type and Format of Each Data Item.
- Location of the Data Items Within the File Records.
- Range or Limits of the Data Items.

The files that were examined in this review included the nine point-based RES database master files and the segmented Highway Planning Inventory file that is generated from the information contained in the RES database files. The Highway Planning Inventory file was included in the review for completeness because of its key role within SDDOT's pavement management system.

Included in this appendix are ten tables summarizing the organization and content of each of the ten key RES files. Tables A-1 through A-9 provide an overview of the organization and contents of the nine RES master database files. The organization and content of the Highway Planning Inventory file is given in Table A-10. Included for each file is the current name of each data item, a brief description of each data item, and a "picture" or pictorial representation of the format in which each data item is stored within the file records.

The "picture" designation is as follows: alpha-numeric data items are indicated with "X's"; numeric and decimal data items are indicated with "9's" with decimals located as shown; the number of characters in each "picture" (excluding decimal points) indicates the length of each data item within each formatted file record.

The information in this appendix is for evaluation purposes only. The accuracy of the information presented herein depends on the accuracy and completeness of the documentation provided and the interpretation of the documentation.

Table A-1. Traffic Inventory Master File Organization

Data Item Name	Description	Picture
RES-KEY.		
DATA-CLASS	State, county, city, or federal (1-4)	x
HIGHWAY.		
HWY-NUMBER	Highway number	xxx
HWY-SUFFIX	Suffix designation, code for road type of this section	xxx
MRM	Mileage reference marker	999.99
DISPL	Displacement from MRM in thousandths of a mile	99.999
TRA-SECTION	Code value for section road type (breaks between readings)	x
TRA-PLAN-DIST	Planning district (1-6)	x
TRA-FUNC-CLASS	Functional class code (01-19), for principle artery vs. local streets	xx
TRA-LOAD-CLASS	Code for load class (01-46)	xx
TRA-DIR-DIST	Directional distribution, % of vehicles traveling in one direction	99.9
TRA-PERC-TRUCKS	Percent of trucks in average daily traffic	99.9
TRA-PEAK-HOUR	Peak hour volume, % ratio of high hour count to ADT	99.9
TRA-DESIGN-HOUR	Design hour volume , % ratio of 30^{th} hour high count to ADT	99.9
TRA-20YR-PRJTD	20 year projected ADT counts, computed if ADT-SHIFT=Y	99999
TRA-CUR-ADT	Current year average daily traffic count	99999
TRA-PREV-ADT	ADT counts for previous year	99999
TRA-OLD-ADT	ADT counts for 2 years ago	99999
TRA-ADT-DATE	Current date ADT was updated	YYYYMMDD
TRA-ADT-SHIFT	ADT shift flag=Y when current ADT is modified	x

Table A-2. Roadway Features Inventory Master File Organization
(Page 1 of 6)

Data Item Name	Description	Picture
RES-KEY.		
DATA-CLASS	State, county, city, or federal (1-4)	X
HIGHWAY.		
HWY-NUMBER	Highway number	XXX
HWY-SUFFIX	Suffix designation, code for road type of this section	XXX
MRM	Mileage reference marker	999.99
DISPL	Displacement from MRM in thousandths of a mile	99.999
SEGMENT-COUNTERS	Counters for the number of records of each record type	16(XX)
UPDATE-DATE	Date of last update	YYMMDD
Record Type A	**System and Location Information**	
KEY-A1	Key	XX
FEA-9	County number	XX
FEA-10	Highway region	X
FEA-11	Planning and development district	X
FEA-12	Boundary identification	XX
FEA-13	City code	XXXX
FEA-14.	Highway system code	
FEA-14A	Federal-aid system designated way	X
FEA-14B	Federal-aid system traveled way	X
FEA-14C	State administrative system	XX
FEA-14D	Special systems code	XX
FEA-15	Maintenance responsibility code	X
FEA-16	Municipal code	X
FEA-17	Rural-urban code	X
FEA-18	Population code	X
FEA-19	Standard metro statistical area (SMSA)	X
FEA-20	Census area code	X
FEA-21	Special planning study area	X
FEA-22	Functional classification of roadway	XX
FILLER	Filler	X(5)

Table A-2. Roadway Features Inventory Master File Organization (Page 2 of 6)

Data Item Name	Description	Picture
Record Type B	**Project and Surfacing Information**	
KEY-B1	Key	XX
FEA-23	Grading project information	X(13)
FEA-24	Year graded	XX
FEA-25	Surfacing project information	X(13)
FEA-26	Year surfaced	XX
FEA-27	Resurfacing project information	X(13)
FEA-28	Year resurfaced	XX
FEA-29	Surface type code	X(4)
FEA-30	Surface width to nearest foot	999
FEA-31	Surface thickness to nearest $\frac{1}{10}$ in.	99.9
FEA-32	Shoulder type code	X
FEA-33	Left shoulder width to nearest foot	99
FEA-34	Right shoulder width to nearest foot	99
FEA-35	Curb and gutter	X
FEA-36	Stage construction code	X
FILLER	Filler	X(15)
Record Type C	**Cross Section Information**	
KEY-C1	Key	XX
FEA-37	Access control	X
FEA-38	Public road	X
FEA-39	Number of lanes	9
FEA-40	One-way – two-way code	X
FEA-41	Divided – undivided code	X
FEA-42	Frontage road existence code	X
FEA-43.	Median type information	
FEA-43-A	Median description	X
FEA-43-B	Mountable code	X
FEA-44.	Median width	
FEA-44-A	Median width to nearest foot	9999
FEA-44-B	Median width variable	X
FILLER	Filler	X(5)

Table A-2. Roadway Features Inventory Master File Organization (Page 3 of 6)

Data Item Name	Description	Picture
Record Type D	**Route Information**	
KEY-D1	Key	XX
FEA-45	Federal-aid route	XXXX
FEA-46	Highway category	X
FEA-47.	First coincident highway	
FEA-47-A	Highway number	XXX
FEA-47-B	Highway suffix	XXX
FEA-48	First coincident highway category	X
FEA-49.	Second coincident highway	
FEA-49-A	Highway number	XXX
FEA-49-B	Highway suffix	XXX
FEA-50	Second coincident highway category	X
FILLER	Filler	X(5)
Record Type E	**Guiderail Information**	
KEY-E1	Key	XX
FEA-51	Left guiderail type	X
FEA-52	Left guiderail height	99
FEA-53	Type of guiderail protection - left	X
FEA-54	Left guiderail length	9999
FEA-55	Right guiderail type	X
FEA-56	Right guiderail height	99
FEA-57	Type of guiderail protection - right	X
FEA-58	Right guiderail length	9999
FILLER	Filler	X(5)
Record Type F	**Right-of-Way Fence Information**	
KEY-F1	Key	XX
FEA-59	Left ROW fence type	X
FEA-60	Left ROW fence height	99
FEA-61	Right ROW fence type	X
FEA-62	Right ROW fence height	99
FILLER	Filler	X(5)

Table A-2. Roadway Features Inventory Master File Organization (Page 4 of 6)

Data Item Name	Description	Picture
Record Type G	**Structure Information**	
KEY-G1	Key	XX
FEA-64	Structure number	X(8)
FILLER	Filler	X(5)
Record Type H	**Comments** (may occur up to 6 times)	
KEY-H1	Key	XX
FEA-64E	Comment number	99
FEA-65	Comment	X(50)
FILLER	Filler	X(5)
Record Type I	**Roadside Area Information**	
KEY-I1	Key	XX
FEA-66	Type of roadside area	X
FEA-67	Name of roadside area	X(18)
FEA-68	Size in acres	99.99
FEA-69	Roadside area location	X
FEA-70	Direction of travel served	X
FEA-71	Roadside area inventory number	XXXX
FEA-72.	Facilities available (Y/N)	
FEA-72-A	Drinking water	X
FEA-72-B	Flush toilets	X
FEA-72-C	Other toilets	X
FEA-72-D	Trailer waste station	X
FEA-72-E	Picnic tables	X
FEA-72-F	Camping	X
FEA-72-G	Tourist information	X
FEA-72-H	Handicapped facility	X
FILLER	Filler	X(5)
Record Type J	**Railroad Signal Information**	
KEY-J1	Key	XX
FEA-73	Railroad signal project	X(13)
FEA-74	Railroad signal type	X(4)
FEA-75	Year built	XX
FILLER	Filler	X(5)

Table A-2. Roadway Features Inventory Master File Organization (Page 5 of 6)

Data Item Name	Description	Picture
Record Type K	**Right-of-Way Width Information**	
KEY-K1	Key	XX
FEA-63.	Right-of-way width	
FEA-63-A	Left width	9999
FEA-63-B	Left width variable code (Y/N)	X
FEA-63-C	Right width	9999
FEA-63-D	Right width variable code (Y/N)	X
FILLER	Filler	X(5)
Record Type L	**Horizontal Alignment Information**	
KEY-L1	Key	XX
FEA-83	Direction of curve (R/L)	X
FEA-84.	Deflection angle	
FEA-84-A	Degrees	999
FEA-84-B	Minutes	99
FEA-84-C	Seconds	99.99
FEA-85.	Degree of curve	
FEA-85-A	Degrees	99
FEA-85-B	Minutes	99
FEA-85-C	Seconds	99.99
FEA-86.	Spiral length	
FEA-86-A	Length preceding curve	9999
FEA-86-B	Length of spiral out of curve	9999
FILLER	Filler	X(5)
Record Type M	**Vertical Alignment Information**	
KEY-M1	Key	XX
FEA-87	Elevation ($\frac{1}{100}$ ft)	9999.99
FEA-88.	Curve length	
FEA-88-A	Distance (ft) to VPI	9999
FEA-88-B	Distance (ft) VPI to end	9999
FEA-89.	Percent grade	
FEA-89-A	Sign (+/-)	X
FEA-89-B	Percent grade preceding curve	99.999
FEA-89-C	Sign (+/-)	X
FEA-89-D	Percent grade leaving curve	99.999
FILLER	Filler	X(5)

Table A-2. Roadway Features Inventory Master File Organization (Page 6 of 6)

Data Item Name	Description	Picture
Record Type N	**Roadbed Lanes Layer Information** (may occur up to 12 times)	
KEY-N1	Key	XX
FEA-76	Roadbed layer number	99
FEA-77.	Roadbed layer code	
FEA-77-A	Major class of the layer (A,B,C,S,T)	X
FEA-77-B	Layer type	X
FEA-77-C	Gradation	X
FEA-78	Roadbed layer modification code (1-2)	X
FEA-79.	Roadbed layer thickness	
FEA-79-A	Roadbed layer thickness ($\frac{1}{10}$ in.)	99.9
FEA-79-B	Thickness variable (Y/N)	X
FEA-80	Roadbed layer year	XX
FILLER	Filler	X(5)
Record Type O	**Roadbed Shoulder Layer Information** (may occur up to 12 times)	
KEY-O1	Key	XX
FEA-76	Roadbed shoulder layer number	99
FEA-77.	Roadbed shoulder layer code	
FEA-77-A	Major class of the layer (A,B,C,S,T)	X
FEA-77-B	Layer type	X
FEA-77-C	Gradation	X
FEA-78	Roadbed shoulder layer modification code (1-2)	X
FEA-79.	Roadbed shoulder layer thickness	
FEA-79-A	Roadbed shoulder layer thickness ($\frac{1}{10}$ in.)	99.9
FEA-79-B	Thickness variable (Y/N)	X
FEA-80	Roadbed shoulder layer year	XX
FILLER	Filler	X(5)
Record Type P	**Soil Information**	
KEY-P1	Key	XX
FEA-81	Soil series number	9999.9
FEA-82	Soil CBR (California bearing ratio)	99
FILLER	Filler	X(5)

Table A-3. Intersection Inventory Master File Organization

Data Item Name	Description	Picture
INT-DELETION	Transaction type (add, change, delete)	x
RES-KEY.		
DATA-CLASS	State, county, city, or federal (1-4)	x
HIGHWAY.		
HWY-NUMBER	Highway number	xxx
HWY-SUFFIX	Highway suffix code	xxx
MRM	Mileage reference marker	999.99
DISPL	Displacement from MRM in thousandths of a mile	99.999
SEQ-NO	Unique sequence number for multi-intersection	9
INT-NODE-IND	Begin or end node indicator (B/E)	x
INT-INTERSECTION	Intersection type code (1-10)	xx
INT-ACCESS	Access indicator (Y/N)	x
INT-INTERSECTED-HIWAY.		
INT-CLASS-2	State, county, city, or federal (1-4)	x
INT-HIGHWAY-2.		
INT-NUMBER-2	Highway number	xxx
INT-SUFFIX-2	Highway suffix code	xxx
INT-MRM-2	Mileage reference marker	999.99
INT-DISPLACE-2	Displacement from MRM in thousandths of a mile	99.999
INT-NODE-NUMBER	Numeric designation for intersection of highways	9999
INT-X-COORD	Horizontal distance from reference point to intersection	9(5).99999
INT-Y-COORD	Vertical distance from reference point to intersection	9(5).99999
INT-NODE-FLAG	Node flag	x
INT-UPDATE.		
INT-YY	Update year	xx
INT-MM	Update month	xx
INT-DD	Update day	xx
FILLER	Filler	x(9)

Table A-4. Sufficiency Inventory Master File Organization (Page 1 of 2)

Data Item Name	Description	Picture
SUF-DELETION	Transaction type (add, change, delete)	X
RES-KEY.		
DATA-CLASS	State, county, city, or federal (1-4)	X
HIGHWAY.		
HWY-NUMBER	Highway number	XXX
HWY-SUFFIX	Highway suffix code	XXX
MRM	Mileage reference marker	999.99
DISPL	Displacement from MRM in thousandths of a mile	99.999
SUF-END-MRM	MRM at end of the section	999.99
SUF-END-DISP	Displacement from end MRM	999.99
SUF-DESCRIPTION	Descriptive information for the rated section	X(39)
SUF-RATING-DATE.	Date the section was rated	
SUF-R-YY	Rating year	XX
SUF-R-MM	Rating month	XX
SUF-R-DD	Rating day	XX
SUF-CONDITION.	Rating data	
SUF-SS	Stability and strength	XX
SUF-RH	Relative height	XX
SUF-DL	Drainage, longitudinal and traverse	XX
SUF-DS	Drainage, surface	XX
SUF-BS	Base and subbase	XX
SUF-WS	Wearing surface	XX
SUF-RL	Estimated remaining life	XX
SUF-SAFETY.	Safety rating data	
SUF-SHOULDER	Shoulder width	XX
SUF-SURFACE	Surface width	XX
SUF-SD	Stopping sight distance	XX
SUF-CA	Consistency of alignment	XX
SUF-SERVICE.	Service rating data	
SUF-A	Alignment	XX

Table A-4. Sufficiency Inventory Master File Organization (Page 2 of 2)

Data Item Name	Description	Picture
SUF-PO	Passing opportunity	XX
SUF-SW	Surface width	XX
SUF-R	Rideability	XX
SUF-MC	Maintenance economy	XX
SUF-SC	Snow control	XX
SUF-UPDATE.		
SUF-U-YY	Sufficiency rating year	XX
SUF-U-MM	Sufficiency rating month	XX
SUF-U-DD	Sufficiency rating day	XX
SUF-OLD-SECT.	Rating section's old numbers (for ref. only)	
SUF-CONTROL-SECT	Old control section number	XXXX
SUF-RATING-SECT	Old rating section number	XX
SUF-CRACK-EVAL.	Crack evaluation	
SUF-CRACK-OPEN	Crack opening	XX
SUF-TRAV-CRACK	Transverse cracks	XX
SUF-LONG-CRACK	Longitudinal cracks	XX
SUF-ALLIG-CRACK	Alligator cracks	XX
SUF-SHRINK-CRACK	Shrinkage cracks	XX
SUF-BEHAVIOR.	Behavioral evaluation	
SUF-OXIDATION	Oxidation	XX
SUF-CORRIG	Corrigations	XX
SUF-RAVEL	Raveling	XX
SUF-POL-AGG	Polished aggregate	XX
SUF-SHOVING	Shoving or pushing	XX
SUF-POT-HOLES	Pot holes	XX
SUF-EX-ASP	Excess asphalt	XX
SUF-DEF-DRAIN	Deficient draining	XX
SUF-RUTTING	Rutting	XX
SUF-PCT-PATCH	Percent patches	XX
SUF-RATING-FREQ	Rating frequency	X
FILLER	Filler	X(10)

Table A-5. DRS Inventory Master File Organization (Page 1 of 2)

Data Item Name	Description	Picture
RES-KEY.		
DATA-CLASS	State, county, city, or federal (1-4)	X
HIGHWAY.		
HWY-NUMBER	Highway number	XXX
HWY-SUFFIX	Highway suffix code	XXX
MRM	Mileage reference marker	999.99
DISPL	Displacement from MRM in thousandths of a mile	99.999
RECORD TYPE	New or delete code: dynaflect, roughometer, or skid information (W,X,Y,or Z)	X
RECORD SEQUENCE	Record sequence number (unused)	X
UPDATE DATE	Date (YYMMDD)	XXXXXX
Record Type W	**Rut Depth Information**	
RUT DEPTH DATA.		
TEST DATE.		
YEAR	Year	XX
MONTH	Month (01-12)	XX
DAY	Day	XX
LANE CODE.	Lane number outside to inside	X
AVERAGE RUT DEPTH	Average rut depth measurement (nearest tenth)	9.9
FILLER	Filler	X(6)
Record Type X	**Dynaflect Information**	
DYNAFLECT DATA.		
TEST DATE.		
YEAR	Year	XX
MONTH	Month (01-12)	XX
DAY	Day	XX
LANE CODE	Lane number outside to inside	X
PAVEMENT TEMP	Pavement temperature °F	999
FILLER	Filler	X
PAVEMENT TYPE	Code for pavement type	X
TIME OF TEST	Test time in military format	XXXX
SEASONAL CORRECTION	Percent of correction	999

Table A-5. DRS Inventory Master File Organization (Page 2 of 2)

Data Item Name	Description	Picture
DEFLECTION	Dynaflect deflection readings	
SENSOR 1	Deflection reading for sensor 1	9.99
SENSOR 2	Deflection reading for sensor 2	9.99
SENSOR 3	Deflection reading for sensor 3	9.99
SENSOR 4	Deflection reading for sensor 4	9.99
SENSOR 5	Deflection reading for sensor 5	9.99
CORRECTED DEFLECTION	Corrected deflection	9.99
SURFACE DESC CODE 1	Surface description codes	XX
SURFACE DESC CODE 2		XX
SURFACE DESC CODE 3		XX
FILLER	Filler	XX
Record Type Y	**Roughometer Information**	
ROUGHOMETER DATA.		
TEST DATE.		
YEAR	Year	XX
MONTH	Month (01-12)	XX
DAY	Day	XX
LANE CODE	Lane number outside to inside	X
AVG ROUGHNESS INDEX	Average roughness index recorded for the roadway location	9.9
FILLER	Filler	X(6)
Record Type Z	**Skid Information**	
SKID DATA.		
TEST DATE.		
YEAR	Year	XX
MONTH	Month (01-12)	XX
DAY	Day	XX
LANE CODE	Lane number outside to inside	X
SKID TEST SPEED	Vehicle speed (MPH)	99
AIR TEMPERATURE	Air temperature °F	999
SKID NUMBER	Friction number, skid resistance of the surface	99
SPECIAL TEST CODE	Code for additional information	XX
CORRECTED SKID NUMBER	Corrected skid number	99
FILLER	Filler	X(7)

Table A-6. Maintenance Inventory Master File Organization

Data Item Name	Description	Picture
RES-KEY.		
DATA-CLASS	State, county, city, or federal (1-4)	X
HIGHWAY.		
HWY-NUMBER	Highway number	XXX
HWY-SUFFIX	Highway suffix code	XXX
MRM	Mileage reference marker	999.99
DISPL	Displacement from MRM in thousandths of a mile	99.999
MAI-UPDATE.	Update Date	
MAI-YEAR	Year	XX
MONTH	Month (01-12)	XX
DAY	Day	XX
MAI-STRUCTURE	Structure number from bridge inventory	X(8)
MAI-FA-ROUTE	Route number	XXXX
MAI-SEG2-COUNTER	Number of occurrences of SEGMENT-2	99
MAI-SEGMENT-2.	Segment 2 may occur 197 times	
MAI-SEG-KEY.		
MAI-REP-UNIT	Maintenance crew number	XXX
MAI-CONST-YEAR	Construction year	XX
MAI-SURFACE-YEAR	Surface year	XX
MAI-FUNCTION	Function code for type of work performed	XXXX
MAI-PROJ-TYPE	Code (1-7) for project type	X
MAI-ACCOMP	Accomplishment field (unit of measurement for amount of work performed)	9(5).99
MAI-QUANT	Quantity amounts	9(5).99
MAI-LABOR-COST	Labor cost prorated per mile	9(7).99
MAI-EQUIP-COST	Equipment cost prorated per mile	9(7).99
MAI-MATERIAL-COST	Material cost prorated per mile	9(7).99
MAI-CONTRACT-COST	Contract cost prorated per mile	9(7).99

Table A-7. Bridge Inventory Master File Organization (Page 1 of 11)

Data Item Name	Description	Picture
STR-NO	Structure number	X(8)
UPDATE-DATE	Date of last update	X(8)
UPDATE-TIME	Time of last update	X(7)
TERM-ID	Term identification	X(8)
SUF-RATE	Current sufficiency rating	999.9
FED-SUF-RATE	Federal sufficiency rating	999.9
FED-SUBMIT-DATE	Date of last submittal to FHWA	XXXXXX
DEFICIENCY	Deficiency classification	X
CANDIDATE	Replacement/rehabilitation candidate classification	X
CARRIED.		
HIGHWAY-CARRIED.		
CODE	Code for type of highway carried	XXX
NUMBER	Number of highway carried by structure	XXXXXX
DATA-CLASS	State, county, city, or federal (1-4)	X
MRM	Highway carried mileage reference marker	999.99
ADT	Average daily traffic	999999
YEAR-ADT	Year of average daily traffic	XXXX
ADT-TRUCK	Average daily truck traffic	99.9
FEATURE-INTERSECTED.		
FEATURE	Feature(s) crossed by the structure	X(25)
CRITICAL-STR	Critical or non-critical structure flag	X
FEATURE-CARRIED	Feature(s) carried by the structure	X(18)
LOCATION	Description of location	X(25)
REGION	State highway region code	X
COUNTY	County code	XX
PLACE	Place code	XXXXX
CUSTODIAN	Agency responsible for maintenance	XX
OWNER	Agency responsible for administration	XX
YEAR-BUILT	Year bridge was built	XXXX
LANES	Number of lanes on structure	XX
LOAD-DESIGN	Design type and load type codes	XX
NAVIG-CONTROL	Over a navigable waterway indicator	X
TYPE-SERVICE	Type of service provided by bridge and under bridge	XX

Table A-7. Bridge Inventory Master File Organization (Page 2 of 11)

Data Item Name	Description	Picture
STR-TYPE-MAIN	Main material and type of design used code	XXX
CONSULT-CODE	Code for agency or consultant which performed inspection	XX
PARALLEL-STR-DESIG	Code to indicate separate structures carry opposite directions of travel	X
TRAFFIC-DIREC	Direction of traffic code	X
DEF-HWY-DESIG	Defense highway designation	X
HWY-SYS	Code for type of highway system carried by structure	X
DESIG-NATL-NETWORK	Designated national network for trucks	X
SCOUR-CRIT-BRIDGES	Scour appraisal rating code	X
RATINGS.	Condition and appraisal ratings	
DECK-RATING	Deck condition rating	X
SUPERSTR-RATING	Superstructure condition rating	X
SUBSTR-RATING	Substructure condition rating	X
CHANNEL-RATING	Channel and chan protection rating	X
CULV-RATING	Culvert condition rating	X
APPR-RATING	Approach roadway condition rating	X
STR-EVAL-RATING	Structural evaluation rating	X
DECK-GEOM-RATING	Deck geometry rating	X
UNDERCLR-RATING	Underclearance appraisal rating	X
SAFE-LOAD-RATING	Safe load appraisal rating	X
WATERWAY-RATING	Waterway adequacy appraisal rating	X
APPR-ALIGN-RATING	Approach roadway alignment rating	X
WEAR-SURF-RATING	Wearing surface condition rating	X
JOINT-RATING	Joint condition rating	X
DRAIN-SYSTEM-RATING	Drainage system condition rating	X
CURB-WALK-RATING	Curb and sidewalk condition rating	X
RAIL-BARRIER-RATING	Railings and barrier condition rating	X
MAIN-MEM-RATING	Main member condition rating	X
MAIN-CONNECT-RATING	Main member connection condition rating	X
FLOOR-MEM-RATING	Floor system member condition rating	X
FLOOR-CONNECT-RATING	Floor system connection condition rating	X
SEC-MEM-RATING	Secondary member condition rating	X
SEC-CONNECT-RATING	Secondary member connection condition rating	X

Table A-7. Bridge Inventory Master File Organization (Page 3 of 11)

Data Item Name	Description	Picture
EXP-BEAR-RATING	Expansion bearing condition rating	X
FIX-BEAR-RATING	Fixed bearing condition rating	X
PROT-COAT-RATING	Protective coating condition rating	X
ABUT-RATING	Abutment condition rating	X
PIER-BENT-RATING	Pier/bent condition rating	X
BANK-RATING	Bank condition rating	X
STREAM-BANK-RATING	Stream bed condition rating	X
RIP-RAP-RATING	Rip rap condition rating	X
DIKE-JET-RATING	Dike/jetties condition rating	X
APPR-EMBANK-RATING	Approach embankment condition rating	X
APPR-PAVE-RATING	Approach pavement condition rating	X
APPR-DRAIN-RATING	Approach drainage condition rating	X
APPR-JOINT-RATING	Approach growth/relief joint condition rating	X
CONDITION.	Condition ratings by and date	
COND-BY	Condition ratings by	XXX
COND-DATE	Condition ratings date	X(8)
INSPECT.	Routine inspection by and date	
INSPECT-BY	Inspection by	XXX
INSPECT-DATE	Inspection date	X(8)
APPRAISAL.	Appraisal ratings by and date	
APPRAIS-BY	Appraisal ratings by	XXX
APPRAIS-DATE	Appraisal ratings date	X(8)
COST-EST.	Cost estimates by and date	
COST-EST-BY	Cost estimates by	XXX
COST-EST-DATE	Cost estimates date	X(8)
OPERATIONS.	Operating ratings	
OPER-TYPE	Load type code	X
OPER-TON	Maximum load	999.9
INVENTORY.	Inventory rating	
INV-TYPE	Inventory load code	X
INV-TON	Inventory max load	999.9
WEAR-SURF-PROTECT-SYS.		
WEAR-SURF-TYPE	Deck wearing surface type code	X
DECK-PROTECTION	Deck protective system code	XX

Table A-7. Bridge Inventory Master File Organization (Page 4 of 11)

Data Item Name	Description	Picture
DECK-STR-TYPE	Deck structure type	X
EST-REMAIN-LIFE	Estimated remaining life	99
INSPECT-FREQ	Routine inspection frequency	99
FUTURE.		
FUTURE-ADT	Forecasted average daily traffic	999999
FUTURE-ADT-YEAR	Year of forecasted average daily traffic	XXXX
PROPOSED-IMPROVEMENTS.		
PROP-TYPE-WORK	Proposed type of work	XXX
PROP-IMP-LENGTH	Length of structure improvement	999999
PROP-ROADWAY-WIDTH	Proposed improvement roadway width	999
PROP-NUM-LANES	Number of lanes of proposed improvement	99
SUBSTR-COST	Substructure costs	99999
SUPERSTR-COST	Superstructure costs	99999
BRIDGE-IMP-COST	Bridge improvement costs	999999
ROADWAY-IMP-COST	Roadway improvement costs	999999
TOTAL-PROJ-COST	Total project cost	999999
LOAD-ANALYSIS-NO	Load analysis number	XXXXXX
DETOUR-LENG	Bypass detour length	99
BYPASS	Bypass code	XX
FA-ROUTE	Federal-aid route number	XXXX
MAINT-PROJ	State maintenance project number	X(9)
ADM-JUR	Administrative jurisdiction	XX
FUNC-CLASS	Functional classification	XX
APPR-ROADWAY-WIDTH	Approach roadway width	999
MEDIAN	Bridge median type	X
STR-FLARED	Structure flared indicator	X
HIST-SIG	Historical significance	X
OPER-STATUS	Operation status	X
APPR-STR-TYPE	Approach span structure type	XXX
SD-STD-TYPE	SD structure type code	XXXX
STR-LENG	Structure length	999999.9
MAX-V-CLR-R.	Practical maximum vertical clearance	
MAX-V-CLR-FT-R	Max clearance (ft.)	99
MAX-V-CLR-IN-R	Max clearance (in.)	99

Table A-7. Bridge Inventory Master File Organization (Page 5 of 11)

Data Item Name	Description	Picture
MAX-V-CLR-L.	Left practical maximum vertical clearance	
MAX-V-CLR-FT-L	Left max clearance (ft.)	99
MAX-V-CLR-IN-L	Left max clearance (in.)	99
LATITUDE.		
LAT-DEG	Latitude (deg)	99
LAT-MIN	Latitude (min)	99.9
LONGITUDE.		
LONG-DEG	Longitude (deg)	999
LONG-MIN	Longitude (min)	99.9
SKEW.	Skew and direction	
SKEW-DEG	Skew direction (deg)	XX
SKEW-MIN	Skew direction (min)	X
TRAFFIC-SAFETY-FEATURES.		
TRAFFIC-SAFETY	Traffic safety features acceptable code	XXXX
BRIDGE-RAIL	Bridge railing description code	XX
RAIL-TRANS	Railing transition description code	XX
APPR-RAIL	Approach rail description code	XX
APPR-RAIL-TERM	Approach rail terminal description code	XX
RAIL-BENEATH	Railing beneath structure description code	XX
NAVIG-CLEAR.	Navigation clearance	
NAVIG-VERT-CLR	Navigation vertical clearance	999
NAVIG-HORIZ-CLR	Navigation horizontal clearance	9999
SPANS.		
NO-MAIN-SPANS	Number of main spans	99
NO-APPR-SPANS	Number of approach spans	99
MAX-SPAN-LENG	Maximum span length	9999.9
HORIZ-CLEAR.		
HORIZ-CLR-R	Horizontal clearance	99.9
HORIZ-CLR-L	Left horizontal clearance	99.9
BOX-CULVERTS.		
BOX-CULV-CELLS	Box culvert number of cells	99
BOX-CULV-WIDTH	Box culvert width	99.9
BOX-CULV-HEIGHT	Box culvert height	99.9
BOX-CULV-LENG	Box culvert length	999.9
BOX-CULV-FILL-HT	Box culvert fill height	99.9

Table A-7. Bridge Inventory Master File Organization (Page 6 of 11)

Data Item Name	Description	Picture
SIDEWALK.		
WALK-WIDTH-R	Right curb or sidewalk width	99.9
WALK-WIDTH-L	Left curb or sidewalk width	99.9
BRIDGE-WIDTH	Bridge roadway width	999.9
DECK-WIDTH	Out to out deck width	999.9
MIN-V-CLR-R.	Absolute minimum vertical clearance	
MIN-V-CLR-FT-R	Minimum vertical clearance (ft.)	99
MIN-V-CLR-IN-R	Minimum vertical clearance (in.)	99
MIN-V-CLR-L.	Left highway minimum vertical clearance	
MIN-V-CLR-FT-L	Left min vertical clearance (ft.)	99
MIN-V-CLR-IN-L	Left min vertical clearance (in.)	99
OVERLAY-THICK	Deck overlay thickness	99.9
DECK-DELAM-AREA	Deck delaminated area	9999
DECK-DELAM-DATE	Deck delaminated date	XXXXXX
VISUAL-DECK-DATE	Visual deck survey date	XXXXXX
DECK-SURVEY-DATE	Delamination survey date	XXXXXX
ELECTRO-POTENT-DATE	Electro-potential survey date	XXXXXX
RESTEEL-DEPTH-DATE	Re-steel depth survey date	XXXXXX
CHLORIDE-SAMPL-DATE	Chloride survey date	XXXXXX
LEGAL-LOAD-CAP.	Load capacity	
LEGAL-LOAD-CAP3	Truck type 3	999
LEGAL-LOAD-CAP3S2	Truck type 3S2	999
LEGAL-LOAD-CAP32	Truck type 3-2	999
INSPECTION.		
CRIT-FRACT-INSPECT	Fracture critical inspection frequency	XX
UNDERWATER-INSPECT	Underwater inspection frequency	XX
SPECIAL-INSPECT	Other special inspection frequency	XX
CRIT-FRACT-INSPECT-DATE	Fracture critical inspection date	X(8)
UNDERWATER-INSPECT-DATE	Underwater inspection date	X(8)
SPECIAL-INSPECT-DATE	Other special inspection date	X(8)
CRIT-FRACT-INSPECT-BY	Fracture critical inspection by	XXX
UNDERWATER-INSPECT-BY	Underwater inspection by	XXX
SPECIAL-INSPECT-BY	Other special inspection by	XXX
BORDER-BRIDGE	State border bridge code	XXXXX
BORDER-STR-NO	Border bridge structure number	X(15)

Table A-7. Bridge Inventory Master File Organization (Page 7 of 11)

Data Item Name	Description	Picture
TEMP-STR-DESIG	Temporary structure designation	X
YEAR-RECONSTRUCT	Year reconstructed	XXXX
PIER-ABUT-PROTECT	Pier or abutment protection	X
NBIS-BRIDGE-LENG	Natl bridge inspection standards bridge length	999999.9
ESSENT-PUB-USE	Essentiality to public use	X
POSTED-SPEED	Posted speed limit	99
DRAIN-AREA	Drainage area	999999.9
HIGH-WATER-ELEV	Observed high water elevation	9999.9
HIGH-WATER-YEAR	Year of observed high water elevation	XXXX
DESIGN-FLOW	Design flow	999999
DESIGN-FREQ	Design flow frequency	999
DESIGN-VELOCITY	Design flow velocity	99.9
DESIGN-AREA	Drainage opening area	99999
DESIGN-YEAR	Design flow year	XXXX
FLOW-100-YEAR-FLOOD	Flow for 100-year flood	999999
SCOUR-SCREEN-STAT	Scour survey screening status	X
APPR-OVERLAY-TYPE	Type of approach overlay	XX
APPR-PAVE-TYPE	Type of approach pavement	XXXX
APPR-JOINT-TYPE	Type of approach joints	XXXX
APPR-SHOULDER-TYPE	Type of approach shoulders	X(8)
APPR-END-BACKFILL-TYPE	Type of approach bridge end backfill	XXXX
CONSTRUCTION-PROGRAM1.		
CONST-PROG-PCEMS1	Construction program PCEMS number	XXXX
CONST-PROG-TYPE1	Construction program type of work	XX
CONST-PROG-YEAR1	Construction program year	XXXX
CONST-PROG-PRIOR1	Construction program priority	XX
CONSTRUCTION-PROGRAM2.		
CONST-PROG-PCEMS2	Second construction program PCEMS number	XXXX
CONST-PROG-TYPE2	Second construction program type of work	XX
CONST-PROG-YEAR2	Second construction program year	XXXX
CONST-PROG-PRIOR2	Second construction program priority	XX
QLTY-ASSUR-INSPECT.	Quality assurance inspection	
QLTY-ASSUR-INIT	QA inspection by	XXX
QLTY-ASSUR-DATE	QA inspection date	8(X)

Table A-7. Bridge Inventory Master File Organization (Page 8 of 11)

Data Item Name	Description	Picture
PAINT-SUPERSTRUCTURE.	Paint system - steel superstructure	
PAINT-STEEL-UNDERCOAT	Paint undercoat type	X
PAINT-STEEL-TOPCOAT	Paint topcoat type	X
PAINT-STEEL-YEAR	Year painted	XXXX
PAINT-STEEL-COLOR	Paint color	X
PAINT-RAILS.	Paint system - bridge rails	
PAINT-RAIL-UNDERCOAT	Paint undercoat type	X
PAINT-RAIL-TOPCOAT	Paint topcoat type	X
PAINT-RAIL-YEAR	Year painted	XXXX
PAINT-RAIL-COLOR	Paint color	X
SKID.	Skid test	
SKID-NO	Skid test number	99
SKID-YR	Skid test date	XX
COMMENTS.		
DECK-COMMENT	Deck condition comment	X(60)
SUPERSTR-COMMENT	Superstructure condition comment	X(60)
SUBSTR-COMMENT	Substructure condition comment	X(60)
CHANNEL-COMMENT	Channel and chan protection comment	X(60)
CULV-COMMENT	Culvert condition comment	X(60)
APPR-COMMENT	Approach roadway condition comment	X(60)
STR-EVAL-COMMENT	Structural evaluation comment	X(60)
DECK-GEOM-COMMENT	Deck geometry comment	X(60)
UNDERCLR-COMMENT	Underclearance appraisal comment	X(60)
SAFE-LOAD-COMMENT	Safe load appraisal comment	X(60)
WATERWAY-COMMENT	Waterway appraisal comment	X(60)
APPR-ALIGN-COMMENT	Approach roadway alignment comment	X(60)
PROP-WORK-COMMENT1	Proposed type of work comment 1	X(60)
PROP-WORK-COMMENT2	Proposed type of work comment 2	X(60)
GENERAL-COMMENT1	General comment 1	X(60)
GENERAL-COMMENT2	General comment 2	X(60)
REGION-COMMENT1	Region comment 1	X(60)
REGION-COMMENT2	Region comment 2	X(60)
FREE-COMMENT1	Free comment 1	X(60)
FREE-COMMENT2	Free comment 2	X(60)
WEAR-SURF-COMMENT	Wearing surface condition comment	X(40)
JOINT-COMMENT	Joint condition comment	X(40)

Table A-7. Bridge Inventory Master File Organization (Page 9 of 11)

Data Item Name	Description	Picture
DRAIN-SYSTEM-COMMENT	Drainage system condition comment	X(40)
CURB-WALK-COMMENT	Curb and sidewalk condition comment	X(40)
RAIL-BARRIER-COMMENT	Railings and barrier condition comment	X(40)
MAIN-MEM-COMMENT	Main member condition comment	X(40)
MAIN-CONNECT-COMMENT	Main member connection condition comment	X(40)
FLOOR-MEM-COMMENT	Floor system member condition comment	X(40)
FLOOR-CONNECT-COMMENT	Floor system connection condition comment	X(40)
SEC-MEM-COMMENT	Secondary member condition comment	X(40)
SEC-CONNECT-COMMENT	Secondary member connection condition comment	X(40)
EXP-BEAR-COMMENT	Expansion bearing condition comment	X(40)
FIX-BEAR-COMMENT	Fixed bearings condition comment	X(40)
PROT-COAT-COMMENT	Protective coating condition comment	X(40)
ABUT-COMMENT	Abutment condition comment	X(40)
PIER-BENT-COMMENT	Pier/bent condition comment	X(40)
BANK-COMMENT	Bank condition comment	X(40)
STREAM-BANK-COMMENT	Stream bed condition comment	X(40)
RIP-RAP-COMMENT	Rip rap condition comment	X(40)
DIKE-JET-COMMENT	Dike/jetties condition comment	X(40)
APPR-EMBANK-COMMENT	Approach embankment condition comment	X(40)
APPR-PAVE-COMMENT	Approach pavement condition comment	X(40)
APPR-DRAIN-COMMENT	Approach drainage condition comment	X(40)
APPR-JOINT-COMMENT	Approach growth/relief joints condition comment	X(40)
SECTION	Section number(s) (up to 4)	XX
TOWN	Township number(s) (up to 2)	XXXX
RANGE	Range number(s) (up to 2)	XXX
ACCIDENT-ID	Accident number(s) (up to 10)	7(X)
MAINTENANCE-COSTS.	Fiscal year maintenance cost	
MAINT-COST	Maintenance cost	999999
MAINT-COST-YEAR	Year costs were accrued	XXXX
MAINTENANCE-NEEDS.		
MAINT-FUNC	Maintenance needs type of work codes	XXXX
MAINT-QUANT	Units of work needed for each type code	999999
MAINT-URGENCY	Urgency code for each type code	X

Table A-7. Bridge Inventory Master File Organization (Page 10 of 11)

Data Item Name	Description	Picture
REHAB-REPAIR.		
REHAB-REPAIR-FUNC	Rehabilitation needs type of work codes	XXXX
REHAB-REPAIR-QUANT	Units of work needed for each type code	999999
REHAB-REPAIR-URGENCY	Urgency code for each type code	X
SUPERSTRUCTURE.		
SPAN-NO	Span number	XX
SPAN-LENG	Span length	999.9
STR-TYPE	Span structure type	XXXXXX
GIRDER-SPACING	Span girder or stringer spacing	99.9
BEARING-TYPE	Span bearing type	XXXX
JOINT-TYPE	Span joint type	XXXX
SUBSTRUCTURE.		
SUBSTR-UNIT-NO	Substructure unit number	XX
SUBSTR-UNIT	Substructure unit type	XX
SUBSTR-FOUND	Substructure foundation type	XX
SOIL-ERODE-INDEX	Soil erodibility index	X
CONSTRUCTION-PROJECT.		
CONST-YEAR	Construction project year	XXXX
CONST-COST	Construction project bridge costs	999999
CONST-PROJ-NO	Construction project number	X(16)
CONST-PCEMS	Construction project PCEMS number	XXXX
CONST-FUNC	Construction project type of work	XXXX
BENEATH.	Highway or railroad beneath information	
HIGHWAY-BENEATH.		
B-CODE	Highway beneath code	XXX
B-NUMBER	Highway beneath number	XXXXXX
B-DATA-CLASS	Data class code	X
B-MAX-V-CLR-R.	Practical maximum vertical clearance	
B-MAX-V-CLR-FT-R	Max vertical clearance (ft.)	99
B-MAX-V-CLR-IN-R	Max vertical clearance (in.)	99
B-MAX-V-CLR-L.	Left highway beneath max vertical clearance	
B-MAX-V-CLR-FT-L	Left max vertical clearance (ft.)	99
B-MAX-V-CLR-IN-L	Left max vertical clearance (in.)	99
B-MRM	Beneath highway mileage reference marker	999.99
B-DETOUR-LENG	Bypass detour length	99

Table A-7. Bridge Inventory Master File Organization (Page 11 of 11)

Data Item Name	Description	Picture
B-BYPASS	Bypass code	XX
B-FA-ROUTE	Federal-aid route	XXXX
B-HWY-SYS	Highway system code	X
B-ADM-JUR	Administrative jurisdiction	XX
B-FUNC-CLASS	Functional class	XX
B-LANES	Beneath number of lanes	XX
B-ADT	Beneath average daily traffic	999999
B-YEAR-ADT	Year of average daily traffic	XXXX
B-DEF-HWY-DESIG	Highway beneath defense designation	X
B-TRAFFIC-DIRECT	HWY beneath direction of traffic	X
B-NATL-NETWORK	HWY beneath designated national network	X
B-HORIZ-CLR-R	HWY beneath horizontal clearance	99.9
B-HORIZ-CLR-L	Left HWY beneath horizontal clearance	99.9
MIN-V-UNDCLR-R.	Absolute minimum vertical underclearance	
MIN-V-UNDCLR-FT-R	Min vertical underclearance (ft.)	99
MIN-V-UNDCLR-IN-R	Min vertical underclearance (in.)	99
MIN-V-UNDCLR-L.	Left absolute min vertical underclearance	
MIN-V-UNDCLR-FT-L	Min vertical underclearance (ft.)	99
MIN-V-UNDCLR-IN-L	Min vertical underclearance (in.)	99
OUTSIDE-UNDCLR-R	Outside lateral underclearance	99.9
OUTSIDE-UNDCLR-L	Outside lateral underclearance - left roadway	99.9
MEDIAN-UNDCLR-R	Median lateral underclearance	99.9
MEDIAN-UNDCLR-L	Median lateral underclearance - left roadway	99.9
NUM-MRM	Highway number, suffix, MRM	X(10)
BNUM-BMRM	Beneath highway number, suffix, MRM	X(10)
OWNER-STRNO	Owner code, structure number	X(10)

Table A-8. Railroad Crossing Inventory Master File Organization (Page 1 of 2)

Data Item Name	Description	Picture
UPDATE-DATE	Date of last update	X(8)
UPDATE-TIME	Time of last update	X(7)
CROSSING	Unique crossing number	X(7)
RAILLINE	Rail line	XXXX
SURFACE	Highway surface type code	9
LANES	Number of traffic lanes	9
DIRECTION	direction of approach	XX
WARN-SIGN-APP	Approach warning sign (Y/N)	X
MARKING-APP	Approach pavement marking (Y/N)	X
CROSSBUCKS-APP	Approach crossbucks (Y/N)	X
SIGNALS	Signals (Y/N)	X
BELLS	Bells (Y/N)	X
GATES	Gates (Y/N)	X
CROSSBUCKS-AWAY	Advance crossbucks (Y/N)	X
MARKING-AWAY	Advance pavement marking (Y/N)	X
WARN-SIGN-AWAY	Advance warning sign (Y/N)	X
CROSSING-ANGLE	Crossing angle (1-3)	9
SIDEWALKS	Sidewalks (Y/N)	X
NO-TRACKS	Number of tracks	9
NO-DISPLAYED	Number displayed on post	X
INV-DATE	Inventory date (MMDDYY)	XXXXXX
COUNTY	County	X(10)
TOWN	Town	X(12)
HWY-ST-LOC	Highway/Street/Location	X(22)
SPEED-LIMIT	Posted speed limit	99
WARN-SIGN-APP-COND	Approach warning sign condition	9
MARKING-APP-COND	Approach pavement marking condition	9
CROSSBUCKS-APP-COND	Approach crossbucks condition	9
LENS-SIZE	Signal lens size (0, 8 or 12)	99
CROSSBUCKS-AWAY-COND	Advance crossbucks condition	9
MARKING-AWAY-COND	Advance pavement marking condition	9
WARN-SIGN-AWAY-COND	Advance warning sign condition	9
CROSSING-PROFILE1	Crossing profile (50, 25, 25, 50 ft)	99
CROSSING-PROFILE2	Same as above	99
CROSSING-PROFILE3	Same as above	99
CROSSING-PROFILE4	Same as above	99

Table A-8. Railroad Crossing Inventory Master File Organization (Page 2 of 2)

Data Item Name	Description	Picture
RAILROAD	Operating railroad	XX
TRAINS	Number of trains per day	99.9
ACCIDENTS	Number of vehicle/train accidents	99
HAZARD-RATING	Hazard rating number	9999
RES-KEY	RES index key	X(17)
NSTRI-KEY	NSTRI index key	X(12)
SIGNAL-TYPE	Signal type (MAST or CANT)	XXXX
TRACKS.	Track information	
MATERIAL	Crossing material code	99
OBSTRUCTIONS	Obstructions (Y/N)	X
QUADRANT1	If OBSTRUCTIONS = 'Y', direction of obstruction in quadrant 1	XX
QUADRANT2	Same as above	XX
QUADRANT3	Same as above	XX
QUADRANT4	Same as above	XX
WIDTH	Crossing width	99
HEIGHT	Height of rail ($0 < h < 10$)	9.999
SURFACE-COND	Surface condition code (1-9)	9
RIDEABILITY	Rideability factor (1-9)	9
SWITCH	Switch present (Y/N)	X
DRAINAGE	Drainage problem (Y/N)	X
YR-IMPROVE-NEEDED	Year of needed improvement	XX
YR-IMPROVE-PROG	Year of improvement program	XX
YR-LAST-IMPROVE	Year of last improvement	XX
REC-TYPE-IMPROVE1	Record type improvement code (1-99)	99
REC-TYPE-IMPROVE2	Same as above	99
REC-TYPE-IMPROVE3	Same as above	99
REC-TYPE-IMPROVE4	Same as above	99
REC-TYPE-IMPROVE5	Same as above	99
REC-TYPE-IMPROVE6	Same as above	99
CROSSING-COST	RR crossing cost	9999999
SIGNAL-COST	Signal cost	9999999
STATEWIDE-RANK	Statewide rank	9999
SYSTEM-PRIORITY	System priority	9999
STATEWIDE-PRIORITY	Statewide priority	9999
RR-ADT	Railroad crossing average daily traffic	99999
UNLOAD-TO-TEST	Unload to test	X

Table A-9. Mileage Reference Marker Inventory Master File Organization

Data Item Name	Description	Picture
DELETE FLAG	Update type (A,B,C,D,E,or M)	X
REGION	Region code (1-4)	X
COUNTY	County code (02-69)	XX
MRM-KEY.		
DATA CLASS	State, county, city, or federal (1-4)	X
HIGHWAY DESIG.		
NUMBER	Highway number	XXX
SUFFIX	Highway suffix code	XXX
MRM	Mileage reference marker	999.99
TYPE OF MRM	Code for type of MRM (1-5)	X
MILEAGE	Mileage of the reference marker	999.999
INSTALLATION DATE.	Installation date	
YEAR	Year	XX
MONTH	Month	XX
DAY	Day	XX
FILLER	Filler	X(5)
ACTIVITY DATE.		
YEAR	Year	XX
MONTH	Month	XX
DAY	Day	XX
DESCRIPTION	Description of location	X(25)

Table A-10. Highway Planning Inventory File Organization (Page 1 of 7)

Data Item Name	Description	Picture
REC-KEY.	**Key Record**	
D-C	Data class: state, county, city, or federal (1-4)	X
HIGHWAY.		
NUMBER	Highway number	XXX
SUFFIX	Highway suffix code	XXX
BEGINNING.	Beginning location MRM	
MRM	Mileage reference marker	999.99
DISP	Displacement from MRM in thousandths of a mile	99.999
UPDATE.	Update date	
Y-Y	Year	XX
M-M	Month	XX
D-D	Day	XX
Record Type A.	**Identification**	
ENDING.	Ending location MRM	
E-MRM	Mileage reference marker	999.99
E-DISP	Displacement from MRM in thousandths of a mile	99.999
LENGTH	Section length	999.999
A01	Scenic road (0-2)	9
A02	County number	99
A03	Highway district	9
A04	Planning and development district	9
A05	Population size code (1-7)	9
A06	Federal-aid route number	9999
A07.	Highway system code	
A07-A	Federal-aid system designated way	9
A07-B	Federal-aid system traveled way	9
A07-C	Administrative system code	99
A07-D	Special system code	99
A08	Municipal code (0-1)	9
A09	Rural-urban code (1-2)	9
A10	Functional classification	99
A11	City code	9999
A12	Maintenance responsibility code	9

Table A-10. Highway Planning Inventory File Organization (Page 2 of 7)

Data Item Name	Description	Picture
Record Type B.	**Geometrics**	
B01	Access control (0-2)	9
B02	Lane width (ft.)	99
B03	Roadway width (ft.)	99
B04	Number of lanes	9
B05	Left shoulder width (ft.)	99
B06	Right shoulder width (ft.)	99
B07	One-way – two-way code	9
B08	Divided – undivided code	9
B09	Frontage road existence code	9
B10.	Number of curves between minute ranges	
B10-A	1:0 – 2:59	9
B10-B	3:0 – 3:59	9
B10-C	4:0 – 4:59	9
B10-D	5:0 – 7:0	9
B10-E	7:1 – over	9
B11.	Number of grades within percent grade ranges	
B11-A	1.9 – 3.0	99
B11-B	3.1 – 5.5	9
B11-C	5.6 – 10.0	9
B11-D	10.1 – 13.0	9
B11-E	13.1 – over	9
B12	Median width	9999
B13	Median type	99
B14	Terrain	9
B15	Right-of-way width (ft)	9999
B16	Percent length with intolerable safe speed	99
B17	Percent with sight dist less than 1500 ft	99
B18	Average highway speed	99
B19	Number of signals and/or stop signs	99
Record Type J.	**Average Cost/Mile/Year - $100**	
J01	Administration cost	999999
J02	Roadway surface maintenance cost	9999999
J03	Structure maintenance cost	9999999
J04	Contract maintenance cost	9999999
J05	Total maintenance cost	9999999

Table A-10. Highway Planning Inventory File Organization (Page 3 of 7)

Data Item Name	Description	Picture
Record Type I.	**Improvement Costs - $100**	
I01	PCS number	9999
I02	Reporting unit	999
I03	Funding prefix	999
I04	Project status (0-9)	9
I05	Year of needed improvement	99
I06	Year of the construction program	99
I07	Type of improvement	99
I08	Grade, drain, and minor structures cost	99999
I09	Subbase, base, surface, and shoulders cost	99999
I10	Major structures cost	99999
I11	Other cost	99999
I12	Right-of-way cost	99999
I13	Utilities cost	99999
Record Type C.	**Traffic**	
C01	Average daily traffic	999999
C02	Percent of trucks	99.9
C03	30^{th} highest hour percent	99.9
C04	Percent directional traffic	99.9
C05	Capacity (hourly)	9999.9
C06	Speed limit	99
C07	Operating speed	99
C08	Accident rate	999.99
C09	Number of fatal accidents	99
C10	Number of injury accidents	99
C11	Number of property damage accidents	99
Record Type D.	**Structural**	
D01	Year graded	99
D02	Year last surfaced	99
D03	Year last sealed	99
D04	Surface type code	9999
D05	Surface width (ft)	999
D06	Surface thickness	99.9
D07	Shoulder type (1-9)	9

Table A-10. Highway Planning Inventory File Organization (Page 4 of 7)

Data Item Name	Description	Picture
D08	Roadbed layer year	XX
D09	Roadbed layer code	XX
D10	Minimum roadbed layer thickness	99.9
D11	Drainage adequacy	9
D12	Average roughometer reading	9.99
D13	Average dynaflect reading	9.99
D14.	Number of skid tests in ranges:	
D14-A	0 – 20	99
D14-B	21 – 30	99
D14-C	31 – 40	99
D14-D	41 – over	99
D15	P.S.R. equivalent	9.99
Record Type E.	**Railroad Crossings**	
E01	Number of protective devices (no. of crossings)	9
E02	Crossbucks (no. of crossings)	9
E03	Flashing lights (no. of crossings)	9
E04	Flashing lights and gates (no. of crossings)	9
E05	Grade separations (no. of crossings)	9
Record Type F1.	**Structures**	
F01	Number of structures	99
Record Type F2.	**Type F2**	
F02	Structure number	9(8)
F03	Structure type code	9999
F04	Total cost of improvement in thousands of dollars	9999
F05	Structure length	9999
F06	Bridge roadway width (ft)	999.9
F07	FHWA sufficiency rating	999
F08	Substructure condition rating	X
F09	Superstructure condition rating	X
F10	Culvert and retaining wall rating	X
F11	Deck condition rating	X
F12	Waterway adequacy	X
F13	Safe load capacity	X

Table A-10. Highway Planning Inventory File Organization (Page 5 of 7)

Data Item Name	Description	Picture
F14	Structural condition	X
Record Type G.	**Deficiency Analysis**	
G01	20-year average daily traffic	999999
G02	Average annual traffic growth	999
G03	% Length w/ intolerable safe speed (20 yrs)	99
G04	Time of pavement condition deficiency	9
G05.	No. of deficiencies (Codes 0-6)	
G05-A	Operating speed	9
G05-B	Lane or roadway width	9
G05-C	Safe speed	9
G05-D	Pavement type and/or condition	9
G05-E	Shoulders	9
G06	Initial deficiency code	X
G07	Secondary deficiency code	X
Record Type G.	**Type G Continued**	
G08	Gap segment	XX
G09.	Sufficiency rating	
G09-A	Conditional	99
G09-B	Safety	99
G09-C	Service	99
G09-D	Net	999
G10	Surface indicator	999
G11	Proximity to population center	X
G12	Railroad abandonment pending	X
G13	No railroad service area	X
G14	Volume group (1 low – 2 high)	X
Record Type H.	**Improvement Description**	
H01	ADT first year after improvement	999999
H02	Design year ADT	999999
H03	Design hour ADT	999
H04	Design standard number	99
H05	Access control	9
H06	Number of lanes	9
H07	Construction cost area	9

Table A-10. Highway Planning Inventory File Organization (Page 6 of 7)

Data Item Name	Description	Picture
Record Type K.	**Project Description**	
K01	Project description	X(50)
K02	Project description	X(50)
K03.		
K03-A	Project description	X(45)
K03-B.		
AGREEMENT	Agreement number of the construction project	99
MILEPOST	milepost if different from MRM	999
Record Type L.	**Plan Comments**	
L01	Plan ID (agreement no. and milepost)	99999
L02	Plan length	999.999
L03	Plan comment	X(35)
L04	Plan comment	X(35)
L05	Plan comment	X(35)
MAP-ID.	**(Strip Map Page Number)**	
M01	Page number	99
Record Type D-EXTRA.	**Structural**	
D16	Application width (ft)	99
D17	Maximum roadbed layer thickness (in.)	99.9
D18	Thickness not consistent (*, ?, _)	X
Record Type N.	**Rank and Priority**	
RANK	Rank	9999
PRIORITY	Priority	9999
FA-PRTY	Federal-aid priority	9999
Record Type G-EXTRA.	**Deficiency Analysis**	
G15.	Surface evaluation	
G15-A	Crack rating	99
G15-B	Behavioral rating	99
G15-C	Net evaluation	999
G16	Rutting	99
G17	Percent patching	99
Record Type L-EXTRA.	**Plan Comments** (Occurs 7 times)	
L06	Construction program priority	9999
L07	Estimate date	YYMMDD

Table A-10. Highway Planning Inventory File Organization (Page 7 of 7)

Data Item Name	Description	Picture
G18	Percent of roadway with rut depth over 0.5 inches	99
G19	Severest rut depth	99.9
UNLOAD-TO-TEST		X
Record Type P.		
DESIGN SPEED.	No. of crest curves for 9 design speed categories (Occurs 9 times)	
P01	No. of crest curves	999
P02	No. of sag curves	999
Record Type Q.		
SURF-COND.	Surface conditions for various surface types (Occurs 15 times)	
Q01	Percent with condition rating 1	999
Q02	Percent with condition rating 2	999
Q03	Percent with condition rating 3	999
Q04	Number of observations	999
Record Type R.		
R01	Rut depth percent in inch categories (Occurs 6 times)	

APPENDIX B

GLOSSARY

ADABAS – Software AG's commercial DBMS system based on the network approach.

Application – A set of records and programs that support a specific requirement. Examples are data acquisition, data analysis, etc.

Attribute – Property of an entity or the name of a column in a table or relation.

Back-end – See server.

B-tree – Balanced tree storage structure.

Catalog – The active, integrated location of physical data definitions.

Client – The process or machine on which the user interface application is executed, typically the client process is run on a personal workstation such as a UNIX workstation, Macintosh, IBM-PC, etc.

Column – See attribute.

Database – An administrative unit encompassing a set of tables.

DBA – DataBase Administrator – One person or a team of persons who has central responsibility of a database system that provides centralized control of its operational data for an enterprise.

DB2 – IBM's commercial RDBMS system for the IBM mainframe environment.

DBD – DataBase Description – Where each physical database is defined, and where the mapping of the physical database to storage is specified.

DBMS – DataBase Management System – Handles all access to the database.

DDL – Data Definition Language – provides for the definition or description of database objects as they are perceived by the user.

DML – Data Manipulation Language – Supports the manipulation or processing of database objects.

DSL – Data SubLanguage – A subset of the total language that is concerned with database objects and operations.

Entity – Any distinguishable object that is to be represented in the database.

Focus – Information Builders, Inc. commercial 4GL and DBMS system that supports access to multiple DBMSs.

Front End – See client.

Hash – A method of organizing data within a file using an algorithm of some value. It's purpose is to randomize the data.

Heap – A method of storing data within a file in straight sequential order using as much space as it may require.

Hierarchical Approach – A network whose multiple links have a many-one relationship from child to parent.

INGRES – Ingres Division of ASK Corporation's RDBMS and related suite of products including application developer tools for both terminal- and window-based applications, knowledge manager, object manager, and networked and distributed database management software.

ISAM – Indexed Sequential Access Method.

Key – An attribute or set of attributes whose values uniquely identify each entity in an entity set.

LAN – Local Area Network.

Menu – A collection of options which appear on the screen.

MRM – Mile Reference Marker – the primary component of the current RES key.

Network Approach – The entity-relationship model with all relationships restricted to be binary, many-one relationships.

Partition – Tables may be split into partitions for availability reasons. Each partition cover a key range. The partitioning is transparent to the program accessing the data, but not to the DBA.

PMS – Pavement Management System.

Primary Key – The unique identifier of a row.

Query – The process of arriving at a summary: defining what items to search, defining the search conditions, and causing the execution of a report.

Query Language – User-written application program that accepts commands from the terminal and in turn issues requests to the DBMS on the end-users behalf.

Record – One row in a table which represents a distinct object or event.

Relation – A set of rows with a common definition.

Relational Approach – Consists of two principal components: (1) relational data structure and (2) relational algebra.

Report – Printed output from the database.

RES – Roadway Environmental Subsystem – The current South Dakota Department of Transportation highway database system.

RDBMS – Relational DataBase Management System – Handles all access to the relational database.

Row – A set of attributes associated with an entity.

Server – The process, device, or machine on which the database resides together with the DBMS on that machine, such as DB2 on the IBM 3090

SQL – Structured Query Language. ANSI, ISO, and SAA standard language for relational database.

Table – A place were data is kept with rows describing distinct objects or events and columns which describe attributes of the rows.

Tuple – Each row in a table or relation.

VSAM – Virtual Storage Access Method.