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16. Abstract

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Spatial Information and Modeling System for Transportation (SIMST)

Final Report - June 1992

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John Hill and Daniel Flint worked on early parts of the remote sensing project. Don DiRosa worked on the design and early implementation of the Archival Management System. Daniel Hebert also worked on the Archival Management System.

Abstract

This project was directed toward research in the development of spatial information systems for transportation. The project and all software development was done in the Intergraph MGE environment. One objective was to investigate software tools for locating spatial data. A system called the Archival Management System (AMS) was developed to assist in the management of a spatial data archive. The AMS can manage data describing aerial photographs, satellite images, maps or Intergraph design files. Pavement Management and Storm Discharge Prediction demonstrations were conducted to study methods of spatial data translation and database integration as well as applications of these databases to pavement management and storm discharge prediction. Highway Needs data and pavement history and quality data were utilized to develop a prototype Pavement Management System. The storm discharge prediction demonstration was designed to study methods for utilizing spatial databases with modeling programs for predictive purposes. Since the cost of acquiring spatial data is high, another objective was to investigate sources of spatial data. Data collected from Global Positioning Systems (GPS) as well as remotely sensed data obtained from satellites and aircraft were studied. These data were examined for their utility in maintaining the cartographic and highway inventory database. We photointerpreted, digitized, and analyzed road networks from SPOT Satellite digital data and transparencies as well as the NHAP (National High Altitude Photography) and NAPP (National Aerial Photography Program) aerial photographs. Video and high resolution aerial photography were interpreted and evaluated for their suitability in providing inventory data.

Implementation Statement

Since most of the equipment and software utilized in this project are available at the LDOTD, the main effort to implement the concepts developed in this work would involve: tailoring the LDOTD systems to the applications, creation of required databases, and training of personnel. The software development was done in the Intergraph MGE environment. Software tools required include: C, Intergraph RtoDto, MicroStation, MDL, MGA, MGE/SX, MGE/ISI, and MSPM. ORACLE is a relational database management system (RDBMS) with the Dynamic Structured Query Language (SQL). The software requirements include the following ORACLE products: 1). SQL *Loader, 2). SQL *Plus, 3). SQL *Forms, 4). SQL *Menu, 5). SQL *Report, and 6). PRO *C.

An issue would be integrating the methods into LDOTD procedures. A suggested approach would be to start with a parish wide project with LDOTD personnel involved in adapting the methods to their needs and requirements. Later, a state-wide implementation would follow upon successful completion of the parish project. The parish project would determine the required functionality to guide the implementation of the system, determine required data, develop methods for collecting data, archiving data, and conversion of data, develop methods for coordinating and sharing data between units, determine hardware and software needs, determine training needs and schedules, customize the systems to LDOTD requirements, and develop additional software as needed.

It would be extremely valuable to describe in detail the desired functionality of each system before the actual state-wide implementation is initiated in order to guide in data collection and the precise manner in which the system is structured. One of the major obstacles in implementing any GIS is the huge cost associated with data gathering and database creation. It is estimated that more than half of the total budget of a GIS project is spent in data gathering and database preparation. Because of this, data sharing between different projects and/or divisions of an organization becomes an important issue for the success of any GIS projects. Intergraph's MGE products, like all other commercial GIS packages, provide only the standard GIS tools. To maintain a productive GIS requires both system customization and trained GIS operators to operate the system. System customization includes two areas. The first one is the development of custom applications to extend the standard GIS functions in certain specific areas. The second area is the development of user interfaces that will make the system easier to use. Operator training is required in order to maintain a reliable and efficient system. The training should include basic GIS and computer mapping, training, and workflow training that is specific to the individual organization or division.

1 Archival Management System.

In order to implement the Archival Management System (AMS), one must meet certain hardware and software requirements. The AMS was developed with LDOTD computing systems in mind. The AMS can be implemented at LDOTD using existing Intergraph workstations. For most general purposes, except when using the graphical interace, the AMS can be used on a VT100 terminal. An effort would be required to build the spatial database. This would include obtaining information about photography, maps, and design files, for example.

2 Pavement Management

The system developed for the SIMST project was a prototype version. The tools developed could all be used in an actual implementation with minimal changes. MDL procedures were used to generate pavement management subsections and to display pavement history views of control sections. RtoDto, SQL, MGE and MGA techniques were used to process the attribute and map data. Once the data is entered and processed, a large number of analysis scenarios can be carried out.

Design files containing maps for each parish consisting of graphical route, control-section and Needs subsection features currently exist in a polyconic projection with 1927 datum. These design files could serve as the basis for the system. The steps needed to implement a state-wide pavement management system are described in the following sections.

2.1 Data Collection

The crucial requirement for implementing the system is adequate data. Data is required for both the pavement history and the pavement quality. It is necessary to identify homogeneous pavement management subsections by the beginning and ending log mile and to determine values for variables such as international roughness index, distress rating, skid resistance, surface type, number of lanes, accidents per motor vehicle mile, and average daily traffic for each of these subsections. The pavement subsections can be generated from pavement history data which describes all pavement projects by beginning and ending log mile and includes information about the material, year, project number, depth and thickness of the layer. The homogeneous history sections are equivalent to the pavement management subsections.

2.2 ORACLE Database Creation

The attribute data for each of the subsections must be entered into the ORACLE database. If the data exists in an ASCII tabular file, it can easily be loaded into ORACLE using the SQL tools utilized in this project. The techniques would require modification based on the format of the input data, but this would not entail significant effort.

A large amount of relevant data collected for Needs analysis already exists in the form of IGDS/DMRS VAX files and in an IBM database. Several points must be kept in mind when using this data. First, the data corresponds to Needs rather than Pavement subsections. Second, the data for the entire state is contained in one very large DMRS database rather than in separate parish specific ones. Several entities including route, control-section, and subsection data must be converted to ORACLE tables via the Intergraph utility RtoDto. Enough space must be available in the ORACLE database to hold and manipulate the converted information if the entire state is processed at one time. In addition, the Needs data changes from year to year. Thus, after the conversion is performed, additional processing will be required to update the graphics and attribute data. When the conversion and updating activities are completed, the resulting products will be MicroStation design files containing graphical Needs sections which are linked to an ORACLE table containing the Needs attributes.

2.3 Graphics Feature Generation and Database Attribution

Presently, the graphics Needs and Pavement subsection features must be generated, preferably through an automated interface, and each new graphic subsection feature tied to the appropriate database record. The basic technique is to use the control-section graphical features as the starting point, access the database to determine the control-section name of each of these features, read the database to obtain the beginning and ending logmile of each subsection of the control-section just identified, create new graphical features for each of these subsections by segmenting the control-section into the appropriate subsections and finally, link the new graphical features to the appropriate row of the relevant table in the relational database. This portion of the workflow will be affected by the use of the new MGE Segment Manager which performs dynamic segmentation of the control-sections based on records in the relational database describing the control-section Needs and Pavement subsections.

2.4 Topology Generation and Spatial Analysis

Topology describes the adjacency and connectivity relationships among geographic data based on their locations relative to one another. Topological relationships are unaffected by distortion. In the MGE environment, a file containing a mathematical representation of the spatial relationships between the graphic elements of a design file is generated using the MGA application Topo Builder. The resulting topological files are the basis for all the spatial analysis performed in the PMS. MGA provides the capabilities to generate query sets based on SQL statements, to produce reports listing the database values of the resulting query sets and to highlight the graphical elements with these desired spatial and/or attribute characteristics. In addition, Needs and Pavement subsections can be overlain to generate a new feature with linkages to both attribute tables. For the purpose of this demonstration project, these MGA capabilities were directly accessed. If the PMS system is to be used by personnel with no Intergraph training, it would be necessary to develop extensive menus covering the full range of queries which need to be carried out. A significant feature of the MGE environment is that many of the commands can be performed outside of the graphical environment in the form of UNIX shell scripts. Report generation capabilities could be quickly encapsulated in these scripts which would be executed at regularly specified intervals.

2.5 Pavement History Profiles

The MDL procedure SHOW PAVEMENT HISTORY written for this project can be used to display the pavement history of each control-section in both a tabular and graphical format. In order to be usable, an ORACLE table must exist which contains the pavement history for each subsection. In addition, a design file for each parish consisting of control-section elements which are linked to a database table containing the control-section name is required. This design file could be the same file used to generate the Pavement and Needs management subsections.

3 Storm Discharge Prediction.

This prototype system for storm discharge prediction was designed to demonstrate the capability of a GIS in handling spatial data related to a modeling program for predicting peak storm discharge. Procedures developed for this project include graphical data preparation, database attribution, spatial query, and data extraction. They can all be used in the actual implementation of a system. The prototype system now contains the required database information for only one watershed (Turkey Hollow Creek) along U.S. Highway 190 near DeRidder in Beauregard Parish. Although it is limited in terms of its database, the prototype system has raised several issues that need to be addressed in any future implementation.

3.1 Data Compatibility and Conversion

Data used in this prototype GIS were derived from various sources and data compatibility became an unavoidable issue. A GIS assumes that all the data used in spatial analysis are compatible in terms of accuracy, scale, and map projection. For the prototype system, we have tried to utilize existing data as much as possible to minimize the total cost of data collection. As a result, we found that these data had different map scales and projections. Data conversion was performed to bring all the data layers into a common base. This situation is likely to be true for any similar project.

In order to perform spatial query to extract information for the storm discharge modeling program, we used Intergraph's MGE projection Manager to transfer all the data into a common map projection. The data transfer functions used in this project will mathematically convert all types of data into a common scale and projection, no matter how much the original data differ with each other. The user has no control on the possible misuse of the converted data. It should be remembered that data overlay and spatial query will generate meaningful results only when all the overlay data have a similar spatial resolution and are in a common map scale and projection. Therefore, a GIS should use data with a similar spatial resolution wherever possible. When data of different scales have to be used in a same project, extra caution must be taken to avoid the misuse of the converted data.

3.2 Data Requirements

Data needed for the storm discharge modeling includes: land-use, soil, watershed boundaries, rainfall intensity, and the drainage network. These geographic features are important data for other projects and applications as well. Therefore, it is desirable to have a general purpose database for the commonly needed geographic features. These features should be digitized and kept in separate Intergraph design files. They should be defined as separate features under different feature categories and administered by a database administrator. He or she will extract the needed features and put them in a new design file based on the requests made by individual project managers. The project managers will then include data unique to his or her projects for spatial analysis. This will greatly reduce the total cost of data gathering and digitization for the organization as a whole.

3.3 System Customization

At present, the output from the prototype system is an input file to the Hydraulics Program (HYDR1130). It would be more efficient if the Hydraulics Program (HYDR1130) could be incorporated into the GIS, and the peak discharge rate could be computed within the GIS environment.

4 GPS/Van Data Collection

GPS/Van derived data sets offer a cost effective alternative to existing Louisiana LDOTD manual methods. When integrated with improving elapsed distance methods, an opportunity exists to automate the collection of physical highway inventory data. This data will be especially useful to the LDOTD cartographic mapping section in maintaining the spatial network for decision map scenarios.

A problem will be to move from manual systems to automated systems. A feasibility study covering a parish is a way to develop procedures while maintaining the manual system. GPS/Van related technology will be applied in two ways; first, as a separate data collection system and second, as a component of more elaborate data collection systems, such as those that collect pavement data. The following steps are suggested:

Step 1: Define explicitly the applications to be supported and the accuracy requirements to support those applications.

Step 2: Develop a base station network to support the accuracies defined in Step 1 above.

Step 3: Establish specific "geographic features" along the routes that have established GPS position and elapsed distance integrity. These "geographic features" should come from the present LDOTD geographic feature file and should consist of those points that are easily identified while operating in a moving vehicle. These points will act like the "control points" in a baseline survey. Future data collection can use these points to adjust data and maintain data consistency.

Step 4: Collect the original network using GPS and elapsed distance data. This will provide flexibility for implementing cost effective digital data collection systems. The new GPS network can be integrated into the existing Intergraph cartographic digital base and will be acceptable for the cartographic digital base and for resultant decision maps.

Step 5: Update new and revised alignments using GPS technology.

5 Remotely Sensed Data

The remotely sensed data were collected only for our study site in Beauregard Parish. This included satellite data, aerial photography, and aerial video. The LDOTD has the necessary computer hardware and software, namely, the Intergraph MGE products, to analyze satellite and aerial photography. Resolution requirements of the LDOTD make photography more useful than the satellite imagery. Photography would be useful to different groups within the LDOTD. For this reason, it would be useful to have the data archived and made available to the different groups. One can photointerpret directly from the photography, but a high quality image scanner capable of scanning photographs would be an asset. The data, if scanned into a digital format, may take up large amounts of computer file space which implies that data compression software should be considered. The digital data could be readily transferred over the computer networks available at LDOTD. Intergraph's MGE products provide only the standard analysis tools. To have a productive environment requires system customization and trained operators. System customization would include the development of user interfaces to make the system easier and more efficient to use. Operator training should include basic GIS and computer mapping training. Training in photointerpretation would also be useful.

One must have an available source of remotely sensed data. The collection of black and white photography is routinely done on a project basis at LDOTD, and this data should be utilized. For some applications, more data may have to be collected. NAPP color photography is readily available when the scale is suitable for the application. Other data would have to be flown as requirements dictate. The implementation of aerial highway inventory using black and white film and existing LDOTD equipment will provide archival materials at a cost higher than the cost of manual road logging as done today.

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1. Introduction

This work addresses the archiving, conversion of digital data, and the use of spatial data by the Louisiana Department of Transportation (LDOTD). This project involved work on an Archival Management System (AMS), and Spatial Data Translation Software as well as applications and demonstrations which included Highway Needs, Pavement Management and Storm Discharge Prediction, GPS/Van Derived Data Sets, and remotely sensed data from satellites and aircraft for maintaining the cartographic and highway inventory databases. The AMS is a menu-based Oracle application which provides Standard Query Language (SQL) access to spatial data. The Spatial Data Translation project was concerned with utilizing spatial data residing on different systems. The Highway Needs, Pavement Management and Storm Drainage Prediction Demonstrations examined issues in spatial data translation as well as developing prototype systems. The GPS/Van data collection project examined issues involved in collecting and utilizing these data. The work with remotely sensed data examined different types of remotely sensed data and methods for analyzing these data.

1.1 Archive Management System (AMS)

A major asset of any institution is its important data. But this data, to be useful, must be archived. The AMS project addresses the problem of archiving spatial data. The AMS is a front-end program designed to assist in the management and querying of the spatial data archive. The AMS has to handle large amounts of data of different types. The main goal of the AMS is to retrieve the data in a very simple and efficient manner. It was desired to implement the system using current database technology. A relational database is a database in which the data visible to the user is organized as tables of data values, and all database operations work on these tables. Different tables having some common fields can be related together. Data can be retrieved from the database in a simple, straightforward way by using SQL. SQL is a standard comprehensive language used for controlling the functions provided by a DataBase Management System (DBMS). Some of the functions are listed below:

1) Data Definition. Define the structure and organization of stored data and relationships among the stored data items.

2) Data Retrieval. Retrieve stored data from the database and use it

3) Data Manipulation. Update database by adding new data, removing old data and modifying previously stored data.

4) Access Control. Restrict a user's ability to retrieve, add and modify data in order to protect data against unauthorized access.

5) Data Sharing. Coordinate data sharing by concurrent users, ensuring that they do not interfere with one another.

6) Data Integrity. Protect database from corruption due to inconsistent updates or system failures.

SQL is also portable across different systems. Therefore, it was decided to use a RDBMS for implementing the AMS. The different types of RDBMS available were again investigated. It was decided to use ORACLE to be compatible with LDOTD, since ORACLE meets our requirements of a RDBMS with SQL.

Data retrieval using SQL directly requires the user to have a good knowledge of RDBMS, SQL and the underlying data structure. The user will have to type out long commands, especially if the query has to be done using many relations. This often results in typographic errors and frustrations. As a solution to all these problems, it was decided to provide a very user friendly interface where the user needs to have no prior knowledge of RDBMS, SQL or the underlying data structure. This gave rise to the present structure of the AMS.

AMS is completely menu driven. The user is taken through a series of menus to make any particular selection, and wherever dynamic information (such as date and scale) is required, forms have been provided for the user to enter the values requested. Complete on-line help has been provided, and the user can get the required information in a very quick, efficient way with minimal effort.

1.2 Pavement Management

This project was implemented to explore issues related to spatial data conversion and reformatting. These issues are of importance to the Louisiana Department of Transportation and Development due to the migration by Intergraph Corporation to the new workstation based platform. This transition allows access to many new tools for data conversion. First, tools are provided to move existing projects into the new environment. Second, since the ORACLE database used in the new environment is Structured Query Language (SQL) compliant, the ease of generating and maintaining a database has been greatly simplified and standardized. Third, the GIS interface has become icon based and customizable via a C based programming language called MicroStation Development Language, and fourth, utilities for importing and exporting graphics data in a variety of formats have been provided as part of the MicroStation package or as additional products available for purchase.

In the process of implementing a Pavement Management System prototype, the first three of these tools were used extensively. Problems encountered in making the transition were resolved and documented for use by LDOTD. Optimal design and development for a cumulative pavement history database were explored. Relevant Intergraph capabilities for implementation of a PMS were utilized, and custom tools for performing specialized pavement management applications were created as needed.

The development of the prototype provided the opportunity to evaluate the GIS-T approach to managing a PMS. Recent FHWA policy mandates that each state highway agency implement a pavement management system encompassing planning, design, construction, maintenance, evaluation and rehabilitation of pavements. A graphical approach enables displays of pavement condition by parish or other geographic boundaries and aids in conveying information to PM personnel as well as funding agencies. A well designed system can be interfaced with other MGE projects to allow for sharing of data and overlaying of relevant spatial information. In addition, an objective allocation of maintenance and resurfacing funds may be encouraged by the analytical capabilities of the system. In the process of carrying out the necessary conversion, development and customization tasks, the potential value of an Intergraph based PMS could be assessed.

1.3 Storm Discharge Prediction

Peak storm discharge from a drainage basin is a major concern to the transportation engineers when they design cross drain structures such as bridges and culverts. This parameter is determined by many factors such as rainfall intensity, duration, distribution over the duration period, watershed size, shape, slope, soil type and land-use status. Standard procedures and computer modeling programs have been developed to estimate this value. However, as the GIS technology becomes an affordable tool, it is gradually realized that spatially oriented data could be handled and used much more efficiently.

The LDOTD is currently using the Soil Conservation Service procedure (S.C.S.) to estimate the peak discharge for ungauged drainage basins of 2,000 acres or smaller. The United States Geological Survey (U.S.G.S.) procedure is used for the drainage basins that are larger than 2,000 acres but less than 3,000 square miles. Both procedures require information on drainage area, rainfall intensity, and slope of the main channel. In addition, the S.C.S. procedure will need information on the hydraulic length and run-off-curve-number of the watershed. Tedious measurements and computations are required to prepare the input parameters before the final computation is performed by a PC computer program (HYDR1130) developed by the the Department of Transportation and Development. The most time consuming task is to gather the required data from various sources in order to calculate the run-off-curve-number value for the watershed under study. A weighted run-off-curve-number value is required for watersheds that have more than one soil type and/or land-use. To determine this value accurately, one needs to get run-off-curve-number values for each soil/land-use combinations and their sizes which will require the overlay of soil and land-use data within the watershed. Once the run-off-curve-number values are determined for each individual polygons, they need to be matched by their corresponding areas so that a weighted value can be computed for the whole watershed. Another tedious task is to measure total watershed area and its hydraulic length. As stated earlier, all of these tedious and labor intensive measurements and computations can be replaced by a more automated approach using a GIS.

A prototype GIS for storm discharge modeling was implemented on one of our Intergraph workstations running the Modular GIS Environment (MGE) products. It utilizes various MGE products to perform digitization, data conversion, attribution, and spatial query. A customized user-friendly interface system was developed to extract the required information from various database tables and to generate an ASCII data file which can be readily used as the input file to the computer program (HYDR1130) run on a local PC. It is demonstrated that the prototype system can greatly improve the way the spatial data are traditionally handled and used in the peak storm discharge modeling process.

1.4 GPS/Van Collected Data Sets

In this project, the researchers wanted to investigate several developing technologies for advancing data collection performance and spatial data integrity. GPS was one of the technologies that was of interest to the DOT's and appeared to offer good data collection capabilities. While static GPS was receiving attention among DOTs for establishing an accurate control survey network, this project was interested in the use of GPS, where the location of a point is computed while moving in a van along the highway at legal speeds. These geographically positioned points could be transformed into road alignment points or physical highway inventory positions. Earlier research work in this area was done for DOT's in Tennessee and Virginia. This work effectively established the feasibility for collecting GPS road alignment track. The research did not address the collection of production level highway inventory data. It was felt that we could provide research in the feature collection activities and initialize the operational feasibility phase for the LDOTD. Each state will have to perform an operational feasibility stage, since the operational feasibility is dependent on the state's reference system and its data collection policies and procedures.

The original research intent was to expose the LDOTD to the technology through a demonstration and to make some analysis of that data as to its practicality for operational development. However, two major events acted as catalysts for interest among the DOTs for GPS/Van derived data, and it was decided to expand the project as much as possible within the project's funding and resources. These two important events were as follows:

1. In the Spring of 1989, it was announced that the space shuttle activity for launching the global positioning satellites would be resumed.
2. A 38 state sponsored research study titled " Application of the Global Positioning System (GPS) for Transportation Planning" commenced in September, 1990, at Ohio State University. The LDOTD was a participant in this study.

The investigators attempted to coordinate activities of the two research efforts. Coordination efforts were made with John Adams, the DOT coordinator, and Phil Johnson, the project coordinator for the Multi-State project. Louisiana was selected to be one of the regional test areas. Plans were established to collect the SIMST test data during the August 1990 Ohio State research team trip to New Orleans, Louisiana, for a project oversight meeting and to regionally demonstrate the collection of data. In August 1990, it became apparent that the SIMST project could not depend upon the Ohio State project to collect data required for the SIMST project. A contingency plan was executed with Navstar Mapping Corporation of Austin, Texas, on September 1, 1990 to collect the necessary GPS/Van data.

1.5 Remotely Sensed Data for Maintaining the Cartographic and Highway Inventory Databases

Remotely Sensed Data can be a source of quality detailed information. We were interested in the use of remotely sensed data in the maintenance of the cartographic database and the highway inventory database. Data considered includes remotely sensed data from satellites, aerial photography, aerial video, and digital databases from federal and state agencies. We have photointerpreted, digitized, and analyzed road networks from SPOT Satellite digital data and transparencies as well as the NHAP (National High Altitude Photography) and NAPP (National Aerial Photography Program) aerial photographs. Some of the photography was digitally scanned. We examined the issue of obtaining highway inventory data by using remote sensing materials and techniques. Videos at three different focal length settings and high resolution aerial photography which was flown at optimum altitudes were interpreted and evaluated.

2. Objectives

The objectives of the Archival management System were to develop a system for archiving spatial data, to enhance and tailor existing DBMS for spatial data, to make the querying and management of the database efficient and user-friendly, and to be compatible with LDOTD computing systems as much as possible.

The primary objective of the pavement management demonstration was to consider Intergraph transition issues for LDOTD with the development of a prototype pavement management systems. A goal was to utilize tools from vendors wherever possible and to develop new tools as needed to ease the transition process. The prototype PMS implemented illustrates general capabilities including map and report generation and display, and visualization of database tables in a customized interface. The effort and necessary data and Intergraph products required for a state-wide implementation can be extrapolated based on the work carried out in designing this system.

The main objective of the storm discharge prediction project was to demonstrate a prototype GIS to effectively store and maintain various types of spatial data and to provide procedures to automate the data extraction for storm discharge modeling. A second objective was to identify and evaluate the usability of the existing data for implementing a GIS for storm discharge prediction.

The objectives of the GPS/Van work were to expose the LDOTD to GPS technology; to verify that previous GPS/Van results were applicable in the Louisiana environment; to determine if GPS/Van data could be used to update the cartographic database, and to determine the efficacy of GPS/Van systems for collecting highway inventory features.

The objective of the remotely sensed data project was to examine methods for analyzing remotely sensed data and to determine the usefulness of these data for maintaining the LDOTD cartographic database. The objective of the highway inventory work was to evaluate the various means of accomplishing highway inventory by aerial remote sensing methods and to determine the role of remotely sensed data for collecting remotely sensed Highway Inventory Data.

3. Scope

The archival management system (AMS) was developed to retrieve the location of aerial photos, satellite images, maps and design files and not to retrieve the actual data itself. The initial scope included the determination of the best way to build the database. The idea was to key-in commands in a language which resembled English, but this proved to be very cumbersome and error prone. The scope was modified to include a friendly and efficient user-interface using menus and forms. The initial set of AMS queries was also very limited. When the details of a place had to be used for querying, one could only specify the name of a place or some area around the place. The routes and control sections with logmiles, which are meaningful to LDOTD personnel and used commonly in their workflow, were included so that the user could specify a place by mentioning the particular logmile, route, or control section along which the photo or image was desired. Finally, the scope was expanded to include

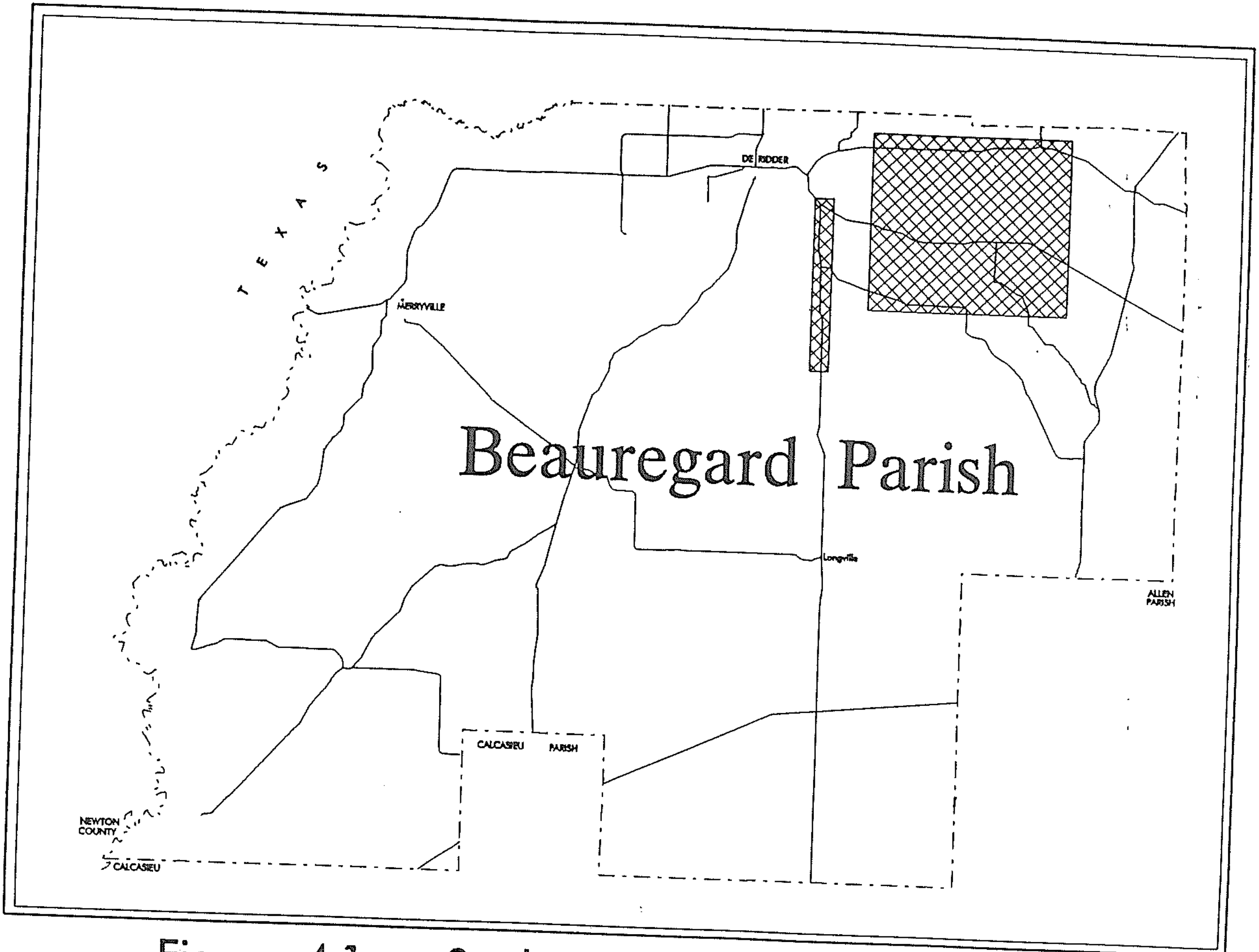

Figure 4.1 Study areas for SIMST project

Consideration was given to problems to be faced by LDOTD as it moves from Intergraph IGDS and DMRS to Intergraph MGE. We have explored the capabilities of the tools Intergraph is providing to migrate from IGDS/DMRS to MGE in the context of creating an MGE GIS system incorporating graphics in the pavement management and storm discharge prediction demonstrations. Because the projects were implemented in the Intergraph MGE system, it is useful to discuss the tools utilized in the project.

Relational Interface System (RIS) is a generic relational database interface developed by Intergraph. It enables users to run the Intergraph workstation based Modular GIS Environment (MGE) suite of products interfaced with any supported proprietary relational database. The currently supported RDBMS are Oracle, Informix, Ingres and DB2. Additional databases will be supported based on user demand. The database administrator can manage the database through the RIS interface and perform functions such as viewing, removing, and modifying tables. Tables generated with MGE as well as system and user generated RDBS tables can be processed. RIS isolates applications and users from the differences in specific vendors' relational database management systems and also allows networked access to supported RDBMSs. The RIS interface is based on the ANSI Structured Query Language (SQL) standard. The PC version of MGE is very similar in look and feel to the workstation version although it offers only a subset of capabilities. The PC version interfaces only to ORACLE at present.

Only one copy of the relational database system needs to be installed on an Intergraph network. A RIS schema on each workstation tells MGE the network address where the RDBMS is located and which RDBMS it is. In addition the communication protocol to communicate with the database is also specified in the RIS schema. The database interface is thus made completely transparent to the MGE user who need not know any details about the currently installed relational database.

RtoDto serves as a translator between the VAX based Intergraph Data Management and Retrieval System (DMRS) database and any relational database that the new Intergraph workstation Relation Interface System (RIS) supports. To use RtoDto, the user must create a relational database and establish an RIS dictionary with schema for this database. One relational database table is created for every user-defined entity that is to be translated. Columns are created for these tables in the same format and structure as defined in DMRS, except an additional integer column, MSLINK, consisting of a record's DMRS occurrence number is created. The MSLINK column is used to create graphics to database linkages. RtoDto may also be used to translate from a relational database back to DMRS.

MGE GIS Translators/US is an Intergraph product which must be separately purchased and provides the translation component of MGE. It provides translators for USGS Digital Line Graph (DLG data), the U.S. Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) files, U.S. Census Bureau GBF/DIME data, and ETAK MapBase files. The user can generate graphics, database information or graphics and database simultaneously. The translation process can be initiated from within the MGE environment or via a UNIX command line. An interactive dialogue is initiated with the user prompting the specification of a variety of parameters. These can be provided as part of a UNIX script to automate the process. When information is to be supplied to a database, MGE or RIS must first be used to create the database tables.

SQL*Loader is a data loading product which enables the user to load data from external files into an ORACLE database. The data must reside on disk or tape and must be accompanied by control information about how to perform the load. The data loading language used is upwardly compatible with the DB2 loader from IBM, and control files for the DB2 Load Utility can also be used with SQL*Loader. Data may be in binary or character format, and the records may be in fixed or variable format. It may be delimited by enclosing fields with a specific character such as a quotation mark or by terminating fields by a specified character such as a comma. Logical records may be composed from multiple physical records.

Raster data translation is supported by MGE Imager which reads Landsat TM, Landsat MSS, Landsat MSS X-Format, Brazil MSS X-Format, SPOT CCT, SPOT QuadMap, AVHRR, EOSAT Geocoded, Landsat MSS JSC, and Generic Format Tapes. Generic Format Tapes may be written after reading in image data from any format. This makes it possible to easily convert image data to formats not supported by Intergraph. For example, Intergraph COT (continuous tone) format files can be exported to a generic raster format using the EXPORT GENERIC command. This produces three binary files (one for each of the red, green and blue bands) which can be converted via a simple C program into an ERDAS format image which may be displayed in ARC/INFO. Since ARC/INFO has no capabilities for contrast enhancement, this is done on the Intergraph workstation.

In addition, Intergraph RGB format, Targa, TIFF, PIC, RenderMan Interface Bytestream (RIB) and GIF formats are supported via IMPORT/EXPORT and MDL Application Modules which are provided as part of the baseline MicroStation product. Both raster images and 3-D vector files may be exported in these formats. DMANDS (Drawing Management and Distribution System) is a new Intergraph tool to permit display of raster data on a PC in a window environment suitable for multiple document display. Managers can view and redline from a PC and transmit images across the network using DMANDS.

Network integration tools include TCP/IP, a UNIX based communication protocol supported by Intergraph, IBM SNA and BSC protocols, file transfer from IBM systems, IBM terminal emulation, and Digital Network Protocols for Digital Equipment Corporation compatibility. The Relational Interface System (RIS) can communicate over the network via TCP/IP with the RDBMS. This means that the RDBDS may be installed on any node on the TCP/IP network.

NFS is layered on top of TCP/IP and enables remote disks to be mounted so that files on the remote disk may be accessed just as if they were on the user's local disk drive. This enables files to be shared among different machines. For example, disk drives on the VAX can be remotely mounted on the Intergraph workstation.

4.1 Archival Management System (AMS)

The Archival Management System (AMS) is a front-end program designed to assist in the management and querying of a spatial data archive. The AMS has been developed under the Oracle Dynamic Structured Query Language, which is a standard industry tool. The AMS is capable of tracking all data types, including digital and non-digital. The AMS enhances the DBMS with features that are tailored for GIS data tracking environments. These features include a simplified user interface, automatic catalog structure navigation, and spatial coverage queries.

The archival catalog is set up as a series of tables in the DBMS, with a different table for each type of archival data such as aerial photos, satellite images, maps, design files, etc. Each table records attributes common to all data sets of that type. Typical attributes common to most data types are geographic coverage, date and time of data capture and archival location. Specialized attributes for photos are film type and altitude, while satellite imagery requires attributes such as spectral bands and resolution.

Bounding boxes are used by the AMS as quick coverage comparisons to speed up catalog searches by geographic area. For each data set, an imaginary bounding box is constructed that is aligned along the coordinate axes and completely contains the data set coverage area. For each archive data set, the catalog entry contains the coordinate locations of two diagonal corner points of the data set's bounding box. A geographic search will then compare the boundaries of the requested area with the bounding box of each data set, and data sets with no intersection can be quickly eliminated while data sets with boundary overlap can be subjected to closer coverage scrutiny. Figure 4.1.1 shows some bounding boxes computed for aerial photos collected over US171. Note that the bounding box coordinates need not be very precise since they are used only as a quick look index. This is the essence of fast database queries: eliminate as many candidate data sets as possible as early in the query as possible.

The representation of geographic coordinates themselves can also be optimized for fast database searches without sacrificing geographic accuracy. The method is to represent earth locations in the spherical longitude-latitude coordinate system using 32-bit integer numbers to represent the coordinate values. When the entire 360 degrees of global circumference is scaled to the maximum number representable by 32 bits (4,294,967,296), the resulting integers resolve approximately 1.25 inches between successive integral numbers. This geographic resolution far surpasses that of ordinary 32-bit floating point numbers because the numerical range of geographic coordinates is a poor fit to the range of floating point numbers. Floating point numbers are represented by dividing the 32-bit word into two parts, the mantissa and the exponent, with enough bits allocated to the exponent to cover a range of usually 75 orders of magnitude. Geographic coordinates only range from 0 to 360 degrees, roughly three orders of magnitude, thus wasting the majority of the floating point bits devoted to the exponent. Additional benefits of integer coordinate representation are the elimination of problems caused by different floating point representations on different computers, and the fact that integer number comparisons are many times faster than floating point comparisons. So, to convert the latitudes and longitudes from spherical format to 32-bit integer format, the following formula has been made used:

$$integer\_latitude = ((3600*degrees)+(60*minutes)+seconds)*1000$$

The integer format is used for storing in the database and spherical format has been used for user-entry.

All the data used while developing and testing AMS corresponds to Beauregard Parish and was loaded to ORACLE. The database contains records for parish and quad maps of Beauregard Parish in the maps relation. For USGS quadrangle maps, the bounding boxes can be readily calculated since the maps cover exactly 7.5 or 15 or 30 minutes of latitude and longitude. The image relation has records for multispectral and panchromatic SPOT data of Beauregard Parish. The photo relation contains low altitude aerial photographs along US 171. Figure 4.1.1 shows some bounding boxes, computed for photography, collected over the study area. The design file relation contains .PCP, .FM and .GIS Intergraph design files obtained from LDOTD which cover the study area.

The Geographic Names Information System (GNIS) database, from the USGS, contains 17,500 geographic place names in Louisiana, along with their coordinate location, site description and a host of other information. Bounding boxes or point locations for over 300 place names located in the vicinity of Beauregard Parish have been taken from this database and stored in ORACLE database in the table GNIS_TABLE. This relation makes it possible to query for *Color Photos of Bundick Lake*. Another table in the database is the control section/logmile relation which contains bounding boxes for logmiles per control section and the route/logmile relation which contains similar bounding boxes for routes. These relations make it possible to form queries of the form *Multispectral Images of control-section 24-4 between logmile 5 and logmile 10*. The precision of the bounding boxes can be adjusted for maximum efficiency. The size of the bounding boxes can be varied by the user.

In the process of creating these relations, a set of tools have been developed for entering ASCII tabular data into the AMS archive (ORACLE database). In the ASCII files, the latitudes and longitudes are in spherical format (deg:min:sec). Separate programs (%_inp.pc) [1] have been written to read these ASCII files, convert any data in spherical format to 32-bit integer format and load all data to ORACLE using SQL *Loader.

The various tables used in AMS are as follows:
(a) *PHOTOS* - to store all data describing aerial photos.
(b) *IMAGES* - to store all data describing the satellite images.
(c) *MAPS* - to store all data describing the maps.
(d) *DESIGNS* - to store all data describing the design files.
(e) *GNIS_TABLE* - to store the place names and the bounding box coordinates of those places.
(f) *CS_BOX* - to store the bounding box coordinates of all control sections.
(g) *ROUTE_BOX* - to store the bounding box coordinates of all routes.
(h) *CS####* [2] - set of tables. Each table corresponds to a different control section and contains the bounding box coordinates for each logmile.
(i) *ROUTE####*- set of tables. Each table corresponds to a different route number and contains the bounding box coordinates for each logmile.
(j) *MASTQRY* - temporary table . Contains the single flag selection, which indicates whether photos, images, maps or design files were selected.

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[1] % represents any name like photo, image, route, etc

[2] # represents any number. CS#### may correspond to CS2341 or CS3400.

(k) *PHTQRY, IMGQRY, MAPQRY, DGNQRY* - temporary tables which each contain a number of flags indicating the conditions selected to form the query.
(l) *TEMP* - temporary table used for storing the data entered in the forms. This table is read by the file *iaxpcc.pc,* which has the user exits, and the main PRO *C file *ams.pc*

The AMS incorporates many different features of ORACLE including PRO *C, SQL *Menu, SQL *Forms, SQL *Loader and SQL *Report, with suitable interfacings between the various products.

The main AMS program has been written in PRO *C, an ORACLE product, which allows embedded SQL in standard C programs. The program is named *ams.pc.* This program provides an interface to the ORACLE environment. The user identification is obtained prior to executing the Oracle application. Once the AMS application is running, the user traverses the menus (in SQL *Menu environment) and forms (SQL *Forms) constructing a query. The SQL *Forms are interfaced to another PRO *C file, *iaxpcc.pc,* which has all the various user exits. SQL*Plus command files store the information required for the query in a temporary Oracle table. After the user completes the query, program control returns to the calling PRO *C program, *ams.pc,* and this temporary table containing the query information is read and a suitable query is built dynamically and executed. The output of the query is displayed on the screen using SQL *Report and can also be directed to a file. This structure of AMS is shown in Figure 4.1.2.

Multiple conditions can be specified for a query, but the query should be only for a single data type like photos or images but not both. The execution of AMS can be best understood by an example. Consider the following query - *Select all Color Photos of Bundick Lake.* To do this, the user has to specify two conditions for the photos: film of type *color* and the place *Bundick Lake.* As soon as the AMS application is started, the user is first taken into SQL *Menu environment. Figure 4.1.3 shows the complete set of menus and forms to be used for this example, next the user consecutively selects the *query, photos, filmtype, and color* options from the hierarchical set of menus. Now some flags in the temporary table *PHTQRY* are set indicating that color photos have been selected. With this, the user has specified color photos. The user still needs to specify the place name. To do this, the user needs to traverse back to the *PHOTOS* menu. The user now consecutively selects the *place, name* options from the menus. The user now sees a form where he needs to specify the place name - *Bundick Lake.* Then a user exit obtains the bounding box coordinates corresponding to Bundick Lake, and again some flags are set in the temporary table, *PHTQRY,* indicating that all photos that include this bounding box have to be selected. The user then returns to SQL *Menu from SQL *Forms and, as all conditions for query have been specified, selects the option for executing the query. The program control now returns to the main PRO *C program, *ams.pc.* The flags in the table *PHTQRY* are read. and the following query is built dynamically using both the conditions:

select nm,flm,alt,dt,loc from ams.photos where flm='COL' and lat_max >= 110628000 and lat_min <= 110628000 and abs(lon_max) >= -335133000 and abs(lon_min) <= -335133000.

This is done using the capabilities of PRO *C. This query is executed, and records in the *PHOTOS* table which satisfies both the conditions are displayed using SQL *Report.

4.1.1 Design and Implementation of AMS Queries:

The main purpose of the AMS is to ease the work of the user by providing a tool to make the queries and update the database in an easy, efficient, and fast method. The difficulty a user faces when making queries is that long query commands may result in numerous typographic errors. One solution to this is to provide menus where the different specifications for the query are given as options, and the user can choose any of the required options. The options selected by the user have to be recorded. and a dynamic query has to be built. This can be implemented using SQL *Menu.

SQL *Menu is very powerful and hierarchical. This menu interface reduces the need for the user to have extensive technical knowledge and minimizes typing errors. The SQL *Menu has several important features which are relevant to AMS. It is hierarchical and allows the user to move up and down the menu structure and also to move from one menu option to another. It supports dynamic menu generation and handling by displaying only those options to which the current user has been granted access. It is possible to customize the SQL *Menu to various terminals by specifying terminal characteristics in the standard ORACLE CRT database. The most important feature of SQL *Menu is the different types of commands that it can handle. These command types are (a). Invoke a sub-menu. (b). Execute Operating System Command. (c). Invoke SQL *Forms. (d). Invoke SQL *Plus. (e). Execute a menu macro command. All the above commands have been made use of in AMS. This simplifies the flow of AMS through the various ORACLE products.

A PRO *C program, *ams.pc,* provides an interface to the ORACLE environment and invokes SQL *Menu. All the options selected by the user will be recorded and later read in by the PRO *C program to build the query. A hierarchical structure of the AMS has been built. Different sets of menus are provided for querying on photos, images, maps, and design files. Within each set, there are different menus for different options, each of which have submenus to specify the sub-options. The set of hierarchical menus for querying photos is shown in Figure 4.1.4. SQL *Menu has no concept of variables where these options can be recorded, so SQL *Plus is used, which is invoked from within SQL *Menu where the options selected by user are recorded in tables. For this, the concept of flags has been used in which each flag (a field in a temporary table) is updated depending on the option selected. As SQL *Menu is hierarchical, with one menu calling another menu, these flags can be updated only once at the end of the query. All the SQL *Plus commands for updating various flags are stored in SQL command files as .SQL files. Now, after the user has completed specifying all the required conditions for the query, the control returns to the calling *ams.pc* program where the flags in the temporary tables are read using Embedded SQL. With this, the AMS structure is as shown in Figure 4.1.5.

All the conditions for the query cannot always be specified using only SQL *Menu and SQL *Plus. For example, the *date, altitude at which photos were taken, resolution of satellite images, etc* cannot be given as options in the menu as specific values have to be given for each of them, and these values are arbitrary within a specified range. So, it is required to use SQL *Forms where the user can exactly specify some of these data.

The SQL *Forms are fill-in-the blank templates on the computer screen which allow the user to enter, update, and query information in a database. Forms are composed of pages, blocks, records, and fields. The SQL *Forms have many distinctive features which have all been made use of in AMS. Some of them are as follows:

1) an automatic help facility which informs the user the exact format in which the data has to be entered,
2) an ability to work with more than one table at a time by making use of blocks,
3) data validation - This is the most important feature and can be implemented in four ways:
   * very simple validation using the validation facility provided for each field,
   * sophisticated validation using different types of triggers,
   * highly advanced validation using user exits which are Embedded SQL C programs called from the triggers, and
   * special functions and commands executed when some particular event occurs.

All the above features and all the other capabilities of SQL *Forms have been fully exploited to provide a very user friendly interface. Different forms are provided for each different type of data entry. For example, four different forms have been built for specifying *Date BEFORE, Date AFTER, Date DURING, and Date RANGE.* This is shown in Figure 4.1.6. An automatic help facility has been used through out the application. Depending on the form selected and the cursor position, a message will be displayed at the bottom of the screen which will inform the user of the type and format of data expected. After the user enters the data, it is immediately validated using *field triggers.* The next task is to update the flags which now include both the menu options selected and the data entered into the forms. These flags will indicate all the specifications for the query. The triggers allow different types of commands to be executed - (a) SQL *Plus commands, (b) SQL *Forms macro commands, and (c) user exits which perform all complicated computations. The flags are set in the temporary tables by using SQL *Plus commands in *Block Triggers* in particular the *post-insert trigger.*

The formats of some data stored in the database are different from the formats familiar to the user. For example, the user will be more familiar with the spherical format(deg:min:sec) or the decimal format for specifying the latitudes and longitudes, as compared to the integer format used for storing the latitudes and longitudes in the database. This requires a suitable interface to be provided between the two formats. This is accomplished using the user exit facility of the SQL *Forms. All user exits are included in the file *iaxpcc.pc,* which is another PRO *C program. These user exits are all additional functions, written using PRO *C, which the SQL *Forms use for complicated computations and validations. This enables the user to enter the data in a familiar and easy format, and the user exits interfaced to the SQL *Forms will convert the data to the correct format and store it in temporary tables. This converted data will then be read by the main calling program and used for specifying the query. The user exits are called from within a trigger in the SQL *Forms, and after execution, control returns to the trigger calling the user-exit. This makes the whole system hierarchical and easy to control.

Many different types of options have been provided for making a query depending on the geographical location. The options are as follows:

(a) **Query by specifying name of place.** For this, a separate form is provided where the user enters the name of the place. Many short cuts are provided, which are all described in the *AMS User's Manual.* A user exit is written which reads the place name, and from the GNIS table, obtains the corresponding bounding box coordinates for that place. The bounding box is the minimum box drawn on the map or design file surrounding a place or region. The end points of the box indicate the latitudes and longitudes. These latitudes and longitudes are stored in the temporary tables which will later be read by the main PRO *C program, *ams.pc* to build the query.

(b) **Query by specifying Routes or Control Section Numbers.** The method employed is the same as for specifying the place name, except that the user specifies the route or control section number, and the user exit will obtain the bounding box coordinates by reading the *route_box or cs_box* table.

(c) **Query by specifying the Route or Control Section Number and a specific range of logmiles within it.** The method employed is a little more complicated. The user first specifies the route or control section number. This is immediately validated for its existence. This validation is done using *field triggers.* Next, the user specifies the exact range of logmiles desired in that route or control section. Another validation is provided here to check if the range specified is correct. This validation is done using a user-exit. Another user exit reads a particular table depending on the route or control section number specified by the user. From this table, the minimum and maximum of both the latitudes and longitudes corresponding to the logmile range, as specified by the user, are calculated and stored as bounding box coordinates in the temporary table to be read by the main PRO *C program *ams.pc* to build a query.

(d) **Query by specifying the coordinates of a place.** In this method, the user has the option to directly specify the coordinates of a place in the format he is most familiar with : degree-minute-second format or decimal format. Separate user exits are written to convert the two formats to integer format. The coordinates (latitudes and longitudes) in the integer format are stored in the temporary table again to be read by the calling PRO *C program, *ams.pc* to build the query.

(e) **Query by specifying the coordinates of a place graphically.** This is a very important feature. In this method, the AMS is indirectly interfaced to the MicroStation available on the Intergraph workstation through the *Projection Manager (PM).* Projection Manager is an application software product that allows conversion of 2-D or 3-D MicroStation graphic files from one co-ordinate system (projection) to another. Various types of map coordinates, either retrieved interactively through key-ins or data points or non-interactively through ASCII files, can be converted to any other supported type of map coordinate. The output of this conversion can be written to an ASCII file. As PM cannot be invoked from within AMS, it is required that the operation with PM be completed prior to selecting this option within AMS. The *geodetic calculator* in the PM is used here. After the user invokes PM using the required design file, the geodetic calculator is invoked and set up in such a way that it will take the user keyed-in point coordinates as input and convert them to latitudes and longitudes in deg:min:sec format and write them into an user specified ASCII file. The user has to specify this ASCII filename within AMS when this option is selected. A user exit reads this ASCII file, converts the latitudes and longitudes in deg:min:sec format to integer format and stores them in a temporary table to be read by the main PRO *C program, *ams.pc,* to build a query.

4.1.2 Design and Implementation of AMS Maintenance

The second main task of AMS is to help in maintaining the database. The task of maintaining the database includes: adding new records, modifying the existing records, and deleting unwanted records. The option of adding new records are provided for all types of data - photos, images, maps, design files, routes, control sections and place names. The option of updating (modifying and deleting) is provided only for photos, maps, images, design files and place names.

A different set of menus has been built to add records. In this case, the whole operation cannot be completed only with SQL *Menu since the user has to enter some new data which does not exist previously in the tables and cannot be specified as options in SQL *Menu. So, SQL *Forms have to be used here again. A form is provided for each different type of data. There are different forms for adding photos, adding images, etc. The task of adding all data except those of photos is very easy. The main reason is whenever any of these data have to be added, the bounding boxes have to be generated. This is a very easy job for maps, images, or design files. The bounds of the maps can be obtained from the quad maps. The satellite images have a label indicating their bounds and the corresponding design file is brought up on the screen and the bounds are obtained graphically by clicking on the relevant places.

Generating bounding boxes for photographs is more difficult. Depending on the accuracy required, different methods may be employed. For high accuracy, one could use a manual procedure, done by a person with photogrammetrist training who compares the photo with a registered map of the same location. A less accurate method, which may be suitable for indexing and locating photographs, would be useful for reels of photographs. One would need to know the flight lines used for the photography. The size (SIZE) of each photo on a reel with n number of photos can be calculated as a constant times the ratio of the camera's focal length divided by its altitude. The flight line can be added as a line in a design file using precision key-in commands to place the points which are the centers of the first and last frame on the roll. The MicroStation command CONSTRUCT POINT ALONG can be used to construct a specified number, n, of points along the line between the two precision key-in data points. An MDL procedure can be used to calculate the bounding box for each point. The size of the box is SIZE. The coordinates for each box are

(point - .5*SIZE, point + .5*SIZE, point + .5*SIZE , point -.5*SIZE).

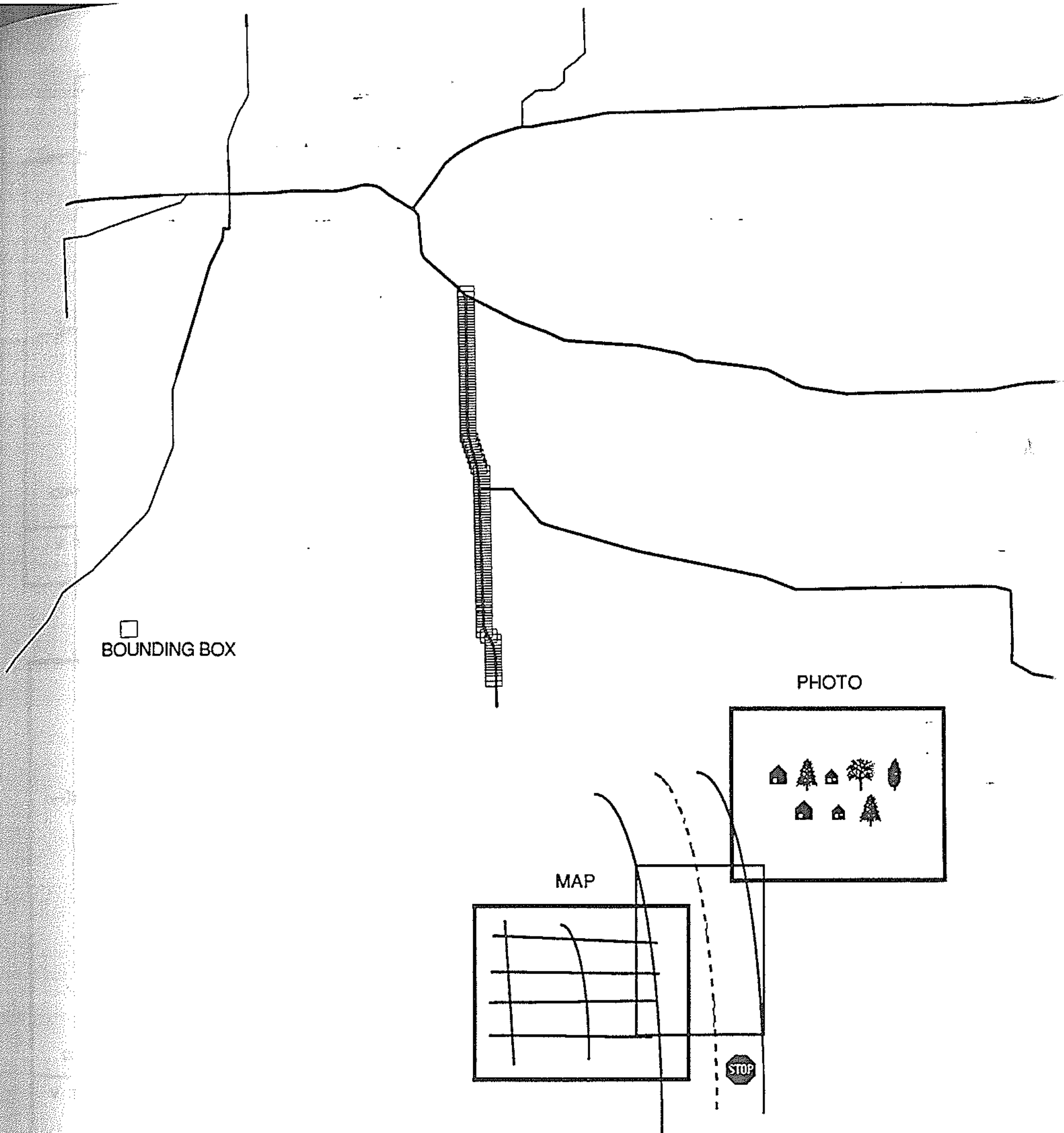
The forms are built so that an ASCII file containing the bounding box information for the frames on a roll of film can be used to update the database. User exits are written which read the data entered in the forms and append them to the corresponding table in the correct format.

Some interesting features have been developed to add new routes and control sections to the database. The concept of the indirect interface between AMS and MicroStation has again been used. Here, two products, MicroStation Development Language (MDL) and Projection Manager (PM), are used.

MDL is designed primarily for interactive applications and uses the standard C programming language. An MDL application consists of a MDL program, plus other resources like Dialog Boxes, Message lists, and Help text. The Dialog boxes are on-screen graphical entities which the user can manipulate to communicate with an application's variables.

A MDL program, *bound.mc*, has been developed that prompts the user to specify the exact route or control section to be added by graphically pointing to it on the design file on the screen. This program then generates bounding boxes at a distance specified by the user on that route or control section and also writes the coordinates of the endpoints of each of these boxes into an ASCII file. The geodetic calculator converts these coordinates into latitudes and longitudes in deg:min:sec format and stores these in an ASCII file. A separate ASCII file is generated for each different route and control section. These routes and control sections can be finally added to the database by selecting the appropriate option in the AMS. Here the user has to specify the new route or control section number and the corresponding ASCII file name containing their bounding boxes. A user exit reads these files and performs three tasks. The first task is to convert the latitudes and longitudes in the ASCII file from deg:min:sec format to integer format. The second task is to create a new table with that route or control section number and to add a record for each logmile and its bounding box coordinates. The third task is to find the minimum and maximum of these latitudes and longitudes and to add a new record in the route_box or cs_box with the bounding box coordinates as specified by the minimum and maximum bounds.

The updating of AMS is implemented using some of the basic features of SQL *Forms itself. In this case, the user has to use the SQL *Forms method for querying the data. This is explained in great detail in SQL *Forms Manual. Once the required records are displayed, the user can modify the record or delete the record. Even in this case, care is taken to display the latitudes and longitudes in a format familiar to the user - the deg:min:sec format. A user exit converts the latitudes and longitudes to integer format and then updates them in the database.



Bounding Boxes Along Highway 171

Figure 4.1.1

4.2 Spatial Data Translation

With the advent of networked computer systems and the availability of GIS packages, there is a great need to move spatial data between platforms and proprietary packages. The problems we considered include the transfer of spatial data between different GIS systems as well as the transfer of spatial data between PC and Intergraph computing systems.

In the course of this project, the functionality of the SIMST reformat compiler translator program has been modified primarily because of major advances in available spatial software. The LDOTD has selected the Intergraph Modular Graphics Environment (MGE) family of products, including MicroStation, as the basis for all of its graphics related applications. Key features of the MGE environment related to the RFC are as follows:

Raster/vector integration
Network database sharing capabilities
Transparent interface to SQL based RDBMS
Spectrum of translator tools
Hardware independent C-based MDL Development Language for Microstation
OSF/Motif User Interface
Published core graphic file formats for open software development

At the same time, the Needs Application of the RFC indicated shortcomings in the RFC concept. YACC and LEX are not industry standard and are unavailable in Intergraph workstation environment. The RFC is not well suited to translation problems involving proprietary software formats where subroutine calls must be made to store and retrieve data. Finally, the DMRS database used in the Needs application will need to be ported to the new MGE environment. A combination of SQL commands and the Intergraph product RtoDto is best suited to the task.

The capabilities of the MGE environment allow PC or Workstation based MGE graphics elements to be tied to a DB2 database running over the network on an IBM machine. Conversion between raster and vector data formats is available via an icon based menu interface. MDL has tools to create, extract, and manipulate graphics elements and the ability to draw and update the screen, communicate with the user and MicroStation, control MicroStation's internal state and create custom dialog boxes, pull down menus, and tool palettes for applications. However, in order to make use of all the new tools provided both by Intergraph and third party vendors, all of the VAX based IGDS/DMRS LDOTD applications must be moved to MGE. Problems encountered in this transition center in learning the full range of capabilities of the new system and how to use them. Differences between the two systems range from slight incompatibilities in mapping projection design file elements to utilizing MGE, which was originally designed for a single user (hence the name MGE/SX), in a multi group/user/computer platform environment such as the LDOTD.

Because of the new developments we have reoriented this task to utilize the new technology. We are making use of SQL to create, maintain, and merge databases; RIS to connect databases over networks; and RtoDto to transfer data from the DMRS database. Work is concentrated on developing user friendly custom interfaces using the latest tools and technology available. Towards this end, work is concentrated in four major areas.

The first is SQL tools. SQL is an easy to use language for querying the database. For the Archive Management Project, we first had to determine the necessary SQL commands to retrieve the desired records from the database. A brief example of a command which would be issued in SQL*Plus is "select route_no,min_lat,max_lat from route_box where route_no='171'" where route_box is the name of a table containing the fields route_no, min_lat, max_lat, etc. These commands are then embedded as dynamic SQL statements with the C precompiler PRO*C. As part of this project, we will include these PRO*C programs.

The second area is DMRS to RDBMS translation using Intergraph RtoDto tools. The illustration of this area will be the conversion of the NEEDS database. The procedure, though documented in the RtoDto manual, is quite complicated and details as to problems encountered and solutions and techniques for simplifying the procedure will be provided.

The third area of concentration is using the MGE Environment to determine optimal work flow procedures. This includes the techniques for moving graphics files between VAX and workstation systems, overcoming problems encountered, determining optimal procedures to integrate raster and vector graphics, tying graphic elements to database tables, and generating tabular reports from the spatial databases. In this area, we are attempting to determine how to incorporate topology problems such as routes which have multiple names because of overlap and tables which have a variable number of entries because, for example, all previous layers of pavement must be stored for each section.

The final area of concentration is developing MDL applications to make custom, user friendly interfaces. Portions of the MGE workflow are too complex for the casual user. These applications will illustrate strategies for data integration based on providing an additional layer of support to simplify the use of the Intergraph data integration and manipulation tools.

4.2.1 Example Spatial Data Translation

An example of a typical translation problem done last year at RSIP for converting between Intergraph and ARC/INFO raster data is given in Appendix A. This example indicates how quickly the tools are changing since better tools are now available. The formats for the ARC/INFO and the Intergraph vector data were not available at the time, a situation sometimes encountered when utilizing proprietary software packages. This example provided some insights into data translation problems. It underscored the need to understand the different vendors schema for storing graphical data and also the need for packages with undisclosed formats to provide tools to enable users to import and export data. ARC/INFO provides the commands ARCIGDS and IGDS to convert between an ARC/INFO coverage and Intergraph design files. Actual programming effort was minimal and concentrated mainly on developing very basic image processing software and writing macros to enhance the presentation. Mechanisms for transferring data are provided by the key GIS vendors but their use is sometimes fairly complicated and not suited to the average user. In such an instance, customized command procedures must be provided to make these packages available to users without assistance.

4.2.2 IBM translator software

LDOTD use IBM systems as its Host machine which is the main repository of LDOTD data. For this reason, the products for data translation on this machine are relevant to LDOTD spatial database development. Appendix B contains a review we conducted of this software last year and indicates the nature of the support available.

4.3 The Reformat Compiler and Highway Needs Demonstration

Many new developments have occurred in the GIS software field during the last several years. At the start of the project, simultaneous raster/vector display and analysis software availability were emerging technologies which are now common-place. Two years ago, GIS software packages interfaced to proprietary DBMS systems supplied only by the GIS vendor. For example, attribute information associated with Intergraph graphic elements was stored in a hierarchical DMRS database created by Intergraph. Today, GIS packages such as Intergraph MGE, and ESRI's ARC/INFO interface transparently with the numerous commercial relational databases. Tools for importing and exporting data between databases and GIS systems are abundant, and the ability to access data stored in a wide variety of formats is an important feature of any GIS system. This is a result of the move by GIS vendors to multi-platform systems. In order to support customers utilizing networked databases and software tools, machine independent interchange formats permitting easy exchange of data between disparate machines are essential.

Despite the ever increasing arsenal of conversion routines, intermediate data formats and software generation tools, the need to write custom reformatting routines still exists. The Reformat Compiler has been designed to serve as an aid in writing these reformatting programs. In particular, it is suited toward reformatting tasks that involve data stored in nonproprietary, nonstandardized formats, examples of which include tabular data extracted from a database or digital data generated by a custom piece of hardware. It is less suited for cases where data is stored in a proprietary format where the user must call subroutines to access the records. For example, the subroutine supplied by one commercial package may return a center point and radius to describe a circle graphic element, and the reformatting routine might be required to generate closely spaced points along the circle's perimeter in order to put it in the format required by another graphics package. The system is implemented in the YACC and LEX systems which are not available on the LDOTD machines.

The purpose of the Highway Needs demonstration was to write a program in the RFC language that would function identically to an already existing program used for highway needs analysis. The data for this project is exported from an IBM Mainframe Database and sorted by Route-Control-Section-Subsection. This sorted tabular data is moved to the Intergraph where it must be merged with an already existing DMRS database attached to a graphics design file.

The procedure used by the LDOTD is to execute a Fortran program NEEDSLOA written at LDOTD which reads in the tabular data, queries the DRMS database and writes out a file containing DMRS commands to query and update the DMRS NEEDS.DBS database. This file of commands is then submitted in a batch job to actually perform the updating procedure.

The Reformat Compiler's (RFC) purpose is to make writing a program such as NEEDSLOA quicker and easier as well as to produce more efficient programs. The advantages gained from rewriting NEEDSLOA in RFC input language are:

(1) The code has clearly defined sections defining input and output. These sections can easily be exchanged and used in other programs.

(2) The code includes no system dependent details regarding I/O such as means for accessing files, checking for record length, end of file and read/write errors.

(3) Efficient buffering strategies for reading and writing of data are implemented automatically in the output code produced by the RFC.

(4) Error checking on data sets is automated.

(5) A unified approach to the formatting of string variables and output records could be employed.

These coding improvements can be seen in the comparison of fragments of code from NEEDSLOA (the LDOTD Fortran program) and the RFC input code.

Reading in of the data from the tabular input file is greatly simplied in the RFC version because the structure of the input file is defined in the data definition section. All that is necessary is a request to read a type 1 record from the input source "filein". The Fortran version requires a very long READ statement accompanied by a detailed format specification.

Fortran:

```
5 READ (1,10,END=902)E2A1,E2A2,E4A1,E3A1,E4A6,E2A5,E1A1,E4A3,
  *  E4A2,E4A4,E4A5,E4A8,E4A10,E4A9,E4A13,E4A16,E4A7,
  *  E4A14,E4A17,E4A21,E4A18,E4A11,E4A12,E4A15,E4A31,E4A29,E4A33,
  *  E4A32,E4A20,E4A19,E4A30,E4A23,E4A24,E4A25,E4A26,E4A28,E4A27,
  *  e4a39
```

The RFC read statement is simple.

```
RFC:    read filein.1
```

The Fortran version of the code to write out a DMRS FIND command is rather convoluted because part of the command includes apostrophes. These apostrophes must each be enclosed in another set of apostrophes so that they are treated as part of the text rather than as string delimiters. In addition, the INTEGER variables E2A1 and E2A2 are first converted to CHARACTER variables CON and SEC before being inserted into the longer CHARACTER variable FIND. A null terminator must be placed at the end of the variable FIND as well. In the RFC code no extra apostrophes are required. The record specification following the // characters is input exactly as it will appear in output with the simple exception that variables enclosed by "^" characters will be replaced with their values. A null character is automatically placed at the end of the character variable as part of the standard C language character string handling.

An important feature of the RFC is that a variable can be defined in a manner identical to the way an output record is specified. In the example here, the variable FIND is defined using the same code required to write an output record. The only difference is that record 31 was defined to be a variable rather that an output record. The statement "write find.31" writes a type 31 record to the variable FIND rather than to the output file pointed to by the name FIND.

Fortran:

```
    ENCODE (3,22,CON)E2A1
    ENCODE (2,23,SEC)E2A2
 22 FORMAT (I3.3)
 23 FORMAT (I2.2)
    FIND='1.1='''//E1A1//'''*2.1='''//CON//'''*2.2='''//
   * SEC//'''!'//CHAR(0)
```

RFC:

```
  record 31
  //1.1='^e1a1^'*2.1='^con^'*2.2='^sec^'!
e1a1    StateRtNo   char   5    6    10;
e2a2      Control   char   3   18    20;
e3a3      Section   char   2   28    29;
  write find.31;
```

A side benefit of the RFC is that the GOTO statements often found in Fortran programs are easily eliminated. The Fortran code for NEEDSLOA included many such statements, while the RFC code contains none. A list of all the GOTO statements is shown below.

Fortran:

```
IF (RC(1) .NE. 0) GOTO 900
IF (KEY1 .EQ. E1A1)GOTO 21
IF (RC(1) .NE. 0) GOTO 15
IF (NUMFND .EQ. 0) GOTO 15
GOTO 21
IF ((KEY2 .EQ. E2A1) .AND. (KEY3 .EQ. E2A2)) GOTO 41
IF (RC(1) .NE. 0) GOTO 25
IF (NUMFND .EQ. 0) GOTO 25
GOTO 41
IF (KEY4 .EQ. E3A1) GOTO 51
IF (RC(1) .NE. 0) GOTO 44
IF (NUMFND .EQ. 0) GOTO 44
GOTO 902
IF (KEY5 .EQ. E4A1) GOTO 61
GOTO 5
GOTO 1000
IF (IATT .EQ. 0) GOTO 1000
IF (RC(1) .EQ. 0) GOTO 1000
```

The experience of coding NEEDSLOA in RFC language also pointed out some difficulties in automating the reformatting process:

(1) Part of many reformatting problems involves moving data between computer systems. The RFC is not relevant to this part of the task although the machine independent nature of RFC code means that it can be easily used on a wide variety of systems.

(2) Dealing with proprietary data sets means calling proprietary subroutines. The actual data structure of the NEEDS.DBS database file is not known and not really of interest. The program that needed to be written, instead, called Intergraph supplied subroutines to access the data and generated DMRS commands that perform the actual updating of the database.

(3) While repetitive (housekeeping) program details can be automated, logic specific to individual translation problems can not. The RFC version of the program required quite a few lines of embedded C code to carry out the logical tests concerning the variables and to recode the variables values appropriately. In addition, it is currently necessary to set off the inline C code with a delimiter. Appendix C gives details of the RFC.

4.4 Pavement Management Demonstration

LDOTD Needs data converted from the Intergraph IGDS/DMRS environment, simulated pavement history, and quality data for Beauregard Parish were utilized to develop a prototype Pavement Management System in the Intergraph MGE environment. The development of the prototype provided the opportunity to evaluate the GIS-T approach to managing a PMS. A graphical approach enables displays of pavement condition by parish or other geographic boundaries and aids in conveying information to PM personnel as well as funding agencies. A well designed system can be interfaced with other MGE projects to allow for sharing of data and overlaying of relevant spatial information. Tools utilized in its development include PC Quattro, ORACLE SQL, SQL*Loader, C programming, Intergraph RtoDto, MicroStation, MDL, MGE and MGA. Tools for performing road segmentation and generating MicroStation displays of control-section pavement history were developed. Figure 4.4.1 gives the structure of the PMS.

The first task carried out was to move the Needs database from the IGDS/DMRS environment to the MGE environment. The Intergraph tool RtoDto was used to convert the hierarchical NEEDS database to ORACLE. In this data, the two entities of interest are *control_section* and *sub_section*. The *sub_section* entity is a child of the *control_section* entity. RtoDto exports each entity into a separate table, so it is necessary to rejoin the two resulting tables after the conversion.

The RtoDto procedure is run on the workstation after moving the DMRS database file (.dbs file) and associated entity files (.ent files) to the workstation. In order for the RtoDto procedure to run successfully, care must be taken to move all the files to uppercase file names and either to rebuild the database file to not allude to any logical names which may have been assigned on the VAX or to define a variable for the logical name definition on the workstation. A command procedure is provided in the RtoDto product directory to convert all of the file names to uppercase. The user must then have an ORACLE ID and password so that the tables can be generated. The names of the tables are identical to the DMRS entity names, except an *_d* is tacked on to the name of each attribute.

A description of each of the tables created by RtoDto is obtained by using the "describe" command in ORACLE. The table control_section_d contains the following information:

CONTROL_SECTION_D TABLE

Name	Type
MSLINK	NUMBER(10)
CONTROL_D	NUMBER(5)
SECTION_D	NUMBER(5)
CSM_LENGTH_D	NUMBER
LENGTH_D	NUMBER
PARISH_D	NUMBER(5)
CONTINUOUS_D	NUMBER(5)
STATUS_1_D	NUMBER(5)
STATUS_2_D	NUMBER(5)
GENERATE_OWNER_D	NUMBER(10)

The table sub_section_d contains the following information:

SUB_SECTION_D TABLE

Name	Type
MSLINK	NUMBER(10)
NUMBER_D	NUMBER(5)
BEGIN_LOGMILE_D	NUMBER
LENGTH_D	NUMBER
FUNC_CLASS_D	NUMBER(5)
FED_AID_SYS_D	NUMBER(5)
AREA_TYPE_D	NUMBER(5)
ROW_WIDTH_D	NUMBER(5)
ACCESS_CONTROL_D	NUMBER(5)
LANES_D	NUMBER(5)
WIDTH_D	NUMBER(5)
SURFACE_TYPE_D	NUMBER(5)
SHLDR_TYPE_D	NUMBER(5)
SHLDR_WIDTH_D	NUMBER(5)
AVG_ADT_D	NUMBER(10)
AVG_ADT_YR_D	NUMBER(10)
AVG_SPEED_D	NUMBER(5)
K_FACTOR_D	NUMBER
OP_SPD_PEAK_D	NUMBER(5)
LEVEL_SERVICE_D	CHAR(2)
V_C_RATIO_D	NUMBER
CAPACITY_D	NUMBER(5)
DIREC_FACTOR_D	NUMBER
OP_SP_VC_D	NUMBER(5)
LANE_ROAD_D	NUMBER(5)
SAFE_SPEED_D	NUMBER(5)
PAVEMENT_D	NUMBER(5)
SHOULDER_D	NUMBER(5)
X_SEC_D	NUMBER(5)
IMP_TYPE_D	NUMBER(5)
REC_WIDTH_D	NUMBER(5)
TIME_PERIOD_D	NUMBER(5)
IMP_COST_D	NUMBER(10)
NUM_STRUCTURES_D	NUMBER(5)
PAVEMENT_SECTION_D	NUMBER(5)
CONSIDER_URBAN_D	NUMBER(5)
GENERATE_OWNER_D	NUMBER(10)

The next step is to use the Structured Query Language (SQL) interface to ORACLE (SQL*Plus) to join the *sub_section_d* and *control_section_d* tables together by joining all records where the value of sub_section_d.generate_owner_d is equal to control_section_d.mslink. This is done using the SQL command:

```
create table needs_tbl as select
var1,var2,...etc. from sub_section_d,control_section_d
where sub_section_d.generate_owner = control_section_d.mslink;
```

The *mslink* variable in the *control_section_d* table is sequential ranging from 1 to 33 in value (one record for each control-section). The *mslink* variable in the *sub_section_d* table also ranges from 1-33, but there are 69 records because multiple subsection records correspond to a single control-section. For simplicity, several unused columns of the resulting *needs_tbl* were dropped and the *_d* portion of the variable names was removed as well.

A new variable was created to measure the lane mileage along each needs subsection. This variable, *lane_distance*, is equal to lanes_d * length_d. In addition to transferring the tabular data, the graphics data was also moved to the workstation and converted to a 1983 datum using Projection Manager. The conversion was done because no datum was defined in the IGDS WMS element, so Projection Manager displayed its datum as *undefined*. MGE Feature Builder was used to build a feature named NEEDS. The GeoDatabase Locate functionality of MGE was then used to match each database record in *needs_tbl* to the appropriate graphics element. Prior to using GeoDatabase Locate the *mslink* variable was set to range from 1-69. Figure 4.4.2(a) and (b) shows the Needs graphics and the Needs database.

4.4.1 Pavement Database Conversion

The synthetic (artificially produced) pavement data provided by LTRC has also been entered into the ORACLE database. To accomplish this, it was first converted to a flat file on the PC and then transferred to the workstation. The UNIX *grep* utility was used to select all the records which correspond to nonlayer information about each pavement subsection. The data was then reformatted to contain separate records for each of the three years (1984, 1986 and 1988) for which data had been provided. This was done because as additional years of data become available, it would be unwieldy to continue to add new columns for each of the variables to the table. Rather, a separate pavement feature for each of the years for which data exists can be generated and associated with the relevant year of data.

Sample Synthetic Pavement Data (Original Format)

Pavement Layer Data for Subsection 1 of Control-Section 188-2

C-S	Start Log Mile	End Log Mile	Layer No.	Depth	Thick	Mat/Year/Project
188-2	0	4.05	1	3.70	3.70	HMAC/1974/026
188-2	0	4.05	1	5.70	2.00	HMAC/1963/018
188-2	0	4.05	1	11.40	5.70	SCG/1963/018

Pavement Quality Data for Year 1988 for Control-Section 188-2
(Note: Data was provided for years 1984, 1986 and 1988)

Subsection Number	Begin log-mile	End log-mile	Ride IRI	Distress Rating	Skid Resistance
1	0	4.05	87	47	43
2	4.05	4.21	327	18	31
3	4.21	4.56	300	27	33
4	4.56	7.09	146	33	28

The table *pave_tbl* with the following structure was created and the data loaded into it using SQL*Loader.

PAVE_TBL TABLE

Name	Type
MSLINK	NUMBER(10)
CONTROL_NO	CHAR(3)
SECTION_NO	CHAR(1)
BEGIN_LM	NUMBER
END_LM	NUMBER
LM_ID_PAVE	NUMBER
YEAR_PMS	CHAR(4)
RIDE_IRI	NUMBER
DISTRESS	NUMBER
SKID_RESIST	NUMBER
ACCIDENTS	NUMBER
ADT	NUMBER

The SQL command to create *PAVE_TBL* is

```
create table pave_tbl
(control        char(3),
section         char(1),
begin_lm        number(5,2),
end_lm          number(5,2),
lm_id           number(5),
year_pms        char(4),
ride_iri        number(3),
distress        number(2),
skid_resist     number(2),
accidents       number(4,2),
adt             number(4,2));
```

and the SQL*Loader command to actually load the data from the *pms.dat* is

```
LOAD DATA
  INFILE pms.dat
  INTO TABLE PMS
  FIELDS TERMINATED BY ',' OPTIONALLY ENCLOSED BY '"'
    (control,
    section,
    begin_lm,
    end_lm,
    lm_id_pms,
    year_pms,
    ride_iri,
    distress,
    skid_resist,
    accidents,
    adt)   .
```

The pavement layer data provided by LTRC was incomplete and was augmented by RSIP to include surface type, project numbers, and dates for those pavement sections which had no data. Though the data entered was artificial, an attempt was made to create realistic records by layering HMAC and SCG surfaces in an appropriate manner. After material, year, and project data had been generated for all pavement sections, the data was input in a separate table named *layer_tbl* with the following structure:

LAYER_TBL LAYER INFORMATION TABLE

Name	Type
MSLINK	NUMBER(10)
LM_ID_LAY	NUMBER(5)
LAYER	NUMBER(5)
DEPTH	NUMBER(5,2)
THICK	NUMBER(5,2)
MATERIAL	CHAR(8)
YEAR_LAY	CHAR(4)

The variable *lm_id_lay* in the *layer_tbl* table can be used to relate the pavement layer data to the proper pavement subsection record through the variable *lm_id_pave* in the *pave_tbl* table. A sample of the *layer_tbl* table is listed here:

SAMPLE LAYER_TBL DATA

LM_ID_LAY	LAYER	DEPTH	THICK	MATERIAL	YEAR	PROJECT
1	1	2.9	2.9	HMAC	1974	32
1	1	2.9	-3.5	HMAC	1974	32
1	1	2.9	3.5	HMAC	1952	6
1	2	7.9	5	SCG	1932	1
2	1	3.2	3.2	HMAC	1958	8
2	2	6	2.8	HMAC	1942	2
2	3	12.1	6.1	SCG	1940	1
3	1	3.2	3.2	HMAC	1988	12
3	2	5.2	2	HMAC	1962	8
3	3	8.1	2.9	HMAC	1947	3
3	4	10.6	2.5	HMAC	1934	1

The *pave_tbl* table has data for each of the 107 pavement sections. There are three years of data for each pavement section (one row each for the years 1984, 1986 and 1988) so the total number of records is 321. The *layer_tbl* table has a variable number of records for each of the 107 pavement sections (one row for each pavement layer of each pavement section). All together there are 305 records of layer information.

4.4.2 Generation of Pavement Subsections Graphical Feature

The next step is to join together *pave_tbl* and *layer_tbl* with the features made from the graphics elements representing each of the pavement management subsections. In order to segment the control-section into the subsections of the appropriate length, the LDOTD had written a user command module (UCM) to perform this task on the VAX. Other UCMs had been written to do related tasks such as mark the start of each control-section. These UCMs do not readily work in the workstation environment in part because they use the TSK command to initiate the .TAN task which is no longer available. In addition, the UCM code is very cryptic in appearance as the

Drainage Basin Feature Table: basin_tbl

mslink	mapid	Basin_name	Basin_code	Basin_size
1	100004	Turkey Hollow Creek	101	2154.1699
2	100004	No Name Basin	102	
	.			
	.			
	.			

Rainfall Intensity Feature: rain_tbl

mslink	mapid	Precip_zone	Precip_value
1	100003	101	8.75
2	100003	102	9.25
	.		
	.		
	.		

Stream Feature Table: stream_tbl

mslink	mapid	Stream_name	Basin_code	Stream_order
1	100021	Turkey Hollow Creek	101	1
2	100021	Turkey Hollow Creek	101	2
3	100021	Turkey Hollow Creek	101	3
	.			
	.			
	.			

Soil Feature Table: soil_tbl

mslink	mapid	Soil Association	Soil_code	Soil_area
1	100001	Beauregard-Caddo	1	
3	100001	Ruston-Bowie	2	
2	100001	Beauregard-Bowie	3	
4	100001	Acadia-Gore	4	
5	100001	Bienville-Eustis	5	
6	100001	Bibb-Mantachie-Chastain	6	
	.			
	.			
	.			

used MGA Query Reporter to report all the elements within the query set. Since features included in the query set maintain the linkages to the the relational database, it is possible to retrieve the attribute values for the included feature elements. A drainage basin might contain more than one rain intensity polygon. In this case, a weighted rainfall intensity value will need to be computed based on the rainfall intensity values and the areas of the polygons within that drainage basin.

To compute hydraulic length of the drainage basin we perform a spatial query to extract only those drainage lines within the selected drainage basin. To do this, we created a topological file containing drainage network features and the drainage boundary features. We also defined a spatial operator before we started the spatial query. MGA provides 15 primary spatial functions which define the spatial relationships between features in a topological file. For this project we defined a customized spatial operator *LINEINSIDE* (functions 4, 5, and 6) to include only these line features that are within a selected area feature. The actual query statement to generate the desired query set looks like

:stream_tbl
:LINEINSIDE
:basin_tbl where basin_code = 101 .

This query statement instructs the system to include only the line segments that are inside basin 101 in the output query set. This query set was then used to generate a report on the include-line features and their attribute values.

To retrieve information for computing the weighted run-off-curve-number value for a drainage basin we performed a spatial query on soil and land-use features within a selected drainage basin (Figure 4.5.3). We first created a topological file consisting of land-use, soil, and drainage basin features. After the topological file was created, we built a query set that contains only the polygons that are within basin 101. The query statements are included here as an example:

:soil_tbl
:AND
:landuse_tbl
:AND
:basin_tbl where basin_code = 101

4.5.6 Generating Reports from Query Sets

Answers to the queries defined in the previous step were kept in the corresponding topological files as query sets. Contents of a query set can be retrieved to generate a report by Query Reporter, a function provided in MGA. The output report will include feature attributes specified in the Report Definition File. The Report Definition File contains information on which relational database table/column to use in producing the output report and whether area or length calculations are to be included in the report. The unit of measure to use for area and/or linear features can also be defined in the Report Definition File. The following is an example of a Report Definition File:

4.6 GPS/Van Data Sets

The LDOTD cartographic database for Beauregard Parish was acquired and transferred to the RSIP Intergraph MGE environment. This data was used for comparison with the GPS/Van data. The remaining effort involved acquiring the data and developing needed software to incorporate the data into the Intergraph database.

4.6.1 Data Collection

Procedures for collecting GPS/Van data were designed to simulate, as closely as practical, LDOTD manual procedures in collecting highway inventory. This GPS van derived data task was subcontracted to Navstar Mapping Corporation (NMC). Alignment track and feature data were collected at speeds that emulate GPS data collection in a production run. The procedures for NMC to collect the data were based on NMC experience derived from the Tennessee and Virginia DOT research efforts, Frank Cooper's longtime familiarity with LDOTD's reference system and operational procedures, and input from the LDOTD's highway inventory staff.

The selected routes for collecting GPS data included an overlap section of US 171 and US 190 and a couplet inside the city of DeRidder. The following list outlines the guidelines used by NMC to collect alignment track and feature points.

1. Collect and provide data to the LDOTD based on Control-Section limits.
2. Collect alignment track east to west for US 190 and south to north for US 171.
3. Collect data for the accuracy alignment track runs for both travelways (both directions).
4. Use easily discernible features from the LDOTD geographic features file (road intersections, RR tracks) for control points as features to be evaluated for positional accuracy.
5. Use structures from the LDOTD bridge files along US 190 and/or US 171 as existing features.
6. Use signs, alignment points (pc,pt,poc), culverts and other features of interest as new feature points.
7. Begin and end the "offsystem" alignment track on one of the US 171 or US 190 alignment tracks.
8. Collect some feature points along the "offsystem" alignment track.

NMC delivered the collected data with a report describing their findings to RSIP.

4.6.2 Software Developed

Software has been written to process the GPS data collected by NAVSTAR MAPPING CORPORATION (NMC). The software is intended to be used in the Intergraph MGE graphics environment to display, update, and optimize the raw road alignment and inventory GPS data collected in the field so that it can be used by the Louisiana Department of Transportation for a variety of functions. A list of the software is given in Table 4.6.1.

The road inventory and alignment data were delivered in a fixed ASCII format. The fields of data in the road inventory file are:

GPS Time in seconds from Saturday midnight
longitude in degrees
latitude in degrees
msl altitude
logmile
vertical velocity
feature description .

An example of the inventory data file follows:

425435.938	-93.232544	30.609818	40.555	0.307	"culvert"
425450.602	-93.232559	30.612614	37.565	0.498	"culvert"
425489.924	-93.232658	30.620838	38.011	1.069	"culvert"
425505.665	-93.232689	30.624222	34.102	1.299	"culvert"
425524.587	-93.232727	30.628170	33.650	1.572	"culvert" .

The fields in the road alignment data are:

GPS time in seconds from Saturday midnight
longitude in degrees
latitude in degrees
msl altitude in meters
horizontal velocity in kilometers/hour
heading in degrees
vertical velocity in meters/second
logmile in miles .

An example of the alignment data is as follows:

425405.625	-93.232529	30.605648	41.0	53.753	357.36	0.278	0.000
425409.313	-93.232529	30.605965	40.8	33.092	358.44	-0.058	0.023
425411.313	-93.232536	30.606146	41.5	39.972	357.85	-0.033	0.037
425413.281	-93.232536	30.606361	38.6	46.061	358.46	-0.044	0.053
425415.313	-93.232536	30.606607	38.0	51.091	359.68	0.001	0.071
425417.313	-93.232536	30.606871	36.4	55.582	350.16	0.005	0.090
425419.313	-93.232529	30.607161	37.6	59.838	359.83	0.037	0.111

The first five software designs are nongraphical in nature and have been coded in C to provide portability. The programs are interactive and prompt the user for all input. They can be run on any platform since they perform no graphical operations, but instead merely update or process ASCII text files. In particular, they could be utilized on the PC where the GPS data is initially gathered or on the Intergraph workstation where the graphics processing will take place.

The first, **add_align**, creates a road alignment data record for a specific control/section/logmile or route milepoint in order to enable the operator to insert additional records into the road alignment data file. The user is prompted to enter the name of the road alignment file and a log mile. The lat/long of the selected log mile is then computed, and the new record is inserted into the file and flagged with an "*".

The second, **add_feature**, creates a feature data record for a specific control section or route milepoint to enable the operator to insert additional records in the road inventory data file. Again, the user is prompted for the file name and log mile and also for the feature description. The new record is inserted and flagged with an "*" as with the alignment records.

The **add_align** and **add_feature** programs accept both interactive input and input from a file containing multiple records. To instruct the program to take input from a file, the UNIX convention is to follow the program name by "< input.file" where input.file is the name of the input file.

The third program, **merge**, merges two road alignment data files. All the records in the first file which fall within the range of the log miles of the records in the second file are replaced by the records in the second file. A fourth program, **weed**, was designed to perform weeding. It reads in the NAVSTAR road alignment data file and writes out a new version where extraneous points have been removed. The points that are removed are those where 1) there has been no change in the north/south direction or in the east/west direction between the preceding and following points, 2) where the slope of the line between the preceding and following points is the same or finally 3) where the change in distance in the x or in the y direction is less than a user supplied value epsilon which is entered as feet. Case three will remove points which very nearly fall on a straight line with adjacent points and, if epsilon is set equal to 0, is identical to case 2. Table 4.6.2 gives the results of the weeding process.

The fifth program, **slope**, is used to adjust the length of the resulting weeded line so as to make it correspond to the LDOTD supplied value which is considered to be the correct distance. The MGE *measure distance along* command can be used to measure the distance along the control section. In addition, another program **distance** has been written to compute the length of a control section. It makes use of the formula to compute the distance D between points A and B: **cos(D) = sin(a)*sin(b) + cos(a)*cos(b)*cos(P)** where a and b are the latitudes of points A and B and p is the degrees of longitude between points A and B. The values a and b must be specified in radians. Once D is determined in arc distance, it may be converted to any convenient unit of measure.

The **weed** program may be used several times with different values of epsilon with the distance of the resulting line being computed each time. Increasing the value of epsilon will decrease the computed line length. If the control section is already too short before any weeding is done, additional points must be added to smooth jagged sections. These points may be added by using the program **slope** which writes a new version of the alignment file with additional points added. The points are added in places where the straight line distance between point 1 and point 3 differs from the sum of the distance between point 1 and point 2 and the distance between points 2 and point 3 by an amount greater than the user supplied value epsilon. The section between points 1 through 3 is checked to see if it is convex or concave, so that the newly added points result in a smoother curve.

Once the data has been assembled and modified, the next task is to generate graphics elements. Several techniques were explored including using the Customer Support Library (CSL) on the VAX to generate IGDS graphics elements. The CSL technique was implemented on the VAX and could be transferred to the workstation environment. The programs **align** and **feature** call CSL routines to place the connected string and text node elements into a design file. Since the software was written on the VAX and the VAX CSL is Fortran based, they were written in Fortran but could easily be converted to the C programming language.

The first graphics software design **connect_string.for** reads the data from the road alignment data file and writes out a connected string to represent a single control section. The second graphics software design **text_node.for** reads the data from the road inventory data file and writes out a text node for each road inventory feature. A text node consists of a point indicating the exact location of the feature and a text string describing the feature. The text string is read from the road inventory data file. The design files that are created are projected files in a geographic projection. The working units are equal to 360000*dd.mm.ss where dd.mm.ss indicates a decimal representation of longitude (x coordinate) or latitude (y coordinate). They are converted to a polyconic projection using MicroStation Projection Manager in the MGE environment.

The design files can easily be incorporated into the MGE environment. The FMU utility is used to move the design files from the VAX to the workstation. Before sending the files, the commands **set cont** and **set igds** should be issued so they will be transmitted properly. Next they are moved to the appropriate directory, in our case /usr/jane/mgeprj/%gps/dgn. The files can be displayed and the text node data loaded to a database by first using ULF generator and feature-builder to build a new design file and then using labelloader to load the text strings (type 17 elements) in the new design file into a database table.

The technique used to generate design files in the MGE environment was to create a program to generate precision key-in files containing the lat/long values for each of the points. These files contain lines in the form;

```
place lstring
ll=30:15:24,-93:20:15
ll=30:15:25,-93:20:17
etc.
```

or

```
place text
ll=30:14:30,-92:10:12
"culvert"
ll=30:14:40,-92:10:14
```

"culvert"
etc.

and can be executed from within the MicroStation environment by entering the command **@filename** at the MicroStation key-in prompt. The only requirement is that the MicroStation Projection Manager (MSPM) product be installed. Projection Manager is used to specify the primary, and if desired, secondary projection of the design file where the graphics will be generated. The program, **align**, creates an ASCII text file consisting of the precision key-in commands needed to place a line string delineating a control section based on the alignment data. The program, **feature**, generates an ASCII text file consisting of the precision key-in command needed to generate text strings for each of the inventory features with the @command option. The graphics that appear on screen as elements are generated. Any color, weight, level, linestyle, etc. settings that have been specified, as well as the defined design file projection, will be used. In this project, the NAD83 datum was selected to correspond to the GPS data collected, and the polyconic projection was selected for compatibility with LDOTD. The LDOTD design files must be converted from NAD27 to NAD83 datum before overlaying them with the design files generated from the GPS data.

A simple user interface was generated by adding additional lines to the MGE applications configuration file. This file contains the menu that is displayed when the MGE applications icon is selected. The user can point and click with the mouse to select the desired GPS program. In addition, options were added to provide the user with a list of available feature and alignment data and key-in files.

The software was also used to analyze GPS data collected by RSIP personnel along US 171 using the RSIP GPS Pathfinder receiver. Only very slight modification of the code, namely the input processing, was required. The generated alignment data was compared with NAVSTAR data by generating road alignment graphics for each data set. The two sets of data were also overlain on the 20M MSS SPOT image of the study area registered to the LDOTD BEAUREGER.FM design file converted to a 1983 datum.

Table 4.6.1 Software Written for GPS Project

Program	Purpose
add_align	Add an alignment record (interactive input or a file)
add_feature	Add a feature record (interactive input or a file)
align	Create a precision key-in alignment file to generate graphics
distance	Compute the distance in an alignment file
feature	Create a precision key-in feature file to generate graphics
merge	Merge to alignment files to replace bad records with good ones
weed	Weed an alignment file
slope	Add points to smooth an alignment file
connect_string	Generate road alignment graphics in VAX IGDS
text_node	Generate textnode graphics in VAX IGDS

Table 4.6.2 Control-Section Road Alignment Data

Total No. Points	Distance Computed (Miles)	C-S Name	Weed 25ft No. Points	Weed 25ft Distance	Weed 50ft No. Points	Weed 50ft Distance
462	6.40	1205e-rm.gps	91	6.40	54	6.40
439	6.40	1205w-rm.gps	88	6.39	53	6.39
947	13.98	2403-1rm.gps	30	13.97	18	13.98
978	14.01	2403-2rm.gps	31	14.01	18	14.01
1076	15.30	2404-1rm.gps	85	15.28	52	15.28
1091	15.28	2404-2rm.gps	122	15.28	74	15.27
288	4.89	2405-1rm.gps	62	4.85	42	4.80
397	6.31	2405-2rm.gps	97	6.31	69	6.30
296	4.88	2405-3rm.gps	64	4.85	42	4.81
205	2.65	2406-1rm.gps	56	2.63	36	2.63
201	2.64	2406-2rm.gps	56	2.63	38	2.63
939	13.26	2803-1rm.gps	69	13.26	47	13.26
	13.28	2803-2rm.gps				
932	13.33	2803-3rm.gps	78	13.28	69	13.26

4.7 Aerial Derived Data Sets for Maintaining the Cartographic Database

The following sections summarize our results on the work related to developing spatial databases from remotely sensed and available digital databases. We acquired data for the two study areas in Beauregard Parish, Louisiana for this part of the project.

4.7.1 USGS Quadrangle Maps

Study area 1 was split between two USGS (1:24,000) quadrangle maps. The most updated version available for the Boneset Creek quadrangle was produced from 1982 aerial photographic data. The Sugartown quadrangle was based on 1975 aerial photographic data. Because of these different dates, the road classification scheme differed between the two maps. On the Sugartown quadrangle, roads were classified as medium-duty, light-duty, and unimproved. On the Boneset quadrangle, roads were classified as improved, unimproved, or trails. For comparison purposes and consistency, medium and light duty roads from the Sugartown quadrangle were grouped into the "improved" category. "Trails" on the Boneset quadrangle were not used.

We digitized the USGS 1:24,000 quadrangles to provide a basis for comparison among different data sources. These data sets were added to an Intergraph digital database consisting of LDOTD's parish road maps in a polyconic projection. Since scale, date, and road type classifications differed between data sources, we developed a standard baseline format by which all data sets could be compared by accuracy of location and classification. Roads were classified as either improved or unimproved. This is because the resolution of the investigated data sets was appropriate for interpretation of these two categories.

4.7.2 IEMIS Database

The Federal Emergency Management Agency (FEMA) has developed the Integrated Emergency Management Information System (IEMIS). It is a mini-computer based automated emergency management system which includes a national database. This database includes such major features as interstate and U.S. highways, railroads, airports, cities, electric power grids, water bodies, federally owned lands, and political boundaries. These data were originally digitized from 1:2,000,000 scale maps. IEMIS also supports a relational database. The system supports a number of complex simulation models. These models provide for detailed emergency planning and support the querying of the system. For example, one can extract the total population residing within the region (from census data) and provide an estimate of the time to evacuate the area based on highway capacities, response times, and vehicular resources available. This system presently supports the following models nuclear plumes, transportation (evacuation), and siren placement. FEMA is constantly updating (e.g., 1:100,000 TIGER and/or DLG) and standardizing IEMIS capabilities. All related software is public domain.

This database was qualitatively evaluated for compiling parish road maps and deemed inaccurate due to the original mapping scale of 1:2,000,000. It, however, would be of use if LDOTD were to need a nationwide digital database for

networking studies with neighboring states.

4.7.3 USGS Digital Data Sets.

United States Geological Survey (USGS) data were considered. These data consisted of the USGS Digital Line Graph (DLG) and land-use (GIRAS). The USGS DLG data was generated by digitizing 1:100,000 quadrangle maps. This DLG data set classifies roads as trails, roads, streets, or. State and US routes. USGS generated digital GIRAS (1:250,000 scale) files represent circa 1976 land-use data. This GIRAS data (Table 4.7.1) represents the only state-wide digital data set of land-use. This data set was generated using a 10 acre minimum mapping unit for urban and/or developed areas and a 40 acre mapping unit for other features (i.e., agriculture, forests, etc.). The USGS generated DLG Roads and Trails data set (1:100,000) was added to the Intergraph database using the USGS Digital Line Graph to Intergraph Translator (DLGIN) and Standard Interchange Format (SIF) software products. Intergraph MGE products for this purpose would be MGE GIS Translator_US which is abbreviated MGT_US.

4.7.4 SPOT Satellite Data

The SPOT program provides data in digital formats at spatial resolutions compatible with mapping requirements [Welch 1985]. The SPOT satellite provides data at a ten meter resolution. The satellite passes over the same area every 26 days (orbit period is 26 days). Since the satellite provides for oblique viewing, the same area can be imaged every four days. Oblique viewing also allows the acquisition of stereo images[SPOT 1989]. The images are affected by lighting conditions, therefore, it is important that these conditions remain the same. For this reason the satellite is in a sun-synchronous orbit, which means the sun is over a point at the same local time on each pass.

SPOT provides data in several formats. RSIP acquired two panchromatic 10 meter resolution SPOT satellite transparencies and digital data taken in February and May 1988. After visual analysis of the leaves-on and leaves-off SPOT satellite transparencies, the leaves-on imagery was used to map roads. The leaves-on imagery provided the best contrast between roads and surrounding features (i.e., trees, crops, grass). This imagery was placed on a Krones rear screen projector (1.4X-4X lens) and registered to the 1:24,000 USGS mylar quadrangle maps for interpretation and digitization. Higher magnification of the imagery was not necessary because of the resolution limitation of the SPOT imagery. These images, with a resolution of 10 meters, are a possible data source for the extraction of major road networks. The leaves-on, digital, panchromatic SPOT satellite imagery taken in May 1988 was chosen to map roads over the leaves-off image (February 1988) because of the better contrast with surrounding features.

Digital multispectral SPOT data (December 1987) was also acquired. It has a spatial resolution of 20 meters and represents three portions of the electromagnetic spectrum. These three channels are green (500-590 nm), red (610-680 nm), and near-infrared (790-890 nm). Because of the coarse spatial resolution of this data set, it was not used to map roads. It can, however, be evaluated as a tool to generate land-cover data.

Another available format is called a county view. This is a black and white photographic print (using 10 meter panchromatic data) of an entire parish (county) at an approximate scale of 1:24,000. This format, which is delivered on several very wide and long roles, is extremely cumbersome to use.

4.7.5 NHAP/NAPP Aerial Photographs

National High Altitude Photography (NHAP) photographs (approximate scale is 1:58,000) were used to photointerpret and digitize improved and unimproved roads. NHAP photographs used in this project were taken in 1981 and 1983. The National Aerial Photography Program (NAPP) has just completed its photo acquisition mission for the state of Louisiana. The NAPP photographs were taken from an altitude of 20,000 feet, on 9-inch film, with a resulting image scale of 1:40,000. It provides standard, uniform-quality, cloud-free aerial photographs of the whole state. Twelve NAPP photos covering the study area were acquired from the USGS EROS Data Center. Those NAPP photographs were acquired during 1989 and early 1990 and provide the most up-to-date off-the-shelf source of photographic data. In addition, NAPP photographs have higher spatial resolution than NHAP photography, making more detailed studies such as road surface types and right of way possible.

In this report, we describe several different types of roads: (1) the state maintained road network, a road network in Louisiana which the DOTD maintains, which is depicted in digital form as the district map; (2) parish road network, a road network maintained by other Louisiana governmental units, which is depicted in digital form as the parish map; and (3) additional roads and trails which are all other roads.

Our objective was to evaluate available data sources for creating LDOTD parish maps from their district map base and to maintain the LDOTD digital base map files. Table 4.7.2 describes the data sets considered. We acquired, photointerpreted, digitized, and analyzed each of the appropriate road networks from the SPOT digital data and transparencies and from the National High Altitude Program (NHAP) photographic transparencies. The fourth data set was digitized from two USGS 1:24,000 quadrangles to provide a basis for comparison among different data sources. These data sets have been added to an Intergraph digital database consisting of the 1:100,000 USGS Digital Line Graphs (DLG) and LDOTD's parish road maps. We made comparisons among these data sets in terms of methodology, accuracy, and cost.

4.7.6 Analysis of Digital Line Graphs (DLG)

The USGS generated DLG Roads and Trails data set (1:100,000) was added to the Intergraph database using the USGS Digital Line Graph to Intergraph Translator (DLGIN) and Standard Interchange Format (SIF) software products. This DLG data set classifies roads as trails, roads, streets, or State and US routes. Hydrographic features, as found on the LDOTD parish road database were digitally overlain on the USGS generated DLG files. The LDOTD data set was originally derived by digitizing 1:24,000 scale USGS quadrangle maps. The USGS DLG data was generated by digitizing 1:100,000 maps. From reviews of the data

sets, it was concluded that the DLG data represent only the major rivers and streams in the study area and overlay relatively well on the corresponding LDOTD files of the same features. The LDOTD files, however, contain many more of the smaller streams (primarily first and second order streams) than the DLG files. The LDOTD files are more detailed (assumed to be more spatially accurate) and are of more use than the DLG data for hydrologic studies.

Table 4.7.1 Land-Use and Land-Cover Classification System *	
Level I (and Map Color)	Level II
1 Urban or built-up land (red)	11 Residential
	12 Commercial and services
	13 Industrial
	14 Transportation, communications, and utilities
	15 Industrial and commercial complexes
	16 Mixed urban or built-up land
	17 Other urban or built-up land
2 Agricultural land (light brown)	21 Cropland and pasture
	22 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas
	23 Confined feeding operations
	24 Other agricultural land
3 Rangeland (light orange)	31 Herbaceous rangeland
	32 Shrub and brush rangeland
	33 Mixed rangeland
4 Forest land (green)	41 Deciduous forest land
	42 Evergreen forest land
	43 Mixed forest land
5 Water (dark blue)	51 Streams and canals
	52 Lakes
	53 Reservoirs
	54 Bays and estuaries
6 Wetland (light blue)	61 Forest wetland
	62 Nonforested wetland
7 Barren land (gray)	71 Dry salt flats
	72 Beaches
	73 Sandy areas other than beaches
	74 Bar, exposed rock
	75 Strip mines, quarries, and gravel pits
	76 Transitional areas
	77 Mixed barren land
8 Tundra (green-gray)	81 Shrub and brush tundra
	82 Herbaceous tundra
	83 Bare ground tundra
	84 Wet tundra
	85 Mixed tundra
9 Perennial snow or ice (white)	91 Perennial snow fields
	92 Glaciers

* Level 1 is based primarily on surface cover; level 11 is derived from both cover and use. Color Codes are based on recommendations of the International Geographical Union.

Table 4.7.2 Data Sets

Product	Quantity	Unit Price	Delivery (Wks)	Total Cost*
USGS mylar Maps	4	72	4-6	288
Aerial Imagery (NHAP)	11	24	6-8	264
USGS Digital DLG		In-house - RSIP		
USGS Digital GIRAS		In-house - RSIP		
SPOT Satellite				
A) B&W Trans.	2	500	2-4	1000
B) Color Trans.	1	500	2-4	500
C) B&W Digital	2	1000	2-4	2000
D) Color Digital	1	600	2-4	600
E) County Scene	1	2326	6-8	2326

* Costs reflect current prices charged to universities for research purposes and do not represent prices for commercial (LDOTD) use.

4.7.7 Analysis of SPOT-Satellite Data

It is advantageous to merge the panchromatic image with the 20 meter SPOT multispectral image, preserving the high resolution of the panchromatic image and, at the same time, having the spectral information of the multispectral image [Cliche 1985, Chavez 1988]. The following steps are required to register two images:

1) As the panchromatic and multispectral data in all SPOT-1 images are not co-registered, the two data sets need to be registered geometrically. This includes location of control points common to both the panchromatic and multispectral images.

2) The software computes the unknown coefficients for a polynomial equation to implement a transformation between the coordinate systems of the two images.

3) A cubic convolution algorithm is used to resample the three multispectral images into the panchromatic image coordinate system.

The merging of the two geometrically registered data sets can be done through the use of intensity-hue-saturation (IHS) transformation method. In the IHS transformation method, the IHS components are derived from the multispectral data; the panchromatic data are then substituted directly for the computed intensity. An alternative is to use the weighted average of twice the panchromatic plus the near-infrared band as a substitute for intensity. The data are then transformed back to the red-green-blue (RGB) color domain, with this resulting RGB composite image having the spatial resolution of the panchromatic image and additional spectral discrimination.

The digital image was processed using the Intergraph MGE Imager software. The study area was extracted from the larger image region and registered to the LDOTD digital map. The image was then histogram stretched to improve contrast between roads and neighboring features. The zoom feature was an interpretative aid during mapping. As a result, it was easier to find and to trace roads from the digital SPOT scene than from the SPOT transparency. Roads were digitized from the raster image, displayed on the computer screen, and stored as vector elements.

4.7.8 Analysis of NHAP Aerial Photographs

NHAP photographs (approximate scale of 1:60,000) were used to photointerpret and digitize improved and unimproved roads in the study area. Each photograph was projected and enlarged about eight times using the 3.5 X- 8.0 X lens through a Krones LZK rear screen projector (with overlain Altek transparent digitizer) for interpretation and digitization. Instead of registering the photographic data to the 1:24,000 transparent mylar quadrangle maps, NHAP photographs were registered to a digital road network design file that was previously digitized from USGS 1:24,000 quadrangle maps by RSIP. By doing so, one can choose different magnifications in order to bring the photographs to the appropriate scale where the roads are easiest to visualize, trace, and digitize. It was determined that 1:10,000 was a convenient scale for digitizing roads from NHAP

photographs. Another benefit of using NHAP photographs for digitizing road networks is that stereointerpretation could be used to clarify details relative to a particular road (on a light table using a Bausch and Lomb zoom stereoscope).

4.7.9 Analysis of High Resolution Photography

We studied image data of various scales for the purpose of updating the LDOTD parish road maps. We feel that there is a need to include high resolution raster data for evaluation. Satellite images are useful because a single scene covers a large area, but they do not provide enough spatial resolution for certain aspects of road mapping. For example, SPOT images do not provide information about road surface types, number of lanes, and road inventory features. RSIP had several color and color infrared aerial photos scanned to generate raster imageries for evaluation. These photos were scanned at 50 micron resolution by Analytical Surveys, Inc. of Colorado Springs, Colorado at the price of 150 dollars per photo.

Table 4.7.3 Resolution of Remotely Sensed Data

Data Source	Scale	Resolution	Minimum extracted feature size	Format	Rows	Columns
Aerial Photo	1:2,500	.1 meter	.2 meters	5x5" film	2440	2570
NAPP CIR	1:40,000	2 meters	5 meters	9x9" film	4700	4700
NHAP CIR	1:60,000	3 meters	8 meters	9x9" film	4700	4700
SPOT PAN		10 meters	15 meters	digital tape	6006	6006
SPOT MSS		20 meters	30 meters	digital tape	3003	3003

Spatial resolution is an involved concept [Colwell 1983]. The system used to acquire the image determines the resolution of the image, and the format of the system determines how resolution is measured. A variety of methods can be used to measure resolution. Intuitively, resolution refers to the fineness of detail that can be distinguished in the image or the minimum distance between objects at which they can be distinguished. Instantaneous field of view (IFOV) is commonly used as a measure of resolution. For satellites, this varies with the focal length of the optical system, detector size, and satellite altitude. Therefore, changes in the altitude of a satellite will affect the IFOV or the resolution of the system. For the SPOT satellite, this resolution is 10 meters for the panchromatic band and 20 meters for the spectral bands. IFOV does not always reflect the smallest object that can be detected. Objects of a smaller size but with high contrast may be detected. Highways and waterways are examples of this phenomenon. Objects of low contrast may have to be much larger to be detected.

Another measure of resolution is based upon patterns of black lines equally spaced upon a white background. As the spacing between the black and white lines gets smaller, the contrast between the lines gets less until the lines are indistinguishable. This measure of resolution is often called line pairs/mm or lines/mm. For example, in high resolution color film ,as commonly flown with mapping cameras, a resolution of 200 lines/mm has been reported for high

contrast lines and 100 lines/mm for low contrast lines. Spatial frequencies of sinusoidal varying patterns in cycles/mm may also be used to characterize resolution. The Modulation Transfer Function (MTF) indicates the response of the camera system to sinusoidal varying signals. The MTF is near unity at low frequencies and decreases at higher frequencies. The effective instantaneous field of view (IEFOV) is the spatial frequency at which the MTF is 50% of its maximum value.

The spatial resolution required depends upon the task. Detection refers to determining the presence of an object. Recognition of different objects may require more resolution. Three times more resolution may be required for identification over detection. Scale is the relationship between the size of objects in images or maps in comparison to their actual size. Scale is not the same as spatial resolution. Digital data can be depicted in a variety of scales. The scale at which data are analyzed influences the information obtained. The objects in a scene may appear quite different at different scales and resolutions. Roads appear as long thin ribbons in small scale SPOT images and appear as objects with lanes, shoulders, surfaces, and vehicle features in large scale photographs. It is important to know the best scale to identify given objects.

We determined a pixel size and a minimum extractable feature size for both the digital imagery and the scanned photography. This enables us to compare the extent of the extractable information related to road mapping of different data sources with a quantifiable parameter. Our procedure to determine a pixel size for the scanned film media (Low altitude photos and NAPP and NHAP transparencies) was to view the scanned photos in MGE Imager, identify objects of known dimension, and count the number of pixels along the object. For example, we chose several cars, zoomed in on each individually until we could see individual pixels and then counted the pixels along the length of the car. The pixel size is then equal to the length of the car divided by the number of pixels averaged among all the cases. We also confirmed this by dividing the ground distance of the scanned image by the rows or columns. The procedure for determining the smallest extractable feature was to find the smallest feature we could photointerpret using the zoom capability of the MGE Imager. For example on NHAP scanned images, cars are recognizable with no details, but using context cues, they can be easily recognized. On the low altitude photos (1:2,500 scale), the color and model of the cars are discernible. The smallest features which could be identified were the painted lines in a parking lot. This number, minimum extracted feature size is an aid in comparing the usefulness of the different data sources.

Our procedure to determine the minimum extractable feature size for the NHAP photography was to perform successive zooms with the Krones projector to find the smallest recognizable feature in the photograph. For example, cars are recognizable with slightly more details than the scanned image but are still the smallest recognizable feature.

Remotely sensed data from different altitudes provide different but complementary spatial resolutions. With SPOT imagery and color infrared aerial photography, it is possible to use the high spectral resolution and machine processing

capabilities of satellite imagery in conjunction with the high spatial resolution and detailed contextual analysis capabilities gained by using aircraft-borne sensors. Table 4.7.3 gives a summary of the resolutions of the different data sets.

4.7.10 Comparison Among Data Sets

We evaluated the suitability of the five collected data sets for updating the LDOTD parish road maps and their potential use in other tasks such as determination of land-use. A comparison among the collected data sets in terms of their scale, resolution, data updating cycle, cost, and road surface information is summarized in Table 4.7.7.

The 1:100,000 DLG data set was tested for its completeness in representing the existing road network. The DLG data set does have more roads than the LDOTD's parish map. However, we found that several newly upgraded or constructed roads are not included in the DLG data set. This is because DLG data were digitized from U.S.G.S. 1:100,000-scale 30- by 60-minute quadrangle maps, and they are not always very up to date. Another limitation of this data set is its scale. In order to have a consistent spatial accuracy with the LDOTD design files, larger scale DLG data (e.g. 1:24,000) might be necessary. For these two reasons, the 1:100,000 DLG data set is not suitable for the purpose of updating the state-wide road network. However, this state-wide data set will be useful for planning and/or routing application at the state level.

NHAP aerial photography was evaluated for its potential in providing road surface information. Although digitizing the road network from NHAP photos takes more time and skill than from the other data sources, it might still be worthwhile because of the possibility to differentiate road surface types to a certain extent from NHAP photos based on color and tone. Our findings indicate that paved roads tend to have light blue color while gravel and dirt roads tend to have white color. Further classification within the two categories is not possible at this stage. The new NAPP aerial photos are more suitable for this purpose. Twelve NAPP photos covering the study area were ordered from the USGS EROS Data Center. The advantage in using those newly available NAPP photographs is that they were obtained during 1989 and early 1990 and can provide the most up to date data source. In addition, NAPP photographs have higher spatial resolution, making the more detailed studies such as road surface types and right-of-way possible.

SPOT imageries were studied again to evaluate their possible use in automatic road network extraction. We have applied different filters to both color and panchromatic imageries to increase the contrast between the road and the non-road pixels. Filtering and classification on color images did not produce satisfactory results due to the spatial resolution limitations of these images. Panchromatic images show great improvement after filtering, and these sharpened images were used to interactively extract road networks. Road extraction from SPOT panchromatic imageries encountered no problems. However, the contrast between roads and surrounding features is weak in urban areas. Higher resolution data such as NHAP and NAPP are required to fill up those gaps.

As anticipated, all of the above five data sets contain roads in addition to those found in the LDOTD digital file of state maintained roads or the LDOTD digital file for the parish road map (see Figure 4.7.1). The data set generated from 1981 and 1983 NHAP photographs provided the most detailed information on the existing roads within the study area. However, due to higher spatial stereoscopic resolution (3m) and the manual interpretation process, it took more time to process than the other data sets. Among the investigated data sets, SPOT satellite imagery provided the most up-to-date (1988) road information. Although the existing DLG data set contains major roads for the entire state, it, however, does not provide up to date (circa 1976) information. For example, some of the newly extended state maintained roads that have already been included in the LDOTD data set are not in the DLG data set.

In terms of spatial accuracy, all the data sets analyzed, except the SPOT transparencies, were fairly comparable to the LDOTD data set even before they were warped. Statistical analysis based on selected common road intersections was conducted to provide quantitative measures of how each data set spatially differed from the DOTD data set. Forty-one major (improved) road intersections that appeared on all data sets were chosen for comparison (see Figure 4.7.2). Their coordinates were acquired from each design file and compared to the corresponding points in the LDOTD data set. Deviations from the LDOTD control points were also calculated for each data set after they were warped (using Intergraph's Elastic Body Small Angle Least Squares software package [EBSALS]) to show any spatial or locational improvements (see Tables 4.7.5 and 4.7.6). Before the warping process, the road data set generated from the USGS quadrangle maps had the smallest spatial deviation from the LDOTD data set (33.7 feet). The LDOTD built their digital road database by originally digitizing 1:24,000 USGS quadrangle maps. After this verification, the LDOTD data set was used as the baseline for comparison with all other data sets. The SPOT transparencies had the largest mean error (112.1 feet). The SPOT digital data set had a deviation of 53.6 feet, and the NHAP data deviated by 55.7 feet. The DLG data set had a mean deviation of 81.1 feet.

Warping of these data sets did improve the spatial accuracy of each, with respect to the LDOTD digital data base. Tables 4.7.5 and 4.7.6 represent summaries of the results of unwarped versus warped data sets as compared to the DOTD data set. Improvement was determined by reviewing the mean deviations. The following numbers represent the difference by data set once warped: USGS quadrangle map (8.23 ft.), NHAP (4.41 ft.), SPOT transparency (48.45 ft.), SPOT digital (8.56 ft.), and DLG (42.53 ft.). The least improved (mean of 4.41 feet or 7.92 percent) was the NHAP. Likely this is due to it being the most initially accurate data set because of its highest spatial resolution (9.84 ft.). The next most accurate (least improved) data set was the digital SPOT data (improved using warping by 8.56 feet or 15.97 percent). Again, this was due primarily to the ability to histogram stretch (enhance contrast) and zoom during the interpretation and mapping process. The SPOT transparency data set was improved by 48.45 feet (43.20 percent). This high level of improvement was likely imposed from the errors originally introduced in our manual interpretation and mapping

process. The USGS quadrangle (1:24,000) and DLG (1:100,000) data sets were improved by 8.23 feet (24.42 percent) and 42.53 feet (52.42 percent), respectively. These improvements are in line with the original map scales. It was determined that warping is a necessary step in the generating of road networks when using any of the above mentioned data sets.

ndix C - Reformat Compiler

Reformatting programs that move data between two clearly defined record for- are often similar in structure and organization, and this enables the generation ess to be automated to a large extent. These programs rearrange, omit, add fields ata, and modify variable types. The RFC allows users to specify the formats and ersion operations in a language customized for writing reformatting programs and mized for self-documentation and efficiency. The reformat compiler then acts on e specifications to produce the desired reformatting code in a target output uage. Portability of code is a requirement of the target output language programs uced by the reformat compiler and, accordingly, C is the target output language of ce. The compiler generation tools LEX and YACC are used to define the RFC t language with the necessary C code embedded for translation operations. Once input program to the reformat compiler has been translated to C, it may be ported y machine that has a C language compiler. Thus the reformatting program in the C input language may be written on one machine while the actual operation is car- out on another.

Figure B.1 indicates the context under which the reformat compiler will operate. re B.2 illustrates the structure of the RFC itself. The input file is read and ences of characters that correspond to token definitions are recognized by LEX. e tokens are used by the YACC section in conjunction with the grammar rule base erify syntax. Actions are initiated by calling C subroutines that interact with sub- ines written specifically for the translation process to generate the output C pro- that will, in fact, perform the data reformatting operation. The operation of the mat compiler is perhaps best understood by examining the structure and syntacti- composition of its input language. In this section, we consider a typical input pro- to the RFC, describe its syntactical aspects and explain how the RFC proceeds to uce output code that corresponds to the input code.

Any program in the RFC input language must start with the keyword "begin" and terminate with the keyword "end". The program must consist of three sections labeled input, output, and program sections, respectively. These sections are delimited by the the keywords "input" and "endin", "output and endout" and "program" and "endprog". The skeletal structure of any such program is illustrated below.

```
begin

        input
        . . .
        . . .
        endin

        output
        . . .
        . . .
        endout

        program
        . . .
        . . .
        endprog

end
```

Example 1

The input section specifies the structure of the input record(s), while the output section does the same for the output. The program section contains the code that will perform the necessary translation operations. The input and output sections are syntactically equivalent. External data is described in the same way in the input as it is in the output, so that structure descriptions that are used in the input may be used without alteration in the output section.

This is an important feature of the RFC, because it allows the building of data templates. If data is frequently transferred between certain structures then we may store these structure descriptions and use them in the input or output section depending on the direction of data transfer. Only the program section may need to be changed.

The input and output sections consist of a series of records. There are two basic types of records. The keywords **record 0** indicate that the structure being described within is a file. In order to distinguish files from other data structures, all record structures describing files must be identified by these keywords. A typical file description in the RFC input language is shown below.

```
record 0
     file       filein1   infil.data ;
endrec
```

Example 2

Within the description, the keyword **file** indicates that a file is being described. ...econd descriptor **filein1** is the RFC language identifier for the file, whose physi- ...ame is given by the third descriptor as **infil.data**. The record description is ter- ...ed with the keyword **endrec**.

The second type of record may describe any type of record structure. It is ...fied by the keyword **record** followed by any digit except 0. This is followed by a ...ption of the various elements that make up the record structure. The first element ...description is the name of the variable. This must be followed by a single word ...ation of the variable's actual purpose. This feature was incorporated to force ...m documentation and increase readability. This is followed, in turn, by the key- ...int or **char** which indicate the nature of the variable (integer or character) and ...a sequence of three digits. The first of these is the length of the variable, while ...xt two indicate its starting and ending positions. The reformat compiler uses ...digits to check for errors in structure descriptions. As before, the record ends ...e keyword **endrec**. A typical record description is shown below.

```
record 4
     var        content   char 5 1 5 ;
     rout       route     int  3 6 8 ;
endrec
```

Example 3

...he record above describes a record consisting of two variables "var" and "rout", ...s the second element tells us represent "content" and "route", respectively. The ...ar) is a character variable of length 5 starting at position 1 and ending at posi- ...The second (rout) is an integer of length 3 starting at position 6 and ending at ...n 8.

...he basic record structure described above may be enhanced by adding templates ...information. The enhanced record structure then consists of two portions. The ...t is the text template while the second part consists of the variable descriptions ...d above. The text template could be used, for example, to print out a statement ...e actual values of the variable descriptions contained within the record struc- ...onsider, for example, the DMRS command to open a database. This command

```
USE DB = "<filename>" !
```

The raster data was transferred by an interesting mechanism. First it was exported from Intergraph COT (continuous tone) format to generic raster format using the EXPORT GENERIC command in Tigris. This produces three binary files (one for each of the red, green and blue bands). Next these three files were moved across the network via TCP/IP FTP protocol along with information about the number of rows and columns in the image. A simple C program was written on the SUN to convert the data for the three bands into an ERDAS format image because ARC/INFO can display ERDAS images on the SUN using the new Image Integrator module. It was quickly determined that ARC/INFO has no capabilities for contrast enhancement, so the translation program was required to compute the maximum and minimum values for each of the bands and to scale the values accordingly so the pixel values would range between 0 and 255. Fine tuning was required since the top and bottom .1% of the pixel values needed to be discarded in order for sufficient contrast stretching to take place. The vector and raster data were registered again in ARC/INFO to compute the coefficients for the warping transformation. Finally the AML to display the vector data was enhanced to use the warp information and to annotate the final display of the raster and vector data.

4.7 Aerial Derived Data Sets for Maintaining the Cartographic Database

The following sections summarize our results on the work related to developing spatial databases from remotely sensed and available digital databases. We acquired data for the two study areas in Beauregard Parish, Louisiana for this part of the project.

4.7.1 USGS Quadrangle Maps

Study area 1 was split between two USGS (1:24,000) quadrangle maps. The most updated version available for the Boneset Creek quadrangle was produced from 1982 aerial photographic data. The Sugartown quadrangle was based on 1975 aerial photographic data. Because of these different dates, the road classification scheme differed between the two maps. On the Sugartown quadrangle, roads were classified as medium-duty, light-duty, and unimproved. On the Boneset quadrangle, roads were classified as improved, unimproved, or trails. For comparison purposes and consistency, medium and light duty roads from the Sugartown quadrangle were grouped into the "improved" category. "Trails" on the Boneset quadrangle were not used.

We digitized the USGS 1:24,000 quadrangles to provide a basis for comparison among different data sources. These data sets were added to an Intergraph digital database consisting of LDOTD's parish road maps in a polyconic projection. Since scale, date, and road type classifications differed between data sources, we developed a standard baseline format by which all data sets could be compared by accuracy of location and classification. Roads were classified as either improved or unimproved. This is because the resolution of the investigated data sets was appropriate for interpretation of these two categories.

4.7.2 IEMIS Database

The Federal Emergency Management Agency (FEMA) has developed the Integrated Emergency Management Information System (IEMIS). It is a mini-computer based automated emergency management system which includes a national database. This database includes such major features as interstate and U.S. highways, railroads, airports, cities, electric power grids, water bodies, federally owned lands, and political boundaries. These data were originally digitized from 1:2,000,000 scale maps. IEMIS also supports a relational database. The system supports a number of complex simulation models. These models provide for detailed emergency planning and support the querying of the system. For example, one can extract the total population residing within the region (from census data) and provide an estimate of the time to evacuate the area based on highway capacities, response times, and vehicular resources available. This system presently supports the following models nuclear plumes, transportation (evacuation), and siren placement. FEMA is constantly updating (e.g., 1:100,000 TIGER and/or DLG) and standardizing IEMIS capabilities. All related software is public domain.

This database was qualitatively evaluated for compiling parish road maps and deemed inaccurate due to the original mapping scale of 1:2,000,000. It, however, would be of use if LDOTD were to need a nationwide digital database for

networking studies with neighboring states.

4.7.3 USGS Digital Data Sets.

United States Geological Survey (USGS) data were considered. These data consisted of the USGS Digital Line Graph (DLG) and land-use (GIRAS). The USGS DLG data was generated by digitizing 1:100,000 quadrangle maps. This DLG data set classifies roads as trails, roads, streets, or State and US routes. USGS generated digital GIRAS (1:250,000 scale) files represent circa 1976 land-use data. This GIRAS data (Table 4.7.1) represents the only state-wide digital data set of land-use. This data set was generated using a 10 acre minimum mapping unit for urban and/or developed areas and a 40 acre mapping unit for other features (i.e., agriculture, forests, etc.). The USGS generated DLG Roads and Trails data set (1:100,000) was added to the Intergraph database using the USGS Digital Line Graph to Intergraph Translator (DLGIN) and Standard Interchange Format (SIF) software products. Intergraph MGE products for this purpose would be MGE GIS Translator_US which is abbreviated MGT_US.

4.7.4 SPOT Satellite Data

The SPOT program provides data in digital formats at spatial resolutions compatible with mapping requirements [Welch 1985]. The SPOT satellite provides data at a ten meter resolution. The satellite passes over the same area every 26 days (orbit period is 26 days). Since the satellite provides for oblique viewing, the same area can be imaged every four days. Oblique viewing also allows the acquisition of stereo images[SPOT 1989]. The images are affected by lighting conditions, therefore, it is important that these conditions remain the same. For this reason the satellite is in a sun-synchronous orbit, which means the sun is over a point at the same local time on each pass.

SPOT provides data in several formats. RSIP acquired two panchromatic 10 meter resolution SPOT satellite transparencies and digital data taken in February and May 1988. After visual analysis of the leaves-on and leaves-off SPOT satellite transparencies, the leaves-on imagery was used to map roads. The leaves-on imagery provided the best contrast between roads and surrounding features (i.e., trees, crops, grass). This imagery was placed on a Krones rear screen projector (1.4X-4X lens) and registered to the 1:24,000 USGS mylar quadrangle maps for interpretation and digitization. Higher magnification of the imagery was not necessary because of the resolution limitation of the SPOT imagery. These images, with a resolution of 10 meters, are a possible data source for the extraction of major road networks. The leaves-on, digital, panchromatic SPOT satellite imagery taken in May 1988 was chosen to map roads over the leaves-off image (February 1988) because of the better contrast with surrounding features.

Digital multispectral SPOT data (December 1987) was also acquired. It has a spatial resolution of 20 meters and represents three portions of the electromagnetic spectrum. These three channels are green (500-590 nm), red (610-680 nm), and near-infrared (790-890 nm). Because of the coarse spatial resolution of this data set, it was not used to map roads. It can, however, be evaluated as a tool to generate land-cover data.

Another available format is called a county view. This is a black and white photographic print .(using 10 meter panchromatic data) of an entire parish (county) at an approximate scale of 1:24,000. This format, which is delivered on several very wide and long roles, is extremely cumbersome to use.

4.7.5 NHAP/NAPP Aerial Photographs

National High Altitude Photography (NHAP) photographs (approximate scale is 1:58,000) were used to photointerpret and digitize improved and unimproved roads. NHAP photographs used in this project were taken in 1981 and 1983. The National Aerial Photography Program (NAPP) has just completed its photo acquisition mission for the state of Louisiana. The NAPP photographs were taken from an altitude of 20,000 feet, on 9-inch film, with a resulting image scale of 1:40,000. It provides standard, uniform-quality, cloud-free aerial photographs of the whole state. Twelve NAPP photos covering the study area were acquired from the USGS EROS Data Center. Those NAPP photographs were acquired during 1989 and early 1990 and provide the most up-to-date off-the-shelf source of photographic data. In addition, NAPP photographs have higher spatial resolution than NHAP photography, making more detailed studies such as road surface types and right of way possible.

In this report, we describe several different types of roads: (1) the state maintained road network, a road network in Louisiana which the DOTD maintains, which is depicted in digital form as the district map; (2) parish road network, a road network maintained by other Louisiana governmental units, which is depicted in digital form as the parish map; and (3) additional roads and trails which are all other roads.

Our objective was to evaluate available data sources for creating LDOTD parish maps from their district map base and to maintain the LDOTD digital base map files. Table 4.7.2 describes the data sets considered. We acquired, photointerpreted, digitized, and analyzed each of the appropriate road networks from the SPOT digital data and transparencies and from the National High Altitude Program (NHAP) photographic transparencies. The fourth data set was digitized from two USGS 1:24,000 quadrangles to provide a basis for comparison among different data sources. These data sets have been added to an Intergraph digital database consisting of the 1:100,000 USGS Digital Line Graphs (DLG) and LDOTD's parish road maps. We made comparisons among these data sets in terms of methodology, accuracy, and cost.

4.7.6 Analysis of Digital Line Graphs (DLG)

The USGS generated DLG Roads and Trails data set (1:100,000) was added to the Intergraph database using the USGS Digital Line Graph to Intergraph Translator (DLGIN) and Standard Interchange Format (SIF) software products. This DLG data set classifies roads as trails, roads, streets, or State and US routes. Hydrographic features, as found on the LDOTD parish road database were digitally overlain on the USGS generated DLG files. The LDOTD data set was originally derived by digitizing 1:24,000 scale USGS quadrangle maps. The USGS DLG data was generated by digitizing 1:100,000 maps. From reviews of the data

sets, it was concluded that the DLG data represent only the major rivers and streams in the study area and overlay relatively well on the corresponding LDOTD files of the same features. The LDOTD files, however, contain many more of the smaller streams (primarily first and second order streams) than the DLG files. The LDOTD files are more detailed (assumed to be more spatially accurate) and are of more use than the DLG data for hydrologic studies.

Table 4.7.1 Land-Use and Land-Cover Classification System *	
Level I (and Map Color)	**Level II**
1 Urban or built-up land (red)	11 Residential
	12 Commercial and services
	13 Industrial
	14 Transportation, communications, and utilities
	15 Industrial and commercial complexes
	16 Mixed urban or built-up land
	17 Other urban or built-up land
2 Agricultural land (light brown)	21 Cropland and pasture
	22 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas
	23 Confined feeding operations
	24 Other agricultural land
3 Rangeland (light orange)	31 Herbaceous rangeland
	32 Shrub and brush rangeland
	33 Mixed rangeland
4 Forest land (green)	41 Deciduous forest land
	42 Evergreen forest land
	43 Mixed forest land
5 Water (dark blue)	51 Streams and canals
	52 Lakes
	53 Reservoirs
	54 Bays and estuaries
6 Wetland (light blue)	61 Forest wetland
	62 Nonforested wetland
7 Barren land (gray)	71 Dry salt flats
	72 Beaches
	73 Sandy areas other than beaches
	74 Bar, exposed rock
	75 Strip mines, quarries, and gravel pits
	76 Transitional areas
	77 Mixed barren land
8 Tundra (green-gray)	81 Shrub and brush tundra
	82 Herbaceous tundra
	83 Bare ground tundra
	84 Wet tundra
	85 Mixed tundra
9 Perennial snow or ice (white)	91 Perennial snow fields
	92 Glaciers

* Level 1 is based primarily on surface cover; level 11 is derived from both cover and use. Color Codes are based on recommendations of the International Geographical Union.

Table 4.7.2 Data Sets

Product	Quantity	Unit Price	Delivery (Wks)	Total Cost*
USGS mylar Maps	4	72	4-6	288
Aerial Imagery (NHAP)	11	24	6-8	264
USGS Digital DLG		In-house - RSIP		
USGS Digital GIRAS		In-house - RSIP		
SPOT Satellite				
A) B&W Trans.	2	500	2-4	1000
B) Color Trans.	1	500	2-4	500
C) B&W Digital	2	1000	2-4	2000
D) Color Digital	1	600	2-4	600
E) County Scene	1	2326	6-8	2326

* Costs reflect current prices charged to universities for research purposes and do not represent prices for commercial (LDOTD) use.

4.7.7 Analysis of SPOT-Satellite Data

It is advantageous to merge the panchromatic image with the 20 meter SPOT multispectral image, preserving the high resolution of the panchromatic image and, at the same time, having the spectral information of the multispectral image [Cliche 1985, Chavez 1988]. The following steps are required to register two images:

1) As the panchromatic and multispectral data in all SPOT-1 images are not co-registered, the two data sets need to be registered geometrically. This includes location of control points common to both the panchromatic and multispectral images.

2) The software computes the unknown coefficients for a polynomial equation to implement a transformation between the coordinate systems of the two images.

3) A cubic convolution algorithm is used to resample the three multispectral images into the panchromatic image coordinate system.

The merging of the two geometrically registered data sets can be done through the use of intensity-hue-saturation (IHS) transformation method. In the IHS transformation method, the IHS components are derived from the multispectral data; the panchromatic data are then substituted directly for the computed intensity. An alternative is to use the weighted average of twice the panchromatic plus the near-infrared band as a substitute for intensity. The data are then transformed back to the red-green-blue (RGB) color domain, with this resulting RGB composite image having the spatial resolution of the panchromatic image and additional spectral discrimination.

The digital image was processed using the Intergraph MGE Imager software. The study area was extracted from the larger image region and registered to the LDOTD digital map. The image was then histogram stretched to improve contrast between roads and neighboring features. The zoom feature was an interpretative aid during mapping. As a result, it was easier to find and to trace roads from the digital SPOT scene than from the SPOT transparency. Roads were digitized from the raster image, displayed on the computer screen, and stored as vector elements.

4.7.8 Analysis of NHAP Aerial Photographs

NHAP photographs (approximate scale of 1:60,000) were used to photointerpret and digitize improved and unimproved roads in the study area. Each photograph was projected and enlarged about eight times using the 3.5 X- 8.0 X lens through a Krones LZK rear screen projector (with overlain Altek transparent digitizer) for interpretation and digitization. Instead of registering the photographic data to the 1:24,000 transparent mylar quadrangle maps, NHAP photographs were registered to a digital road network design file that was previously digitized from USGS 1:24,000 quadrangle maps by RSIP. By doing so, one can choose different magnifications in order to bring the photographs to the appropriate scale where the roads are easiest to visualize, trace, and digitize. It was determined that 1:10,000 was a convenient scale for digitizing roads from NHAP

photographs. Another benefit of using NHAP photographs for digitizing road networks is that stereointerpretation could be used to clarify details relative to a particular road (on a light table using a Bausch and Lomb zoom stereoscope).

4.7.9 Analysis of High Resolution Photography

We studied image data of various scales for the purpose of updating the LDOTD parish road maps. We feel that there is a need to include high resolution raster data for evaluation. Satellite images are useful because a single scene covers a large area, but they do not provide enough spatial resolution for certain aspects of road mapping. For example, SPOT images do not provide information about road surface types, number of lanes, and road inventory features. RSIP had several color and color infrared aerial photos scanned to generate raster imageries for evaluation. These photos were scanned at 50 micron resolution by Analytical Surveys, Inc. of Colorado Springs, Colorado at the price of 150 dollars per photo.

Table 4.7.3 Resolution of Remotely Sensed Data

Data Source	Scale	Resolution	Minimum extracted feature size	Format	Rows	Columns
Aerial Photo	1:2,500	.1 meter	.2 meters	5x5" film	2440	2570
NAPP CIR	1:40,000	2 meters	5 meters	9x9" film	4700	4700
NHAP CIR	1:60,000	3 meters	8 meters	9x9" film	4700	4700
SPOT PAN		10 meters	15 meters	digital tape	6006	6006
SPOT MSS		20 meters	30 meters	digital tape	3003	3003

Spatial resolution is an involved concept [Colwell 1983]. The system used to acquire the image determines the resolution of the image, and the format of the system determines how resolution is measured. A variety of methods can be used to measure resolution. Intuitively, resolution refers to the fineness of detail that can be distinguished in the image or the minimum distance between objects at which they can be distinguished. Instantaneous field of view (IFOV) is commonly used as a measure of resolution. For satellites, this varies with the focal length of the optical system, detector size, and satellite altitude. Therefore, changes in the altitude of a satellite will affect the IFOV or the resolution of the system. For the SPOT satellite, this resolution is 10 meters for the panchromatic band and 20 meters for the spectral bands. IFOV does not always reflect the smallest object that can be detected. Objects of a smaller size but with high contrast may be detected. Highways and waterways are examples of this phenomenon. Objects of low contrast may have to be much larger to be detected.

Another measure of resolution is based upon patterns of black lines equally spaced upon a white background. As the spacing between the black and white lines gets smaller, the contrast between the lines gets less until the lines are indistinguishable. This measure of resolution is often called line pairs/mm or lines/mm. For example, in high resolution color film ,as commonly flown with mapping cameras, a resolution of 200 lines/mm has been reported for high

contrast lines and 100 lines/mm for low contrast lines. Spatial frequencies of sinusoidal varying patterns in cycles/mm may also be used to characterize resolution. The Modulation Transfer Function (MTF) indicates the response of the camera system to sinusoidal varying signals. The MTF is near unity at low frequencies and decreases at higher frequencies. The effective instantaneous field of view (IEFOV) is the spatial frequency at which the MTF is 50% of its maximum value.

The spatial resolution required depends upon the task. Detection refers to determining the presence of an object. Recognition of different objects may require more resolution. Three times more resolution may be required for identification over detection. Scale is the relationship between the size of objects in images or maps in comparison to their actual size. Scale is not the same as spatial resolution. Digital data can be depicted in a variety of scales. The scale at which data are analyzed influences the information obtained. The objects in a scene may appear quite different at different scales and resolutions. Roads appear as long thin ribbons in small scale SPOT images and appear as objects with lanes, shoulders, surfaces, and vehicle features in large scale photographs. It is important to know the best scale to identify given objects.

We determined a pixel size and a minimum extractable feature size for both the digital imagery and the scanned photography. This enables us to compare the extent of the extractable information related to road mapping of different data sources with a quantifiable parameter. Our procedure to determine a pixel size for the scanned film media (Low altitude photos and NAPP and NHAP transparencies) was to view the scanned photos in MGE Imager, identify objects of known dimension, and count the number of pixels along the object. For example, we chose several cars, zoomed in on each individually until we could see individual pixels and then counted the pixels along the length of the car. The pixel size is then equal to the length of the car divided by the number of pixels averaged among all the cases. We also confirmed this by dividing the ground distance of the scanned image by the rows or columns. The procedure for determining the smallest extractable feature was to find the smallest feature we could photointerpret using the zoom capability of the MGE Imager. For example on NHAP scanned images, cars are recognizable with no details, but using context cues, they can be easily recognized. On the low altitude photos (1:2,500 scale), the color and model of the cars are discernible. The smallest features which could be identified were the painted lines in a parking lot. This number, minimum extracted feature size is an aid in comparing the usefulness of the different data sources.

Our procedure to determine the minimum extractable feature size for the NHAP photography was to perform successive zooms with the Krones projector to find the smallest recognizable feature in the photograph. For example, cars are recognizable with slightly more details than the scanned image but are still the smallest recognizable feature.

Remotely sensed data from different altitudes provide different but complementary spatial resolutions. With SPOT imagery and color infrared aerial photography, it is possible to use the high spectral resolution and machine processing

capabilities of satellite imagery in conjunction with the high spatial resolution and detailed contextual analysis capabilities gained by using aircraft-borne sensors. Table 4.7.3 gives a summary of the resolutions of the different data sets.

4.7.10 Comparison Among Data Sets

We evaluated the suitability of the five collected data sets for updating the LDOTD parish road maps and their potential use in other tasks such as determination of land-use. A comparison among the collected data sets in terms of their scale, resolution, data updating cycle, cost, and road surface information is summarized in Table 4.7.7.

The 1:100,000 DLG data set was tested for its completeness in representing the existing road network. The DLG data set does have more roads than the LDOTD's parish map. However, we found that several newly upgraded or constructed roads are not included in the DLG data set. This is because DLG data were digitized from U.S.G.S. 1:100,000-scale 30- by 60-minute quadrangle maps, and they are not always very up to date. Another limitation of this data set is its scale. In order to have a consistent spatial accuracy with the LDOTD design files, larger scale DLG data (e.g. 1:24,000) might be necessary. For these two reasons, the 1:100,000 DLG data set is not suitable for the purpose of updating the state-wide road network. However, this state-wide data set will be useful for planning and/or routing application at the state level.

NHAP aerial photography was evaluated for its potential in providing road surface information. Although digitizing the road network from NHAP photos takes more time and skill than from the other data sources, it might still be worthwhile because of the possibility to differentiate road surface types to a certain extent from NHAP photos based on color and tone. Our findings indicate that paved roads tend to have light blue color while gravel and dirt roads tend to have white color. Further classification within the two categories is not possible at this stage. The new NAPP aerial photos are more suitable for this purpose. Twelve NAPP photos covering the study area were ordered from the USGS EROS Data Center. The advantage in using those newly available NAPP photographs is that they were obtained during 1989 and early 1990 and can provide the most up to date data source. In addition, NAPP photographs have higher spatial resolution, making the more detailed studies such as road surface types and right-of-way possible.

SPOT imageries were studied again to evaluate their possible use in automatic road network extraction. We have applied different filters to both color and panchromatic imageries to increase the contrast between the road and the non-road pixels. Filtering and classification on color images did not produce satisfactory results due to the spatial resolution limitations of these images. Panchromatic images show great improvement after filtering, and these sharpened images were used to interactively extract road networks. Road extraction from SPOT panchromatic imageries encountered no problems. However, the contrast between roads and surrounding features is weak in urban areas. Higher resolution data such as NHAP and NAPP are required to fill up those gaps.

As anticipated, all of the above five data sets contain roads in addition to those found in the LDOTD digital file of state maintained roads or the LDOTD digital file for the parish road map (see Figure 4.7.1). The data set generated from 1981 and 1983 NHAP photographs provided the most detailed information on the existing roads within the study area. However, due to higher spatial stereoscopic resolution (3m) and the manual interpretation process, it took more time to process than the other data sets. Among the investigated data sets, SPOT satellite imagery provided the most up-to-date (1988) road information. Although the existing DLG data set contains major roads for the entire state, it, however, does not provide up to date (circa 1976) information. For example, some of the newly extended state maintained roads that have already been included in the LDOTD data set are not in the DLG data set.

In terms of spatial accuracy, all the data sets analyzed, except the SPOT transparencies, were fairly comparable to the LDOTD data set even before they were warped. Statistical analysis based on selected common road intersections was conducted to provide quantitative measures of how each data set spatially differed from the DOTD data set. Forty-one major (improved) road intersections that appeared on all data sets were chosen for comparison (see Figure 4.7.2). Their coordinates were acquired from each design file and compared to the corresponding points in the LDOTD data set. Deviations from the LDOTD control points were also calculated for each data set after they were warped (using Intergraph's Elastic Body Small Angle Least Squares software package [EBSALS]) to show any spatial or locational improvements (see Tables 4.7.5 and 4.7.6). Before the warping process, the road data set generated from the USGS quadrangle maps had the smallest spatial deviation from the LDOTD data set (33.7 feet). The LDOTD built their digital road database by originally digitizing 1:24,000 USGS quadrangle maps. After this verification, the LDOTD data set was used as the baseline for comparison with all other data sets. The SPOT transparencies had the largest mean error (112.1 feet). The SPOT digital data set had a deviation of 53.6 feet, and the NHAP data deviated by 55.7 feet. The DLG data set had a mean deviation of 81.1 feet.

Warping of these data sets did improve the spatial accuracy of each, with respect to the LDOTD digital data base. Tables 4.7.5 and 4.7.6 represent summaries of the results of unwarped versus warped data sets as compared to the DOTD data set. Improvement was determined by reviewing the mean deviations. The following numbers represent the difference by data set once warped: USGS quadrangle map (8.23 ft.), NHAP (4.41 ft.), SPOT transparency (48.45 ft.), SPOT digital (8.56 ft.), and DLG (42.53 ft.). The least improved (mean of 4.41 feet or 7.92 percent) was the NHAP. Likely this is due to it being the most initially accurate data set because of its highest spatial resolution (9.84 ft.). The next most accurate (least improved) data set was the digital SPOT data (improved using warping by 8.56 feet or 15.97 percent). Again, this was due primarily to the ability to histogram stretch (enhance contrast) and zoom during the interpretation and mapping process. The SPOT transparency data set was improved by 48.45 feet (43.20 percent). This high level of improvement was likely imposed from the errors originally introduced in our manual interpretation and mapping

process. The USGS quadrangle (1:24,000) and DLG (1:100,000) data sets were improved by 8.23 feet (24.42 percent) and 42.53 feet (52.42 percent), respectively. These improvements are in line with the original map scales. It was determined that warping is a necessary step in the generating of road networks when using any of the above mentioned data sets.

ndix C - Reformat Compiler

Reformatting programs that move data between two clearly defined record for- are often similar in structure and organization, and this enables the generation ess to be automated to a large extent. These programs rearrange, omit, add fields ata, and modify variable types. The RFC allows users to specify the formats and ersion operations in a language customized for writing reformatting programs and mized for self-documentation and efficiency. The reformat compiler then acts on e specifications to produce the desired reformatting code in a target output uage. Portability of code is a requirement of the target output language programs duced by the reformat compiler and, accordingly, C is the target output language of ice. The compiler generation tools LEX and YACC are used to define the RFC t language with the necessary C code embedded for translation operations. Once input program to the reformat compiler has been translated to C, it may be ported y machine that has a C language compiler. Thus the reformatting program in the C input language may be written on one machine while the actual operation is car- out on another.

Figure B.1 indicates the context under which the reformat compiler will operate. re B.2 illustrates the structure of the RFC itself. The input file is read and ences of characters that correspond to token definitions are recognized by LEX. se tokens are used by the YACC section in conjunction with the grammar rule base erify syntax. Actions are initiated by calling C subroutines that interact with sub- ines written specifically for the translation process to generate the output C pro- m that will, in fact, perform the data reformatting operation. The operation of the mat compiler is perhaps best understood by examining the structure and syntacti- composition of its input language. In this section, we consider a typical input pro- m to the RFC, describe its syntactical aspects and explain how the RFC proceeds to uce output code that corresponds to the input code.

Any program in the RFC input language must start with the keyword "begin" and terminate with the keyword "end". The program must consist of three sections labeled input, output, and program sections, respectively. These sections are delimited by the the keywords "input" and "endin", "output and endout" and "program" and "endprog". The skeletal structure of any such program is illustrated below.

```
begin

        input
        . . .
        . . .
        endin

        output
        . . .
        . . .
        endout

        program
        . . .
        . . .
        endprog

end
```

Example 1

The input section specifies the structure of the input record(s), while the output section does the same for the output. The program section contains the code that will perform the necessary translation operations. The input and output sections are syntactically equivalent. External data is described in the same way in the input as it is in the output, so that structure descriptions that are used in the input may be used without alteration in the output section.

This is an important feature of the RFC, because it allows the building of data templates. If data is frequently transferred between certain structures then we may store these structure descriptions and use them in the input or output section depending on the direction of data transfer. Only the program section may need to be changed.

The input and output sections consist of a series of records. There are two basic types of records. The keywords **record 0** indicate that the structure being described within is a file. In order to distinguish files from other data structures, all record structures describing files must be identified by these keywords. A typical file description in the RFC input language is shown below.

```
record 0
     file        filein1   infil.data ;
endrec
```

Example 2

Within the description, the keyword **file** indicates that a file is being described. econd descriptor **filein1** is the RFC language identifier for the file, whose physi- ame is given by the third descriptor as **infil.data**. The record description is ter- ed with the keyword **endrec**.

The second type of record may describe any type of record structure. It is ified by the keyword **record** followed by any digit except 0. This is followed by a iption of the various elements that make up the record structure. The first element description is the name of the variable. This must be followed by a single word ation of the variable's actual purpose. This feature was incorporated to force m documentation and increase readability. This is followed, in turn, by the key- int or **char** which indicate the nature of the variable (integer or character) and a sequence of three digits. The first of these is the length of the variable, while xt two indicate its starting and ending positions. The reformat compiler uses digits to check for errors in structure descriptions. As before, the record ends e keyword **endrec**. A typical record description is shown below.

```
record 4
     var        content   char 5 1 5 ;
     rout       route     int  3 6 8 ;
endrec
```

Example 3

e record above describes a record consisting of two variables "var" and "rout", s the second element tells us represent "content" and "route", respectively. The ar) is a character variable of length 5 starting at position 1 and ending at posi- The second (rout) is an integer of length 3 starting at position 6 and ending at n 8.

e basic record structure described above may be enhanced by adding templates information. The enhanced record structure then consists of two portions. The t is the text template while the second part consists of the variable descriptions d above. The text template could be used, for example, to print out a statement e actual values of the variable descriptions contained within the record struc- onsider, for example, the DMRS command to open a database. This command

```
USE DB = "<filename>" !
```

The raster data was transferred by an interesting mechanism. First it was exported from Intergraph COT (continuous tone) format to generic raster format using the EXPORT GENERIC command in Tigris. This produces three binary files (one for each of the red, green and blue bands). Next these three files were moved across the network via TCP/IP FTP protocol along with information about the number of rows and columns in the image. A simple C program was written on the SUN to convert the data for the three bands into an ERDAS format image because ARC/INFO can display ERDAS images on the SUN using the new Image Integrator module. It was quickly determined that ARC/INFO has no capabilities for contrast enhancement, so the translation program was required to compute the maximum and minimum values for each of the bands and to scale the values accordingly so the pixel values would range between 0 and 255. Fine tuning was required since the top and bottom .1% of the pixel values needed to be discarded in order for sufficient contrast stretching to take place. The vector and raster data were registered again in ARC/INFO to compute the coefficients for the warping transformation. Finally the AML to display the vector data was enhanced to use the warp information and to annotate the final display of the raster and vector data.

4.7 Aerial Derived Data Sets for Maintaining the Cartographic Database

The following sections summarize our results on the work related to developing spatial databases from remotely sensed and available digital databases. We acquired data for the two study areas in Beauregard Parish, Louisiana for this part of the project.

4.7.1 USGS Quadrangle Maps

Study area 1 was split between two USGS (1:24,000) quadrangle maps. The most updated version available for the Boneset Creek quadrangle was produced from 1982 aerial photographic data. The Sugartown quadrangle was based on 1975 aerial photographic data. Because of these different dates, the road classification scheme differed between the two maps. On the Sugartown quadrangle, roads were classified as medium-duty, light-duty, and unimproved. On the Boneset quadrangle, roads were classified as improved, unimproved, or trails. For comparison purposes and consistency, medium and light duty roads from the Sugartown quadrangle were grouped into the "improved" category. "Trails" on the Boneset quadrangle were not used.

We digitized the USGS 1:24,000 quadrangles to provide a basis for comparison among different data sources. These data sets were added to an Intergraph digital database consisting of LDOTD's parish road maps in a polyconic projection. Since scale, date, and road type classifications differed between data sources, we developed a standard baseline format by which all data sets could be compared by accuracy of location and classification. Roads were classified as either improved or unimproved. This is because the resolution of the investigated data sets was appropriate for interpretation of these two categories.

4.7.2 IEMIS Database

The Federal Emergency Management Agency (FEMA) has developed the Integrated Emergency Management Information System (IEMIS). It is a mini-computer based automated emergency management system which includes a national database. This database includes such major features as interstate and U.S. highways, railroads, airports, cities, electric power grids, water bodies, federally owned lands, and political boundaries. These data were originally digitized from 1:2,000,000 scale maps. IEMIS also supports a relational database. The system supports a number of complex simulation models. These models provide for detailed emergency planning and support the querying of the system. For example, one can extract the total population residing within the region (from census data) and provide an estimate of the time to evacuate the area based on highway capacities, response times, and vehicular resources available. This system presently supports the following models nuclear plumes, transportation (evacuation), and siren placement. FEMA is constantly updating (e.g., 1:100,000 TIGER and/or DLG) and standardizing IEMIS capabilities. All related software is public domain.

This database was qualitatively evaluated for compiling parish road maps and deemed inaccurate due to the original mapping scale of 1:2,000,000. It, however, would be of use if LDOTD were to need a nationwide digital database for

networking studies with neighboring states.

4.7.3 USGS Digital Data Sets.

United States Geological Survey (USGS) data were considered. These data consisted of the USGS Digital Line Graph (DLG) and land-use (GIRAS). The USGS DLG data was generated by digitizing 1:100,000 quadrangle maps. This DLG data set classifies roads as trails, roads, streets, or State and US routes. USGS generated digital GIRAS (1:250,000 scale) files represent circa 1976 land-use data. This GIRAS data (Table 4.7.1) represents the only state-wide digital data set of land-use. This data set was generated using a 10 acre minimum mapping unit for urban and/or developed areas and a 40 acre mapping unit for other features (i.e., agriculture, forests, etc.). The USGS generated DLG Roads and Trails data set (1:100,000) was added to the Intergraph database using the USGS Digital Line Graph to Intergraph Translator (DLGIN) and Standard Interchange Format (SIF) software products. Intergraph MGE products for this purpose would be MGE GIS Translator_US which is abbreviated MGT_US.

4.7.4 SPOT Satellite Data

The SPOT program provides data in digital formats at spatial resolutions compatible with mapping requirements [Welch 1985]. The SPOT satellite provides data at a ten meter resolution. The satellite passes over the same area every 26 days (orbit period is 26 days). Since the satellite provides for oblique viewing, the same area can be imaged every four days. Oblique viewing also allows the acquisition of stereo images[SPOT 1989]. The images are affected by lighting conditions, therefore, it is important that these conditions remain the same. For this reason the satellite is in a sun-synchronous orbit, which means the sun is over a point at the same local time on each pass.

SPOT provides data in several formats. RSIP acquired two panchromatic 10 meter resolution SPOT satellite transparencies and digital data taken in February and May 1988. After visual analysis of the leaves-on and leaves-off SPOT satellite transparencies, the leaves-on imagery was used to map roads. The leaves-on imagery provided the best contrast between roads and surrounding features (i.e., trees, crops, grass). This imagery was placed on a Krones rear screen projector (1.4X-4X lens) and registered to the 1:24,000 USGS mylar quadrangle maps for interpretation and digitization. Higher magnification of the imagery was not necessary because of the resolution limitation of the SPOT imagery. These images, with a resolution of 10 meters, are a possible data source for the extraction of major road networks. The leaves-on, digital, panchromatic SPOT satellite imagery taken in May 1988 was chosen to map roads over the leaves-off image (February 1988) because of the better contrast with surrounding features.

Digital multispectral SPOT data (December 1987) was also acquired. It has a spatial resolution of 20 meters and represents three portions of the electromagnetic spectrum. These three channels are green (500-590 nm), red (610-680 nm), and near-infrared (790-890 nm). Because of the coarse spatial resolution of this data set, it was not used to map roads. It can, however, be evaluated as a tool to generate land-cover data.

Another available format is called a county view. This is a black and white photographic print .(using 10 meter panchromatic data) of an entire parish (county) at an approximate scale of 1:24,000. This format, which is delivered on several very wide and long roles, is extremely cumbersome to use.

4.7.5 NHAP/NAPP Aerial Photographs

National High Altitude Photography (NHAP) photographs (approximate scale is 1:58,000) were used to photointerpret and digitize improved and unimproved roads. NHAP photographs used in this project were taken in 1981 and 1983. The National Aerial Photography Program (NAPP) has just completed its photo acquisition mission for the state of Louisiana. The NAPP photographs were taken from an altitude of 20,000 feet, on 9-inch film, with a resulting image scale of 1:40,000. It provides standard, uniform-quality, cloud-free aerial photographs of the whole state. Twelve NAPP photos covering the study area were acquired from the USGS EROS Data Center. Those NAPP photographs were acquired during 1989 and early 1990 and provide the most up-to-date off-the-shelf source of photographic data. In addition, NAPP photographs have higher spatial resolution than NHAP photography, making more detailed studies such as road surface types and right of way possible.

In this report, we describe several different types of roads: (1) the state maintained road network, a road network in Louisiana which the DOTD maintains, which is depicted in digital form as the district map; (2) parish road network, a road network maintained by other Louisiana governmental units, which is depicted in digital form as the parish map; and (3) additional roads and trails which are all other roads.

Our objective was to evaluate available data sources for creating LDOTD parish maps from their district map base and to maintain the LDOTD digital base map files. Table 4.7.2 describes the data sets considered. We acquired, photointerpreted, digitized, and analyzed each of the appropriate road networks from the SPOT digital data and transparencies and from the National High Altitude Program (NHAP) photographic transparencies. The fourth data set was digitized from two USGS 1:24,000 quadrangles to provide a basis for comparison among different data sources. These data sets have been added to an Intergraph digital database consisting of the 1:100,000 USGS Digital Line Graphs (DLG) and LDOTD's parish road maps. We made comparisons among these data sets in terms of methodology, accuracy, and cost.

4.7.6 Analysis of Digital Line Graphs (DLG)

The USGS generated DLG Roads and Trails data set (1:100,000) was added to the Intergraph database using the USGS Digital Line Graph to Intergraph Translator (DLGIN) and Standard Interchange Format (SIF) software products. This DLG data set classifies roads as trails, roads, streets, or State and US routes. Hydrographic features, as found on the LDOTD parish road database were digitally overlain on the USGS generated DLG files. The LDOTD data set was originally derived by digitizing 1:24,000 scale USGS quadrangle maps. The USGS DLG data was generated by digitizing 1:100,000 maps. From reviews of the data

sets, it was concluded that the DLG data represent only the major rivers and streams in the study area and overlay relatively well on the corresponding LDOTD files of the same features. The LDOTD files, however, contain many more of the smaller streams (primarily first and second order streams) than the DLG files. The LDOTD files are more detailed (assumed to be more spatially accurate) and are of more use than the DLG data for hydrologic studies.

Table 4.7.1 Land-Use and Land-Cover Classification System *	
Level I (and Map Color)	Level II
1 Urban or built-up land (red)	11 Residential
	12 Commercial and services
	13 Industrial
	14 Transportation, communications, and utilities
	15 Industrial and commercial complexes
	16 Mixed urban or built-up land
	17 Other urban or built-up land
2 Agricultural land (light brown)	21 Cropland and pasture
	22 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas
	23 Confined feeding operations
	24 Other agricultural land
3 Rangeland (light orange)	31 Herbaceous rangeland
	32 Shrub and brush rangeland
	33 Mixed rangeland
4 Forest land (green)	41 Deciduous forest land
	42 Evergreen forest land
	43 Mixed forest land
5 Water (dark blue)	51 Streams and canals
	52 Lakes
	53 Reservoirs
	54 Bays and estuaries
6 Wetland (light blue)	61 Forest wetland
	62 Nonforested wetland
7 Barren land (gray)	71 Dry salt flats
	72 Beaches
	73 Sandy areas other than beaches
	74 Bar, exposed rock
	75 Strip mines, quarries, and gravel pits
	76 Transitional areas
	77 Mixed barren land
8 Tundra (green-gray)	81 Shrub and brush tundra
	82 Herbaceous tundra
	83 Bare ground tundra
	84 Wet tundra
	85 Mixed tundra
9 Perennial snow or ice (white)	91 Perennial snow fields
	92 Glaciers

* Level 1 is based primarily on surface cover; level 11 is derived from both cover and use. Color Codes are based on recommendations of the International Geographical Union.

Table 4.7.2 Data Sets

Product	Quantity	Unit Price	Delivery (Wks)	Total Cost*
USGS mylar Maps	4	72	4-6	288
Aerial Imagery (NHAP)	11	24	6-8	264
USGS Digital DLG		In-house - RSIP		
USGS Digital GIRAS		In-house - RSIP		
SPOT Satellite				
A) B&W Trans.	2	500	2-4	1000
B) Color Trans.	1	500	2-4	500
C) B&W Digital	2	1000	2-4	2000
D) Color Digital	1	600	2-4	600
E) County Scene	1	2326	6-8	2326

* Costs reflect current prices charged to universities for research purposes and do not represent prices for commercial (LDOTD) use.

4.7.7 Analysis of SPOT-Satellite Data

It is advantageous to merge the panchromatic image with the 20 meter SPOT multispectral image, preserving the high resolution of the panchromatic image and, at the same time, having the spectral information of the multispectral image [Cliche 1985, Chavez 1988]. The following steps are required to register two images:

1) As the panchromatic and multispectral data in all SPOT-1 images are not co-registered, the two data sets need to be registered geometrically. This includes location of control points common to both the panchromatic and multispectral images.
2) The software computes the unknown coefficients for a polynomial equation to implement a transformation between the coordinate systems of the two images.
3) A cubic convolution algorithm is used to resample the three multispectral images into the panchromatic image coordinate system.

The merging of the two geometrically registered data sets can be done through the use of intensity-hue-saturation (IHS) transformation method. In the IHS transformation method, the IHS components are derived from the multispectral data; the panchromatic data are then substituted directly for the computed intensity. An alternative is to use the weighted average of twice the panchromatic plus the near-infrared band as a substitute for intensity. The data are then transformed back to the red-green-blue (RGB) color domain, with this resulting RGB composite image having the spatial resolution of the panchromatic image and additional spectral discrimination.

The digital image was processed using the Intergraph MGE Imager software. The study area was extracted from the larger image region and registered to the LDOTD digital map. The image was then histogram stretched to improve contrast between roads and neighboring features. The zoom feature was an interpretative aid during mapping. As a result, it was easier to find and to trace roads from the digital SPOT scene than from the SPOT transparency. Roads were digitized from the raster image, displayed on the computer screen, and stored as vector elements.

4.7.8 Analysis of NHAP Aerial Photographs

NHAP photographs (approximate scale of 1:60,000) were used to photointerpret and digitize improved and unimproved roads in the study area. Each photograph was projected and enlarged about eight times using the 3.5 X- 8.0 X lens through a Krones LZK rear screen projector (with overlain Altek transparent digitizer) for interpretation and digitization. Instead of registering the photographic data to the 1:24,000 transparent mylar quadrangle maps, NHAP photographs were registered to a digital road network design file that was previously digitized from USGS 1:24,000 quadrangle maps by RSIP. By doing so, one can choose different magnifications in order to bring the photographs to the appropriate scale where the roads are easiest to visualize, trace, and digitize. It was determined that 1:10,000 was a convenient scale for digitizing roads from NHAP

photographs. Another benefit of using NHAP photographs for digitizing road networks is that stereointerpretation could be used to clarify details relative to a particular road (on a light table using a Bausch and Lomb zoom stereoscope).

4.7.9 Analysis of High Resolution Photography

We studied image data of various scales for the purpose of updating the LDOTD parish road maps. We feel that there is a need to include high resolution raster data for evaluation. Satellite images are useful because a single scene covers a large area, but they do not provide enough spatial resolution for certain aspects of road mapping. For example, SPOT images do not provide information about road surface types, number of lanes, and road inventory features. RSIP had several color and color infrared aerial photos scanned to generate raster imageries for evaluation. These photos were scanned at 50 micron resolution by Analytical Surveys, Inc. of Colorado Springs, Colorado at the price of 150 dollars per photo.

Table 4.7.3 Resolution of Remotely Sensed Data

Data Source	Scale	Resolution	Minimum extracted feature size	Format	Rows	Columns
Aerial Photo	1:2,500	.1 meter	.2 meters	5x5" film	2440	2570
NAPP CIR	1:40,000	2 meters	5 meters	9x9" film	4700	4700
NHAP CIR	1:60,000	3 meters	8 meters	9x9" film	4700	4700
SPOT PAN		10 meters	15 meters	digital tape	6006	6006
SPOT MSS		20 meters	30 meters	digital tape	3003	3003

Spatial resolution is an involved concept [Colwell 1983]. The system used to acquire the image determines the resolution of the image, and the format of the system determines how resolution is measured. A variety of methods can be used to measure resolution. Intuitively, resolution refers to the fineness of detail that can be distinguished in the image or the minimum distance between objects at which they can be distinguished. Instantaneous field of view (IFOV) is commonly used as a measure of resolution. For satellites, this varies with the focal length of the optical system, detector size, and satellite altitude. Therefore, changes in the altitude of a satellite will affect the IFOV or the resolution of the system. For the SPOT satellite, this resolution is 10 meters for the panchromatic band and 20 meters for the spectral bands. IFOV does not always reflect the smallest object that can be detected. Objects of a smaller size but with high contrast may be detected. Highways and waterways are examples of this phenomenon. Objects of low contrast may have to be much larger to be detected.

Another measure of resolution is based upon patterns of black lines equally spaced upon a white background. As the spacing between the black and white lines gets smaller, the contrast between the lines gets less until the lines are indistinguishable. This measure of resolution is often called line pairs/mm or lines/mm. For example, in high resolution color film ,as commonly flown with mapping cameras, a resolution of 200 lines/mm has been reported for high

contrast lines and 100 lines/mm for low contrast lines. Spatial frequencies of sinusoidal varying patterns in cycles/mm may also be used to characterize resolution. The Modulation Transfer Function (MTF) indicates the response of the camera system to sinusoidal varying signals. The MTF is near unity at low frequencies and decreases at higher frequencies. The effective instantaneous field of view (IEFOV) is the spatial frequency at which the MTF is 50% of its maximum value.

The spatial resolution required depends upon the task. Detection refers to determining the presence of an object. Recognition of different objects may require more resolution. Three times more resolution may be required for identification over detection. Scale is the relationship between the size of objects in images or maps in comparison to their actual size. Scale is not the same as spatial resolution. Digital data can be depicted in a variety of scales. The scale at which data are analyzed influences the information obtained. The objects in a scene may appear quite different at different scales and resolutions. Roads appear as long thin ribbons in small scale SPOT images and appear as objects with lanes, shoulders, surfaces, and vehicle features in large scale photographs. It is important to know the best scale to identify given objects.

We determined a pixel size and a minimum extractable feature size for both the digital imagery and the scanned photography. This enables us to compare the extent of the extractable information related to road mapping of different data sources with a quantifiable parameter. Our procedure to determine a pixel size for the scanned film media (Low altitude photos and NAPP and NHAP transparencies) was to view the scanned photos in MGE Imager, identify objects of known dimension, and count the number of pixels along the object. For example, we chose several cars, zoomed in on each individually until we could see individual pixels and then counted the pixels along the length of the car. The pixel size is then equal to the length of the car divided by the number of pixels averaged among all the cases. We also confirmed this by dividing the ground distance of the scanned image by the rows or columns. The procedure for determining the smallest extractable feature was to find the smallest feature we could photointerpret using the zoom capability of the MGE Imager. For example on NHAP scanned images, cars are recognizable with no details, but using context cues, they can be easily recognized. On the low altitude photos (1:2,500 scale), the color and model of the cars are discernible. The smallest features which could be identified were the painted lines in a parking lot. This number, minimum extracted feature size is an aid in comparing the usefulness of the different data sources.

Our procedure to determine the minimum extractable feature size for the NHAP photography was to perform successive zooms with the Krones projector to find the smallest recognizable feature in the photograph. For example, cars are recognizable with slightly more details than the scanned image but are still the smallest recognizable feature.

Remotely sensed data from different altitudes provide different but complementary spatial resolutions. With SPOT imagery and color infrared aerial photography, it is possible to use the high spectral resolution and machine processing

capabilities of satellite imagery in conjunction with the high spatial resolution and detailed contextual analysis capabilities gained by using aircraft-borne sensors. Table 4.7.3 gives a summary of the resolutions of the different data sets.

4.7.10 Comparison Among Data Sets

We evaluated the suitability of the five collected data sets for updating the LDOTD parish road maps and their potential use in other tasks such as determination of land-use. A comparison among the collected data sets in terms of their scale, resolution, data updating cycle, cost, and road surface information is summarized in Table 4.7.7.

The 1:100,000 DLG data set was tested for its completeness in representing the existing road network. The DLG data set does have more roads than the LDOTD's parish map. However, we found that several newly upgraded or constructed roads are not included in the DLG data set. This is because DLG data were digitized from U.S.G.S. 1:100,000-scale 30- by 60-minute quadrangle maps, and they are not always very up to date. Another limitation of this data set is its scale. In order to have a consistent spatial accuracy with the LDOTD design files, larger scale DLG data (e.g. 1:24,000) might be necessary. For these two reasons, the 1:100,000 DLG data set is not suitable for the purpose of updating the state-wide road network. However, this state-wide data set will be useful for planning and/or routing application at the state level.

NHAP aerial photography was evaluated for its potential in providing road surface information. Although digitizing the road network from NHAP photos takes more time and skill than from the other data sources, it might still be worthwhile because of the possibility to differentiate road surface types to a certain extent from NHAP photos based on color and tone. Our findings indicate that paved roads tend to have light blue color while gravel and dirt roads tend to have white color. Further classification within the two categories is not possible at this stage. The new NAPP aerial photos are more suitable for this purpose. Twelve NAPP photos covering the study area were ordered from the USGS EROS Data Center. The advantage in using those newly available NAPP photographs is that they were obtained during 1989 and early 1990 and can provide the most up to date data source. In addition, NAPP photographs have higher spatial resolution, making the more detailed studies such as road surface types and right-of-way possible.

SPOT imageries were studied again to evaluate their possible use in automatic road network extraction. We have applied different filters to both color and panchromatic imageries to increase the contrast between the road and the non-road pixels. Filtering and classification on color images did not produce satisfactory results due to the spatial resolution limitations of these images. Panchromatic images show great improvement after filtering, and these sharpened images were used to interactively extract road networks. Road extraction from SPOT panchromatic imageries encountered no problems. However, the contrast between roads and surrounding features is weak in urban areas. Higher resolution data such as NHAP and NAPP are required to fill up those gaps.

As anticipated, all of the above five data sets contain roads in addition to those found in the LDOTD digital file of state maintained roads or the LDOTD digital file for the parish road map (see Figure 4.7.1). The data set generated from 1981 and 1983 NHAP photographs provided the most detailed information on the existing roads within the study area. However, due to higher spatial stereoscopic resolution (3m) and the manual interpretation process, it took more time to process than the other data sets. Among the investigated data sets, SPOT satellite imagery provided the most up-to-date (1988) road information. Although the existing DLG data set contains major roads for the entire state, it, however, does not provide up to date (circa 1976) information. For example, some of the newly extended state maintained roads that have already been included in the LDOTD data set are not in the DLG data set.

In terms of spatial accuracy, all the data sets analyzed, except the SPOT transparencies, were fairly comparable to the LDOTD data set even before they were warped. Statistical analysis based on selected common road intersections was conducted to provide quantitative measures of how each data set spatially differed from the DOTD data set. Forty-one major (improved) road intersections that appeared on all data sets were chosen for comparison (see Figure 4.7.2). Their coordinates were acquired from each design file and compared to the corresponding points in the LDOTD data set. Deviations from the LDOTD control points were also calculated for each data set after they were warped (using Intergraph's Elastic Body Small Angle Least Squares software package [EBSALS]) to show any spatial or locational improvements (see Tables 4.7.5 and 4.7.6). Before the warping process, the road data set generated from the USGS quadrangle maps had the smallest spatial deviation from the LDOTD data set (33.7 feet). The LDOTD built their digital road database by originally digitizing 1:24,000 USGS quadrangle maps. After this verification, the LDOTD data set was used as the baseline for comparison with all other data sets. The SPOT transparencies had the largest mean error (112.1 feet). The SPOT digital data set had a deviation of 53.6 feet, and the NHAP data deviated by 55.7 feet. The DLG data set had a mean deviation of 81.1 feet.

Warping of these data sets did improve the spatial accuracy of each, with respect to the LDOTD digital data base. Tables 4.7.5 and 4.7.6 represent summaries of the results of unwarped versus warped data sets as compared to the DOTD data set. Improvement was determined by reviewing the mean deviations. The following numbers represent the difference by data set once warped: USGS quadrangle map (8.23 ft.), NHAP (4.41 ft.), SPOT transparency (48.45 ft.), SPOT digital (8.56 ft.), and DLG (42.53 ft.). The least improved (mean of 4.41 feet or 7.92 percent) was the NHAP. Likely this is due to it being the most initially accurate data set because of its highest spatial resolution (9.84 ft.). The next most accurate (least improved) data set was the digital SPOT data (improved using warping by 8.56 feet or 15.97 percent). Again, this was due primarily to the ability to histogram stretch (enhance contrast) and zoom during the interpretation and mapping process. The SPOT transparency data set was improved by 48.45 feet (43.20 percent). This high level of improvement was likely imposed from the errors originally introduced in our manual interpretation and mapping

process. The USGS quadrangle (1:24,000) and DLG (1:100,000) data sets were improved by 8.23 feet (24.42 percent) and 42.53 feet (52.42 percent), respectively. These improvements are in line with the original map scales. It was determined that warping is a necessary step in the generating of road networks when using any of the above mentioned data sets.

ndix C - Reformat Compiler

Reformatting programs that move data between two clearly defined record for- t are often similar in structure and organization, and this enables the generation ess to be automated to a large extent. These programs rearrange, omit, add fields ata, and modify variable types. The RFC allows users to specify the formats and ersion operations in a language customized for writing reformatting programs and mized for self-documentation and efficiency. The reformat compiler then acts on e specifications to produce the desired reformatting code in a target output uage. Portability of code is a requirement of the target output language programs uced by the reformat compiler and, accordingly, C is the target output language of ce. The compiler generation tools LEX and YACC are used to define the RFC t language with the necessary C code embedded for translation operations. Once input program to the reformat compiler has been translated to C, it may be ported y machine that has a C language compiler. Thus the reformatting program in the C input language may be written on one machine while the actual operation is car- out on another.

Figure B.1 indicates the context under which the reformat compiler will operate. re B.2 illustrates the structure of the RFC itself. The input file is read and ences of characters that correspond to token definitions are recognized by LEX. se tokens are used by the YACC section in conjunction with the grammar rule base erify syntax. Actions are initiated by calling C subroutines that interact with sub- ines written specifically for the translation process to generate the output C pro- m that will, in fact, perform the data reformatting operation. The operation of the mat compiler is perhaps best understood by examining the structure and syntacti- composition of its input language. In this section, we consider a typical input pro- m to the RFC, describe its syntactical aspects and explain how the RFC proceeds to uce output code that corresponds to the input code.

Any program in the RFC input language must start with the keyword "begin" and terminate with the keyword "end". The program must consist of three sections labeled input, output, and program sections, respectively. These sections are delimited by the the keywords "input" and "endin", "output and endout" and "program" and "endprog". The skeletal structure of any such program is illustrated below.

```
begin

        input
        . . .
        . . .
        endin

        output
        . . .
        . . .
        endout

        program
        . . .
        . . .
        endprog

end
```

Example 1

The input section specifies the structure of the input record(s), while the output section does the same for the output. The program section contains the code that will perform the necessary translation operations. The input and output sections are syntactically equivalent. External data is described in the same way in the input as it is in the output, so that structure descriptions that are used in the input may be used without alteration in the output section.

This is an important feature of the RFC, because it allows the building of data templates. If data is frequently transferred between certain structures then we may store these structure descriptions and use them in the input or output section depending on the direction of data transfer. Only the program section may need to be changed.

The input and output sections consist of a series of records. There are two basic types of records. The keywords **record 0** indicate that the structure being described within is a file. In order to distinguish files from other data structures, all record structures describing files must be identified by these keywords. A typical file description in the RFC input language is shown below.

```
record 0
     file        filein1   infil.data ;
endrec
```

Example 2

Within the description, the keyword **file** indicates that a file is being described. ...econd descriptor **filein1** is the RFC language identifier for the file, whose physi- ...ame is given by the third descriptor as **infil.data**. The record description is ter- ...ed with the keyword **endrec**.

The second type of record may describe any type of record structure. It is ...fied by the keyword **record** followed by any digit except 0. This is followed by a ...ption of the various elements that make up the record structure. The first element ...description is the name of the variable. This must be followed by a single word ...ation of the variable's actual purpose. This feature was incorporated to force ...m documentation and increase readability. This is followed, in turn, by the key- ...int or **char** which indicate the nature of the variable (integer or character) and ...a sequence of three digits. The first of these is the length of the variable, while ...xt two indicate its starting and ending positions. The reformat compiler uses ...digits to check for errors in structure descriptions. As before, the record ends ...e keyword **endrec**. A typical record description is shown below.

```
record 4
     var        content   char 5 1 5 ;
     rout       route     int  3 6 8 ;
endrec
```

Example 3

...he record above describes a record consisting of two variables "var" and "rout", ...as the second element tells us represent "content" and "route", respectively. The ...ar) is a character variable of length 5 starting at position 1 and ending at posi- ...The second (rout) is an integer of length 3 starting at position 6 and ending at ...n 8.

...he basic record structure described above may be enhanced by adding templates ...information. The enhanced record structure then consists of two portions. The ...t is the text template while the second part consists of the variable descriptions ...d above. The text template could be used, for example, to print out a statement ...e actual values of the variable descriptions contained within the record struc- ...onsider, for example, the DMRS command to open a database. This command

```
USE DB = "<filename>" !
```

The raster data was transferred by an interesting mechanism. First it was exported from Intergraph COT (continuous tone) format to generic raster format using the EXPORT GENERIC command in Tigris. This produces three binary files (one for each of the red, green and blue bands). Next these three files were moved across the network via TCP/IP FTP protocol along with information about the number of rows and columns in the image. A simple C program was written on the SUN to convert the data for the three bands into an ERDAS format image because ARC/INFO can display ERDAS images on the SUN using the new Image Integrator module. It was quickly determined that ARC/INFO has no capabilities for contrast enhancement, so the translation program was required to compute the maximum and minimum values for each of the bands and to scale the values accordingly so the pixel values would range between 0 and 255. Fine tuning was required since the top and bottom .1% of the pixel values needed to be discarded in order for sufficient contrast stretching to take place. The vector and raster data were registered again in ARC/INFO to compute the coefficients for the warping transformation. Finally the AML to display the vector data was enhanced to use the warp information and to annotate the final display of the raster and vector data.