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16. Abstract

This report documents an assessment of needs for TxDOT divisions, districts, and area offices with respect to integrating geographic information systems (GIS) technologies with the department's existing Pavement Management Information System (PMIS). The report also describes the adequacy of existing TxDOT base maps and points out the potential shortcomings of those maps. The report documents problems associated with using a global positioning system (GPS) with real-time, satellite-broadcast differential correction for TxDOT. The report provides information on the use and availability of raster images for enhancing the interpretation of pavement management data. Recommendations are provided regarding TxDOT's requirements for GIS implementation with PMIS at four department levels.

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GEOGRAPHIC INFORMATION SYSTEM (GIS) NEEDS ASSESSMENT FOR TXDOT PAVEMENT MANAGEMENT INFORMATION SYSTEMS

by

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and

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Research Report Number 0-1747-2

Research Project No. 0-1747

Recommend a Geographic Information System (GIS) for the Pavement Management Information System

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

April 2000
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Implementation Statement

Texas Department of Transportation (TxDOT) district personnel interested in GIS/GPS technology or in pavement management systems may use the information presented in this report. This research report has no implementation items per se; the project summary report will contain the researchers' recommendations for implementation.

Disclaimers

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Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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CHAPTER 1. PROBLEM SCOPE

The objective of this chapter is to describe the background of the current situation in the Texas Department of Transportation (TxDOT) with respect to geographic information systems (GIS) and pavement management. Before a complete needs assessment can be completed, one must first understand the situation with respect to the objectives of pavement management information systems (PMIS), the ways in which pavement management information data are currently used, and the probability of changes that may occur that will affect the current PMIS. Once the current situation is understood, a decision can be reached on how best to meet TxDOT's GIS needs.

THE OBJECTIVES OF PAVEMENT MANAGEMENT INFORMATION SYSTEMS

What constitutes a pavement management system and what its objectives are may be quite different for each type of agency, whether it manages airports, state highway networks, municipal street networks, or toll roads. The purpose of this research effort is to implement an improvement to a pavement management information system currently in use by TxDOT in order to optimize the performance of on-system pavements throughout the state of Texas. Before implementing a GIS for improving the efficiency of the system, it is a good idea to look at the goals and objectives of the current system.

The Texas pavement management information system (PMIS) has been in development and in use for many years. The goals of the system have primarily emphasized the need for the central design division to manage pavement rehabilitation and new construction budgets. Considerable resources have been directed toward improving the individual models in the system to accurately predict pavement performance over time, despite the wide variability of pavement performance. The current PMIS uses highly complex analytical processes to aggregate pavement evaluation and pavement inventory data from all over the state in order to predict the best remediation projects for each of the twenty-five districts within the state.

Texas is a very large state with significant differences in weather and soil conditions. Pavement designs for the hot, dry West Texas districts that have soils with good load-carrying capability differ substantially from those for the districts having wet conditions with poor load-carrying soils in East Texas. Open-graded asphalt pavements perform better in the southern regions of the state that have fewer freeze-thaw cycles than the Texas Panhandle. TxDOT recognizes that because of the wide variability of pavement performance attributed to the diverse weather and soil conditions throughout this state, local decisions in each district must be made for pavement remediation and prioritization.

Although pavement evaluation data are aggregated statewide at the pavement section of the design division and then analyzed and reported back to the district in report format, the district engineer and his staff develop their own prioritization and remediation strategy. The management strategies can include routine maintenance, contract maintenance, surface treatments, overlays, rehabilitation projects, or the option to defer all action until future years.

The goals of the Texas PMIS reach beyond simply reporting all the pavement evaluation data taken each year. The data can become the agency's most valuable weapon in fighting the deterioration of the pavement network owing to consumption by the vehicles using the road network, the ravages of the environment, and, most importantly, the interaction of traffic loads and environment acting together to accelerate pavement deterioration. Analysis of accurate data relating the variability of pavement condition, pavement behavior, pavement characteristics, traffic loads, environmental characteristics, soil conditions, and rideability is needed to accurately quantify and predict future pavement performance.

The goals of the Texas PMIS must include:

- the accurate collection of the necessary pavement evaluation data and pavement characterization,
- the ability to detect errors in databases, which can skew analyses and optimization programs,
- the ability to analyze the data with all the external variables including geographic location, soil conditions, weather, and environmental conditions,
- the ability to present those data as useful information to decision-makers, engineers and researchers,
- the ability to provide easy access to the data at the area, district, division, and executive levels,
- the ability to develop optimal maintenance and rehabilitation strategies for each pavement,
- the ability to determine the success of current and future pavement designs, and
- the ability to provide the information necessary to create better maintenance and rehabilitation strategies for individual custom locations.

THE REALITIES OF FIELD USE OF PMIS DATA

The ideal situation would be that the data collected and the sophisticated analysis models developed for pavement performance would be used in the optimization of design and rehabilitation in the area office level. The ideal situation has little in common with the realities of the current TxDOT method of operation.

TxDOT has twenty-five independent district offices. Each district office is comprised of several counties and has several area offices or urban offices. Money for rehabilitation and design is allocated by formula to the district offices. In many districts, a bottom-up approach is used to identify projects for rehabilitation or design. Personnel in area offices are familiar with the roads in their areas and have a general understanding of their relative condition in comparison to other roads in the same area. In most districts, the area offices are asked to submit descriptions of potential rehab projects, and the district office prioritizes the projects and allocates funds among the area offices. The area offices that submit the most requests and best descriptions of project scope tend to get the most funding.

Although the data sample is small, it was reported that area offices almost never see any of the PMIS data products, such as a condition status report or ride and skid data. Because there are far more needs than construction dollars available, compromises are made. The compromises that are made to fit the realities of limited funding, finite design staff, and poor access to information result in inefficiencies of the system.

Through interviews, the researchers discovered that it was common in the area office to design a section based upon the budget rather than on engineering requirements to meet longevity goals. Often, the engineer estimates that a section requires X in. of asphalt and base material to last 20 years, but the budget for that section permits only 6 in. of base and 2 in. of asphalt.

Other inefficiencies result from designs based upon historical estimations rather than on engineering designs. Rather than using design programs such as Flexible Pavement System (FPS), many projects are designed to the standard section, i.e., using certain measurements and quantities only because they worked in another project. However, one of the shortcomings at the area office level is that are few data from which to evaluate whether the standard design has performed as expected. Unless the engineer has been in the district 15 or 20 years, he does not really know which pavement sections have performed well. In the absence of database written information, the pavement performance evaluation is limited to a rating of good or bad. In the absence of database variables, it cannot be known why the bad projects were bad.

THE UNCERTAIN FUTURE OF MAINFRAME PMIS

The PMIS data resides on a mainframe, not in a relational database. The current workaround requires that data downloads be converted to a relational database such as ACCESS. The question of whether this database will be converted to a client-server relational database technology was specifically excluded from this research project. TxDOT has been considering this technology for several years, and no clear decision is available as of April 2000. However, a decision to convert to database software that supports client-server technology will have a great impact on the needs and implementation of GIS for the PMIS application.

THE PROBABILITY OF PAVEMENT DATA COLLECTION WITH GPS

The probability is very good that pavement evaluation data will be collected with differentially corrected global positioning system (GPS) receivers. The reasons for this evolution toward GPS implementation include the following:

- All the department data collection is performed using computer and electronic files.
- GPS provides accurate position information.
- Field use of GPS will allow greater automation and less user input in the field.
- The cost of differential is affordable, and its use will soon be commonplace.
- The resulting data collection with D-GPS will result in time savings, cost savings, and more accurate data.

The TxDOT Pavements Section has already ordered many receivers for installation on pavement-evaluation vehicles. There are a few technical issues to resolve, but these can be easily overcome. The technical issues revolve around the limits of GPS reception and differential-correction reception and whether inertial navigation units are required to determine position during periods of reception loss.

Because D-GPS provides more accurate positioning and cost savings, it is inevitable that GPS data collection will be implemented. The database of collected pavement information will need to be changed to accommodate GPS data collection.

CHAPTER 2. NEEDS ASSESSMENT

Any reasonable and justified recommendations should be based on a clear and correct understanding of the user's needs. This chapter will review at the historic need for GIS in pavement management and will examine the results of interviews with TxDOT personnel. An expert task group (ETG) meeting was held in Austin to help the researchers identify the needs of TxDOT with respect to GIS and pavement management. This chapter will discuss the results of the interviews and the ETG meeting and will make recommendations to meet TxDOT's needs.

HISTORIC NEEDS

Many people have written about or stated the need for TxDOT to implement GIS or GIS capabilities that will visualize data from PMIS onto maps prepared for that purpose. The Texas Transportation Institute (TTI) conducted one preliminary study over 10 years ago that pointed out some of TxDOT's needs that still have not been met (Ref 1). In that study the following conclusions were presented:

- The most urgent need of the districts is the production of maps highlighting sub-standard pavement sections.
- The districts have a need for *graphically* accessing, manipulating, analyzing, displaying, and reporting information on the road network.
- Of top priority to the districts is the automated production of graphics output in the form of maps to convey information on the highway network.

The conclusions presented in the TTI report identified a few unfulfilled needs that a properly designed and implemented GIS could meet.

Most state departments of transportation have either begun to implement GIS systems or will do so in the near future. Several states have integrated GIS with pavement management systems. See CTR Report 1747-1 for a discussion of the state of the art of GIS and pavement management and the extent of Texas's involvement in GIS integrated with pavement management.

In Texas, as in most other states, the department of transportation is the official agency designated as the state cartographer. It is natural for an agency that is responsible for the map production for the state also to consider using GIS for pavement management. In the state of Wisconsin, the pavement management system was designed and developed together with the state geographical information system. In Wisconsin, a committee formed for the development of the Pavement Management Decision Support System mandated that the system be developed to include the following features (Ref 2):

- an expert system to analyze pavement problems and recommend rehabilitation strategies,
- spatial data concepts to be used in the design of a large decision-support database,
- spatial analysis routines to integrate pavement inventory, performance, and management data,
- GIS display and cartography tools used to portray complex relationships among many decision elements, and
- development of dynamic cross sections constructed from project inventory data.

INTERVIEWS

The research team met with two district pavement engineers, Pat Downey from the San Antonio District and Andrew Wimsatt from the Fort Worth District. Dr. Mike McNerney and Mr. Tony Krauss, a former TxDOT area engineer, met with Mr. Pat Downey in his office in San Antonio in August 1998 and with Mr. Andrew Wimsatt at the Center for Transportation Research in June 1998. Notes from these two interviews are combined to present a single list of needs.

One of most significant findings of these interviews was the need for a system to provide quick and immediate feedback to the engineers in the area office, the level at which the projects are being designed. Area engineers usually have the responsibility for planning and designing new projects. These projects are usually limited by budget and are time-critical; therefore, compromises are made to meet time deadlines and budgetary constraints. There is not enough money in the TxDOT budget to build or rehabilitate all the needed projects. Consequently, area engineers in many offices have relied on a design technique that may not be the most efficient, but gets the work accomplished.

An area engineer, realizing the budget limitations, may design a road without using the optimum thickness design programs because of inadequate knowledge of the pavement life performance within his district. Thickness designs can and have been reduced to whatever the budget will allow and whatever was used previously for the same classification of road.

This lack of knowledge results in the high probability that a road can be under-designed and will last only a few years before major maintenance is required. Very rarely can the area office get feedback from the pavement management system as to the performance of the roads in its district with respect to thickness and material properties. If area personnel are using this empirical method of pavement design, they need a database of information about roads that have already been constructed, including data for thickness, the properties of each layer, and the relative performance of these pavements. Without long-term knowledge or a pavement history database, area engineers have to rely upon their personal knowledge of what has been constructed. Even if they have used a design for several years, they will not discover that a pavement is under-designed until significant maintenance is required. More probably, however, the designer will not have the opportunity to monitor the maintenance that is required, and no one in the district will capture this valuable design feedback information.

The second striking discovery made in the interviews was that even if the area office had access to the information, the PMIS does not contain an inventory of pavement layer thickness. Therefore, it is necessary to request design documents to determine the thickness and cross-section of any given roadway in the district. Even a district pavement engineer may have to wait several weeks to receive construction drawings in order to determine the pavement layer thickness and material properties of any specific pavement. This information on pavement inventory is needed in district and area offices.

The district pavement engineers interviewed also identified a primary need for a way to develop maps and display data quickly for district engineers. The district engineer (DE) makes the decisions regarding the work that will be covered by the budget for his district. He divides his construction, rehabilitation, and maintenance resources among his area and maintenance offices. The district pavement engineer must provide the DE with all the information necessary to make these decisions. Currently, the pavement engineer can take reports from PMIS and use those data to color code maps; he can ride the roads and make his own maps based upon his observations; and he can develop in-house databases to keep historical records on maintenance actions. The district pavement engineer needs GIS to assist in locating and analyzing data and to display data on maps. Currently, the pavement engineer responds to requests from the DE by preparing this information by hand. One district engineer stated that a simple request from the DE could result in 2 or 3 days of work to prepare a map that will provide an answer to the district engineer's query. These are the types of tasks that could be either predefined queries that are instantly viewable or queries that ordinarily could be completed in 1 to 2 hours with a GIS that has the necessary data.

Based on the interviews with district pavement engineers, a list of potential needs was identified. A GIS for PMIS must have the ability to:

- Validate data that has been collected.
- Visualize the trends in road conditions.
- Explain road conditions to non-engineers.
- Project potential problems.
- Design and prepare data for decision-makers in area engineering offices.
- Perform spatial analysis to determine differences in factors that could impact pavement performance such as ADT, weather, and soil type.
- Capture MMIS data in order to determine the maintenance actions performed on a given roadway.
- Differentiate between pavement types (asphalt and concrete).
- Print maps of HPMS sections.

- Make maps of roadway conditions and assign colors to indicate road condition.
- Differentiate between types of distress versus reporting only a single distress/condition rating.
- Evaluate pavement performance by pavement type and material properties.
- Locate and track the performance of test sections.
- Evaluate data across jurisdictional lines (control section, county, district, etc.).
- Provide multiple-year reports and multiple-year analysis tools for justification of choices.
- Act as a tool for forensic analysis.
- Be user friendly so that upper management can view queries without assistance.
- Use aerial photography to view the topography and location specifics of different road sites.

EXPERT TASK GROUP MEETING

One of the objectives of this research project was to determine the user requirements of the GIS to be used with the pavement management information system. With the assistance of the project director, Mr. Stephen G. Smith from the Odessa District, an expert task group was assembled to discuss the needs of a GIS for pavement management. The meeting was held at the Center for Transportation Research on August 6–7, 1998. The attendees included TxDOT representatives from divisions, districts, and area offices.

The purpose of the meeting was to provide the ETG members an opportunity for brainstorming and to collect their opinions on the user requirements of GIS for pavement management. The meeting started with a background review of the project. A tentative list of potential PMIS functions that could be improved by GIS operations and their benefits was provided in a handout to the participants. The ETG meeting attendees discussed this tentative list and gave their opinions on the user requirements of GIS for PMIS from the perspective of both statewide PMIS functions and district level PMIS functions.

During the first day of the meeting, Dr. McNerney led a discussion about the needs of a GIS for PMIS and how it might be used. The discussion built upon the needs that were developed from the interviews with the district pavement engineers and continued with implementation issues. At the end of the first day, a list of needs and applications that could be required of a GIS integrated with pavement management was completed. Before the meeting was convened on the second day, the list of needs was consolidated and grouped into a list of needs in a survey form.

On the second day a discussion was conducted about each item on the list and its relative importance to the division, district, and area office levels. At the conclusion of the meeting, each TxDOT participant was provided a copy of the survey and a return envelope and asked to rate the relative priority of each need or capability of GIS, based upon his or her experience as a TxDOT engineer.

The results of the survey are provided in Table 2.1. Each column represents an individual participant's rating on a scale of 1 to 4. A rating of 4 indicated a high priority for that need for that individual, whether a division-, district-, or area-level potential GIS user. A rating of 3 indicates a medium priority, and 2 is a low priority rating. A rating of 1 indicates that there is no need for that particular item in that rater's opinion. The needs or characteristics of the GIS were grouped into six functional areas:

- GIS System Characteristics,
- Data Entry,
- Management, Transformation, and Transfer of Data,
- Integration of Data,
- Query and Analysis, and
- Display and Reporting.

Notice in Table 2.1 that each individual rating is provided and that the table is sorted from the highest average rating to the lowest within each of the six areas of GIS functions. For example, in the first functional area, GIS System Characteristics, notice that all participants rated "User friendly" as 4, high priority. Also notice that "Dynamic segmentation" was rated as 4, high priority, by all except one participant who rated it as 1, no need. Table 2.1 provides very useful information about the relative priorities of needs. Although the ratings differed by participant, one can conclude that any item that averaged a rating of 3.00 or better had the consensus of the group of TxDOT raters and is thus a priority for development in the GIS system for pavement management information system implementation.

TABLE 2.1 TxDOT EXPERT PANEL PRIORITY RASTING OF GIS NEEDS AND CHARACTERISTICS

1. GIS System Characteristics	**Priority** 4 = high, 3 = medium, 2 = low, 1 = no need										
User friendly	4	4	4	4	4	4	4	4	4	4	4	4.00
Dynamic segmentation	4	4	4	1	4	4	4	4	4	4	4	3.73
2. Data Entry												
Project FWD data	4	4	4	3	4	4	4	4	4	3	4	3.82
Contract routine maintenance	4	4	3	4	4	4	3	4	4	3	4	3.73
Data collection	3	4	4	3	4	4	4	4	4	3	3	3.64
Local databases	4	2	3	4	3	3	4	4	3	4	4	3.45
Field construction testing	3	3	3	3	3	4	4	4	3	3	4	3.36
GPR data	3	3	4	3	3	3	4	3	4	3	3	3.27
Digital camera	3	2	3	4	3	3	4	4	3	3	4	3.27
Aggregate source data	3	3	3	3	3	4	3	3	3	3	4	3.18
Scanning/digitizing	3	3	3	2	3	3		4	3	3	4	3.10
Location of heavy load generator	4	3	3	2	2	4	2	3	3	3	4	3.00
Depth to bedrock	3	4	4	3	3	2	2	3	2	3	3	2.91
Availability of materials	3	3	3	1	3	4	3	3	4	2	3	2.91
Windshield survey	2	3	3	3	2	3	3	3	3	3	3	2.82
Blade patches	3	4	3	3	2	3	2	2	4	2	3	2.82
3. Management, Transformation and Transfer of Data												
Data storage	4	4	3	4	4	4	4	4	4	4	4	3.91
Common locational reference sys	4	4	4	4	4	4	4	4	2	4	4	3.82
Roadbed, centerline, lanes and ramps	4	3	3	3	4	4	4	4	4	3	4	3.64
Import, export	4	4	3	3	4	3	4	4	4	3	4	3.64
Map projection	4	2	3	4	4	4	4	4	4	3	4	3.64
As-built drawings	3	4	3	4	4	4	3	4	3	3	4	3.55
Stiffness data	4	4	3	2	4	4	3	4	4	3	4	3.55
Control Section Job (CSJ)	4	3	4	4	4	3	3	3	2	3	4	3.36
Material characterization	3	3	3	2	3	4	4	4	4	3	4	3.36
Network transfer	4	2	3	3	4	4	4	4	3	3	3	3.36
Construction files	3	4	3	3	3	3	4	4	2	3	4	3.27
DGPS- geocoding	2	3	4	2	3	4	3	4	4	3	4	3.27
English/Metric conversion	3	2	3	4	3	4	3	4	3	1	3	3.00

TABLE 2.1 TxDOT EXPERT PANEL PRIORITY RATING OF GIS NEEDS AND CHARACTERISTICS (CONT.)

4. Integration Of Data	**Priority** 4 = high, 3 = medium, 2 = low, 1 = no need										
PMIS database	4	4	4	4	4	4	4	4	4	4	4	4.00
History of work and maintenance performed	4	4	4	4	4	4	4	4	4	4	4	4.00
Pavement inventory/ pavement layers	4	4	4	4	3	4	4	4	4	4	4	3.91
Reliable maintenance costs	4	4	4	4		4	4	4	4	3	4	3.90
MMIS -- by individual types	4	3	4	4	4	4	4	3	4	4	4	3.82
Road life	4	3	4	4	3	4	4	4	4	4	4	3.82
Traffic data	4	3	4	4	4	4	4	4	4	3	4	3.82
TRM	4	4	4	3	4	3	3	4	4	4	4	3.73
Soil data	4	3	4	3	3	4	4	4	4	3	4	3.64
Load zone data/overheight and overweight data	4	3	3	4	4	3	3	4	4	3	4	3.55
TIP	4	3	4	4	3	3	3	3	2		4	3.30
Research database/test section	4	3	4	3	3	3	3	3	3	3	4	3.27
BRINSAP	4	3	4	4	4	3	2	3	3	3	3	3.27
Site manager	3		3	2	3	3	4	3	4	2	4	3.10
Climate data	3	3	4	2	3	3	3	3	3	3	4	3.09
Drainage structures	3	2	3	2	3	4	2	4	2	3	3	2.82
Hydrology data	3	3	3	2	3	3	3	4	2	2	3	2.82
HPMS/federal data	3	3	4	3	2	2	2	3	4	1	3	2.73
Elevation data	3	2	3	2	3	3	2	4	1	3	3	2.64

5. Query And Analysis												
Pavement life analysis	4	4	4	4	4	4	4	4	4	4	4	4.00
Pavement performance/pavement life	4	4	4	4	4	4	4	4	4	4	4	4.00
Pavement performance by characteristic	4	4	4	2	3	4	4	4	4	4	4	3.73
Budget/funding allocation -- pavement scores	4	4	4	4	3	3	4	4	4	3	4	3.73
Spatial analysis	4	2	4	2	4	4	4	4	4	4	4	3.64
Comparative analysis	4	3	4	2	4	4	3	4	4	4	4	3.64
Forensic analysis	4	3	4	4	3	3	3	3	4	4	4	3.55
Performance versus specification	4	4	4	2	3	4	4	4	3	3	4	3.55
Trend information	4	4	4	4	3	3	3	3	3	3	4	3.45
Analysis by classification	4	3	4	3	4	3	3	3	4	3	4	3.45
Budget preparation	4	4	4	4	3	3	3	4	1	3	4	3.36
Triaxial analysis	3	3	4	2	4	4	3	3	4	3	4	3.36
Analysis by shrink/swell	4	3	4	2	4	4	2	4	3	3	4	3.36
Update of performance curves	3	3	4	4	4	2	4	3	3	3	4	3.36
Statistical analysis correlation studies	3	3	4	2	3	3	3	4	4	3	4	3.27
Present rate of funding versus trends	4	3	4	3	3	3	3	3	3	3	4	3.27
Analysis by geography	4	3	4	2	3	4	2	3	2	4	4	3.18
Skid versus polish value	4	1	3	3	4	3	3	3	4	3	4	3.18
Validation of specification	4	3	4	2	3	3	3	2	3	3	4	3.09
Accident versus skid	4	1	3	3	4	3	3	3	2	3	4	3.00
Design/plan review	3	2	3	3	2	3	3	4	3	3	4	3.00
Analysis by different raters	4	2	4	2	3	2	3	2	4	3	4	3.00
Soundness correlation	4	2	3	2	3	3	3	3	2	3	4	2.91
Trials to prioritize	4	3	3	2	2	3	2	2	2	2	4	2.64

TABLE 2.1 TxDOT EXPERT PANEL PRIORITY RATING OF GIS NEEDS AND CHARACTERISTICS (CONT.)

6. Display And Report **Priority** 4 = high, 3 = medium, 2 = low, 1 = no need

Color maps	4	4	4	4	4	4	4	4	4	3	4	3.91
Condition of roads -- pavement needs report	4	4	4	4	4	4	4	4	4	3	4	3.91
Pavement performance	4	4	4	4	4	4	4	4	4	3	4	3.91
Date of last surface	4	4	4	4	3	4	4	4	4	3	4	3.82
Tool to convey information to decision-makers	4	4	4	4	4	2	4	4	4	3	4	3.73
Automated reports	3	3	4	4	4	4	4	4	4	3	4	3.73
Seal coat map	4	3	4	3	4	4	3	4	4	3	4	3.64
Cross section diagrams	4	3	4	3	3	4	4	4	4	3	4	3.64
Construction projects -- TIP	4	3	4	3	3	3	4	4	3		4	3.50
Effectiveness of maintenance	3	3	4	3	3	3	3	4	4	3	4	3.36
Straight line diagrams	3	3	4	3	2	3	4	4	1	3	4	3.09
Aerial photography	2	2	3	3	3	3	4	4	4	2	3	3.00
Internet/Intranet	2	2	3	2	4	4	3	4	2	3	4	3.00
Multimedia	2	2	4	2	3	3	3	3	3	2	3	2.73
Web-based applications	2	2	3	2	4	2	3	2	2	3	4	2.64

CHAPTER 3. ADEQUACY OF TxDOT BASE MAPS

The objective of this portion of the research was to learn whether the TxDOT base maps would be sufficient for the GIS for PMIS. "Base map" is a term for the underlying map and map scale upon which a GIS is built. The importance of the base map is seen in performing spatial analysis in the graphic data. When spatial analysis is performed on areas (polygons), the horizontal accuracy of the data sets has a greater impact upon the resulting analysis than using point data.

Some systems for GIS analysis have been built upon scanned United States Geological Survey (USGS) paper maps or upon USGS digital line graphs. The intended scale of the application and the extent of the geographic area of coverage are important in GIS. It is easier to build a highly accurate GIS if the total extent of the area is only a few square miles. If the entire state of Texas is to be included, the map scale and horizontal positional accuracy become major problems. Additional problems are introduced by map projections.

Other GIS analysis systems developed more recently have relied less upon the base map by using digital imagery as the base map. Digital imagery, especially digital orthophotography, has become more affordable and readily available in the last few years. One advantage of using digital orthophotography as a base map is that it can be updated and replaced more readily than vector data maps. However, in the case of the pavement management application, a vector representation of roads and highways will provide features that can be analyzed.

AVAILABILITY OF TXDOT BASE MAPS

TxDOT has two different types of base maps available for GIS use that were prepared by the department. The first-generation maps were built from USGS quad sheets that had been digitized. The files were developed as Intergraph MicroStation Design files in the ".dgn" format. The department converted the CADD files into Intergraph MGE GIS files with minimal attribution. However, error analysis and cleaning of the files was not completed in the Intergraph format.

These files are available for each county in the ".dgn" format in a Lambert conic conformal projection. However, the horizontal accuracy of roadbed alignment is somewhat in question. The Transportation Planning and Programming (TPP) Division did additional supplemental work on these maps to add county roads and MGE topology for the roadways.

The Information Systems Division prepared the second generation of base maps in the ArcInfo ".e00" format. This second-generation map was prepared by doing additional cleaning of the files to eliminate overrun and underrun intersecting lines and other topological errors in the original files. The data files were not complete for all counties at the start of this project, but were completed during the project. However, no additional work was completed to improve or verify the horizontal accuracy of the roadways.

ABILITY OF TXDOT BASE MAPS TO MEET PMIS GIS NEEDS

The ability of the base maps to completely fulfill the needs of the pavement management information system with GIS was evaluated. To meet the needs of the PMIS, the base maps must meet the following criteria:

- Be readily available and GIS compatible.
- Provide horizontal accuracy that is acceptable for each specific application.
- Provide representation of individual roadbed alignments.
- Provide a system that can be kept current to reflect changes over time.

TESTING WITH GIS COMPATIBILITY

At the beginning of this project, the software that was used to test the base maps was Intergraph MGE version 6, using Windows NT and ArcView 3.0. At the start of this project, ArcView had not been released in a Windows NT operating system. The software releases have continued to improve the compatibility of both the Intergraph and ESRI products.

As the project began, there was a decided effort to look at the capabilities of each of three major types of software, ESRI, Intergraph, and Bentley, to determine whether the differences were significant enough to justify recommending one implementation for the application of PMIS over the others. As the research project progressed it became apparent that the researchers could recommend any software they wished as long as it was implemented with ESRI ArcView to conform to the ISD recommended GIS architecture.

There were some compatibility problems in importing the TxDOT base maps prepared by the TPP division at the start of this project. However, as details of the files became known and tricks of the software were worked out, ability to import the maps increased. Now, with newer releases of the software and revisions to the maps from TPP, there do not appear to be any remaining issues regarding importing TPP maps into any of the major vendors' software packages.

The ISD corrections to TPP base maps were prepared specifically as ESRI-compatible files and are available and directly importable to ArcView. More specifically, ISD has established the linkages and topology in ESRI-compatible format, so the map link to the attribute database for roadway segments is completed. As part of the pilot project, the district maps of Lufkin and Odessa were completely imported into ArcView. In Lufkin, the data were matched without problems to the PMIS data provided by Craig Cox of the Pavements Section of the Design Division.

TESTING FOR HORIZONTAL POSITIONAL ACCURACY

In order to test the horizontal positional accuracy of the TxDOT base maps, the researchers at CTR obtained a differentially corrected GPS receiver system. The

OMNISTAR model L-8 was chosen because of performance and also because it fit the TxDOT GPS architecture, which at that time was in draft form from ISD. The eight-channel model L3000-8 was later upgraded to a twelve-channel model L3000-12.

The GPS receiver is an OEM card-mounted unit integrated within the OMNISTAR satellite receiver that receives correction signals from a geostationary satellite in the L band. OMNISTAR sells the differential correction service, corrected from OMNISTAR's twenty ground stations in the U.S., as a yearly subscription. The advantage for TxDOT and this research project is that full coverage is provided anywhere in the state of Texas or in the continental United States.

To test the map accuracy, data were collected for several main roadway intersections in Dallas and Austin with differential GPS receivers to laptop computer. The data were then compared to the digital orthophotography available to the researchers for the Dallas County and excerpts of digital orthophotography provided by the Capital Area Planning Council.

The North Texas Geographical Information Systems Consortium (NTGISC) provided the 0.5 m pixel resolution digital orthorectified image files for Dallas County in the State Plane Projection System on 8 mm computer tape. These data were stored on three 9 GB disk drives. The Analytical Systems Incorporated (ASI) Company of Colorado Springs, Colorado, loaned its proprietary DODI interface used to access the image files in an extremely efficient manner from MicroStation. The DODI interface allowed seamless access to digital orthophotography for the entire county without tiles. The image stacking mechanism allows nearly instantaneous views at any scale from the entire county down to maximum pixel resolution.

Several prominent interchanges in Dallas County were chosen for analysis because the roadways crossed each other at approximately 90 degrees, were geographically dispersed in Dallas County, and were both part of the state system: IH 20 and US 175 in the southeast, IH 635 and SH 78 in the northeast, SH 114 and SL 12 in the northwest, IH 30 and IH 345 in the central downtown area, and FM 1382 and US 67 in the southwest.

The TxDOT urban map of Dallas County in the State Plane Coordinate System was obtained in MicroStation design file format from the TxDOT Transportation Planning and Programming Division. The urban map was displayed in MicroStation with the image files in the background. An operator accurately placed tangent lines at the centers of the roadways and placed arcs of circles tangent to these tangent lines using the 0.5 m imagery. If a median barrier was visible, the center of the median barrier was used. Otherwise, a line was drawn from one edge of median pavement to the other edge of median pavement and the center of that line was used.

The tangent lines and the arcs of the circles were made into a complex centerline and a point was placed every 200 ft along the centerline. An error line was drawn from each of these points on the centerline from the 0.5 m imagery to the closest point on the centerline from the TxDOT urban map file. A MicroStation Development Language (MDL) application was written to count and add the lengths of lines on each level within a MicroStation design file using sixteen digits of precision arithmetic and to produce a tab-separated file for each line recording the level: beginning x, beginning y, beginning z, ending x, ending y, ending z, length, and angle. The graphics for the error lines and the angles were analyzed to determine whether there was a systematic error such as a shift, all in one direction, but none was found. The error is randomly distributed around the county and would not be eliminated by rubber-sheeting the photography.

Appendix B provides a photographic record of each intersection. As shown in Table 3.1, there were 622 points near the IH 20 and US 175 interchange in the southeast, for a total length of error lines of 18,208.12 ft and an average error of 29.27 ft. There were 90 points near the IH 635 and SH 78 interchange in the northeast, for a total length of error lines of 3,601.41 ft and an average error of 40.02 ft. There were 216 points near the SH 114 and SL 12 interchange in the northwest, for a total length of error lines of 11,842.06 ft and an average error of 54.82 ft. There were 113 points near the IH 30 and IH 345 interchange in the central downtown area, for a total length of error lines of 4,053.49 ft and an average error of 35.87 ft. There were 50 points near the FM 1382 and US 67 interchange in the southwest, for a total length of error lines of 1,297.42 ft and an average error of 25.95 ft. There were a total of 1,091 points in Dallas County, for a total length of error lines of 39,002.50 ft and an average error of 35.75 ft.

TABLE 3.1 AVERAGE ERROR IN SELECTED INTERSECTIONS IN DALLAS COUNTY

Intersection	Location	Number Points	Average Error
IH 20 and US 175	SE	622	29 ft
IH 635 and SH 78	NE	90	40 ft
SH 114 and SL 12	NW	216	55 ft
IH 30 and IH 345	Central	113	36 ft
FM 1382 and US 67	SW	50	26 ft
All combined		1,091	36 ft

CENTERLINE VERSUS MULTIPLE ROADBED ALIGNMENT

Probably the biggest potential problem in merging the PMIS data and future pavement data collection with existing TxDOT base maps is the fact that each roadway is represented in the vector data as a single line entity representing the roadway center. For divided highways, the single line representation is located on the grassy median rather than on any pavement surface. In cases where there is significant separation or uneven separation between each roadbed in a divided highway, attributing and analyzing data can be difficult because the data are often different in each roadbed. Even in single roadbed highways, data on pavement condition can be quite different for each traffic direction.

The fact that the current graphical representation of the highways in the base maps is centerline only is a significant limitation to the implementation of a fully functional pavement management system using GIS. Adding dual roadbeds, frontage roads, and ramps could be a significant advantage in the use of the system and in its adoption. The only way that the centerline approach will still work is to provide a seamless integration of current orthophotography to allow the user to identify frontage roads, divided roadbeds, and ramps that are visible in the photography.

CHAPTER 4. AVAILABILITY OF RASTER IMAGES

The addition of background raster images to GIS greatly enhances the ability to analyze and display spatially referenced attribute data. Raster images and digital orthophotography are available from a variety of sources in both the commercial and government sectors. The Texas Natural Resource Information System (TNRIS) is the primary source of raster images for Texas agencies and for the researchers on this project because of the selection and availability it provides. TxDOT and all other state agencies have access to TNRIS data for the cost of reproduction. TNRIS is located in downtown Austin. The address is Stephen F. Austin Building, 1700 North Congress Avenue, and the Internet address is http://www.tnris.state.tx.us. TNRIS has been involved in collecting digital ortho quad (DOQ) data from Texas for a number of years. The company is involved in a program called the Texas Orthoimagery Program (TOP). The purpose of this program is to create a database to hold 3.75 minutes quadrangles for the entire state of Texas. Because Texas is so large, this is a long-term project, and every city and county has not been completed. Figure 4.1 shows the progress that has been made.

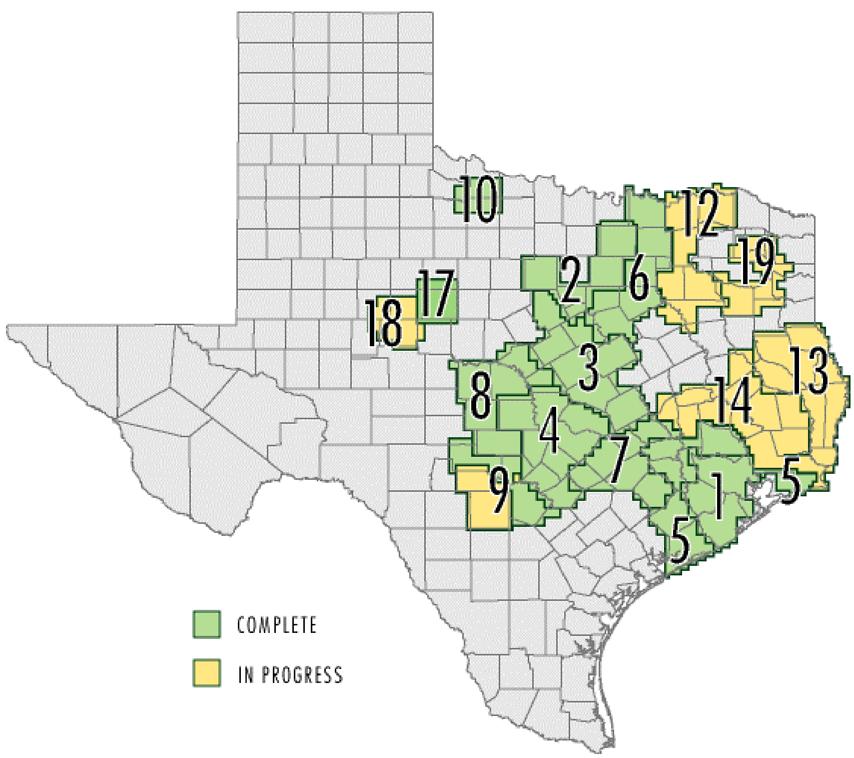

Figure 4.1 Availability of Raster Maps in the Texas Orthoimagery Program

Acquisition of DOQ data can be either downloaded from the TNRIS ftp site or ordered. There are five different types of DOQs: 30 m 24 bit digital ortho quads, 10 m 24 bit DOQs, 10 m 8 bit DOQs, 2.5 m 8 bit DOQs, and 1 m 8 bit DOQs. A better representation of the size and resolution can be seen in Table 4.1. Because the 1 m DOQ file size is over 100 MB, these files will have to be ordered from TNRIS. The price for one DOQ (which carries four DOQQ) is $54.

TABLE 4.1 TYPE OF DOQ AVAILABLE

Image Resolution	Color Depth	File Coverage	File Size
1 m	24 bit CIR	USGS 1/4 quads	158 Mb
2.5 m	8 bit CIR	USGS 1/4 quads	9 Mb
10 m	8 bit CIR	USGS quads	2 Mb
10 m	24 bit CIR	USGS quads	6 Mb
30 m	8 bit CIR	USGS quads	0.5 Mb
30 m	24 bit CIR	USGS quads	1 Mb

DIGITAL ORTHOPHOTOGRAPHY QUADS

Digital orthophotography quads are 3.75 minutes of a standard 1:24,000 scale 7.5 minute USGS map. They can be represented as true maps. These DOQs are in the color infrared band. The DOQs will provide users with large-scale, highly accurate, and relatively current images that can be used as base maps and combined with other digital map data in an integrated database or used as a detailed information source. To compensate for relief, the tilt distortion from the camera is removed so it will meet horizontal National Map Accuracy Standards (NMAS). The accuracy requirements are at 1:12,000 scales.

At CTR the DOQs are used with GPS and GIS. The DOQs provide an accurate base map with which to work. The DOQs are used as a reference datum onto which differentially corrected GPS data can be overlaid. With this method the accuracy of the differentially corrected GPS data can be ascertained with respect to the DOQ. With this information the differential signal can be calculated to determine whether the tolerances have been met. The DOQs give a realistic quality unmatched by other maps. With the interrogation of GIS the DOQs further their importance by providing a source map to append terrain, roads, lakes and cities. As can be seen in Figure 4.2, accuracy is very important. For this reason GIS relies heavily on DOQs.

Figure 4.2 DOQ with Overlay of Differentially Corrected GPS Data

LOCAL GOVERNMENT ACQUISITIONS

A GIS or image database of smaller areas is more easily developed than a GIS or image database of larger areas. Consequently, it is often local governments or airports that are more at the forefront of new technology than governments of large states. TxDOT should consider the coordination and pooling of resources with local governments. With a close relationship to local governments TxDOT can obtain fresh, new ideas regarding uses for GIS hardware and software. Often local governments and planning organizations also have a need for digital orthophotography and GIS. Sometimes, these organizations have pooled funds for digital orthophotography. Digital orthophotography is available to TxDOT from local sources including the North Texas GIS Consortium and the Capital Area Planning Council (CAPC).

The Capitol Area Planning Council is in the process of obtaining digital orthophotography of a three-county area that includes imagery of 0.5 ft resolution. The primary purpose of this imagery is to provide a base map for a GIS for the application of 911 emergency vehicle routing and dispatch. The CAPC is one of the leaders in Austin with the integration of digital orthoimagery with GIS and GPS. Capital Area Planning Council has commissioned Analytical Systems Incorporated (ASI) to fly digital orthophotography for Hayes, Travis, and Williamson Counties at an urban resolution of 0.5 ft and rural resolution of 0.5 m.

The product that is being delivered from ASI in Colorado Springs, Colorado, is a seamless stacked imagery system. This proprietary DODI digital imaging software allows the seamless viewing of all or any portion of the imagery without looking at individual tiles of images. The DOQs are in individual tiles, and most software programs require the loading and unloading of each tile for viewing. In the ASI system, the image data are resampled and stored, permitting rapid viewing, panning, and zooming of the images because only a small 1k image is viewed at any one time. Also, the higher resolution of images provides better interpretation of the data. Using a small sample of this highly accurate imagery, one can measure the accuracy of GPS data from control points in the DODI imagery. Again, working with a local government agency has proven to be an excellent median between research and a federal agency.

PROJECT-LEVEL PHOTOGRAPHY

Many different types of imagery are used at the project level. Imagery has proved to be very reliable and widely used in the GIS community. The types of imagery currently used depend on the need. If a simple DOQ is needed to overlap some important intersections or streets, a 30 to 10 m DOQ would probably be used, depending on the resolution wanted. As more detail is needed and calculations with GPS input are begun, a higher resolution would probably be desired. For a resolution of 1 m or even 0.5 m, DODI is recommended. The researchers have worked with and are pleased with both, but if more accuracy is desired, 0.5 would be a better choice than 1 m.

Project-level photography is always in demand. The problem most companies are faced with is price, and DOQ and DODI can be expensive. That is why it is best to avoid the middleman and go directly to the source. Doing so has proved to be a wise decision because imagery companies seem to be willing to cut their prices if they are included in a project. Another source that has proved to be invaluable is the TNRIS web site. This free web site is maintained by TNRIS, which gives daily updates to its DOQ database. One can log on and download 30, 10, and even 2.5 m resolution DOQs. The researchers have found this to be very reliable and beneficial for GPS and GIS integration. As more projects are leading into the GIS realm, these avenues are becoming increasingly more valuable.

SEAMLESS INTEGRATION

The main priority of this project is to make the transition between different imageries less cumbersome. Seamless integration is used mostly in acquisition of DOQ and DODI data. The differences between DODI integration and DOQ integration are size and management. DODI is widely used because of its management capabilities. Using DODI, one is able to view a larger area with less time to upload (as compared with a standard 1 m DOQ). A DOQ with the same area size as the DODI imagery will require a longer time to read than the DODI file. On the other hand, a DODI image will require more space, and a larger hard drive would be needed to hold all of this data. DOQs will fit on a CD, and any area can be opened individually and viewed separately, which is not an option with the DODI. Both types of imagery are attractive, DOQ for its flexibility and size and DODI for its management and strength.

In using ArcView, a choice has to be made. It is best to understand the needs of the project before ordering imagery. If a large area is to be studied that encompasses a county or more, DODI is the better choice. However, if a specific intersection or roadbed is to be studied, a standard infrared DOQ would manage the job.

ArcView uses each of these imageries in a different way. For a standard DOQ it must first read the individual DOQ before it produces a picture. The time needed to read the DOQ depends on the size of the data. Please refer to Table 4.1 for specifics on size and resolution. The higher the resolution, the longer it takes for ArcView to read.

DODI is another issue altogether. In order for DODI to work, a script must first be developed to view the imagery. ASI can supply one, or the user can customize one. An entire area can be viewed with the script. One of the failings of DODI is that no segments can be drawn from this imagery. The time needed to view this imagery is not as long as that required for the DOQ. The response is faster, and manipulation of the data is easier. The direction of the project should determine which data are needed for future projects.

CHAPTER 5. USING DIFFERENTIAL GLOBAL POSITIONING SYSTEM FOR PAVEMENT DATA COLLECTION

DIFFERENTIAL GPS

The U.S. Federal Aviation Administration (FAA) is implementing the Wide Area Augmentation System (WAAS). The WAAS augments the GPS in meeting the basic requirements for a navigation system. WAAS will provide the following capabilities:

- an integrity capability to notify users when GPS should not be used for navigation,
- an accuracy enhancement capability that will improve the accuracy of GPS to meet the requirements for precision approaches, and
- an improvement in availability by providing ranging sources from geostationary satellites that can be used for user position determination.

WAAS was expected to have initial operational capability (IOC) in 1999. WAAS, already in operation at twenty-five reference stations, is scheduled to reach initial operational capability in September 2000. The FAA is expected to approve full operational capability for the WAAS to be used as the primary navigation system in all phases of flight by the year 2001. However, due to congressional delays in the aviation reauthorization act, funds for further development of the WAAS and the Local Area Augmentation System (LAAS) have been put on hold until the FAA can provide additional justification for the planned expenditures. WAAS consists of the following components:

- Wide-Area Reference Stations (WRSs),
- Wide-Area Master Stations (WMSs),
- Ground Stations, and
- Geostationary Satellites.

Each WRS is located at a known position. The WRS receives and collects data continuously from GPS. The WRSs send the data to the WMSs via a wide-area network. The WMSs calculate the error of the GPS-received position. The corrections from the GPS-received position are transmitted to a ground station. The ground station receives the GPS correction data from the WMS via the wide-area network and transmits the data to the geostationary satellites. The geostationary satellites receive the GPS correction data from the ground stations and retransmit the data to user receiver sets. The user first calculates the GPS received position and then uses the GPS correction data to refine its actual position. The WAAS correction data will give aviation users accurate positioning information down to Category I precision approaches, which are the best approaches available to pilots today and can be made without the special certification used by some commercial operators for Category II or III approaches.

The WAAS is not operational at this time, and GPS receivers with the capability to use the WAAS signals for differential correction are not yet available to the public. However, when the WAAS becomes operational, nonaviation use of this system for real-time differential correction will become commonplace because the system is free to users. In addition, the differential correction signal is received on the same frequency as the primary GPS signal; therefore, no special receiver or antenna is required.

Currently, the second best option is to use the OMNISTAR differential correction system. The OMNISTAR system works in essentially the same way as the FAA-developed WAAS, with two exceptions:

- The OMNISTAR system does not provide an integrity capability to notify the users when GPS should not be used for navigation.

- The OMNISTAR does use geostationary satellites to provide a communication link on L-band or C-band to transmit the differential correction to the GPS receivers. However, the geostationary satellite cannot provide ranging sources that can be used for user position determination

The OMNISTAR and FAA WAAS systems differ in accuracy and reliability. The WAAS has a requirement for air navigation to provide 4 m accuracy, 99.999 percent of the time. The OMNISTAR system has no user requirements for such high reliability, and reports are accurate to within 2 m, 95 percent of the time. The OMNISTAR system claims 3 m accuracy 99.5 percent of the time. However, actual accuracy and reliability are determined from actual field conditions.

TESTING SET UP

The following pavement data-collection equipment was acquired and tested. Initial tests were taken with the OMNISTAR L-3000 L8 receiver, and later tests were taken with the upgraded twelve-channel model. The data were collected using a laptop computer, the GeoLink Power Map software, and the Delorme Street Atlas 6.0 software.

The equipment required an external antenna to receive both the L-Band geostationary satellite communications and a GPS antenna to receive the GPS signal. Field tests were conducted using both the separate antenna system and the single combined antenna system. The antennae were mounted on the roofs of the test vehicles with a magnetic mount.

Tests were conducted over a 1-year period in Austin, Dallas, Fort Worth, San Angelo, and Laredo. In addition, a few tests were conducted outside the state of Texas at several airport locations. Tests included stationary tests on the roof of the building housing the Center for Transportation Research. These tests provided a measure of wander of the differentially corrected position under static conditions. Another test site was a closed-circuit course that was used as the reference course around the perimeter of Austin's Robert Mueller Airport along the public highway. Tests were conducted in both daylight and nighttime conditions.

TEST RESULTS

Static test results showed that the OMNISTAR eight-channel and twelve-channel receivers could meet the 2 m accuracy standard more than 90 percent of the time. One set of static tests exceeded expectations, and the receiver was sent back to the manufacturer for service. The antenna cord was replaced once because of the potential for kinking and crimping in the cable, which reduced the accuracy of the receiver.

In one dynamic test on an airport runway, the antenna seemed to have better reception and less loss of differential correction signal in one direction than it did in the other. This directional difference was reported, and the manufacturer replaced the antenna when the unit was serviced for GPS rollover week.

The differential correction signal from the geostationary satellite was received with interference in two locations near airports. The L-Band model was used specifically because it was expected to have less interference than a C-Band model. In both the newer L-Band and older C-Band receivers, OMNISTAR uses a frequency band that is open to other commercial users. There is considerable traffic in these frequency bands, and strong signals in nearby frequencies can cause signal-to-noise-ratio interference for the differential correction signal. Keeping the receiver in the nonscanning mode may improve the reception in these situations.

In both these cases, the interference was localized, and moving the receiver as little as 100 to 200 ft would regain the differential signal. These were locations where a line-of-sight path to the geostationary satellite could be maintained, but interference, rather than obstructions, was causing loss of signal. The interference problem was discussed extensively with the technical support staff for the OMNISTAR system, but the source of the interference was never identified or resolved. The limited areas of interference were not significant enough to consider not using this system for pavement data collection methods.

There is always a limitation with GPS that requires it to have sufficient line-of-sight with the moving constellation of GPS satellites in order to have a sufficient number of satellites to calculate a position. The geometry and number of satellites in view determine the accuracy of the position that a receiver can calculate. This limitation can be a factor in cities where buildings will block the view of a certain percentage of the sky. In addition, heavy tree cover or natural terrain can also block out several satellites.

This limitation of GPS was taken into account before the start of the project. The application of pavement data collection was developed with this limitation in mind. The TxDOT road network has a large rural component, and a percentage of "drop outs" can be compensated for in other ways, such as inertial referencing or post-processing. One objective of this research was to determine whether techniques other than the OMNISTAR unit alone might be required.

However, in addition to the line-of-sight problem of the GPS satellites, the OMNISTAR differential correction also has a similar limitation. In this case, the differential correction signal is continuously broadcast from a geostationary satellite. This setup provides a single satellite at a single location that can be more readily obstructed.

A geostationary satellite remains in the same position in the sky because it actually is orbiting the earth at the same relative speed at which the earth is rotating. Therefore, the only locations where satellites can be in a geostationary orbit are directly above the equator. In Austin, at latitude of 30º north, the geostationary satellite is approximately 60º above the horizon in the southern sky. The farther north (or south) of the equator the receiver is located, the lower in the sky the geostationary satellite becomes. At 45º north latitude, a geostationary satellite is approximately 45º above the horizon.

The test results indicate that the differential correction signal can be interrupted while traveling in a vehicle during the following conditions:

- when the test vehicle passes under overpasses or fly-overs,
- when the test vehicle travels in the north-south direction near large overhead traffic signs, and
- near tall trees and buildings that block the southern exposure of the sky.

Normally, short-duration interruptions of the differential correction signal are not a problem because the position does not move too far off line. Also, the receiver sends position location information every second in NEMA 0183 format that includes a code that indicates whether the signal is differentially corrected. However, depending upon the software in the receiver and whether a navigation filter is installed in the receiver, different results can be achieved.

The following example is a test case that yielded unacceptable performance of the OMNISTAR eight-channel receiver. This example was discussed with the manufacturer, and the only method of resolution was to upgrade to the twelve-channel receiver. Although “drop outs” occurred with the twelve-channel receiver, none were ever as significant as this single test case.

While GPS data was being collected for accuracy verification at Dallas/Fort Worth (DFW) Airport, the following situation was encountered. Using the OMNISTAR 3000L8 receiver and GeoLink Powermap software, data was collected at 1-second intervals with a laptop computer. As shown by a white line in the right side of Figure 5.1, while traveling southbound on the main spine road, the receiver broke lock for about 7 seconds while passing under the taxiway overpass. The receiver then reestablished lock and reported full differential correction in the NEMA string, but it was reporting 76 m to the east of true position. It then slowly corrected back to position, taking 90 seconds to report a position that was within the roadway on which the vehicle was traveling. Based on interpretation of the data collected in NEMA format and included in Appendix B, the receiver was reporting a good position dilution of precision (PDOP) and was receiving differential correction.

The problem was not that 7 seconds of dropout occurred, because the NMEA string reported correctly the loss of differential correction. The problem was that the position jumped 76 m to the east, though the receiver reported this position as a differentially corrected position. Because the receiver had no navigation filter installed, the unusual jump in position did not raise any indications that a large deviation had occurred. Also troubling was that the position took 90 seconds to steadily correct back to track.

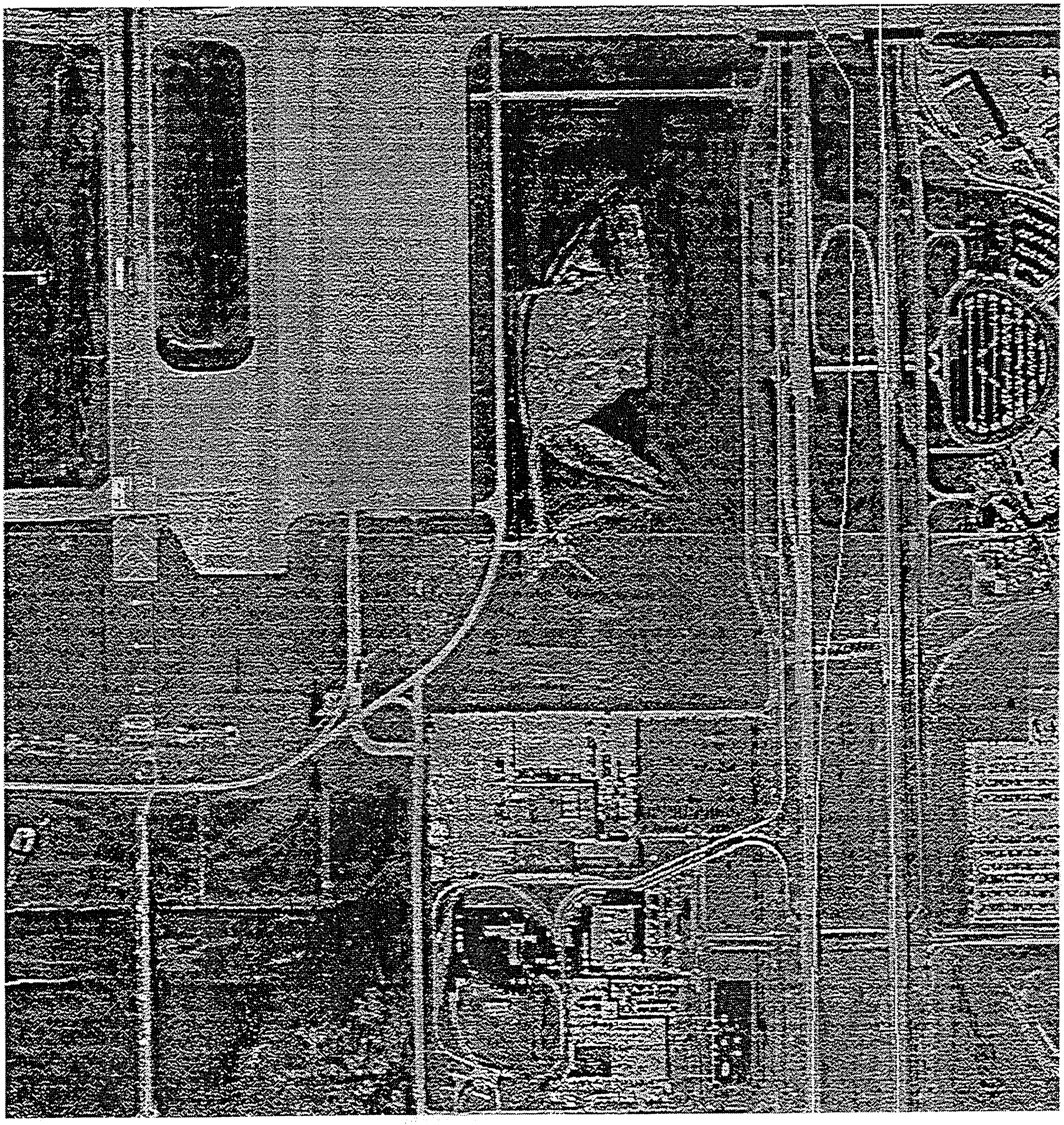

Figure 5.1 Jump in DGPS Location after Passing under Overpass

After an investigation of several months by the manufacturer and discussion among the research staff and GPS receiver experts, no answer to the problem was determined. An upgrade to the OMNISTAR 3000-L12 receiver was made by the manufacturer, and testing resumed.

The OMNISTAR system has the option of using a receiver built into the unit or proving the differential correction to an external receiver. A twelve-channel built-in unit has the advantage over an eight-channel built-in unit in that the GPS reacquisition time is faster and less likely to drift position. Only twelve GPS satellites are normally available in view at any one time, and, therefore, a twelve-channel receiver does not have to use a channel to skip between satellites. The GPS accuracy and resistance to multi-path errors can be improved by using a higher-quality external receiver.

Repeating the experiment at DFW Airport with the 12-channel receiver eliminated the large 76 m jump that was recorded the first time. However, as shown in Figure 5.2, at another airport the large jumps occurred even without passing under an underpass, but normally the position returned back to the runway location immediately upon reacquiring the signal.

Figure 5.2 shows GPS data collected along a runway centerline and a few taxiways, plotted as line strings in MicroStation and displayed in ArcView 3.0. Notice that the data show a jump of 850 m in position occurring from the runway, across a second runway and two parallel taxiways, but immediately returning. Notice also, in the same figure, that at approximately 1,000 ft from the end of the runway, another smaller anomaly of the DGPS data was observed. This smaller anomaly is enlarged for detail in Figure 5.3.

In Figure 5.3, there are two GPS tracks. One was taken on the aircraft centerline at high speed and appears in the figure as a straight line. The second set of data was taken at low speed slightly off the centerline of the runway. Figure 5.3 shows the DGPS data collection with three deviations from correct position. The data collected (in white on the figure) were reported as differentially corrected, and the data in black were reported as a lost differential correction signal. When the differential correction signal is lost, selective availability, the intentional error introduced by the military, is not corrected. Therefore, deviations of 50 to 100 m are possible.

In this case, data collected, as shown in Figure 5.3, would require that manual revisions to the data be made to delete those deviations if the required accuracy distance is exceeded. The deviations cannot be automatically corrected by software by deleting all non-differentially corrected reported locations. As shown in Figure 5.3, there are reported points that still indicate differential corrections (shown in white), but they are up to 20 m in error.

Figure 5.2 Jump of 850 m in GPS Position

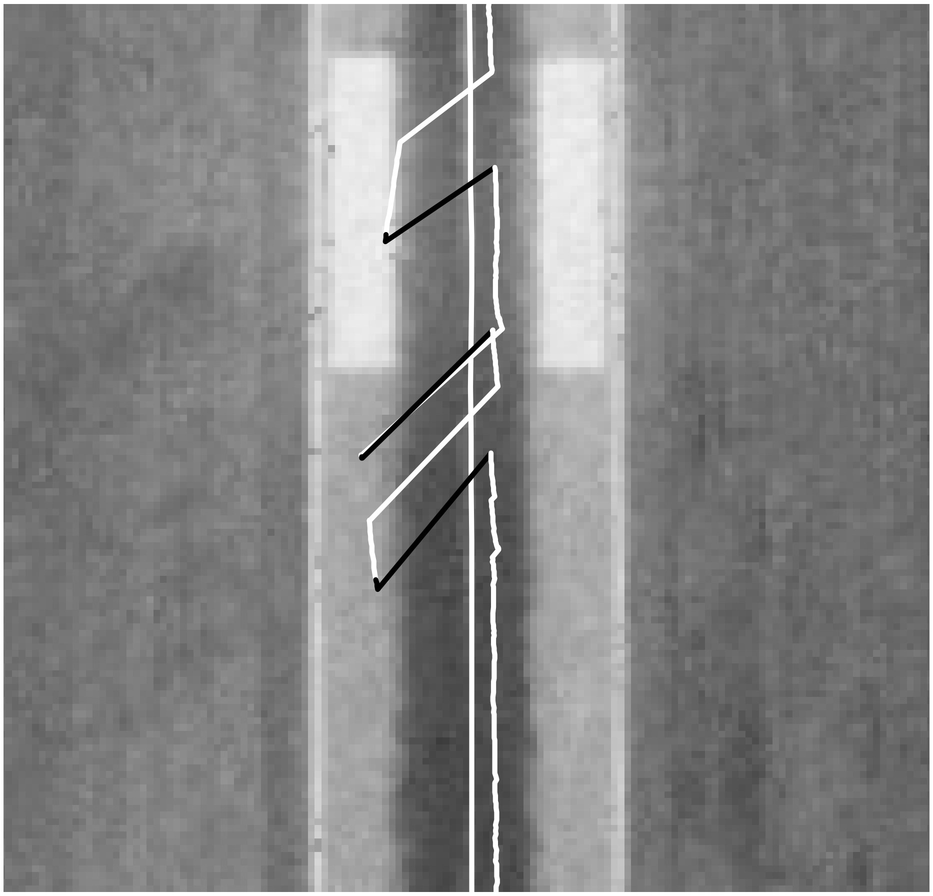

Figure 5.3 Smaller Jumps of 20–30 m in DGPS Position

Additional tests were conducted using the Delorme Street Atlas 6.0 software, which is inexpensive, allows data collection, and provides a background map with reasonable accuracy. A possible data collection scenario would be to use the Delorme Street Atlas software as a navigation tool, showing position on a background map while recording the GPS track to the laptop computer. Field tests indicated the plausibility of the data collection method. The principal drawback was the non-standard data collection format of the Delorme software. However, this problem can probably be overcome with software. There is an unofficial program available on the World Wide Web called GPL2ASC that converts a Delorme gpl format file into an ASCII format location file.

Surprisingly, the Delorme software generally had very accurate maps for road alignments. In both the Delorme Software and the TxDOT maps, it was observed that corrections had been made to the alignment of the highway to smooth out curves that were not correct, either on the Delorme software or the TxDOT map. However, as a navigation tool the Delorme software was quite user friendly and provided very useful information. It even indicated individual unpaved driveways in rural areas on the map quite accurately.

RECOMMENDATIONS

The first recommendation is that the OMNISTAR 3000L12 or 3000L8 receivers should not be used alone because they are inadequate for the data collection problem of attaching pavement data to the GIS road network. There are simply too many data "dropouts" to automatically correct the data. Attempts to write programs that plotted data only if the previous point did not exceed a given distance were successful. However, even with these corrected data there are significant gaps and sufficiently poor location points to make manual editing of the data a necessity.

The second recommendation is that the OMNISTAR differential correction system be coupled with an external, high-quality GPS receiver, such as the Trimble Pathfinder Pro XR. A better quality receiver than the built-in card solution will most likely reduce the dropout rate and result in better positional accuracy.

The third recommendation is that a solution for pavement data collection should investigate the need for adding an inertial reference unit to keep track of relative position during times of loss of differential correction or GPS satellite reception. Inertial reference units, such as laser ring gyroscopic units, have proved their ability to be coupled to GPS units, improve accuracy, and keep track of vehicle movements during reception loss. The main issue is the trade-off between the cost of the integration of the inertial reference unit and the requirements of vehicle speed during data collection and its influence on the accuracy and reliability of location data.

The forth recommendation is that the Delorme Street Atlas software be considered for vehicle navigation rather than TxDOT maps for inspection of highways and pavement data collection. An agreement could possibly be negotiated with Delorme for TxDOT to provide corrections to alignment where errors are found, and Delorme could provide license for TxDOT's use of the software. This type of agreement would benefit the department, Delorme, and all Texas users of the Delorme software.

CHAPTER 6. RECOMMENDED DEPARTMENT REQUIREMENTS FOR GIS PAVEMENT MANAGEMENT

This chapter will discuss the recommended department needs for the technical capabilities of the GIS required for applications for the Texas pavement management information system (PMIS). This report does not discuss such implementation issues as training, staffing, or costs. A separate report has been written concerning implementation plans and recommendations.

APPLICATION OF TEXAS GIS ARCHITECTURE

The Information Systems Division (ISD) has developed a core technology architecture and GIS architecture to define the information technology directions, standards, policies, and procedures for adopting GIS and other computer applications for TxDOT. The scope of this research project changed when the GIS architecture was published after the research project started. The scope no longer permitted the researchers to establish research needs independent of the established software standards. Therefore, the needs analysis is software independent and assumes that the Texas GIS architecture can meet the needs.

GIS technology and GIS software architecture are changing rapidly. TxDOT should review the GIS architecture biannually and establish GIS spatial data standards. TxDOT should participate in national organizations that are writing spatial data standards.

USING GIS TO MEET PMIS OBJECTIVES

There are always different levels of users in all organizational implementations of GIS. The power users are responsible for the policies, direction, and administration of the data. Some need the data on a system-wide basis and others need only their district's data or occasionally another district's data for comparison and analysis. Another group is interested only in viewing reports, graphics, and products of the GIS.

The difference among power users, data custodians, and viewers is well described in many publications. Most GIS software providers have different software versions for each level of use or have security controls so that viewers can only view or query data but cannot change it. This report does not deal directly with these security controls, but rather analyzes the actual data needs of the different TxDOT user levels.

This report examines ways in which PMIS is actually used and how it can be improved to make the best use of the valuable data that can be maintained in the pavement management GIS. Whether these data are being used at the field level, in the area office, or at the highest division level, there are certain needs that apply to the pavement management of GIS.

Chapter 2 describes the needs assessment made as a result of the expert task group meeting. The needs and characteristics of the GIS were grouped into functions, and priorities were derived from the survey of the expert task group. The six GIS functions are:

1. GIS System Characteristics,
2. Data Entry,
3. Management, Transformation, and Transfer of Data,
4. Integration of Data,
5. Query and Analysis, and
6. Display and Reporting

Assuming that user friendliness and dynamic segmentation are requirements of the GIS software, the other five priorities are discussed as a function of location: area, district, division, and executive levels.

Table 6.1 (page 40) shows data needs for PMIS integrated with GIS in five categories and indicates the need for each item at the area, district, division, and executive levels. The five categories are:

1. Preparation of Maps for Decision-Making,
2. Integration of Existing Databases,
3. Integration of New Databases,
4. Project Level Data, and
5. Pavement Inspection Data.

NEEDS AT AN AREA OFFICE

DATA ENTRY

The area office is on the front line of pavement design, maintenance, and rehabilitation. Currently, pavement design at many area offices is based on previous experiences. However, with the computerization of area offices and access to GIS technology, pavement designs will be improved. Many area offices rely upon the experience of engineers who have worked in the area for many years. Area offices need the opportunity to add data to the GIS, whether through local knowledge or windshield surveys. The area office should be responsible for populating the new databases that are not yet fully populated, such as those for pavement layers, soils, drainage structures, and maintenance actions.

MANAGEMENT, TRANSFORMATION, AND TRANSFER OF DATA

The area office needs all the project-level data it can manage in a GIS. A local knowledge of data such as weather conditions, construction information, as-built drawings, soil conditions, pavement layers, and material characterization information will lead to better local designs. In addition, personnel in the local offices are most likely to notice errors and corrections that are needed in the database; therefore, they should have the capability to make those changes.

INTEGRATION OF DATA

The area office needs access to data that are necessary for pavement design and performance review. The area office needs access to the PMIS database, pavement evaluation data, and maintenance data. The area office needs all the project-level data it can manage in order to make optimum design decisions.

QUERY AND ANALYSIS

Users at the district level and higher will perform most of the pavement analysis techniques. However, area office users will need the capability to conduct analyses of pavement performance, pavement conditions, and maintenance actions.

DISPLAY AND REPORTING

Area office users should have their fingers on the pulse of project-level data. The area office is most likely to spot and correct errors in the data and to use web-based applications for analysis. Aerial photography and color maps are required. The area office needs the ability to make custom reports and queries.

NEEDS AT A DISTRICT OFFICE

DATA ENTRY

Districts are responsible for collecting the data that are entered into the PMIS. Except for devices used only by the Pavements Section of the Design Division, districts are responsible for falling weight deflectometer (FWD) and other pavement evaluation testing. The district office should have the ability to enter all data that it needs.

MANAGEMENT, TRANSFORMATION, AND TRANSFER OF DATA

The district office will become the power user of GIS for pavement management applications. Personnel need the ability to make maps, import and export data, add digital photography, make changes to roadway alignment, and review construction documents.

INTEGRATION OF DATA

The district office needs to perform many queries and analyses and therefore needs to integrate many different types of data. Personnel need to integrate existing PMIS, TRM, and traffic data with future databases that include weather, soils, pavement layers, and actual test results for pavement test devices. Currently, district pavement engineers would like to perform new analyses to evaluate different environmental and pavement materials factors, but they don’t have the data. This is the user level that most needs GIS to develop better rehabilitation options and better pavement designs.

Query and Analysis

Although the central pavement section performs very complex analyses for management of the entire statewide system, district pavement engineers have a need to perform pavement performance and pavement life predictions using local knowledge and data. Some district pavement engineers have developed in-house databases and maps to record information they need to analyze their road network. Pavement district engineers have a need for extensive analysis. This is the user level at which additional innovations will come from using an integrated GIS. Pavement district engineers from all the districts should have regularly scheduled workshops to discuss their findings from the data they have.

Display and Reporting

District-level users have an urgent need for maps to display the data they need. Everything from pavement condition data to accident data needs to be visualized on specialized maps customized by the districts. Standardization of predefined maps is required so that users at the division level and higher can easily interpret the same information from each of the districts.

Needs at the Division Level

The Pavements Section of the Design Division is responsible for maintaining the PMIS database, performing the network analysis, making recommendations of allocation of resources, and developing the annual reporting. This section also coordinates all research relative to new methods for better pavement design and rehabilitation strategies.

Data Entry

The Pavements Section maintains and develops the system-wide pavement testing and either performs the testing or schedules the districts to perform it. Personnel need to enter specialized test data and have control over all research and test section data.

Management, Transformation, and Transfer of Data

The Pavements Section needs to be able to make corrections to the database and review all the district submissions. Although much of the data entry will be delegated to the districts, the division needs to perform quality control for all new data before it is used in complex analyses. The manager of the PMIS and other statewide databases will remain at the division level.

Integration of Data

The effective PMIS system will use data for analyses from divisions other than the Pavements Section. Planning and traffic databases and construction data will have to be analyzed. This has been a problem in the past because the pavement section must rely on others to provide the necessary data for complex analyses. The accuracy of existing and forecast traffic data is an essential ingredient in pavement design. Other division offices will want to manage their data with GIS once they discover the advantages of using it.

QUERY AND ANALYSIS

As databases become populated on a system-wide basis, queries that are more complex will be developed at the division level. A phased GIS implementation plan could possibly limit the queries and analyses to predefined areas until the new databases become operational.

DISPLAY AND REPORTING

Division-level users have an urgent need for maps to display the data they need. Standardization of predefined maps is required so that users at the division level and higher can easily interpret the same information from each of the districts and the state level. Because of the large size of the state of Texas, statewide maps cannot be as detailed as district-level mapping. However, most of the GIS information provided to the public will be prepared at the division level. The Pavements Section will continue to provide PMIS reporting although most of the current reports will become electronic and graphical. The ability to distribute maps and data using web-browser-enabled reports is critical to the efficient use of the information. The millions of dollars spent to collect pavement data are wasted unless the data become information that managers and decision-makers can have readily accessible and whose accuracy they can trust.

NEEDS AT THE EXECUTIVE LEVEL

Although the researchers have not interviewed personnel at the executive level of TxDOT, some general observations have been made as to requirements for the executive-level users. The executive level probably has no requirement or need to enter, manage, transform, or integrate data.

QUERY AND ANALYSIS

Executive-level users will probably have predefined queries developed for them. Reports can be automatically prepared and sent to them. GIS can also be simplified so that frequently viewed data can be updated by others and reviewed upon demand. If the executive-level user has a need for querying the system, he will ask someone to develop and send it to him.

DISPLAY AND REPORTING

Executive-level users will have extensive display and reporting capability. Depending upon the level at which executives embrace GIS technology, the capabilities at this level can be quite complex. If support from the executive level is beneficial for implementation, then considerable emphasis should be placed on developing reports customized for the executive level.

DATA REQUIREMENTS FOR TXDOT PAVEMENT MANAGEMENT USING GIS

Table 6.1 is provided as a listing of data needs and requirements for pavement management. Not all the items have the same priority. The implementation planning should take into account what can be done with existing databases while still leaving the functionality to add new databases and new analysis capability in the future.

TABLE 6.1 GIS DATA NEEDS BY OFFICE LEVEL

Needs	Area	District	Division	Executive
1. Preparation of Maps for Decision Making				
Condition of Roads	Y	Y	Y	Y
Construction Projects	Y	Y	Y	Y
Allocation of Funds within District	N	Y	N	N
Effects of Maintenance	Y	Y	N	N
Budget Planning	N	Y	Y	Y
Budget Preparation Tools	Y	Y	Y	Y
Accident Data	Y	Y	Y	N
Network Trend Information	N	Y	Y	Y
Pavement Performance History	Y	Y	N	N
Pavement Condition Projection Based upon Budget Cases	N	Y	Y	Y
2. Integration of Existing Databases				
PMIS Database — Current Year Data	Y	Y	Y	Y
PMIS Database — Multi-Year Data	Y	Y	Y	N
PMIS Reports	Y	Y	N	N
Traffic Database	Y	Y	Y	N
TRM Database	Y	Y	Y	Y
Local Traffic Counts	Y	Y	N	N
Road Life Cross Section Data	Y	Y	Y	N
Bridges (location only)	Y	Y	N	N
BRINSAP Data	Y	Y	Y	N
HPMS & Federal Databases	N	Y	Y	N
TIP Projects	N	Y	Y	Y
Aerial Photography	Y	Y	Y	Y
Load limited roadways and Bridges	Y	Y	N	N

Table 6.1 GIS DATA NEEDS BY OFFICE LEVEL (cont.)

Needs	Area	District	Division	Executive
3.Integration of New Databases				
Soil Conditions	Y	Y	N	N
Weather Conditions – Rainfall	Y	Y	N	N
Weather Conditions – Temperature	Y	Y	N	N
Maintenance Database	Y	Y	N	N
Elevation Data	Y	N	N	N
Significant Trip Generators, Heavy Load Sites	Y	Y	N	N
Drainage Structures	Y	Y	N	N
Digital Copy of Plans	Y	Y	N	N
Research & Special Pavement Test Section Database	Y	Y	Y	N
4. Project Level Data				
Control Section Job (CSJ) Delineation	Y	Y	N	N
Aggregate Source	Y	N	N	N
Material Characteristics by Layer	Y	Y	N	N
Construction Cost	Y	Y	Y	Y
Triaxial Data	Y	N	N	N
5. Pavement Inspection Data				
Falling Weight Deflectometer	Y	Y	N	N
Profilometer Data	Y	Y	N	N
Rutting Data	Y	Y	N	N
Digital Camera Photography	Y	Y	N	N
Skid Data	Y	Y	N	N
Windshield Survey	Y	Y	N	N
Blade Patches	Y	Y	N	N
Ground Penetrating Radar (GPR) Data	Y	Y	N	N

REFERENCES

1. Fernando, Emmanual, Miguel Paredes, and Tom Scullion, "An Initial Evaluation of the Feasibility of a GIS to Support PMS Applications," Texas Transportation Institute, Research Report 930-4, August 1989.

2. Wisconsin DOT, Pavement *Management Decision Support Using a Geographic Information System*, May 1990.

APPENDIX A. POTENTIAL PMIS ACTIVITIES THAT CAN BE IMPROVED BY GIS

PRIMARY GIS OPERATIONS

Table A.1 summarizes six primary categories of GIS operations or tasks serving this purpose. They are:

- Data Entry,
- Management, Transformation, and Transfer of Data,
- Integration Platform and Common Location Reference System,
- Query and Analysis, and
- Display and Reporting.

DATA ENTRY

Before data can be used in a GIS, it must be in a suitable digital format. Forms such as hard copy maps, tables of attributes, photos, and satellite imagery can be converted into a suitable digital format. **Digitizing** is a widely used method for converting data from other sources into computer files. Modern computer technology can automate this process using **scanning technology**; small jobs may require manual digitizing. In addition to these two main methods and the existing digital files that can be loaded directly into a GIS, the following data entry methods can also be used to support GIS:

- **global positioning system (GPS)** receivers and other electronic data collectors providing spatial data information directly in electronic format,
- **digital cameras and remote-sensing technology** capturing digital images directly in raster form, and
- **photogrammetric stations** and **coordinate geometry (COGO)** from field surveys.

TABLE A.1 PRIMARY GIS OPERATIONS

<table>
<tr><th>CATEGORY</th><th>SUBCATEGORY</th></tr>
<tr><td>Data Entry</td><td>Digitizing
Scanning (automatic or semi-automatic)
Global positioning system
Digital cameras, remote sensing
Stereo plotter
Photogrammetric stations
COGO
Voice
Keyboard</td></tr>
<tr><td>Management, Transformation, and Transfer of Data</td><td>Storage of data
Access, retrieval and editing of data
Handling of raster and vector data and converting between them
Searching and sorting of data
Classification and reclassification of data
Data import and export
❖ Traditional media (tape, disk, CD-ROM)
❖ Network transfer
Map projection
Spatial data exchange
Geocoding</td></tr>
<tr><td>Integration Platform and Common Location Reference System</td><td>Integration of different systems
Integration of different processes
Integration of different technologies</td></tr>
</table>

TABLE A.1 PRIMARY GIS OPERATIONS (CONT.)

CATEGORY	SUB-CATEGORY
Query and Analysis	Query and analysis • Point-and-click queries • Logical query ❖ Spatial and attribute query • Spatial analysis • Buffering Network Analysis • Dynamic segmentation • Network overlay • Other (shortest path analysis, optimum tour routing) Polygon overlay
Display and Reporting	On-screen display • Thematic mapping ❖ Attribute classification ❖ Color coding or patterning of attributes, such as pavement condition • Zooming in, zooming out, panning, etc. Layout & report (Maps, tables, charts, statistics, etc.) • Cartographic output • Thematic mapping ❖ Attribute classification ❖ Color coding or patterning of attributes, such as pavement condition Static versus dynamic Multimedia • Video-logging • Photo-logging Internet

MANAGEMENT, TRANSFORMATION, AND TRANSFER OF DATA

Access, retrieve operations on both spatial and nonspatial data involve selective searches of databases and output of retrieved data in response to various queries. Queries can be made by location or by characteristics.

Editing includes zooming and panning, adding, deleting, copying, moving, and transforming objects by pointing, encompassing within an area, or by attribute values. **Spatial and non-spatial data management** is typically handled by a GIS package with customized software that functions as a database management system (DBMS) to handle attribute data.

Spatial data exchange is important for the integration of disparate data sets from various computer systems or GIS software packages. The two basic methods for data exchange between different GISs are: 1) direct conversion of data from one system to another using proprietary formats and 2) translation of data via a standardized neutral exchange format.

Data transformation is either between data models or between coordinate systems. Transformations between data models include raster-to-vector conversion and vector-to-raster conversion. Coordinate systems transformation can be 1) arbitrary-to-ground, 2) between geodetic datums, or 3) ground-to-ground.

INTEGRATION PLATFORM AND COMMON LOCATION REFERENCE SYSTEM

The most important benefits of using GIS for any project stem from its role as an "integrator." Transportation management systems have been developed and implemented by state DOTs in many forms. However, most of these systems were developed and operated as stand-alone systems. The data structure and computing environment, including software, hardware, etc., vary tremendously. The incompatibilities among these systems are serious obstacles for data sharing and free information flow. Because most of the data for all organization levels, policies, management, and operations, are geographically referenced, GIS makes it possible to link and integrate different systems, processes, and technologies that are difficult to associate through any other means. GIS is the most effective computerized common location reference system.

QUERY AND ANALYSIS

GIS provides both simple point-and-click query capabilities and sophisticated analysis tools to provide timely information to users. Query is the process of selecting information from a GIS by asking spatial or logical questions of the geographic data. Spatial query is the process of selecting features based on location or spatial relationship. Logical query is the process of selecting features whose attributes meet specific logical criteria. Analysis is the process of extracting or creating new information about a set of geographic features. There are two important types of analysis in GIS: spatial analysis and network analysis.

Spatial analysis functions distinguish GIS from other information systems and from computer-aided mapping systems.

Network analysis is the most important GIS operation for transportation applications. Dynamic segmentation and network overlay are two critical network analysis operations which enable spatial analysis and integration of highway inventory databases and any other databases that are linearly referenced. Dynamic segmentation is the ability to store attribute data in a single storage item for multiple and partial segments of graphic elements. If used effectively, it can reduce the data input requirements and data storage requirements.

Polygon overlay operations combine separate spatial databases and at the same time integrate their attributes. There are three variations: 1) Polygon-on-Polygon. 2) Line-in-Polygon. 3) Point-in-Polygon.

It is the overlay functions (both network overlay and polygon overlay) that best exploit the data integration power of GIS. The purpose is to combine existing databases in such ways that new information is created.

DISPLAY AND REPORTING

GIS allows users to display visually the results of database queries and pavement management analyses on a map. Through color-coding of pavement conditions, users can view network conditions and projected work programs. Integrated with graphs, tables, charts, multimedia data, etc., maps are very efficient in helping PMIS engineers communicate with the public.

IDENTIFICATION OF POTENTIAL PMIS ACTIVITIES THAT CAN BE IMPROVED BY GIS

TxDOT PMIS is defined as an automated system for storing, retrieving, analyzing, and reporting information to help with a pavement-related decision-making process. All pavement management activities can be grouped into the following two basic working levels: network level and project level. The primary purpose of the network level management activities is to develop a priority program and schedule of rehabilitation, maintenance, or new pavement construction work within overall budgets. Project level work comes "on stream" at the appropriate time in the schedule. As seen in Table A-2, the PMIS activities for both network level and project level are aggregated and sorted in the order of sequence.

TABLE A.2 POTENTIAL PMIS ACTIVITIES THAT CAN BE IMPROVED BY GIS

Network-Level PMIS Activities	Project-Level PMIS Activities
• Segmentation • Data acquisition and processing • Identification of available resources • Summarization of current status • Identification of present needs and future needs • Identification of candidate projects for improvement • Generation of maintenance & repair alternatives • Technical and economic analysis • Prioritization of maintenance & repair alternatives • Budget planning and distribution • Development of maintenance & repair programs • Summarization of future status • Justification of budget requests: Legislators are faced with a variety of competing • Effects of less capital • Effects of deferring work or lowing standards • Effects of increased load limits • Effects of the implementation of maintenance & repair • Updating of data • Feedback of information for improvement of model • Updating of maintenance & repair program	• Subsectioning • Data acquisition and processing • Summarization of current status • Generation of alternatives • Technical and economic analysis • Selection of best alternatives • Summarization of future status • Implementation • Effects of implementation • Updating of data • Rescheduling measures • Feedback for improvement of models

GIS ACTIVITIES THAT CAN IMPROVE PMIS ACTIVITIES AND CORRESPONDING BENEFITS

Table A.3 and Table A.4 summarize the primary GIS operations that have the potential to improve the existing PMIS activities at both network level and project level. For each PMIS activity, the potential benefits owing to the adaptation of GIS are also summarized.

TABLE A.3 POTENTIAL GIS OPERATIONS TO IMPROVE PMIS (NETWORK LEVEL) AND RELATED SPECIFIC BENEFITS

NETWORK-LEVEL PMIS ACTIVITIES	POTENTIAL PRIMARY GIS OPERATIONS TO IMPROVE THE PMIS	SPECIFIC BENEFITS
Segmentation	Dynamic segmentation, thematic mapping, classification and reclassification of data, etc.	Reduction of data input requirements and data storage requirements, information that is easier to obtain and more meaningful (visually investigated data)
Data acquisition and processing	GPS, Geocoding, access and retrieval of data, data import and export, spatial data exchange, handling of raster and vector data and converting between them, searching and sorting of data, map projection, on-screen display, etc.	More efficient and accurate data collection, identification of omitted or wrong pavement attributes, verification of spatial accuracy, information that is easier to obtain and more meaningful (visually investigated data)
Identification of available resources	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, point-and-click query, logic query, polygon overlay, thematic mapping, geocoding, etc.	Information that is easier to obtain and more meaningful (visually investigated data), better decision-making, more efficient and effective retrieval of expected new information
Summarization of current status	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logical query, thematic mapping, layout of report, etc.	Reduction of data input requirements and data storage requirements, more efficient and effective retrieval of expected new information, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, better decision-making
Identification of present needs and future needs	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlays, point-and-click query, logic query, thematic mapping, layout of report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements
Identification of candidate project for improvement	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, point-and-click query, logic query, dynamic segmentation, network overlay, thematic mapping, layout, report, etc.	Better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, better decision-making, more efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements

TABLE A.3 (cont.)

NETWORK-LEVEL PMIS ACTIVITIES	POTENTIAL PRIMARY GIS OPERATIONS TO IMPROVE THE PMIS	SPECIFIC BENEFITS
Generation of maintenance & repair alternatives	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, better decision-making
Technical and economic analysis	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), better decision-making
Prioritization of maintenance & repair alternatives	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), better decision-making
Budget planning and distribution	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), better decision-making
Development of maintenance & repair programs	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	Better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, better decision-making, more efficient and effective retrieval of expected new information
Summarization of future status	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature

TABLE A.3 (cont.)

NETWORK-LEVEL PMIS ACTIVITIES	POTENTIAL PRIMARY GIS OPERATIONS TO IMPROVE THE PMIS	SPECIFIC BENEFITS
Justification of budget requests	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, point-and-click query, logic query, thematic mapping, layout, report, etc.	Better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, more efficient and effective retrieval of expected new information
Effects of less capital	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, point-and-click query, logic query, thematic mapping, layout, report, etc.	Better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, more efficient and effective retrieval of expected new information
Effects of deferring work or lowing standards	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, point-and-click query, logic query, thematic mapping, layout, report, etc.	Better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, more efficient and effective retrieval of expected new information
Effects of budget requests on future status	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, point-and-click query, logic query, thematic mapping, layout, report, etc.	Better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, more efficient and effective retrieval of expected new information
Effects of increased load limits	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, point-and-click query, logic query, thematic mapping, layout, report, etc.	Better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, more efficient and effective retrieval of expected new information

TABLE A.3 (cont.)

NETWORK-LEVEL PMIS ACTIVITIES	POTENTIAL PRIMARY GIS OPERATIONS TO IMPROVE THE PMIS	SPECIFIC BENEFITS
Effects of the implementation of maintenance & repair	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, point-and-click query, logic query, thematic mapping, layout, report, etc.	Information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, more efficient and effective retrieval of expected new information
Updating of data	GPS, access and retrieval of data, storage of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, data import and export, on-screen display, etc.	More efficient and accurate collection of data, identification of omitted or wrong pavement attributes, reduction of data input requirements and data storage requirements, information that is easier to obtain and more meaningful (visually investigated data)
Feedback of information for improvement of model	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, point-and-click query, logic query, thematic mapping, etc.	More efficient and effective retrieval of expected new information, information that is easier to obtain and more meaningful (visually investigated data)
Updating of maintenance & repair programs	Access and retrieval of data, storage of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, better decision-making

TABLE A.4 POTENTIAL GIS OPERATIONS TO IMPROVE PMIS (PROJECT LEVEL) AND RELATED SPECIFIC BENEFITS

PROJECT-LEVEL PMIS ACTIVITIES	POTENTIAL PRIMARY GIS OPERATIONS TO IMPROVE PMIS	SPECIFIC BENEFITS
Subsectioning	Dynamic segmentation, thematic mapping, classification and reclassification of data, etc.	Reduction of data input requirements and data storage requirements, information that is easier to obtain and more meaningful (visually investigated data)
Data acquisition and processing	GPS, geocoding, access and retrieval of data, data import and export, spatial data exchange, handling of raster and vector data and converting between them, searching and sorting of data, map projection, on-screen display, etc.	More efficient and accurate collection of data, identification of omitted or wrong pavement attributes, verification of spatial accuracy, information that is easier to obtain and more meaningful (visually investigated data)
Summarization of current status	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logical query, thematic mapping, layout of report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, better comprehension of complex relationships among many decisions, information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, better decision-making
Generation of alternatives	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, information that is easier to obtain and more meaningful (visually investigated data), better decision-making
Technical and economic analysis	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, information that is easier to obtain and more meaningful (visually investigated data), better decision-making

TABLE A.4 (CONT.)

PROJECT-LEVEL PMIS ACTIVITIES	POTENTIAL PRIMARY GIS OPERATIONS TO IMPROVE PMIS	SPECIFIC BENEFITS
Selection of best alternatives	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, information that is easier to obtain and more meaningful (visually investigated data), better decision-making
Summarization of future status	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, polygon overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, information that is easier to obtain and more meaningful (visually investigated data), better decision-making, more efficient and effective communication with public and legislature
Implementation	GPS, access and retrieval of data, storage of data, searching and sorting of data, classification and reclassification of data, geocoding, on-screen display, thematic mapping, etc.	More efficient and accurate collection of data, identification of omitted or wrong pavement attributes, verification of spatial accuracy, information that is easier to obtain and more meaningful (visually investigated data), better decision-making
Effects of implementation	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, dynamic segmentation, network overlay, point-and-click query, logic query, thematic mapping, layout, report, etc.	Information that is easier to obtain and more meaningful (visually investigated data), more efficient and effective communication with public and legislature, more efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements
Updating of data	GPS, access and retrieval of data, storage of data, searching and sorting of data, classification and reclassification of data, data import and export, on-screen display, thematic mapping, etc.	More efficient and accurate collection of data, information that is easier to obtain and more meaningful (visually investigated data)
Rescheduling measures	Access and retrieval of data, storage of data, classification and reclassification of data, point-and-click query, logic query, dynamic segmentation, network overlay, thematic mapping, layout, report, etc.	More efficient and effective retrieval of expected new information, reduction of data input requirements and data storage requirements, information that is easier to obtain and more meaningful (visually investigated data), better decision-making, more efficient and effective communication with public and legislature
Feedback for improvement of models	Access and retrieval of data, searching and sorting of data, classification and reclassification of data, etc.	

APPENDIX B. GPS DOCUMENTATION

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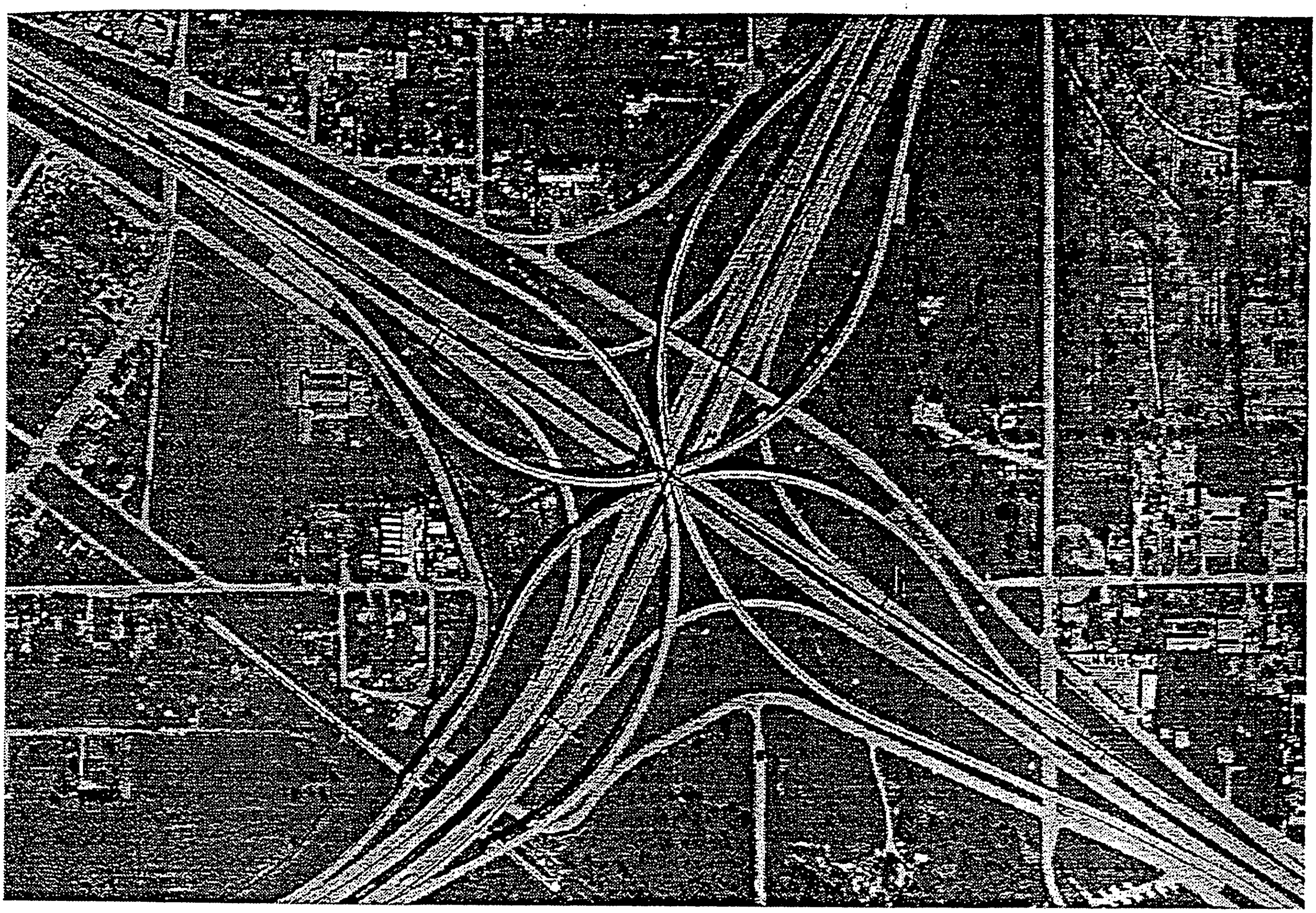
IH0020 and US0175 in southeast Dallas County



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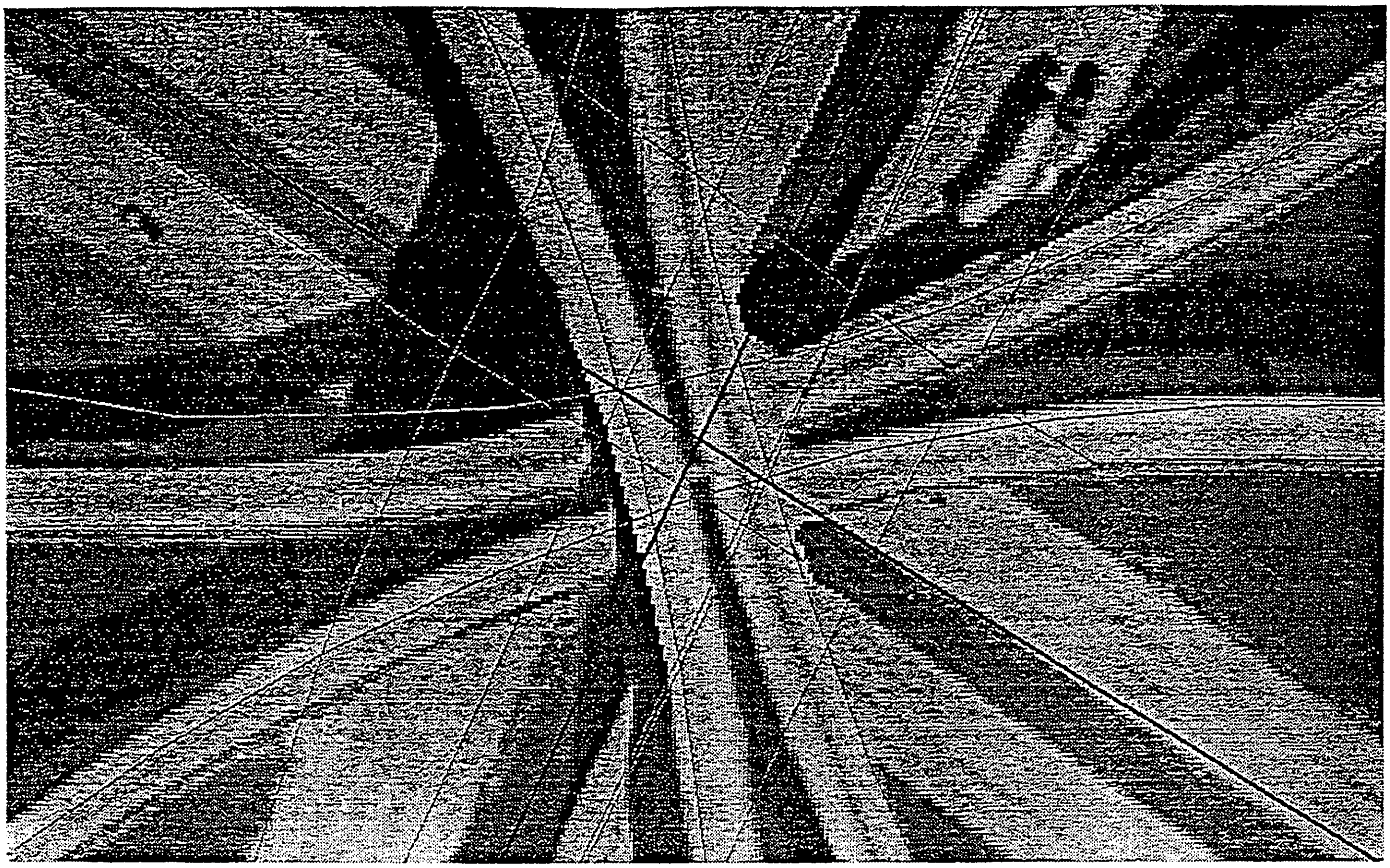
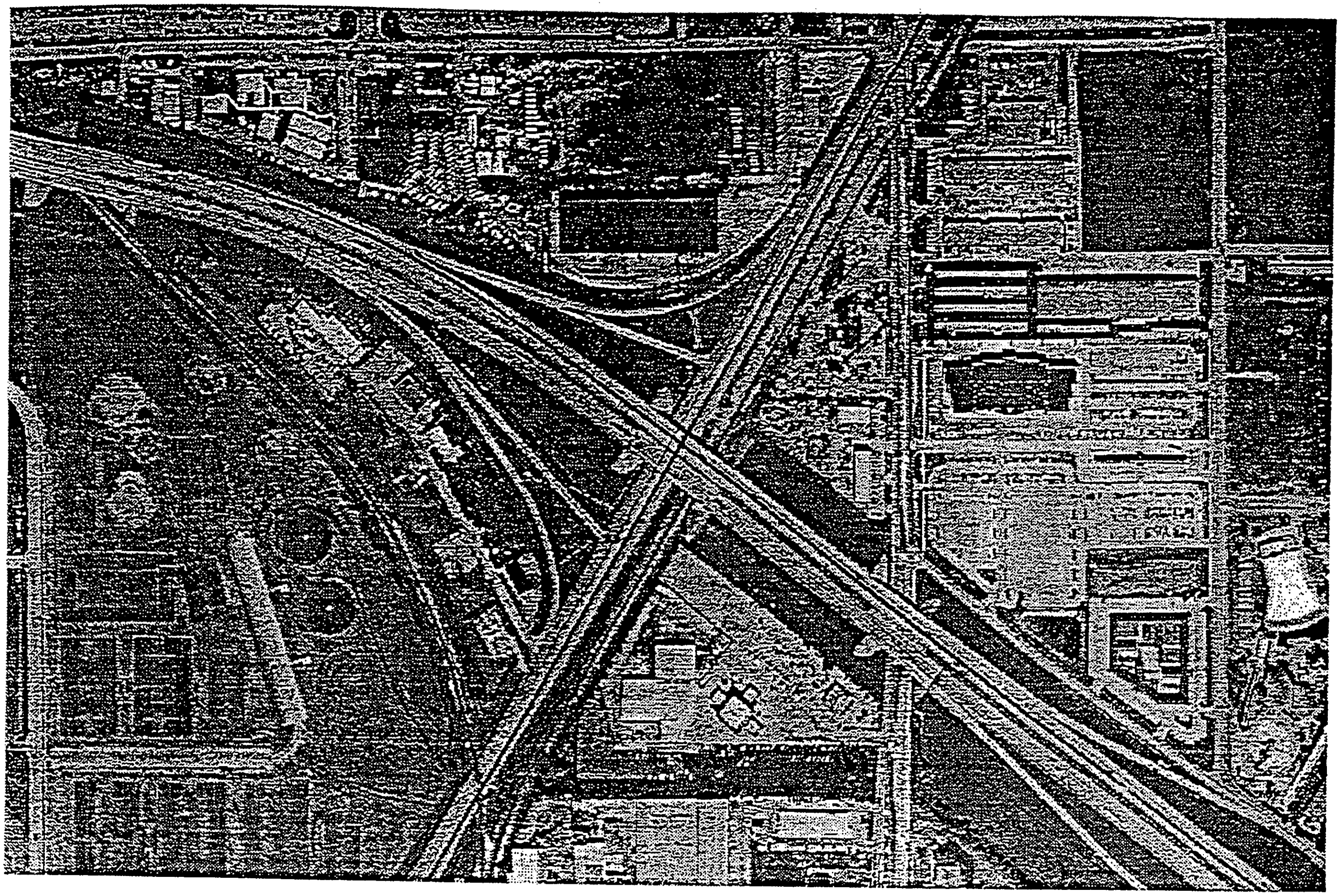


IH0635 and SH0078 in northeast Dallas County



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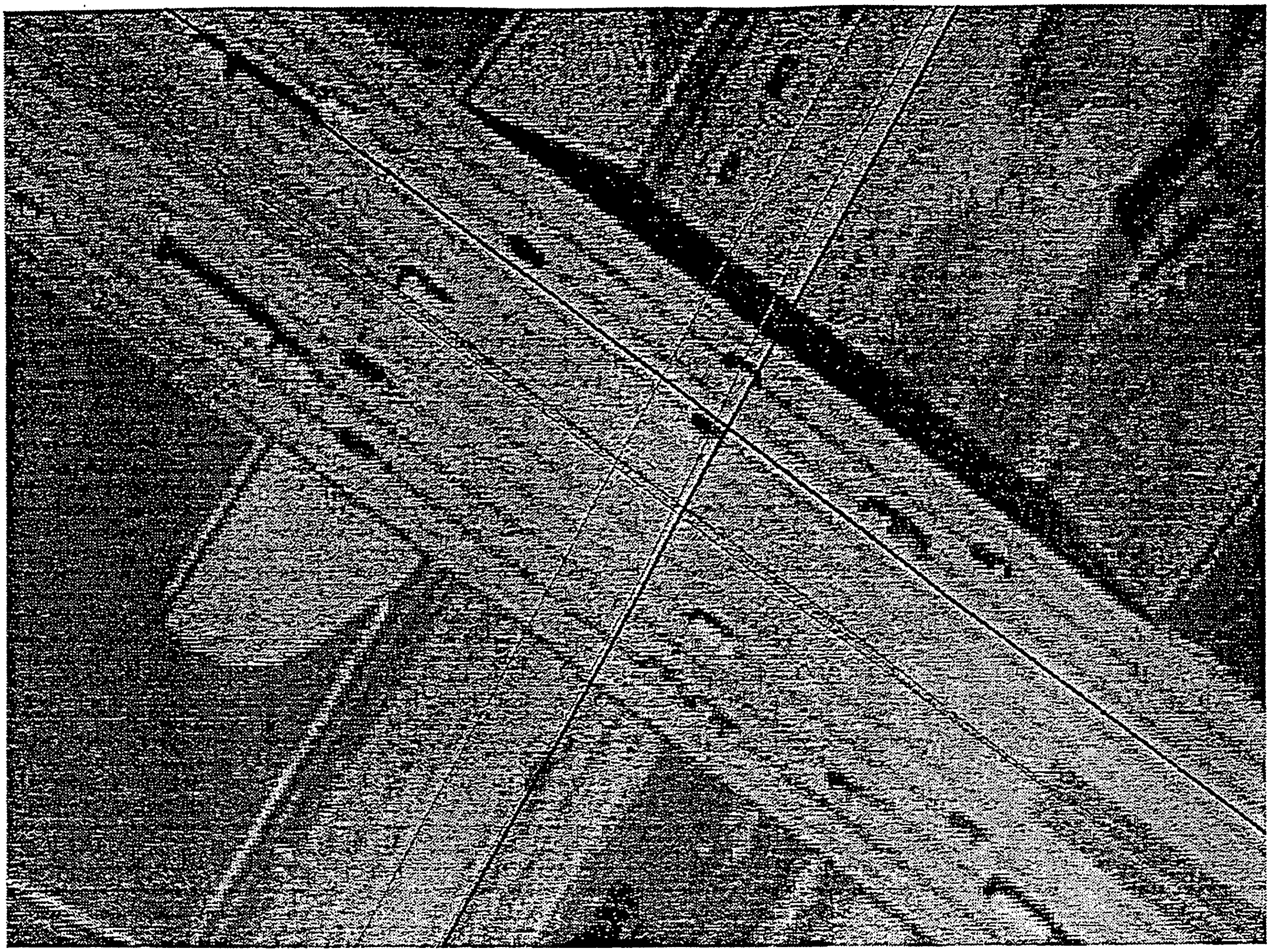
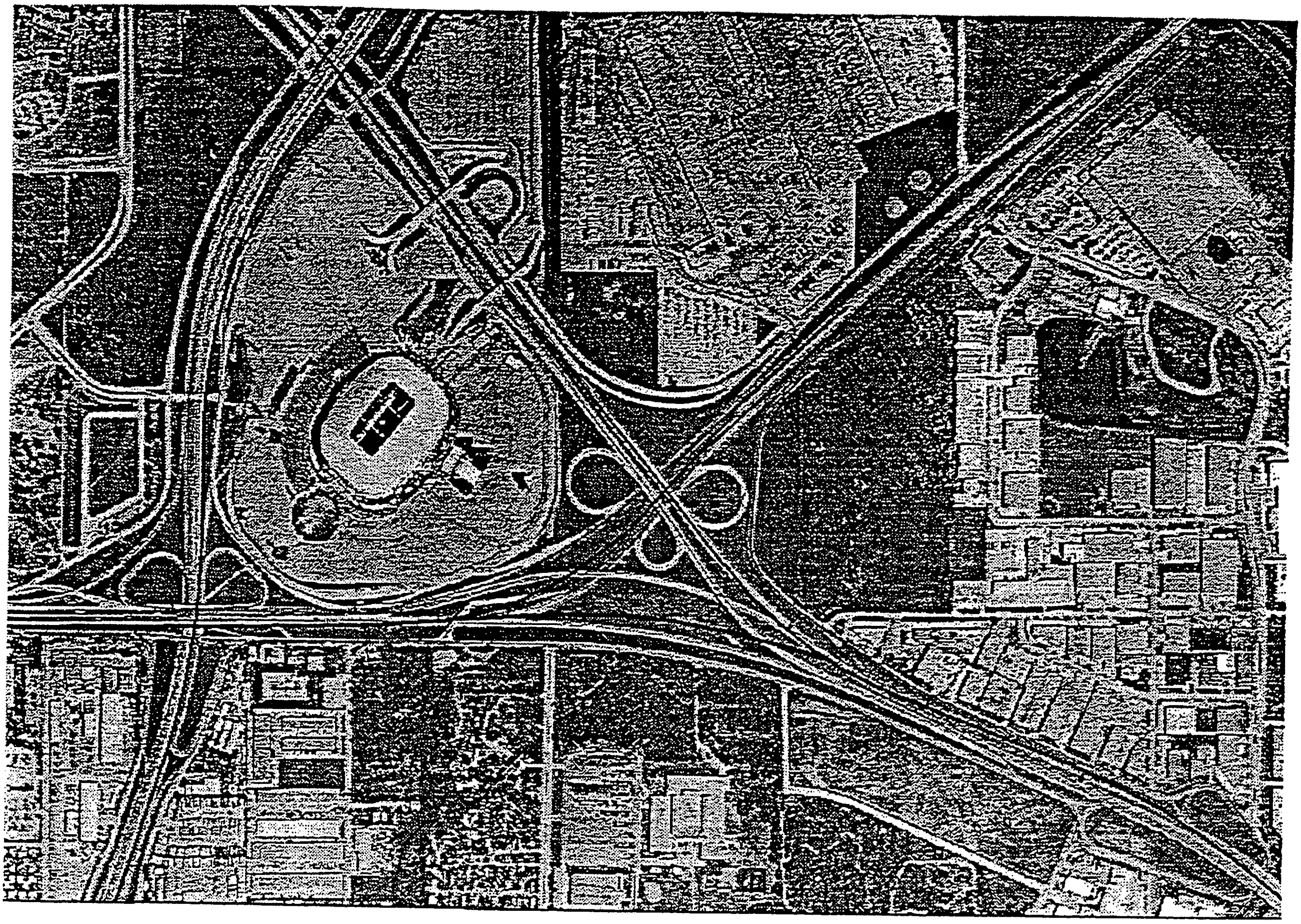


SH0114 and SL0012 in northwest Dallas County



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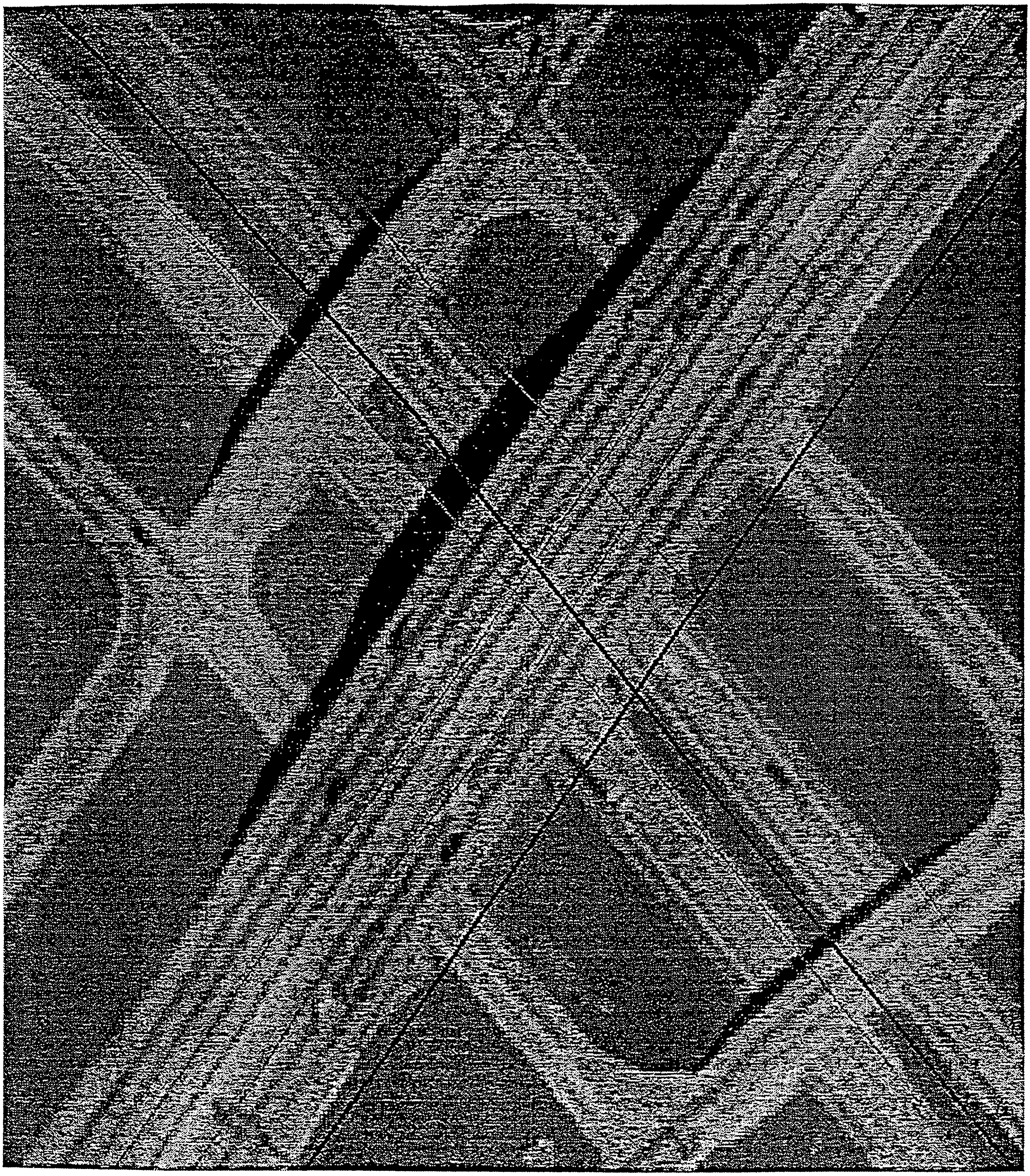
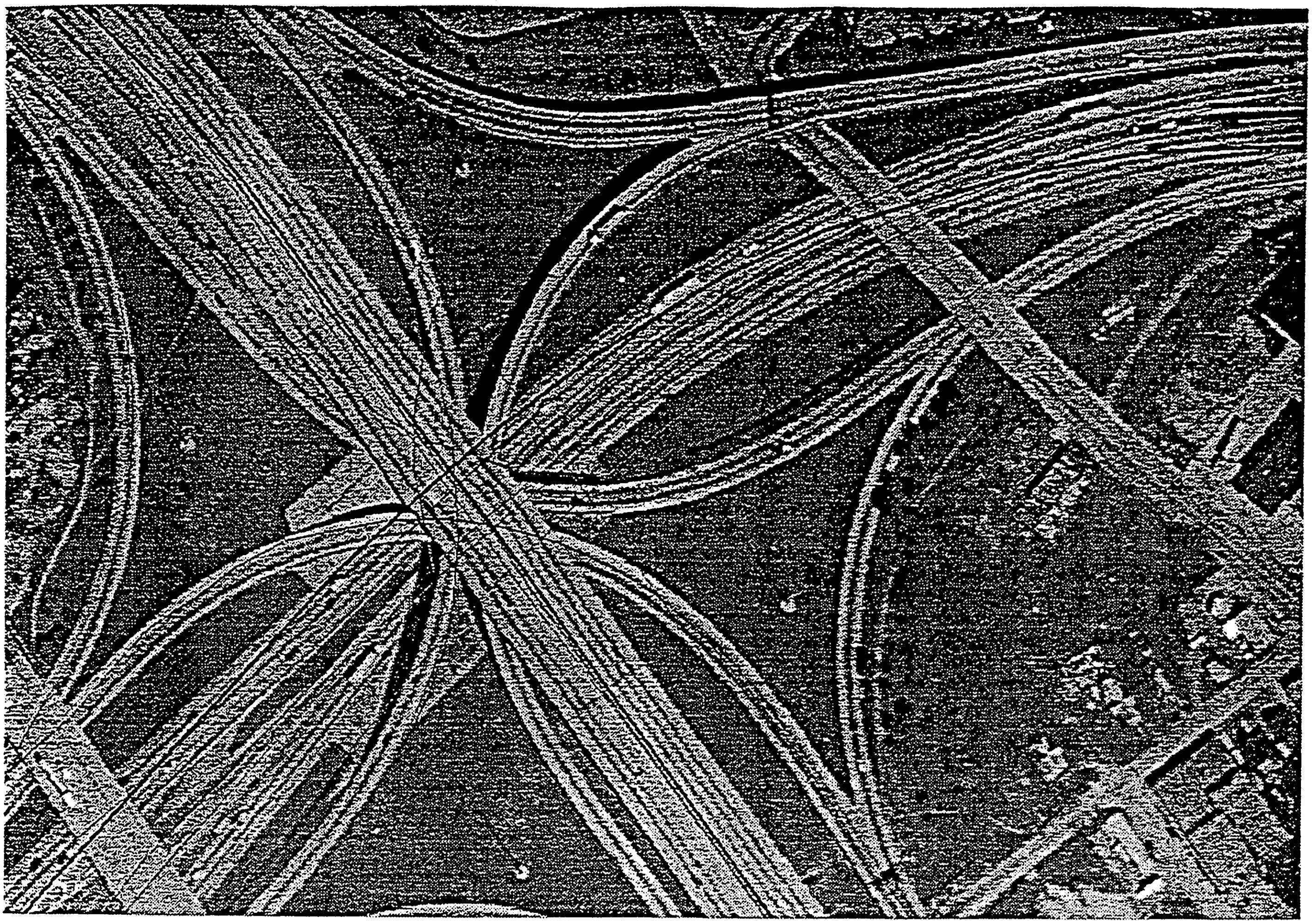


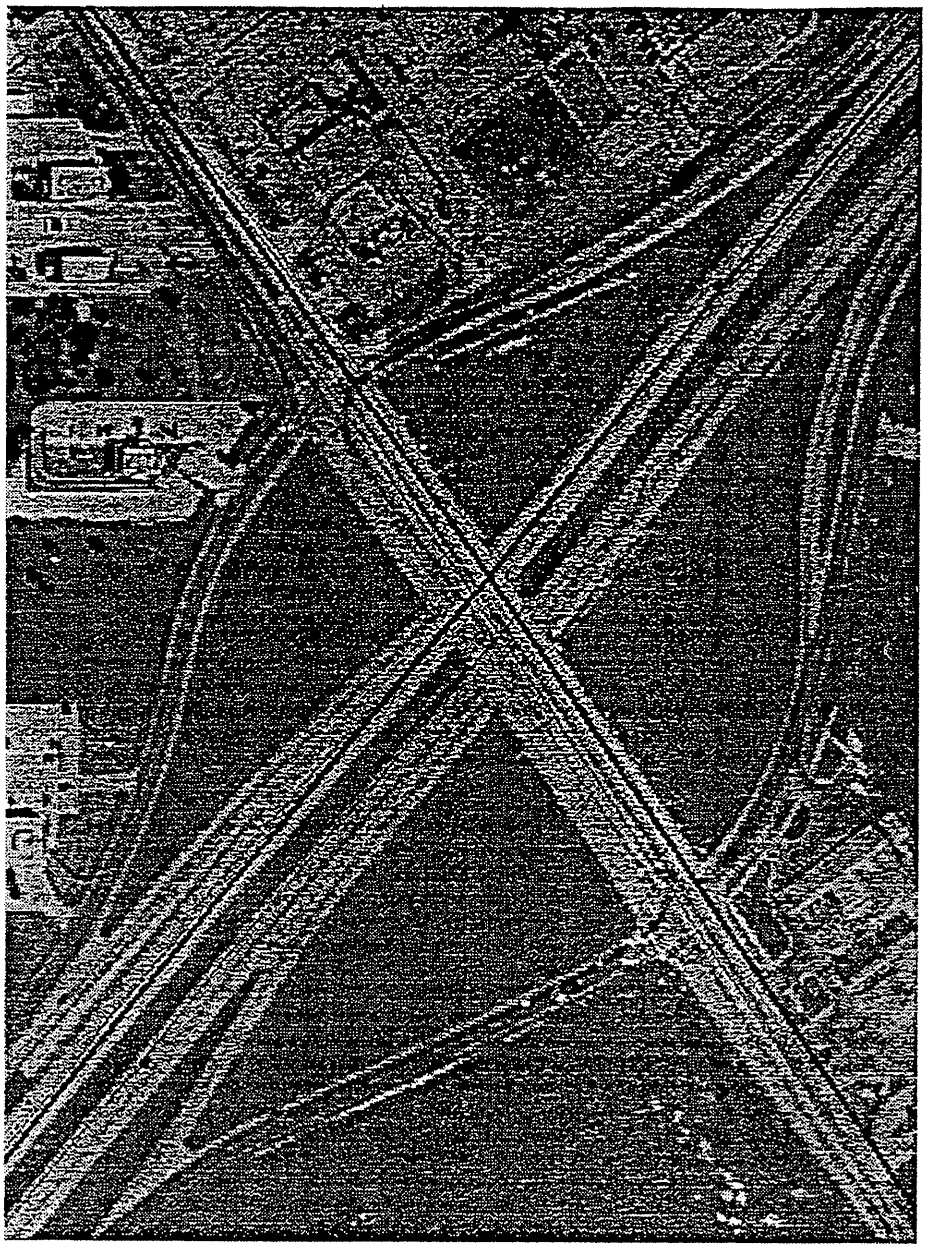
IH0030 and IH0345 in central Dallas County

IH0030 and IH0345 in central Dallas County



IH0030 and IH0345 in central Dallas County

FM1382 and US0067 in southwest Dallas County



FM1382 and US0067 in southwest Dallas County