Pavement Management Applications of GIS: A Case Study

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Despite ever-increasing budget limitations, more effective ways of establishing maintenance and rehabilitation requirements are needed to optimize the use of available highway funds. Like many other state transportation agencies, the Texas State Department of Highways and Public Transportation (SDHPT) already has in-place, analytical tools for assisting state highway engineers in the management of their roadways. The MICRO-PES package, for example, is a suite of computer programs developed to assist state district engineers with their network level pavement management activities. This analysis package, as the name implies, is implemented on a microcomputer. Because the MICRO-PES system is modular, it can be expanded to include other PMS analysis tools for which the Texas SDHPT may have need. A recent survey has revealed an urgent need by the districts for an automated procedure to generate maps highlighting substandard pavement sections. Currently, the production of these maps is a tedious process, accomplished by manually color-coding maps using pavement condition information from the Pavement Evaluation System (PES) data base. A computerized procedure would assist the engineering districts in the management of their roadways. In this regard, a small-scale study was conducted to evaluate the potential of using geographic information system (GIS) technology within the MICRO-PES environment to satisfy the need of the districts for graphics output capability. A prototype GIS module was developed that provided the capability for graphically displaying the output from the existing MICRO-PES analysis subsystems. The study demonstrated the applicability of GIS as a tool for pavement management.

Many transportation agencies in the United States have operational Pavement Management Systems (PMSs) in one form or another. The past decade has witnessed growth in developing pavement inventories and associated models that assist state departments of transportation (DOT) in prioritizing projects and anticipating future needs. Most agencies are experiencing increasing competition for available state and federal funds. PMSs have become important tools in quantifying overall needs and in evaluating the consequences of budget limitations. FHWA, in recognition of the increasing importance of PMS, has published its pavement initiative, a key element of which is that each state DOT must have in operation an approved PMS no later than February 1993.

The federal policy has prompted several states to accelerate their PMS development. Resulting improvements often mean upgrading of existing systems to meet federal guidelines and to provide additional capabilities for system users. The Texas State Department of Highways and Public Transportation (SDHPT) has recently completed a review of its existing PMS activities (*1*). One aspect of this study was a questionnaire sent to each of the 24 Texas districts that asked the district staff to rank PMS output requirements. By far the most urgent current need identified was for "maps highlighting substandard pavement sections." Many districts are manually color-coding maps using PMS data available only in standard tabular format. The need to evaluate the potential for geographic information systems (GISs) to support PMS activities is obvious. Initial efforts have been made to implement this technology within the Texas SDHPT.

Initial efforts to implement GIS technology to assist pavement management activities involved the incorporation of a prototype GIS module into the MICRO-PES system (*2*). This microcomputer-based system, which was developed by the Texas Transportation Institute, provides Texas SDHPT personnel with tools for analyzing the information stored within the network level Pavement Evaluation System (PES) data base. For each 2-mi section in the highway network, the following data items are available from PES:

1. Width and number of lanes;
2. Functional class;
3. Current condition in terms of
   a. Surface distress (e.g., rutting, cracking);
   b. Roughness;
   c. Structural strength;
4. Annual average daily traffic; and
5. Estimated traffic loads (in 18-kip ESALs).

Included in the MICRO-PES package are the following three analysis subsystems for network level pavement management:

1. A 1-year maintenance and rehabilitation system that consists of a series of decision trees that were based on the recommendations of experienced highway engineers from the Maintenance and Pavement Divisions of the Texas SDHPT. The decision trees relate characteristics such as pavement distress, roughness, pavement type, and whether the road is rural or urban, to the appropriate maintenance and rehabilitation strategies.
2. The Rehabilitation and Maintenance Optimization System (RAMS–DO1), which selects an optimal combination of projects that maximize benefits at a given budget level. The optimization procedure uses a 0–1 integer programming algorithm to maximize the overall maintenance effectiveness.
3. A routine maintenance estimation system that estimates type, extent, and cost of routine maintenance requirements for any highway or network of highways on the basis of user-specified trigger levels of pavement distress types.

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TABLE 1 RAMS DO-1 OUTPUT FOR ANGELINA COUNTY

Segm Num	Dist Num	County Code	Highway Number	From	To	LN	Strategy	Benefit	Cost	Percent Budget	AADT	18 Kips	Pvmnt. Score	PSI Raw
1	11	003	FM0058	000+00	002+00	R	Seal Coat	12833.	57960.00	1.82	9200	6476	34	4.0
2	11	003	FM0058	002+00	004+00	L	Seal Coat	3964.	23920.00	.75	7000	5827	51	4.2
3	11	003	FM0058	004+00	006+00	R	Seal Coat	3913.	23920.00	.75	2300	1444	69	3.9
7	11	003	FM0304	000+00	000+15	R	L.D. Reconstrt.	20888.	120000.00	3.76	940	591	31	2.2
23	11	003	FM0842	002+00	004+00	L	Seal Coat	3010.	18400.00	.58	870	610	59	3.0
24	11	003	FM0842	004+00	006+00	L	L.D. Reconstrt.	26072.	160000.00	5.01	870	610	24	2.2
25	11	003	FM0842	006+00	008+02	L	L.D. Reconstrt.	31480.	176000.00	5.52	190	119	12	1.9
33	11	003	FM1194	000+00	004+00	L	L.D. Reconstrt.	36408.	240000.00	7.52	2700	1678	9	1.9
43	11	003	FM1669	010+00	012+00	L	L.D. Reconstrt.	41644.	312000.00	9.78	5500	3949	39	2.5
45	11	003	FM1818	002-20	002+00	L	L.D. Reconstrt.	29378.	208000.00	6.52	3300	2073	26	2.4
46	11	003	FM1818	006+00	008+00	L	Thin Overlay	15373.	83580.00	2.62	790	495	70	2.7
50	11	003	FM1818	018+00	020+08	L	L.D. Reconstrt.	34832.	224000.00	7.02	380	238	42	2.1
62	11	003	FM3150	000+00	000+17	R	L.D. Reconstrt.	19291.	144000.00	4.51	1550	1041	32	1.9
68	11	003	SH0094	006+00	008+00	L	Seal Coat	9020.	51520.00	1.61	10900	12941	41	4.3
75	11	003	SH0103	022+00	024+00	R	Thin Overlay	10909.	72436.00	2.27	3500	3791	34	2.8
80	11	003	SH0278	000+00	000+09	R	Thin Overlay	11670.	91341.00	2.86	11000	13915	43	2.2
83	11	003	SH0287	002+00	004+00	L	Seal Coat	7975.	46000.00	1.44	14400	18273	31	3.7
84	11	003	SH0287	004+00	008+00	R	Seal Coat	9222.	55200.00	1.73	12400	15685	48	4.0
91	11	003	SH0287	012+00	014+09	L	Seal Coat	10911.	66700.00	2.09	21000	25762	41	3.3
92	11	003	SH0339	000+00	002+01	S	Thin Overlay	22473.	171936.00	5.39	7300	9386	68	2.3
94	11	003	SH0339	002+01	002+04	L	Thin Overlay	4475.	28656.00	.90	8800	9460	56	2.4
96	11	003	US0059	006+00	006+16	L	Seal Coat	7656.	44160.00	1.38	19400	21079	58	3.6
98	11	003	US0059	010+00	010+12	R	Thin Overlay	34907.	148056.00	4.64	28000	35638	28	2.7
99	11	003	US0059	014+00	016+00	R	Seal Coat	10538.	44160.00	1.38	18400	19565	53	3.5
100	11	003	US0059	014+00	016+00	L	Thin Overlay	31349.	191040.00	5.99	18400	19565	43	2.8
105	11	003	US0069	000+00	000+08	L	Seal Coat	3853.	23552.00	.74	5500	5913	52	3.9
108	11	003	US0069	002+00	004+01	L	Seal Coat	7668.	46368.00	1.45	5500	5913	57	3.5
109	11	003	US0069	004+01	006+00	L	Seal Coat	12343.	55936.00	1.75	6500	6759	43	4.1
110	11	003	US0069	006+00	008+00	L	Seal Coat	12799.	58880.00	1.85	8500	10128	31	4.2
115	11	003	US0069	022+00	024+00	S	Seal Coat	6901.	47840.00	1.50	10500	9778	52	4.0
116	11	003	US0069	024+00	026+00	R	Seal Coat	8294.	47840.00	1.50	10200	10923	41	3.9
117	11	003	US0069	038+00	040+00	R	Thin Overlay	14479.	103480.00	3.24	4900	5304	66	2.5
							TOTALS:	516526.	3186881.00	99.87	260690	284929	1384	99.0

When using MICRO-PES, the user is presented with a menu from which any one of the analysis subsystems can be selected for execution.

Before this GIS study, the output from the MICRO-PES package was in standard tabular format. For example, Table 1 presents a typical output from the optimization program. In order to add graphics capability to the system and thus satisfy the need of highest priority of the engineering districts, a prototype GIS implementation was developed as an additional option for presenting MICRO-PES output. The primary goal was to develop an interface between the GIS and the PMS analysis subsystems of MICRO-PES. This interface was intended to provide the following improvements to the MICRO-PES package:

1. Capability for graphically displaying, on a microcomputer color monitor, a map of a selected highway network and for evaluating the general condition of the selected network through queries on the PES data base using the data base management system (DBMS) of the GIS.

2. Capability for generating the input files for the PMS analysis modules using the GIS's DBMS to extract the relevant input data from the PES data base.
3. Capability for graphically displaying the output from the PMS analysis modules and for generating graphical output on hard copy devices that can be included as material for PMS reports.

Initial GIS implementation efforts led to the development of a prototype GIS that provided the enhancements to the MICRO-PES package. Development of this prototype GIS is described in what follows.

DEVELOPMENT OF A PROTOTYPE GIS MODULE FOR MICRO-PES

The main objective of the research effort described herein was to evaluate the feasibility of using GIS technology to satisfy the requirements of the Texas SDHPT for the production of maps identifying deficient pavement sections. The approach selected for accomplishing this task was to perform a case study in which GIS software would be integrated with the MICRO-PES computer system to support the latter's PMS analysis packages.

The support rendered by the GIS software to the PMS analysis subsystems is viewed as yet another option within MICRO-PES; an option that will allow the user to produce a map display, either in the computer screen or as a hard copy, of an area (e.g., a county or district) that has previously been selected for PMS analysis. The GIS option will eventually allow the user to graphically display the output from any of the PMS analysis subsystems. For example, the user will be able to generate a map that shows highway sections that have been selected for some maintenance and rehabilitation work by the RAMS program. By maintaining the GIS as a separate option within MICRO-PES, as opposed to using its mapping capabilities alone through each of the three PMS analysis subsystems, the user is ensured access to all of the GIS capabilities. This feature means that the GIS could be accessed directly to perform other functions, such as PES data subsetting using the GIS data base manager to generate input files for any of the PMS analysis subsystems, or production of maps based on simple queries to the PES data base.

The framework for developing the case study can be subdivided into five main tasks: (a) selection of a GIS software package, (b) selection of an appropriate county, (c) acquisition of the PES data for the selected county, (d) development of the land base, and (e) development of the interfaces between the GIS and the PMS analysis modules. A detailed description of how these tasks were performed follows.

Selection of a GIS Software Package

The two GIS packages that were available for the development of the case study were Environmental Systems Research Institute's PC ARC/INFO and Caliper Corporation's TransCAD. The final decision for selecting PC ARC/INFO over TransCAD rested on the fact that the latter did not have a digitizing capability in its current version (Version 1.20). This capability was crucial to the case study because the land base was to be created from scratch, by digitizing county highway maps provided by the Transportation Planning Division (D-10) of the Texas SDHPT.

A brief description of the modules and capabilities of PC ARC/INFO is in order. PC ARC/INFO is a software system for managing geographic information. This system integrates geographic analysis and modeling capabilities with a fully interactive system for acquisition, management, and display of spatial data.

PC ARC/INFO consists of a series of modules, including

- Starter Kit—used for map creation and digitization, attribute table creation, topologic data structuring, map plotting system, and host computer communication.
- PC INFO—a stand-alone fully featured data base management system.
- PC ARCPLOT—used for interactive map creation and display, graphical query, and generation of high-quality hardcopy maps.
- PC ARCEDIT—supports sophisticated graphics editing for coverage creation and update.
- PC OVERLAY—supports polygon overlay, line and point-in-polygon overlay, and buffer generation.
- PC NETWORK—handles analytical functions for modeling real networks and performs optimal routing, districting, address matching, and geocoding.
- PC DATA CONVERSION—converts grid cell and vector formats to ARC/INFO or vice versa.

The Starter Kit is the foundation of the system, and as such it has to be installed before any other modules. It provides the basic GIS tools such as

1. Arc Digitizing System (ADS) used to digitize map coverages,
2. CLEAN and BUILD procedures to create topology from coordinates,
3. The TABLES program that directly interacts with PC INFO to integrate attribute data with map entities,
4. HELP menus and screens that provide reference to both ADS and TABLES commands,
5. ESRI's Plot System for viewing maps on the screen or for sending them to a plotter or graphics printer, and
6. The Simple Macro Language (SML) that can be used to create a user interface.

Of the PC ARC/INFO modules, only the Starter Kit PC, ARCEDIT, and PC ARCPLOT were used to develop the case study. Both the Starter Kit and PC ARCEDIT were used to digitize and edit the highway network, county boundaries, and city limits coverages that conformed the base map of the area selected for the study. PC ARCPLOT was used to create the display map; assign colors, line types, line weights, and labels to map entities; perform queries highlighting selected highway sections; and plot maps from various analysis queries.

Selection of an Appropriate County

An appropriate county for the case study had to have

- A representative sample of the Texas highway network, that is, a highway network representing several of the following functional classes: Interstate highways, state highways, U.S. highways, farm-to-market highways, park roads, and state loops or spurs.

- A complete PES database for the highway network. This requirement meant that each PES highway section in the county's highway network had to have at least one data record in the PES data base.

Of the 254 counties in Texas, several satisfied these criteria. It was decided to use Angelina County in the Lufkin District (District 11) for developing the case study shown in Figure 1. Angelina County was used because it had been the subject of a previous research study aimed at evaluating the effectiveness of the RAMS–DO1 program in optimizing the allocation of limited funds to maintenance and rehabilitation needs (*3*). By selecting Angelina County for the case study, the results from the research project (*3*) could be recreated in graphic form, thereby demonstrating the application of GIS as a PMS tool.

Acquisition of PES Data For The Selected County

The PES data base file was provided by the Safety and Maintenance Operations Division (D–18) of the Texas SDHPT. This data base was the same one that was used for the RAMS research study mentioned previously. It contained data from the 1985 PES survey.

Development of The Land Base

Several sources were available from which an appropriate base map could be obtained. These included various digital and paper map products from agencies such as the Bureau of the Census, the U.S. Geological Survey, and the Transportation Planning Division of the Texas SDHPT. The final decision on the map base was to use the Texas SDHPT General Highway Map product for Angelina County. Besides incorporating the complete highway network for the county, it also included the 2-mi highway sections used by the state to maintain its roadway inventory. In order to gain some experience in map preparation and digitization, it was further decided to use a paper map product instead of a digital one. This procedure ensured that the base map would contain only the elements that were of interest to the case study: county boundaries, highway networks, and city limits.

The creation of the base map for the case study was accomplished in three phases: (a) map digitization, (b) PES attribute data integration, and (c) final base map production. Descriptions of the three phases follow.

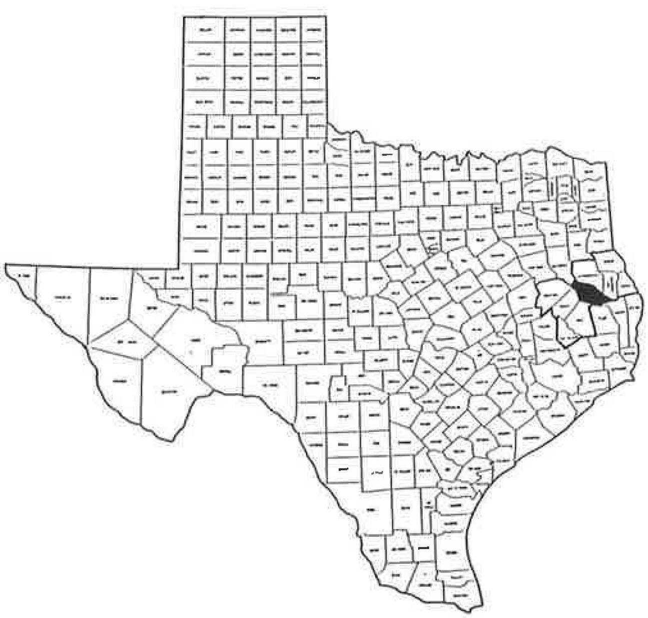


FIGURE 1 Location of Angelina County within District 11 and Texas.

Map Digitization

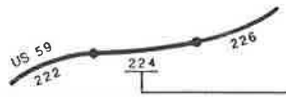
The digitization of all base map coverages was performed with the Starter Kit's Arc Digitizing System (ADS) utility. The Texas SDHPT General Highway Map for Angelina County consisted of two base sheets and one supplementary sheet. Because the base sheets cover the whole county whereas the supplementary sheets show adjacent areas of the county in greater detail, it was decided that the base sheets would be used for the digitizing exercise. Two steps had to be performed before the digitizing process could begin. First, six reference points or tics were marked on the map and labeled 1 through 6. The locations of these tics were arbitrary so they were made to correspond with the intersections of the map's latitude-longitude grid.

The highway network to be included in the land base comprised almost all of the county roadways, with the exception of some short roadways that were considered insignificant to the study. All the roadways were digitized into a single layer or coverage named "HIGHWAYS." The other two coverages, BORDERS and CITYBOUN, that made up the land base, contain the county boundary and Angelina city limits, respectively. These two coverages were digitized using the same set of reference tics as the one in the HIGHWAYS coverage allowing them to be perfectly overlaid, thus generating the complete land base. Because both the CITYBOUN and BORDERS coverages represented only boundaries for visual orientation, no topology was built into them.

In contrast, because the HIGHWAYS coverage represented the highway network, each 2-mi section was digitized as an arc connecting a beginning and an ending node. Thus, the whole network was represented by a series of sequential arcs joined together by nodes. During digitizing, a unique ID number was assigned to each of the arcs representing highway sections. Once the digitizing of this coverage was complete, the BUILD utility was used to make an arc attribute table (AAT), which contained the topological relationships of the arcs that formed the highway network (Figure 2).

PES Attribute Data Integration

The data base used for the case study was a subset of the 1985 PES data set for District 11. The Angelina County data were extracted from this subset using Option 1 of the MICRO-PES program. Furthermore, because PES records contained 47 variables and many of them were not relevant to the study,



HIGHWAYS.AAT

FROM NODE	TO NODE	L POLYGON	R POLYGON	LENGTH	HWY #	HWY ID
2	3	0	0	1.012	2	222
3	4	0	0	1.005	3	224
4	5	0	0	0.918	4	226
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.

HWY ID	PRE	NUM	LANE	RUTT	BLOCK	PAT	FAIL	ALLIG	LONG	TRANS	PSI	SPEED	PTYPE	FC	WIDTH	AADT	18KIPS	STRATEGY	BENEFIT	COST	BUDGET%
222	US	59	S	100	0	0	0	100	10	0	42	65	5	1	36	0920	30126	0	0	0	0
224	US	59	S	100	0	0	0	0	100	0	40	65	5	1	36	9166	38809	0	0	0	0
226	US	59	R	100	0	0	0	0	100	0	40	65	5	1	36	16666	55456	0	0	0	0
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

FIGURE 2 The Arc Attribute Table is linked together with the HIGHWAYS database through the HWY–ID variable, which was used as the key.

only the variables that were the most applicable to the problem at hand were used. Table 2 lists the 22 variables that were selected for the PES attribute data base. The first variable in the table, HWY–ID, does not belong to the PES data set. It was added to it to store the highway section ID number that was used to link the attribute data with the topological data in the AAT created during the digitizing process just described. The four variables STRATEGY, BENEFIT, COST, and BUDGET % (following the KIPS variable) were also added to the HIGHWAYS data base to accommodate output values from the RAMS–DO1 analysis module.

The TABLES utility from the STARTER KIT was used to create an INFO template with the 22 variables that formed the attribute data set and to input the data. Special care was taken to ensure that the HWY–ID variable in the attribute data set matched the HWY–ID variable of its corresponding highway section in the AAT. Once this match was accomplished, the records in these tables were linked together using the common HWY–ID variable as the key (Figure 1), resulting in a fully relational geographic data base for the highway network.

Base Map Production

Once the geographical data base was complete, the next step was to produce the base map that would be used as a basis for displays and queries. This step was accomplished by using the map composition features of PC ARCPLOT. PC ARCPLOT allows the user to display maps created from a number of coverages using different colors, line types, line widths, text annotations like labels and titles, legend and title boxes, and frames.

Map composition in PC ARCPLOT is a process that is performed one step at a time. For instance, the creation of the base map for the case study was done by first defining the map extent (boundaries); then, each of the coverages (BORDERS, HIGHWAYS, and CITYBOUN) were drawn, one at a time, using desired colors and line types until the map was completed. Next, all text (i.e., labels and titles) was added to complete the base map (Figure 3). This step-by-step process had to be repeated every time the map was displayed. In order to avoid such a tedious task, PC ARCPLOT included SML, which could be used to create a batch type file that executed all steps for creating the base map so that map composition could be performed by typing in a single command. For the case study, the macro ANGELINA.SML was created to display the complete base map.

Developing the Interface Between the GIS and the PMS Analysis Modules

Interaction of the MICRO-PES software package and the PC ARC/INFO GIS can be accomplished at the following two levels:

- *Level 1 Integration*—Basic, and entails the exchange of data files while running both packages independently of each other. An example of Level 1 integration would be the case in which the user first selects to run the RAMS–DO1 program and then to run the GIS to display a map of the highway sections that were selected for maintenance or rehabilitation by the RAMS–DO1 program. The user starts MICRO-PES and then the RAMS analysis subsystem. Then, when RAMS is done the user terminates the MICRO-PES session and exits to DOS. From DOS, a PC ARC/INFO session is initiated by entering the ARCPLOT module and by querying the system on the basis of any of the four RAMS–DO1 output variables (STRATEGY, BENEFIT, COST, and/or BUDGET%) to produce the desired map display.
- *Level 2 Integration*—Although Level 1 integration is straightforward, it also involves several steps that require a sound knowledge of PC ARC/INFO operation and principles. In Level 2 integration, the user will not have to be concerned with the operating principles of PC ARC/INFO because the interface makes the communications between PC ARC/INFO and MICRO-PES totally transparent. That is, the user will

TABLE 2 VARIABLES USED TO CREATE THE HIGHWAYS DATABASE

Column	Item Name	Width	Output	Type
1	HWY-ID	3	4	I
4	PRE	2	3	C
6	NUM	3	4	I
9	LANE	1	2	C
10	RUTT	3	4	I
13	BLK	3	4	I
16	PAT	3	4	I
19	FAIL	3	4	I
22	ALLIG	3	4	I
25	LONG	3	4	I
28	TRANS	3	4	I
31	PSI	2	3	I
33	SPEED	2	3	I
35	PTYPE	2	3	I
37	FC	1	2	I
38	WIDTH	2	3	I
40	AADT	5	6	I
45	KIPS	5	6	I
50	STRATEGY	2	2	I
52	BENEFIT	7	7	N
58	COST	11	11	N
69	BUDGET %	6	6	N

Columns 10 thru 30: Pavement distress types
31 thru 32: Pavement roughness
40 thru 44: Annual average daily traffic
50 thru 51: Recommended rehabilitation strategy from RAMS-D01
52 thru 57: Benefit of applying strategy
58 thru 68: Cost of rehabilitation strategy
69 thru 74: Percent of budget spent by applying said strategy

enter the GIS environment to either select highway sections to be analyzed through MICRO-PES analysis subsystems, or to display output from them, by means of an option in the MICRO-PES menu screen. Once the GIS options are executed, the interface will return program control back to the same menu so the user can either perform a new analysis or terminate the session.

The main concern of the present case study is to demonstrate the feasibility of attaining Level 1 integration. Level 2 integration, although it presents an ideal final product, requires more time and resources than those allotted to the study.

SUMMARY AND RECOMMENDATIONS

A GIS is a computerized data base management system for managing spatially defined data. Applications of a GIS are varied, and the capability for presenting information visually, in a form that the user can readily comprehend, is a distinct advantage over conventional data base management systems that present information in tabular form.

Using a GIS has potential to satisfy the need of the engineering districts in Texas for an automated procedure to generate maps highlighting substandard pavement sections. The development of a prototype GIS option for graphically

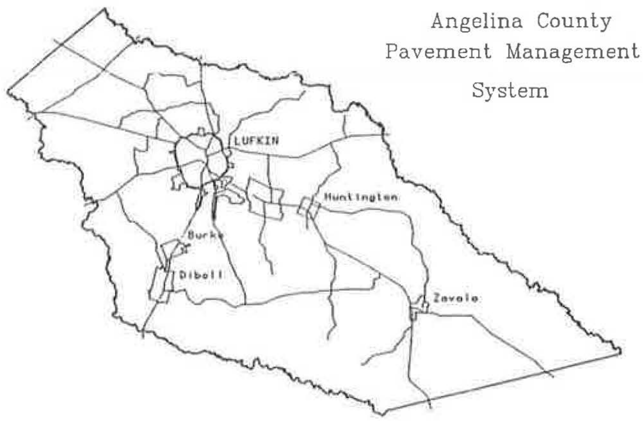


FIGURE 3 Base map for the case study.

displaying output from the existing MICRO-PES analysis subsystems is a significant step toward satisfying the need by the engineering districts for graphics output capability. Although this prototype GIS is at the basic level of integration with the existing MICRO-PES analysis subsystems, it nevertheless has demonstrated the applicability of this technology as a tool for pavement management. Undoubtedly, improvements can be made later on so that the operation of the GIS within the MICRO-PES environment will be more transparent to the user. These improvements in the level of integration of the GIS with the PMS analysis subsystems in MICRO-PES will require the investigation of alternative methods of getting around the 640K memory address limitation of the current DOS environment.

The prototype GIS module for MICRO-PES developed in this study shows the potential of the GIS as a tool for pavement management. Consequently, the development of PMS and other transportation applications of GIS should be pursued, and the following recommendations for future studies are hereby made:

1. A survey of user requirements for a departmentwide GIS should be conducted.
2. The applicability of using existing digitized maps from the department and elsewhere to develop the land base for a GIS should be investigated.
3. An implementation plan for GIS should be developed.
4. Technical issues remain to be resolved, such as the incorporation of dynamic segmentation that would provide different alternatives for reporting highway-related data, i.e., by 2-mi section, from intersection to intersection or at user-supplied limits.

The prototype GIS developed in this study addresses applications of GIS specific only to the pavement management area, and many other applications exist for which a GIS may be used within a transportation agency. With this broader perspective, the recommendations set forth have been made.

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