Geographic Information System Decision Support System for Pavement Management

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The development of an attribute data base in a geographic information system (GIS) for pavement management is addressed. Two primary types of roadway data are considered: inventory data describing the physical characteristics of the traveled way, and pavement management data describing the actual surface condition of the roadway. The resolution of problems inherent in tying data bases with different geographical references is addressed. The resulting data base is applied to demonstrate how the information is used to support decisions regarding pavement maintenance and rehabilitation. The applications described include annual pavement condition reporting, annual change in pavement condition, change in condition over extended periods of time, and analysis of remaining pavement service life. It is shown that the spatial data base must include the smallest possible roadway segments based on available attribute data bases. It is also shown that once relational links are established between spatial and attribute data, any application within the attribute data file can become accessible through the GIS.

A key element of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) is the requirement for each state to develop and implement management systems in six areas:

1. Highway pavement of federal-aid highways,
2. Bridges on and off federal-aid highways,
3. Highway safety,
4. Traffic congestion,
5. Public transportation facilities and equipment, and
6. Intermodal transportation facilities and systems.

The states must also establish traffic monitoring systems for highways and public transportation.

It is the goal of these management systems to provide data that will improve decision making regarding the infrastructure of multimodal transportation systems. Transportation infrastructure managers are typically concerned with three fundamental questions: What is the current condition of their area of responsibility? What is the trend in this condition? How long before some major action is necessary? This information is needed not only for deciding which technical course of action to take, but also for forecasting budgets.

These requirements can be accomplished with the aid of geographic information system (GIS) technology. The GIS is designed to handle both topology and attribute data. Topology is concerned with the spatial relationship between connecting or adjacent spatial objects such as points, lines, and polygons. Spatial data are used for the graphical representation of a map's subject (e.g., roads, rivers, jurisdictional boundaries, etc.). Attribute data are facts and figures that describe the subject (e.g., pavement width, surface type, thickness, etc.), and they are layered on a geographical base.

For example, consider the application of GIS to pavement management. Here, the decision-making process is enhanced by

- Identifying current pavement conditions,
- Identifying current pavement condition trends, and
- Forecasting where and when major maintenance and rehabilitation actions will be needed.

PURPOSE AND SCOPE

This paper describes the development of an attribute data base for pavement management purposes. A spatial data reference has been developed and described elsewhere (*1*). Two primary types of roadway data are considered: inventory data describing the physical characteristics of the traveled way, and pavement management data describing the actual surface condition of the roadway. The resolution of problems inherent in tying data bases with different geographical references together is addressed. The resulting data base was applied to demonstrate how the information is used to support decisions regarding pavement maintenance and rehabilitation. The process that is described can be extended to each of the individual management systems required by ISTEA, and it can also be expanded to integrate a master data base for all of the management systems.

INFORMATION SOURCES

The desired attribute data for a pavement management information base were found in various files that were converted to the GIS base. The Roadway Inventory System (RIS) and the Highway Traffic Record Information System (HTRIS), both maintained by the Virginia Department of Transportation (VDOT), were used as primary sources of roadway inventory information. Other sources included the Virginia "tourist" map and individual county roadway maps, also produced by VDOT. Pavement management data were found in two places: HTRIS and its predecessor, the Pavement Management Information System (PMIS).

In reviewing the data, it was found that only 1992 pavement management data were being entered into HTRIS and that pave-

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ment rating data for other years, which are contained in PMIS, would not be converted. The significance here is that the old PMIS and the new HTRIS use different referencing systems. PMIS, like RIS, employs a milepost system, which begins anew at each county line for each route. Although in many cases a regimen is followed for assigning these milepost numbers (i.e., north to south, east to west), this has not always been so. HTRIS, on the other hand, strictly follows such a regimen (south to north or west to east) and does not reset its mileposts (referred to as "nodes") at county lines. Furthermore, even though 1992 ratings have been incorporated into HTRIS, no file or map equating the two referencing systems was found. This makes simultaneous use of the two data bases difficult and is an example of how two data bases that cover identical information can be incompatible because of format.

It was also determined that individual ratings were tied to roadway maintenance sections, which are the portions of the roadway between mileposts or nodes. The problem is that these maintenance sections can vary as each maintenance project is undertaken. In other words, only part of a segment that was resurfaced in earlier years might be resurfaced in a subsequent year, and at that time the maintenance sections are redefined. This points to an incompatibility resulting from data storage and collection techniques, since identical maintenance section numbers from different years may or may not represent the same section of highway.

Thus, automating the existing data bases was not straightforward, because compatibility issues had to be resolved. For the manual data, information was directly entered into the GIS using the keyboard. Information extracted here was limited to route numbers and political jurisdiction names. Information from the RIS was also entered using the keyboard, since the two computer environments (the mainframe for RIS and the microcomputer for the GIS) could not be linked effectively. Data from the PMIS were provided on computer diskette in dBase format. Data from HTRIS were provided on computer diskette in both dBase and text formats as well as in printouts, depending on the subject of the data.

Table 1 presents a summary of the attribute data transferred into the GIS. Also shown is the source of the data item, in what form it was received, and the manner in which it was transferred into the GIS. Since the GIS can directly read dBase-formatted data, the term "data bridge" is used to describe this transfer process.

To minimize the amount of new information that a pavement manager would need to learn, the original coding of the attribute data was retained. Five years of pavement rating data were received: 1988–1991 (from PMIS) and 1992 (from HTRIS). Since this amount of data is impractical to include in detail, a common technique is to generate a data dictionary. Data dictionaries identify the name of the data item, the type of data (alphabetic, numeric, logical, etc.), the number of characters contained in the field, and, for numeric fields, the number of decimal places included in the number. Additionally, when similar data covering multiple years, or periods, are stored in a common data base, a data dictionary will typically include a series of flags to notify the potential user of what data are available for what years or periods. Table 2 presents such a data dictionary for the attribute data included in the GIS.

As is indicated in Table 2, many field names were changed between 1991 and 1992 when HTRIS was implemented. In many cases, the contents of the fields actually remained the same or were altered only slightly. More important, however, information concerning the pavement surface type and its current condition were removed from the main data base in HTRIS and established in separate lookup data bases. These are the data referred to as "Q???" fields at the end of Table 2. These "Q???" fields are links to separate data bases. No particular explanation was found for this major change in data storage. The point is that even where the fields contain the same data between years, if the field name changes, the information cannot be linked electronically—even in normal data processing applications—without considerable additional work. For this reason, data structures should be changed only when absolutely necessary.

DATA INTEGRATION

The next step in building the GIS involved integrating the attribute data base and spatial data base. To accomplish this, geographic control must be established between all related data bases. As in

TABLE 1 Summary of Feature Data

Data	Source	Form	GIS Entry
Route Numbers	Maps/RIS	Paper	Keyboard
Political Jurisdiction Names	Maps	Paper	Keyboard
Highway Type	PMIS/HTRIS	*dBase*	Data Bridge
Surface Mix	PMIS/HTRIS	*dBase*	Data Bridge
Ride Index	PMIS/HTRIS	*dBase*	Data Bridge
Ride Rating	PMIS/HTRIS	*dBase*	Data Bridge
Cracking Frequency	PMIS/HTRIS	*dBase*	Data Bridge
Cracking Severity	PMIS/HTRIS	*dBase*	Data Bridge
Rutting Frequency	PMIS/HTRIS	*dBase*	Data Bridge
Rutting Severity	PMIS/HTRIS	*dBase*	Data Bridge
Pushing Frequency	PMIS/HTRIS	*dBase*	Data Bridge
Pushing Severity	PMIS/HTRIS	*dBase*	Data Bridge
Patching Frequency	PMIS/HTRIS	*dBase*	Data Bridge
Patching Severity	PMIS/HTRIS	*dBase*	Data Bridge
Ravelling Frequency	PMIS/HTRIS	*dBase*	Data Bridge
Ravelling Severity	PMIS/HTRIS	*dBase*	Data Bridge
Flushing Frequency	PMIS/HTRIS	*dBase*	Data Bridge
Flushing Severity	PMIS/HTRIS	*dBase*	Data Bridge
Date of Survey	PMIS/HTRIS	*dBase*	Data Bridge

TABLE 2 Pavement Rating Data Dictionaries

Field Name	Field Type	Field Width	# of Dec	'88	'89	'90	'91	'92
District	Character	20		yes	yes	yes	yes	yes
Residency	Character	20		yes	yes	yes	yes	yes
County	Character	20		yes	yes	yes	yes	yes
RteNum	Character	4		yes	yes	yes	yes	no
BegMile	Numeric	5	2	yes	yes	yes	yes	no
EndMile	Numeric	5	2	yes	yes	yes	yes	no
Length	Numeric	5	2	yes	yes	yes	yes	yes
BegDes	Character	19		yes	yes	yes	yes	no
EndDes	Character	19		yes	yes	yes	yes	no
System	Character	10		yes	yes	yes	yes	yes
CompMonth	Character	2		yes	yes	yes	yes	no
CompYear	Character	2		yes	yes	yes	yes	no
SurfMix	Character	20		yes	yes	yes	yes	no
SurfPrt	Character	8		yes	yes	yes	yes	no
SurfCode	Character	2		yes	yes	yes	yes	no
SurveyDate	Date	8		yes	yes	yes	yes	no
SDate	Character	6		yes	yes	yes	yes	no
RideRating	Numeric	3	1	yes	yes	yes	yes	no
RideRate	Character	2		yes	yes	yes	yes	no
DMR	Numeric	3	0	yes	yes	yes	yes	no
Remarks	Character	80		yes	yes	yes	yes	yes
HwyCode	Character	2		yes	yes	yes	yes	no
HwyType	Character	45		yes	yes	yes	yes	no
DirCode	Character	1		yes	yes	yes	yes	no
LaneCode	Character	1		yes	yes	yes	yes	no
MasterKey	Character	22		yes	yes	yes	yes	no
CrkFreq	Character	1		yes	yes	yes	yes	no
CrkSevr	Character	1		yes	yes	yes	yes	no
RutFreq	Character	1		yes	yes	yes	yes	no
RutSevr	Character	1		yes	yes	yes	yes	no
PushFreq	Character	1		yes	yes	yes	yes	no
PushSevr	Character	1		yes	yes	yes	yes	no
PatcFreq	Character	1		yes	yes	yes	yes	no
PatcSevr	Character	1		yes	yes	yes	yes	no
RavlFreq	Character	1		yes	yes	yes	yes	no
RavlSevr	Character	1		yes	yes	yes	yes	no
FluFreq	Character	1		yes	yes	yes	yes	no
FluSevr	Character	1		yes	yes	yes	yes	no
Factors	Character	6		no	no	no	yes	no
Rte_Id	Character	14		no	no	no	no	yes
BMP	Numeric	5	2	no	no	no	no	yes
EMP	Numeric	5	2	no	no	no	no	yes
Dir	Character	1		no	no	no	no	yes
Lane	Character	2		no	no	no	no	yes
Surf_Date	Character	4		no	no	no	no	yes
Surf_Code	Character	3		no	no	no	no	yes
Surf_Type	Character	2		no	no	no	no	yes
Beg_Desc	Character	30		no	no	no	no	yes
End_Desc	Character	30		no	no	no	no	yes
Rd_Key	Numeric	5	0	no	no	no	no	yes
Rec_Pref	Character	4		no	no	no	no	yes
DRC	Character	6		no	no	no	no	yes
Ref_Node	Character	6		no	no	no	no	yes
Ref_Off	Character	5	0	no	no	no	no	yes
No_Lane	Character	2	0	no	no	no	no	yes
Rated	Logical	1	0	no	no	no	no	yes
Rate_Date	Date	8	0	no	no	no	no	yes
Sched	Character	1	0	no	no	no	no	yes
Q111	Numeric	4	0	no	no	no	no	yes
Q112	Numeric	4	0	no	no	no	no	yes
Q113	Numeric	4	0	no	no	no	no	yes
Q114	Numeric	4		no	no	no	no	yes
Q115	Numeric	4		no	no	no	no	yes
Q117	Numeric	4		no	no	no	no	yes
Q412	Numeric	4		no	no	no	no	yes
Q414	Numeric	4		no	no	no	no	yes

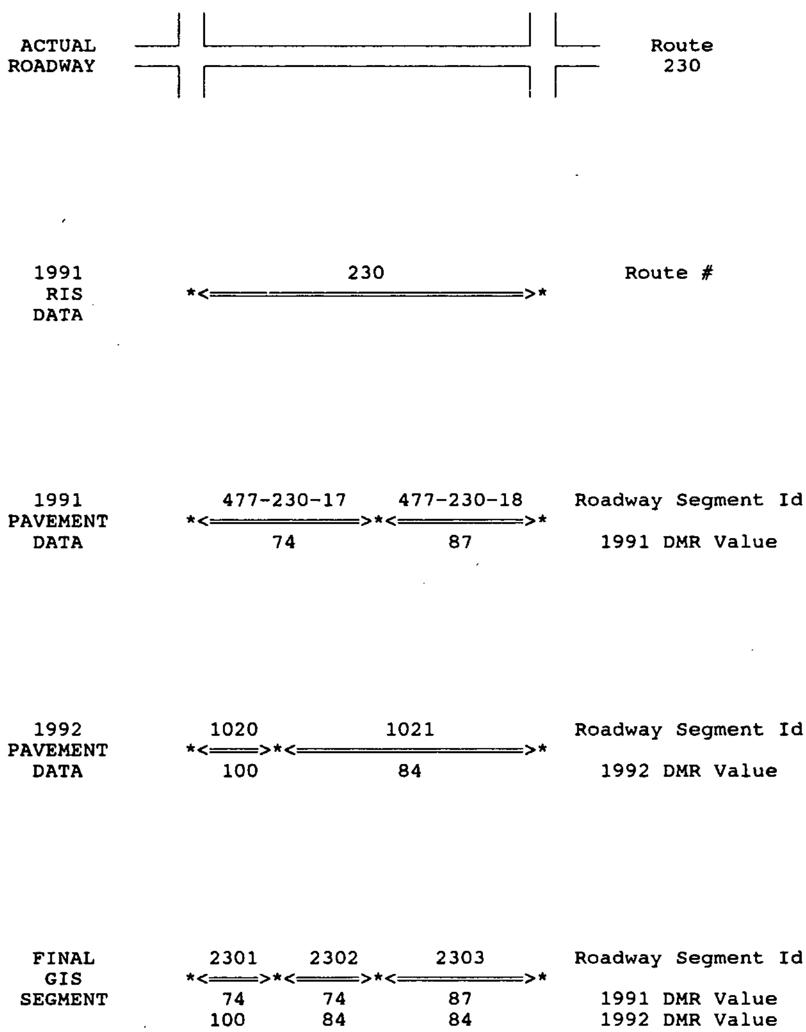

FIGURE 1 Comparison of attribute data structures.

any relational data base, data are linked by fields that contain the same information. For example, the field "address" in one data base can be linked (matched) to the field "address" in another data base, and desired information from the two data bases can then be combined into a single data base.

In a GIS, however, this concept must be extended to encompass the spatial nature of the base-map data. In this research, this was accomplished at the link, or roadway segment, level. Although all of the attribute data bases key data records to a segment of roadway, each data base has its own independent referencing system. Therefore, between the RIS, PMIS, and HTRIS, three numbering schemes exist. Each one, while often describing a similar location, is nevertheless numerically different.

To begin matching these different files, data were sorted and examined by link segment and year. This revealed how often these roadway sections changed. In the case of this study, most sections remained unchanged over the 5 years of pavement data, although the termini of the segments often changed between 1991 and 1992 as the HTRIS coding regime was initiated. An example of this is shown in Figure 1.

Figure 1 displays an actual segment of a hypothetical Route 230. The top of the figure illustrates how this segment exists on the ground. Below this, in order, is the way that this segment is recorded in the RIS, the PMIS (for 1991), and HTRIS (for 1992). In 1991 this segment of roadway was divided into two segments numbered 477-230-17 and 18. These segments had distress management rating (DMR) values of 74 and 87, respectively. In 1992, this same segment was still divided into two segments; however, the termini of the segments had changed as a result of the resurfacing of part of 1991 Segment 477-230-17. The 1992 segment numbers, now in HTRIS, were 1020 and 1021 with DMRs of 100 and 84, respectively. To properly represent this segment in the GIS, it would be necessary to establish three segments for this portion of Route 230 (Figure 1). With this type of geographic referencing, the data from both 1991 and 1992 are now accessible even though they are in differently structured data bases. The GIS establishes an equivalency such that an inquiry as to the 1991 condition of Segment 2301 is retrieved from PMIS Segment 477-230-17 and an inquiry as to the 1992 condition of Segment 2301 is retrieved from HTRIS Segment 1020.

To establish a link between the spatial and attribute data bases, each data base had to include a common reference field. Since none existed, one was established and named "seq" to represent a sequence number for each link along a route. This number was composed of the route number and a sequence number. The route sequence number shown at the bottom of Figure 1 is an example of the "seq" field.

The next step in establishing the link between spatial and attribute data involved combining these spatial roadway segments into groups that matched the pavement condition data records. This was an interactive process using both spatial and attribute data bases. As a spatial group was defined (i.e., Segments 601, 602, and 603 may represent one PMIS roadway maintenance section), the "seq" field that had been added to the PMIS data base was assigned the sequence numbers 601, 602, and 603. In this example, the single PMIS roadway maintenance section data record was duplicated twice, and the resulting three data records were each assigned a unique "seq" number. After the PMIS data base was completely processed in this manner, the HTRIS data base was processed.

Herein lies a drawback to GIS. After this processing, the resulting attribute data bases were significantly larger than they had

TABLE 4 Pavement Condition GIS Data Dictionary (Typical)

Field Name	Field Type	Field Width	# of Decimals
Fnode_	Numeric	11	0
Tnode_	Numeric	11	0
Lpoly_	Numeric	11	0
Rpoly_	Numeric	11	0
Length	Numeric	13	6
Primary_	Numeric	11	0
Primary_id	Numeric	11	0
Rt_Number	Numeric	4	0
Rt_Suffix	Character	3	
Rt_Name	Character	11	
Line_Code	Numeric	2	0
Distance	Numeric	5	2
Seq	Character	5	
DMR_xx	Numeric	3	0
BegMile	Numeric	5	2
BegDes	Character	19	
EndMile	Numeric	5	2
EndDes	Character	19	
Miles	Numeric	5	2
Dir	Character	4	
Surf_Year	Numeric	11	0
Suf_Type	Character	21	
MasterKey	Character	22	
No_Lane	Numeric	1	0
Lane_Miles	Numeric	9	2
Rate_Year	Numeric	11	0
Remarkds	Character	80	
DMR_??	Numeric	3	0
DMR_Chg	Numeric	4	0
DMR_PChg	Numeric	6	1
RideRating	Numeric	3	1
CrkFreq	Character	1	
Crk Sevr	Character	1	
RutFreq	Character	1	
RutSevr	Character	1	
PushFreq	Character	1	
PushSevr	Character	1	
PatcFreq	Character	1	
PatcSevr	Character	1	
RavlFreq	Character	1	
RavlSevr	Character	1	
FluFreq	Character	1	
FluSevr	Character	1	

TABLE 3 Pavement Condition GIS Coverages

Coverage Name	Coverage Type	Description
RATE1988	Line	1988 Pavement Condition Ratings
RATE1989	Line	1989 Pavement Condition Ratings
RATE1990	Line	1990 Pavement Condition Ratings
RATE1991	Line	1991 Pavement Condition Ratings
RATE1992	Line	1992 Pavement Condition Ratings

been previously as a result of the number of data records that had to be duplicated. Whereas in the original PMIS data base, only one data record existed for this particular section of VA-6, inclusion in the GIS broke this single segment into three segments; thus one data record was replaced with three. An alternative concept was envisioned during this processing that might overcome this drawback. A master roadway reference equivalency might be created to function as a bridge between the spatial and attribute data bases. This lookup table could be entered with either the spatial sequence number or the attribute maintenance section number, and the respective equivalent reference number could be found. The advantage of this is that it would eliminate the need to augment the attribute data base. The disadvantage is that a new data base would need to be developed and maintained. Further, in a more powerful computing platform, such as a UNIX-based computer, the GIS software offers a dynamic segmentation option that automatically segments the attribute data records.

At the conclusion of these steps, spatial data and attribute data were tied to a common geographic referencing system through the use of these sequence numbers. The final step in building the data base involved auditing and editing the various data bases to ensure their relative accuracy. Although in this project this effort was straightforward (if not labor-intensive), a more complicated application could require that significant time be spent carrying out this step. This step should not be overlooked, since any subsequent analysis performed on these data will reflect any errors contained in it.

APPLICATION FOR DECISION ANALYSIS

Having now established, linked, and edited both the spatial and attribute data bases, an applied analysis to demonstrate how the GIS can be used to quickly provide information for evaluating pavement conditions was undertaken. The first step was to combine the spatial data base with the individual pavement rating data bases. This process established five "new" GIS data bases, one for each of the rating years. Since these new data bases contain their own spatial and attribute data sets, they are considered coverages as defined earlier. These new coverages are given in Table 3.

Each of these five data bases is structured in a similar fashion. Table 4 presents the typical data dictionary for one of these new coverages. Those fields shown above the dashed line in the table represent the spatial component of this combined data base; those below represent the attribute component.

Figure 2 displays the condition of roadways that were asphalt-surfaced and rated in 1991, as evidenced by the existence of DMR

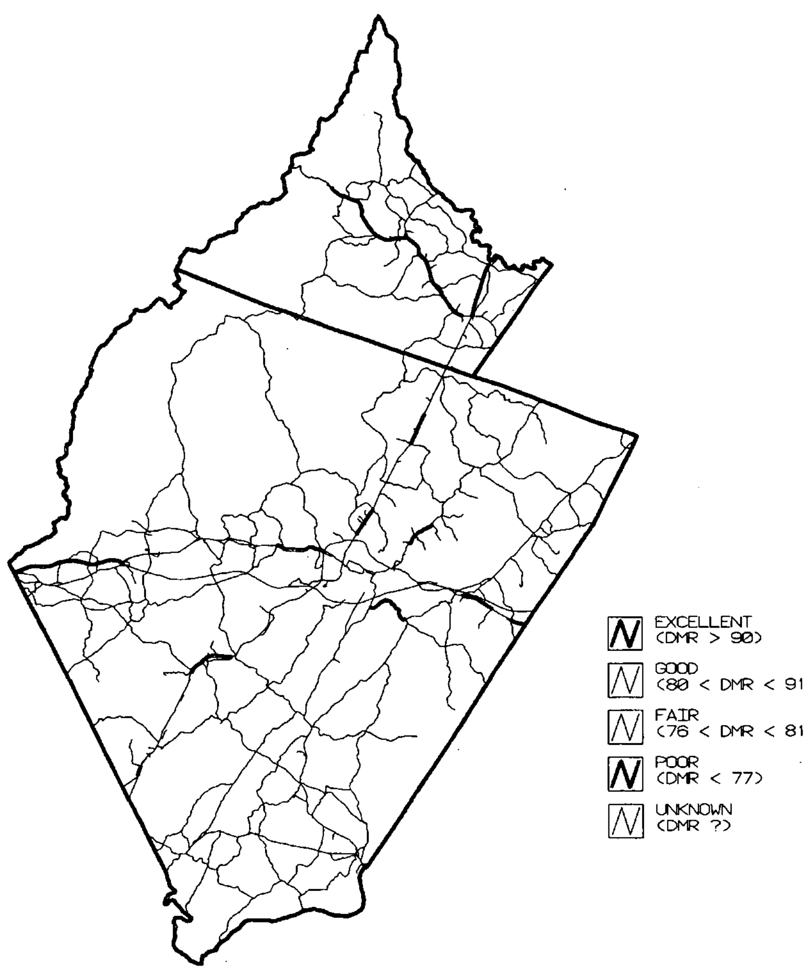

FIGURE 2 Condition of roadways asphalt-surfaced and rated in 1991.

values. This rating, which currently exists only for asphalt-surfaced roadways in Virginia, is derived by formula from the frequency and severity of a number of pavement distresses (Table 1). Within VDOT, a DMR value of 100 represents a roadway in perfect condition, whereas a value of 76 is the threshold at which, ideally, a section is scheduled for maintenance (typically, an overlay for bituminous pavements).

Figure 2 highlights those segments of roadway that in 1991 had DMR values of less than 76. These segments would be considered in poor condition and in need of major maintenance during the next maintenance season. Depending on the needs of the analyst, this map could also represent ranges of DMR values. As shown, 941.66 lane-mi of roadways were rated in 1991. Of these, 143.12 lane-mi (15.2 percent) were in poor condition.

Another goal of this research was to examine the change in a roadway's DMR during consecutive years (Figure 3). It is important to point out that Figure 2 was generated by linking the spatial data base to the PMIS data base, whereas Figure 3 linked the spatial data base to the HTRIS data base. The display categories in Figure 3 are identical to those used in Figure 2; thus, of the 941.66 lane-mi of roadway rated in 1991, 37.5 lane-mi were rated in 1992 as being in poor condition.

To better clarify these changes, Figure 4 was generated by, in effect, subtracting Figure 2 from Figure 3. The display in Figure 4 is based on the change in the DMR values between years and highlights those roadway segments that were acceptable in 1991 but poor in 1992, and it demonstrates the ability of GIS to integrate data between disparate data bases. The 37.5 lane-mi highlighted in Figure 3 as being in poor condition were in either acceptable condition in 1991 or they were already in poor condition. By integrating the two data bases, it was found that 35.1 lane-mi (94 percent) were considered to be in acceptable condition in 1991. Put another way, although between 1991 and 1992 the total quantity of roadway surface rated poor decreased (from 143.12 to 37.5 lane-mi), 35.1 lane-mi (3.7 percent of the Interstate and primary roadway network, which was rated in both years) deteriorated enough to be considered poor in 1992, whereas 96.3 percent either remained the same or improved. These figures support a first-in/first-out policy of performing major maintenance activities, since only 2.4 lane-mi of the 143.12 lane-mi that rated poor in 1991 were still rated poor in 1992. This represents a backlog of only 1.7 percent.

Another application of the GIS was to show the change in pavement condition over an extended period. Present in the PMIS and

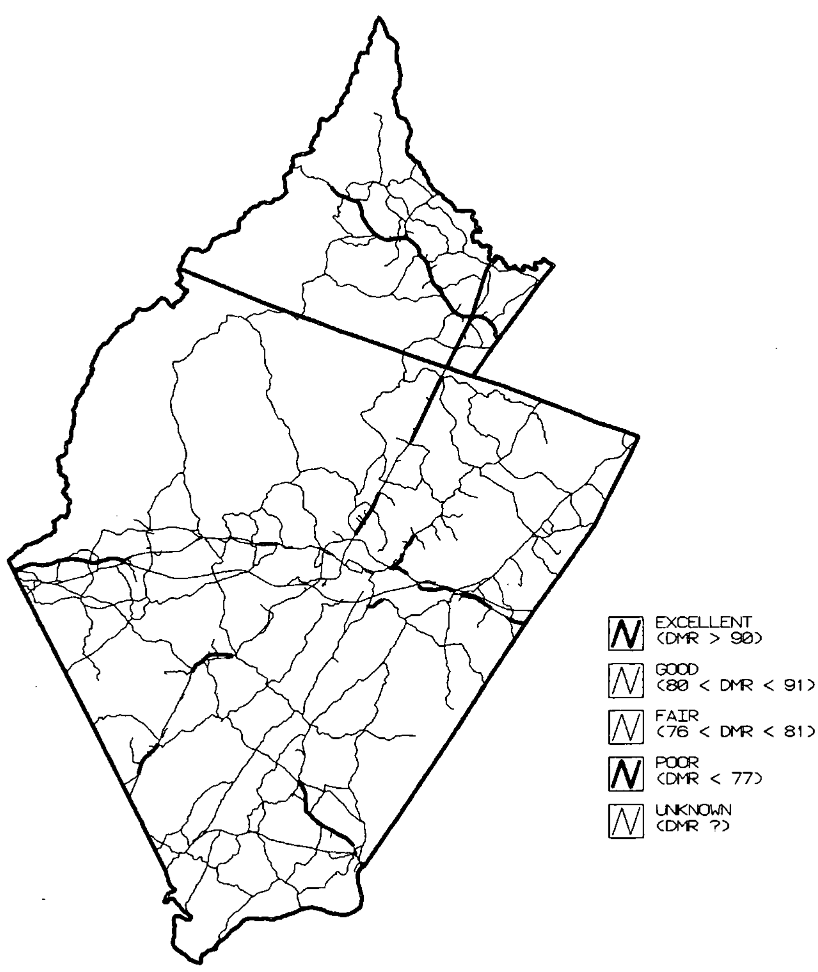

FIGURE 3 Change in DMR values during consecutive years (covers: Boundary, Primary, Majorsec, and Rate1992).

HTRIS data was a field that identified when a roadway section was last surfaced. In some cases, the data went back to 1980. Figure 5 summarizes the average change in DMR value per year since the last resurfacing and highlights those sections in which the DMR had dropped the most (by more than five points per year). This rate of decline would reduce a newly resurfaced roadway to poor condition in fewer than 5 years. As shown, 7.96 lane-mi (0.8 percent) fall into this category. On observing this rate of deterioration, particularly if the proportion was greater than 0.8 percent of the system, the pavement manager might opt to further investigate those roadway sections to ascertain the cause for the accelerated wear.

The remaining goal of this research was to examine the issue of the remaining service life of pavements. Figure 6 illustrates these findings. Building from Figure 5, the individual DMR values from each of the five pavement rating data bases (1988 through 1992) were extracted into a new data base. These values were then examined and, through linear regression, a trend line was established. This trend line was then extended (if necessary) until it reached a DMR value of 76. The number of years until this occurred is displayed in Figure 6. Pavement sections that are currently at or below the DMR threshold of 76 and those with 1 to 5 years of remaining service life are highlighted.

As shown, 623.92 lane-mi (66.3 percent) of the rated pavements will need to be replaced within the next 5 years. This lane mileage includes the 37.5 with no remaining service life, as well as 586.42 that are likely to fall below the DMR threshold of 76 within the next 5 years. This is a substantial percentage of an area's roadways. This type of examination not only aids in projecting maintenance needs, but it is also useful for budgetary planning.

Another type of remaining service life examination looks at the change in the individual distress indexes (e.g., cracking, rutting, etc.) and establishes a trend line. Although this type of analysis was not performed herein, the data necessary for this type of analysis are contained in the five pavement rating data bases. Additionally, although the existing DMR calculations were used in this research, the actual formula used to generate these values could also be incorporated into the GIS, thereby allowing the user to vary the weights assigned to each of the individual distress indexes.

As with most computerized information management systems, once the data have been entered into the automated environment,

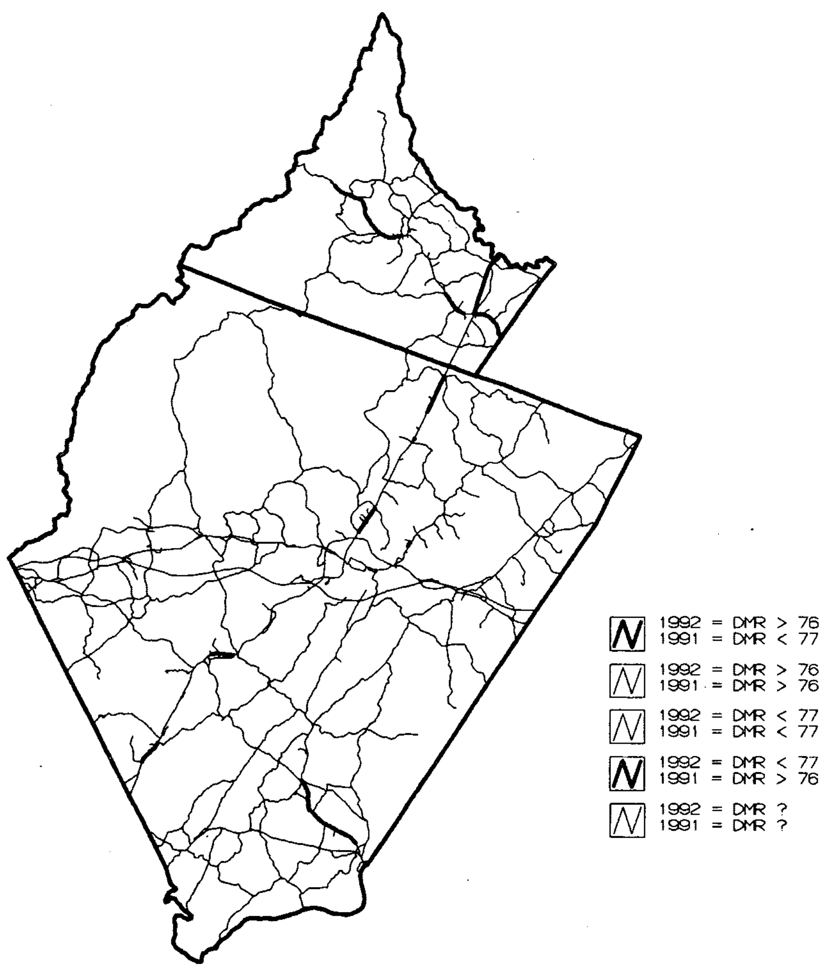

FIGURE 4 Change in DMT values between years.

the types of analysis that are possible are limited only by the user's imagination.

CONCLUSIONS

The development and use of a pavement attribute data base within a GIS environment to support pavement management decision making was demonstrated using several types of applications, including annual pavement condition reporting, changes in pavement condition from one year to the next, changes in pavement condition over an extended period, and an analysis of remaining pavement service life. The data used by the GIS covered two adjacent counties and came from eight independent sources, including three U.S. Geological Survey digital line graphs, four VDOT pre-HTRIS pavement management data bases, and the VDOT HTRIS pavement management data base. These data were transformed into information using standard locational referencing techniques and were displayed in both map and tabular form.

Evaluating whether using GIS in this effort was more efficient than not using GIS is not a simple matter. In this specific effort, the hundreds of hours spent in developing the GIS environment could easily have been equal to or greater than the hundreds of hours required to complete the effort manually. As with any automated decision support system, few if any benefits are realized as a result of one application of the technology. The benefits accrue over time. A second application of this GIS decision support system (i.e., changing the DMR threshold by 10 percent) will require far less time to complete than the same change would take to process manually. Subsequent applications (within pavement management) will take even less time as system operators continue to learn how the system functions. Other applications of the technology within the HTRIS data base will also proceed much faster, since locational referencing has now been established at least in these two counties.

This clearly points to the systematic nature of GIS. Although it is no longer necessary for the format of all data to be identical in order to be processed by computer as with traditional management information systems, still some measure of routine and commonality proves beneficial to the GIS environment. In the end, garbage in equals garbage out. For example, if established common data collection techniques do not exist, it might be extremely difficult (but not necessarily impossible) to establish links between data sets. In this application, for example, roadway segments were

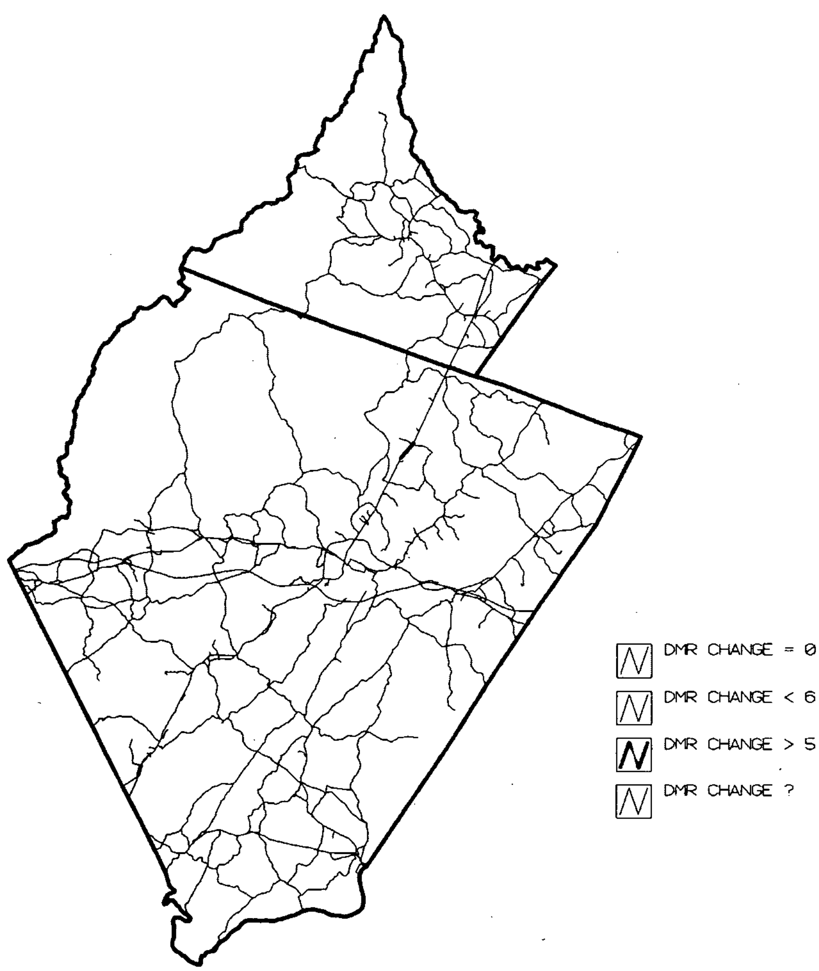

FIGURE 5 Average change in DMR values per year since last resurfacing.

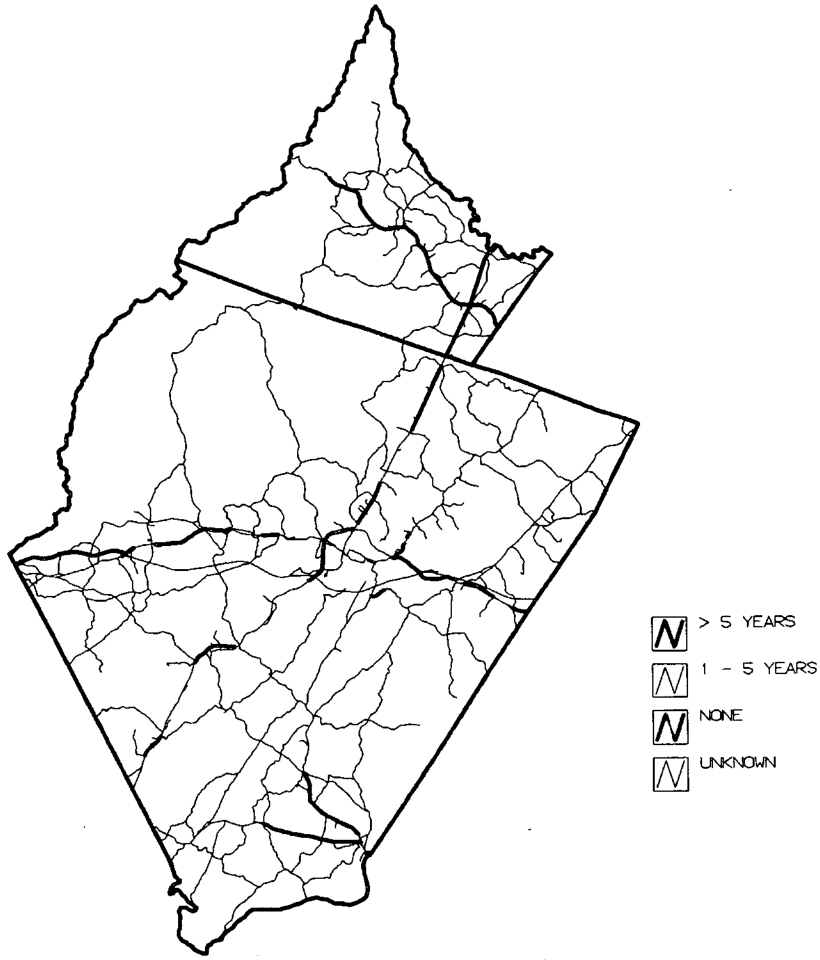

FIGURE 6 Remaining service life of pavements.

fairly stable over time. If this had not been the case, the matching of roadway segments by year would have been far more difficult.

Because of this, a key conclusion from this research was that the spatial data base must include the smallest possible roadway segment based upon the available attribute data bases. This facilitated combining the roadway sequences to relate to PMIS and HTRIS record keeping. In the larger GIS platforms—for example, those based on UNIX—this factor is minimized through dynamic segmentation. This technology allows roadway sections to be segmented on the fly.

Another key conclusion is that once the relational link was established between spatial and attribute data, particularly HTRIS data, any application within HTRIS becomes accessible through the GIS. HTRIS is composed of a number of application modules, of which pavement management is only one. Other applications include (or will include) accident data, traffic volumes, and so forth. These data sets can now be accessed by the GIS through the sequence field, thereby allowing for the integration, for example, of pavement rating and accident data, or pavement ratings and traffic volumes, or even pavement ratings, traffic volumes, and accident data. Therefore, GIS also allows for data integration within existing data bases.

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REFERENCE

1. Johnson, B. H., and M. J. Demetsky. *A Geographic Information System Environment for Transportation Management Systems*. Report UVA/529685/CE93/101. Mid-Atlantic Universities Transportation Center, University of Virginia, Charlottesville, 1993.

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