Geographic Information System Environment for Transportation Management Systems

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The management systems that are required of states by the Intermodal Surface Transportation Efficiency Act of 1991 have a common element in their need for a well-established data base. In this regard, computerized geographic information systems (GISs) are emerging as efficient and effective tools for managing transportation information resources. These systems integrate geographic (or spatial) information displayed on maps, such as roadway alignment, with attribute (or tabular) information characterizing features, such as composition and age. The development of a prototype transportation management GIS data base for pavement management is described to illustrate the use of a GIS framework for transportation management systems. The data base that was developed covered two counties in Virginia, and the representation of the roadway system in these two jurisdictions established the reference for the pavement attribute data. The same geographic data base could be used for other management systems, although it would need to include slight additions for safety and bridge management and additional facilities for congestion, intermodal, and public transportation management.

In December 1991, the President signed into law the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (P.L. 102-240). Among the provisions of ISTEA is a requirement for state highway agencies to establish formal information management systems related to bridge management, intermodal transportation, pavement management, public transportation, safety, and traffic congestion.

At least one of these systems, pavement management, has existed since March 6, 1989, when FHWA issued a series of guidelines "to set forth a policy to select, design, and manage federal-aid highway pavements in a cost-effective manner and identify pavement work eligible for federal-aid funding" (*1*).

The policies in the *Federal-Aid Highway Program Manual* (FHPM) address five functional areas: pavement management systems, general pavement design considerations, pavement design of new and reconstructed pavements, pavement design of rehabilitated pavements, and safety. In light of the provisions of ISTEA, the portion of FHPM concerned with pavement management systems is of particular significance. According to the FHPM, a pavement management system is "a set of tools or methods that assist decision makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in a serviceable condition" (*2*).

The policy section of the FHPM establishes the federal policy concerning pavement management systems as follows: "each State Highway Agency (SHA) shall have a pavement management system (PMS) that is acceptable to FHWA and is based on concepts described in American Association of State Highway and Transportation Officials publications including its 1985 *Guidelines on Pavement Management*" (*2*).

In establishing this policy, FHWA recognized that because of rising costs, reduced resources, increased system utilization, needs that exceed revenues, and a changing emphasis from system expansion to system preservation and rehabilitation, a systematic approach to managing pavements was needed to protect the investment in today's highway network infrastructure and to maximize the use of every available highway dollar. FHWA judged that a pavement management system could give decision makers key information to address these needs.

A frequent problem with providing this information, however, is that the relevant data have typically been collected and compiled by a number of units within state and local government. Even when the existence of these data is known, often the data are not readily usable in the decision-making process because they are of a form or content different from other data being used. This is the classic condition of being data rich and information poor.

At this time, state departments of transportation have gained experience only in developing pavement and bridge management systems, although some are only in the formative stages of development, especially bridge management. The states are only beginning to consider the scope and structure of management systems for highway safety, traffic congestion, public transportation facilities and equipment, and intermodal transportation facilities and equipment.

One common element of all these management systems is the need for its data base to include information from a variety of sources. The data base is the driver of a process that includes assessment, forecasting, development of alternatives, evaluation of alternatives, decision analysis, and implementation.

Thus for any transportation management system to be effective, a sound data base methodology is required. In this regard, computerized geographic information systems (GISs) are emerging as efficient and effective tools for managing transportation information resources. These systems integrate geographic (or spatial) information displayed on maps, such as roadway alignment, with attributes of the geographic features, such as the composition and age of the roadway's pavement structure.

PURPOSE AND SCOPE

This paper describes the development of a prototype transportation management GIS geographic information base for pavement man-

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agement. It was decided to use Virginia's Albemarle and Greene counties as the geographic study area. This will serve as a demonstration of the capabilities of GIS for providing the framework for any type of management system. For example, the entire data set for a safety management system may differ from that of the pavement management system, but some elements will be common and the geographic base will be the same. Hence, an integrated data base that serves both systems is a more effective design than separate systems.

Infrastructure managers are typically concerned with three fundamental questions: What is the current condition of their area of responsibility? What is the trend of this condition? How long before some major action is necessary? The more informed the manager is, the more effective the manager's decisions are. Managers also need to know average trends in order to identify anomalies and act before small problems become major problems. Managers need to know how much time they have to act, as well. This information is needed not only for deciding which technical course of action to take, but also for forecasting budgets.

Pavement management, for example, is concerned primarily with budgetary issues, such as how much money is needed to maintain the roadway system at a prescribed level of condition, which is usually set by policy. Therefore, to support this decision-making process, the GIS will need to

- Identify current pavement conditions,
- Identify current pavement condition trends, and
- Forecast when and where major maintenance actions will be needed.

Such requirements for pavement management illustrate the types of questions that drive any transportation management system. For example, an intermodal management system might need to

- Identify current conditions of intermodal terminals,

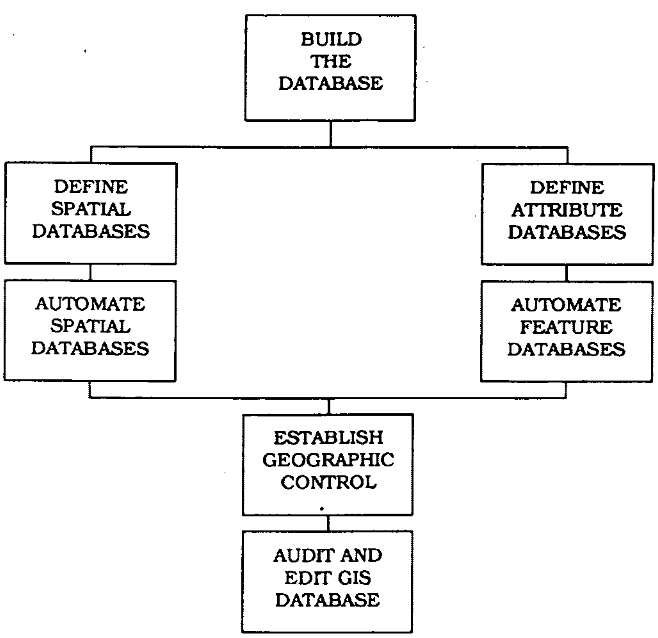

FIGURE 1 Building of GIS data base.

FIGURE 2 Study area (cover: DLG-orig).

- Identify ground access to intermodal facilities, and
- Forecast intermodal facility needs.

These management systems are viewed as providing information for decision makers for planning and programming. All will possess a common geographic base and require similar data bases among themselves.

METHODOLOGY

The approach to developing a GIS data base for pavement management was organized around three major tasks: defining the problem, developing the GIS, and developing GIS applications.

GIS Development

A review of current microcomputer architecture and software was undertaken, and an appropriate workstation was acquired. With regard to software, compatibility between programs was critical, since the condition/format of relevant spatial and attribute data was unknown. Therefore, software was selected that would access the widest possible spectrum of data formats.

TABLE 1 Unique Graphic Line Elements

Interstate Routes	Virginia Routes	National Routes	Political Boundaries
I-64	VA-6	US-29	Albemarle County
	VA-20	US-29 Business	Charlottesville (M)
	VA-22	US-33	Charlottesville (C)
	VA-53	US-250	Jack Jouett (M)
	VA-151	US-250 Business	Rivanna (M)
	VA-230		Samuel Miller (M)
	VA-231		Scottsville (M)
	VA-240		Scottsville (T)
	VA-302		White Hall (M)
	VA-317		Greene County
	VA-388		Monroe (M)
			Ruckersville (M)
			Shenandoah (NP)
			Standardsville (M)
			Standardsville (T)

NOTES: (C) = city
(M) = magisterial district
(NP) = national park
(T) = town

The microcomputer GIS software PC-Arc/Info was offered for evaluation. Since this is one of the more frequently used GIS platforms and since it offers data interchange capabilities with a wide range of other GIS and non-GIS formats, it was chosen for this research. Other off-the-shelf software packages used in this research included AutoCAD, dBase, Lotus 1-2-3, and WordPerfect. The use of these five software packages eliminated the need for custom programming.

GIS Application Development

GIS application development involved bringing all of the pieces of the management system together: the establishment of the geographic base map (or spatial data base as it is commonly called); the establishment of the thematic, or attribute, data base related to the management system of concern; and, most important, the establishment of the geographic referencing scheme, which will tie the spatial and attribute data bases together.

Before proceeding, it is important to understand how a GIS organizes its data bases into a single data base. Within a GIS data base, data are organized into one of four types (*3*): lines (or arcs), points, areas (or polygons), and attributes (or features). Lines, points, and areas refer to spatial data, and attributes refer to the thematic data associated with the management system. Last, a coverage is the term that Arc/Info assigns to a GIS data base once it has been established within the GIS environment. Since a coverage has both spatial data and attribute data, it is used to distinguish integrated data sets from component spatial and attribute data sets.

Spatial Data Base Development

Spatial data base development, as shown on the left side of Figure 1, began with an extensive search to determine whether any local agency had previously established a GIS within the two-county study area. None was found. The search then concentrated on finding existing automated cartographic data bases for the two counties within the public sector, of which only one was found: U.S. Geological Survey (USGS) digital line graphs (DLGs).

The DLGs for Albemarle and Greene counties had recently been updated in conjunction with the U.S. Census Bureau's 1990 Decennial Census for use in its Topologically Integrated Geographic Encoding and Referencing (TIGER) system. These DLGs were developed from the 1:100,000 scale USGS map series. The quadrangle maps constitute the foundation of the spatial data bases. A copy of the DLGs for these counties was obtained from the State Data Center at Alderman Library (Government Documents Section) at the University of Virginia.

The DLGs had been processed into three Arc/Info coverages, but no other processing had taken place. These three coverages encompassed Albemarle County (excluding the city of Charlottesville), the city of Charlottesville, and Greene County.

The three coverages contained political boundaries; electric, gas, and telephone trunk lines; rivers and lakes; as well as the

TABLE 2 Initial GIS Coverages

Coverage Name	Coverage Type	Contents
BOUNDARY	Polygon	Albemarle & Greene County Boundaries
JURISDIC	Line	Magisterial & Municipal Boundaries
COUNTIES	Polygon	BOUNDARY & JURISDIC contents
PRIMARY	Line	Interstate & Primary Highways
MAJORSEC	Line	Major Secondary Highways

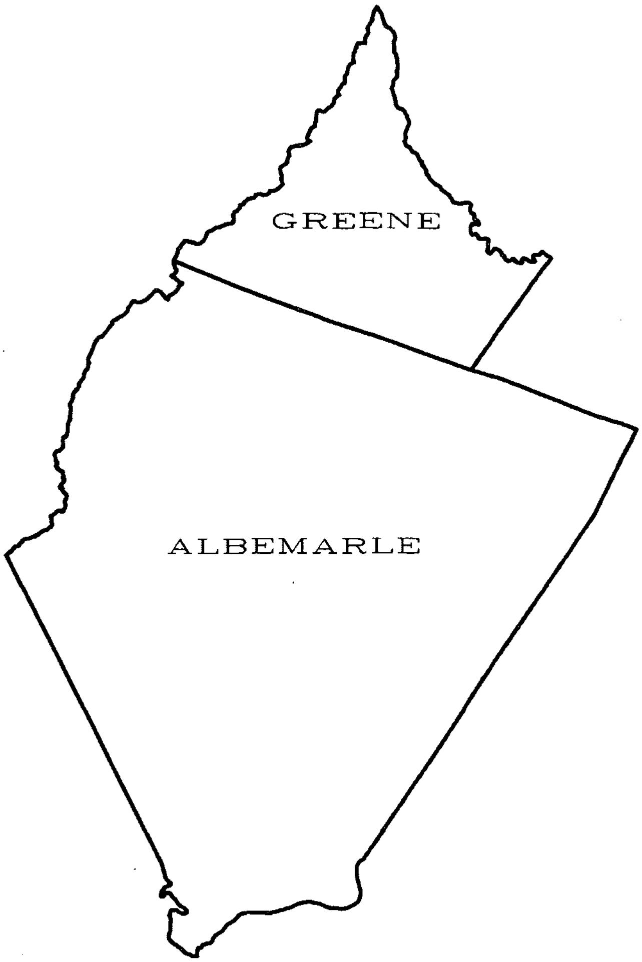

FIGURE 3 Limits of study area (cover: Boundary; source: DLG-Orig).

roadway system. However, these features were intermingled in such a way that a road was indistinguishable from a river or any other line feature. This was an error not in the data, but in the way that the data are routinely distributed.

Automating these spatial data bases required digitizing by the USGS, conversion of the initial DLGs to Arc/Info GIS coverages, and editing the resultant coverages to define individual graphic elements. The first two steps were accomplished external to this research and no verification of the accuracy of the original data was performed. In fact, several errors were found during data editing (e.g., lines representing no apparent physical feature).

Editing the spatial data (defining the individual line elements) was completely within the scope of this research. The first step was to combine the three coverages (Albemarle County, Charlottesville, and Greene County) into one coverage encompassing the entire study area (Figure 2). Although this step was not technically necessary, it aided the editing process.

This combined coverage was next transferred to a computer-aided design and drafting (CADD) environment for graphic editing. This transfer was done because the CADD environment is better suited than the GIS environment to the nature of the graphic editing task. The GIS software contains an established set of routines for accomplishing this task.

Once transferred to CADD, each graphic element contained in the file had to be examined to ascertain whether it was a segment of a road and whether it was a segment of an Interstate highway, primary highway, secondary highway, or another road. If the graphic element was a road and part of an Interstate, primary, or an intersecting secondary road, the element was copied to a new layer within CADD. If it was not a road but a political boundary, it was also copied to a new layer within CADD. If the element was neither, a new element was selected.

When this task was completed, each new layer was examined with individual segments of each roadway or boundary connected to form a continuous line element. For example, after the first step, one might have 30 or even 130 discrete pieces of roadway, which when combined represent the extent of a given roadway. This step combined these individual pieces into one piece. After this step, the line elements shown in Table 1 had been established.

After graphic editing, the next step was to reintroduce the edited graphic file back into the GIS. Arc/Info also contains a routine to accomplish this task. On completion of this step, five unique coverages had been established within the GIS (Table 2).

Arc/Info establishes four standard fields in polygon data bases: "area," "perimeter," "cover_," and "cover_id." Although "area" and "perimeter" are self-explanatory, "cover_" and "cover_id" need further clarification. "Cover_" is a reference number that Arc/Info assigns to each polygon within the coverage. "Cover_id" is a reference number that the user may assign to each polygon within the coverage.

Figure 3 displays the polygon coverage Boundary, the limits of the study area. The data dictionary (or structure of the data base) for this coverage is shown in Table 3. The cover_id, "boundary. i," was assigned the respective Virginia Department of Transportation county reference number: 2 for Albemarle and 39 for Greene. In this fashion, existing search, sort, and reporting routines could be used. The last three fields ("co_name," "co_symbol," and "sq_miles") were added to facilitate processing. The field "co_name" is self-explanatory. "Co_symbol" contains a number used for shading the counties on displays (Figure 4). "Sq_miles"

TABLE 3 Boundary Data Dictionary

Field Name	Field Type	Field Width	No. of Decimals
Area	Numeric	13	6
Perimeter	Numeric	13	6
Boundary_	Numeric	11	0
Boundary_i	Numeric	11	0
Co_Name	Character	9	
Co_Symbol	Numeric	2	0
Sq_Miles	Numeric	6	2

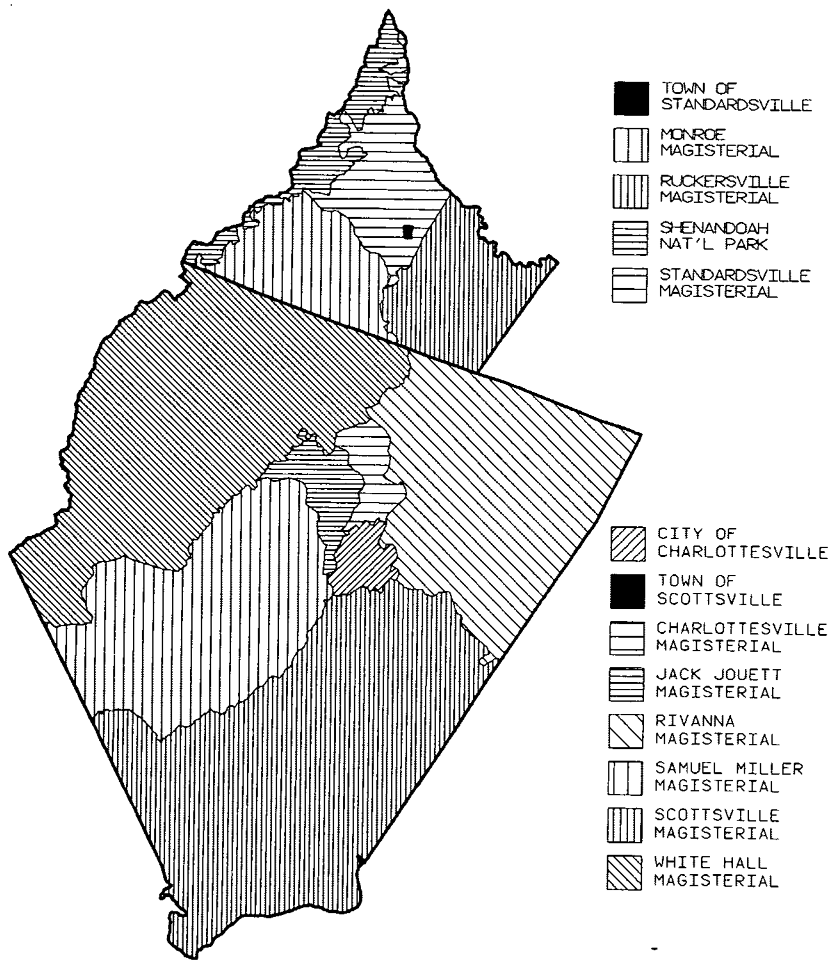

FIGURE 4 Counties in study area.

is also self-explanatory and has been calculated on the basis of the value for "area," which was entered in square meters in the original DLGs.

Arc/Info establishes seven standard fields in line data bases: "fnode_," "tnode_," "lpoly_," "rpoly_," "length," "cover_," and "cover_id." "Fnode_" is the internal Arc/Info node number from which the line originates, and "tnode_" is the internal node number at which the line ends. "Lpoly_" is the "cover_" of the polygon to the left of the line, and "rpoly_" is the "cover_" to the right. "Length" is self-explanatory; "cover_" and "cover_id" are similar to those used in the polygon data base except that here they are related to line elements.

Table 4 gives the data dictionary for the line coverage Jurisdic. When overlaid with the Boundary coverage, internal political jurisdiction boundaries are shown as in Figure 4. This new coverage, Counties, functions as both a polygon and a line coverage. The data dictionary for this coverage is shown in Table 5.

TABLE 4 Jurisdic Data Dictionary

Field Name	Field Type	Field Width	No. of Decimals
Fnode_	Numeric	11	0
Tnode_	Numeric	11	0
Lpoly_	Numeric	11	0
Rpoly_	Numeric	11	0
Length	Numeric	13	6
Jurisdic	Numeric	11	0
Jurisdic_	Numeric	11	0

TABLE 5 Counties Data Dictionaries

Database	Field Name	Field Type	Field Width	No. of Decimals
Poly	Area	Numeric	13	6
Poly	Perimeter	Numeric	13	6
Poly	Counties	Numeric	11	0
Poly	Counties_i	Numeric	11	0
Poly	Boundary_	Numeric	11	0
Poly	Boundary_i	Numeric	11	0
Poly	Co_Name	Character	9	
Poly	Co_Symbol	Numeric	2	0
Poly	Jurisdic	Numeric	11	0
Poly	Jurisdic_i	Numeric	11	0
Poly	Jur_Name	Character	25	
Poly	Jur_Symbol	Numeric	2	0
Poly	Sq_Miles	Numeric	6	2
Line	Fnode_	Numeric	11	0
Line	Tnode_	Numeric	11	0
Line	Lpoly_	Numeric	11	0
Line	Rpoly_	Numeric	11	0
Line	Length	Numeric	13	6
Line	Counties	Numeric	11	0
Line	Counties_i	Numeric	11	0
Line	Line_Code	Numeric	2	0

TABLE 6 Primary Data Dictionary

Field Name	Field Type	Field Width	No. 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

TABLE 7 Majorsec Data Dictionary

Field Name	Field Type	Field Width	No. of Decimals
Fnode_	Numeric	11	0
Tnode_	Numeric	11	0
Lpoly_	Numeric	11	0
Rpoly_	Numeric	11	0
Length	Numeric	13	6
Majorsec	Numeric	11	0
Majorsec_i	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

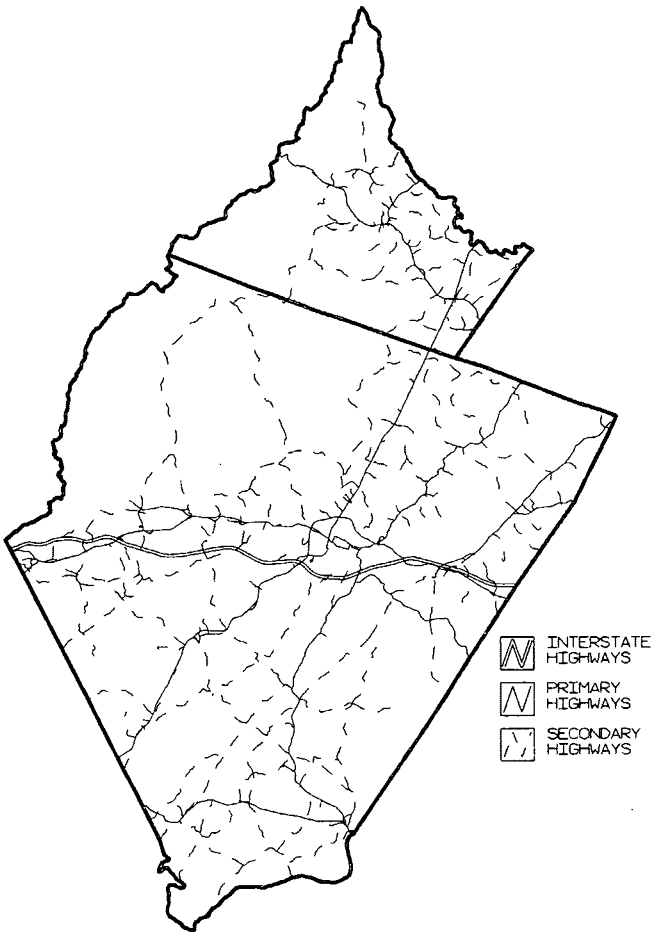

FIGURE 5 Major roadways in study area (covers: Boundary, Primary, and Majorsec).

The data dictionaries for the line coverages, Primary and Majorsec, are given in Tables 6 and 7. Overlaying Counties with Primary and Majorsec produced Figure 5 showing the major roadways within the study area.

Attribute Data Base Development

The spatial data base established a referencing framework for all transportation management systems. The common activities inherent within the management systems that will dictate the requirements for the attribute data of the catalogued facilities include

- Defining and monitoring the magnitude of the problems,
- Identifying transportation improvement needs,
- Analyzing alternative solutions to the problems and assessing their effectiveness in solving them, and
- Measuring the effectiveness of the implemented actions.

To address these issues, data, such as traffic volumes, will be required for all of the management systems; others will be tied only to a specific management system such as pavement design data, bridge structure data, or transit vehicle data.

A GIS must therefore start by evolving from a basic reference system to a highly sophisticated collection of attribute data that can be used to illustrate and analyze the questions and issues of decision making.

CONCLUSIONS

A roadway data base was developed on a GIS for aiding in the pavement management decision process. The data base that was developed encompassed two counties in Virginia. A representation of the roadway system in these two jurisdictions provides the basis for establishing attribute data to be used for pavement management purposes. Other roadway-based management systems, such as safety or bridge management, can use this reference base with only slight additions. Other management systems—such as congestion, public transportation, and intermodal management—can supplement the data with additional facilities data and subsequently add to the attribute data. Ultimately, the facility or infrastructure reference system can be used to support all six management systems and share various attribute files as well.

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