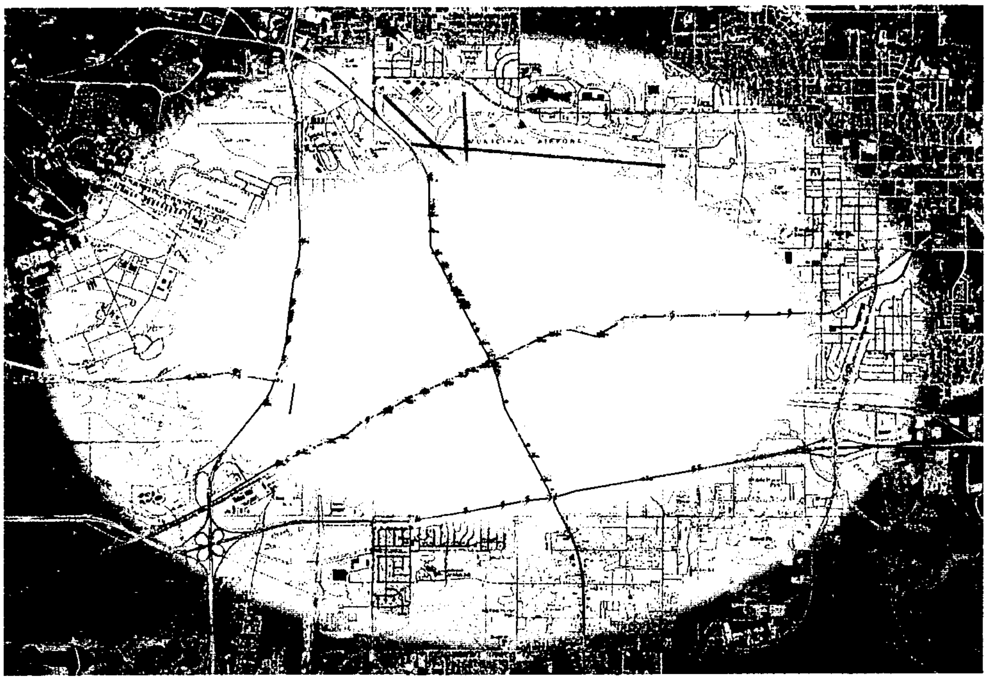
PB2000-103393

FINAL REPORT

FHWA-WY-00/02F

State of Wyoming
Department of Transportation

U.S. Department of Transportation
Federal Highway Administration



THE WYOMING DEPARTMENT OF TRANSPORTATION GEOGRAPHIC INFORMATION SYSTEM IMPLEMENTATION PROJECT

By:

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January, 2000

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Technical Report Documentation Page

Report No. FHWA-WY-00/02F	Government Accession No.	Recipients Catalog No.

Title and Subtitle	
THE WYOMING DEPARTMENT OF TRANSPORTATION GEOGRAPHIC INFORMATION SYSTEM IMPLEMENTATION PROJECT	Report Date: January 2000 Performing Organization Code
Author(s): Environmental Systems Research Institute, Inc.	Performing Organization Report No.
Performing Organization Name and Address: Environmental Systems Research Institute, Inc. 4875 Pearl East Circle, Suite 200 Boulder, Colorado 80301-6103	Work Unit No. RS04(199) Job No. Z3A4 Contact or Grant No.
Sponsoring Agency Name and Address: Wyoming Department of Transportation 5300 Bishop Blvd. Cheyenne, WY 82009-3340 Planning - Research Unit (307) 777-4182	Type of Report and Period Covered: Final Sponsoring Agency Code

Supplementary Notes
WYDOT Technical Contact: B. Patrick Collins, P.E., State Bridge Engineer

Abstract
A geographic information system (GIS) was needed by the Wyoming Department of Transportation (WYDOT) to complement existing information management procedures and leverage the spatial component of its data. WYDOT contracted with Environmental Systems Research Institute, Inc. (ESRI), to provide planning and implementation services aimed at establishing GIS technology within the department.

The methodology consisted of three distinct but tightly integrated planning states: an initial plan that aligned GIS development with organizational goals and objectives, a conceptual plan that defined what the GIS was to accomplish, and a detailed plan that defined how the system would operate. The planning activities were followed by system deployment efforts that considered the acquisition, installation, construction, and integration of GIS hardware, software, data, applications, and organizational procedures. The design methodology offered the following strategic benefits for WYDOT:

- Implementation was founded in a planning environment. Financial commitments to hardware, software, and data were deferred until system requirements were fully understood. The approach ensured that each GIS investment decision met well-defined needs and long-term organizational goals.
- Convenient stopping points, built into the methodology, enabled WYDOT staff to assess the feasibility of GIS development at various stages of the implementation. In this manner, WYDOT staff gained confidence in, and control of, their GIS development decisions.
- Active participation by WYDOT staff resulted in an internal GIS knowledge base that serves to reduce their reliance on outside consultants and enable them to effectively direct future GIS investment.

Working together, WYDOT and ESRI delivered an operational GIS on time and within budget.

Key Words		Distribution Statement	
Wyoming, geographic information system, GIS, planning, implementation, design methodology		Unlimited	
Security Classif. (of this report): Unclassified	Security Classif. (of this page): Unclassified	No. of Pages: 134	Price

SI* (Modern Metric) Conversion Factors

Approximate Conversions from SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
Area				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
Volume				
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
Mass				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lbs)	T
Temperature (exact)				
°C	Centigrade temperature	1.8 C + 32	Fahrenheit temperature	°F
Illumination				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
Force and Pressure or Stress				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

Approximate Conversions to SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
Area				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
Volume				
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
Mass				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lbs)	0.907	megagrams	Mg
Temperature (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
Illumination				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
Force and Pressure or Stress				
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

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1.0 Executive Summary

A geographic information system (GIS) was needed by the Wyoming Department of Transportation (WYDOT) to complement existing information management procedures and leverage the spatial component of its data. WYDOT contracted with Environmental Systems Research Institute, Inc. (ESRI), to provide planning and implementation services aimed at establishing GIS technology within the department.

ESRI is the leader in geographic information systems technology, with worldwide markets. Founded in 1969, ESRI has fine-tuned a design methodology that considers the unique organizational, technical, and financial environment surrounding GIS. ESRI relied on experience with similar organizations and worked with WYDOT staff to tailor a design methodology that promoted the successful implementation of GIS within the department.

The methodology consisted of three distinct but tightly integrated planning stages: an initial plan that aligned GIS development with organizational goals and objectives, a conceptual plan that defined what the GIS was to accomplish, and a detailed plan that defined how the system would operate. The planning activities were followed by system deployment efforts that considered the acquisition, installation, construction, and integration of GIS hardware, software, data, applications, and organizational procedures. The design methodology offered the following strategic benefits for the Wyoming Department of Transportation:

- Implementation was founded in a planning environment. Financial commitments to hardware, software and data were deferred until system requirements were fully understood. The approach ensured that each GIS investment decision met well-defined needs and long-term organizational goals.
- Convenient stopping points, built into the methodology, enabled WYDOT staff to assess the feasibility of GIS development at various stages of the implementation. In this manner, WYDOT staff gained confidence in and control of their GIS development decisions.
- Active participation by WYDOT staff resulted in an internal GIS knowledge base that serves to reduce their reliance on outside consultants and enable them to effectively direct future GIS investment.

Working together, WYDOT staff and ESRI delivered an operational GIS on time and within budget. **Figures 1** and **2** below present active GIS sessions from a typical WYDOT user.

Figure 1
GIS View

A user employs ArcView® GIS software to integrate Oracle-based utility data with map-based Federal Aid system routes. The *Wyoming Reference Marker* book provided the linear measurement scheme that defined the spatial context for utility information.

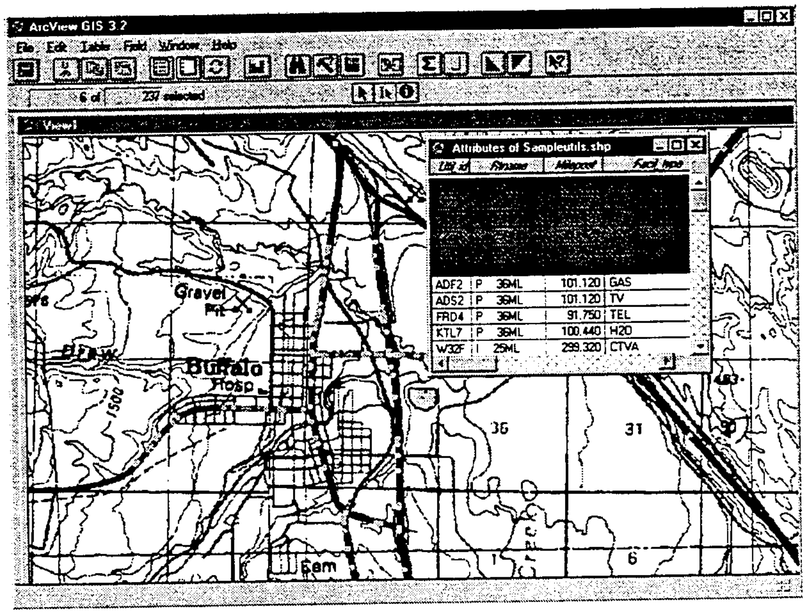
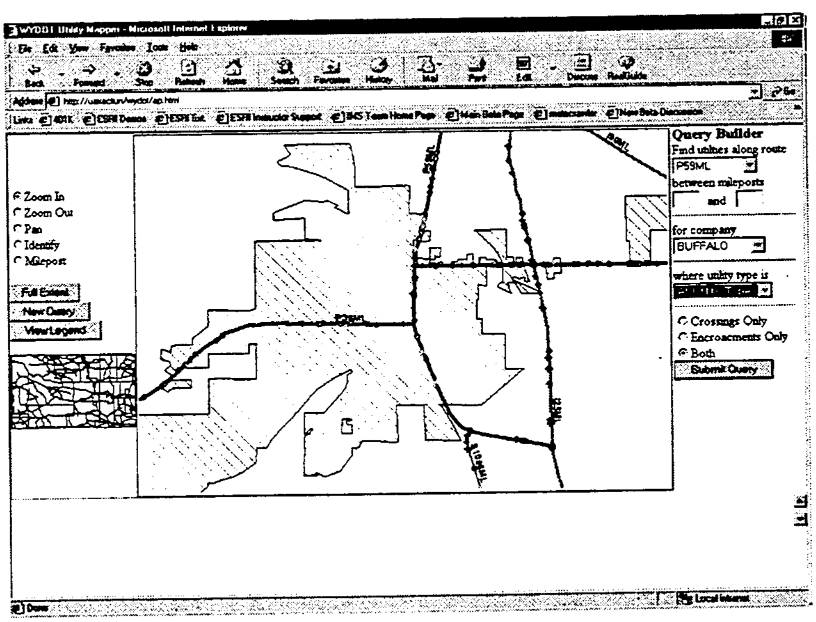


Figure 2
Intranet-Based Utility Application



This custom application provides mapping functionality within standard Web browsers to support the display, query, and analysis of utility information. Users throughout WYDOT can access the application by simply clicking a link on their Intranet home page.

The geographic information system implemented within WYDOT offers robust tools to capture, store, analyze, display, and present all types of geographically related information. By nature, it is an integrative technology, uniting people, departments, and organizations around their common information processing needs. GIS technology offers WYDOT real promise for being able to help people interrelate and work more closely together. It enables WYDOT staff to see the context as well as the substance of their problems more clearly and perhaps deal with them more effectively.

2.0 Problem Statement

WYDOT is responsible for close to 7,000 miles of on-system roads and interstates. They are concerned with all aspects of the roadway system from safety to construction and maintenance activities to long-term planning and forecasting. WYDOT relies on vast information stores, collected and updated over the past twenty-five years, to successfully meet the day-to-day obligations of the department. The ability to manage information, in terms of eliminating data redundancies, reducing data inconsistencies, and providing access to data in a timely manner, enables WYDOT to excel in its mandate as a service provider.

Currently, WYDOT maintains information in a multitude of digital and hard-copy formats. The majority of that data is spatial in nature. Data records contain descriptive information about a particular location along the roadway infrastructure.

In an attempt to standardize information management within WYDOT, executive staff directed a departmentwide migration toward an Oracle-based relational database management system. While the Oracle solution offered robust tools to create, store, maintain, and organize descriptive information, it did not have tools readily available to exploit the spatial component of WYDOT data stores. A geographic information system was needed by WYDOT to leverage the spatial component of its data.

3.0 Project Objectives

GIS technology has matured over the last thirty years to provide robust data models and capabilities that effectively manage all types of geographically related information. However, many implementations of GIS have failed because managers did not fully anticipate the unique organizational, technical, and financial environment needed to support GIS. The purpose of this study was to design a methodology that promoted the successful implementation of GIS within WYDOT.

Specifically, the objectives of the study were as follows:

- Develop a design methodology that related GIS requirements to well-defined user needs.
- Develop an internal GIS knowledge base within WYDOT to support ongoing GIS activities.
- Construct a shared, geographic basemap that supported the integration of Oracle-based Utility records with map-based Federal Aid route systems.
- Construct a mapping application that provided Web-based access to geographic data layers and related Utility records.
- Deploy a hardware, software, and network solution that provided distributed GIS processing of centralized data stores.
- Develop a cost-effective training solution that provided WYDOT staff with the skills necessary to operate and maintain the GIS.
- Deploy an operational GIS, including hardware, software, data, and applications, within six months of project initiation.
- Document the issues, findings, and conclusions of WYDOT's GIS implementation efforts.

4.0 Task Descriptions

GIS offers the strategic benefits of efficient information management and effective decision making support. However, GIS involves more than simply purchasing hardware and software. By nature, GIS is an integrative technology that crosses disciplines and organizational constructs. GIS implementation tasks undertaken by WYDOT and ESRI served to frame GIS development within the long-term goals and objectives of the Department.

4.1 Develop a Design Methodology to Guide GIS Implementation Efforts

WYDOT contracted with ESRI to provide planning and implementation services aimed at establishing GIS technology within WYDOT. ESRI is the leader in geographic information system technology with worldwide markets. Founded in 1969, ESRI has fine-tuned a GIS design methodology that addresses the unique organizational, technical, and financial considerations necessary to promote successful GIS integration within an organization. ESRI relied on experience with similar organizations and built upon the past achievements of WYDOT to tailor a design methodology that supported internal needs and complemented State-wide GIS efforts.

4.2 Project Organization

Project organization tasks served to set the stage for GIS implementation within WYDOT. During several meetings, ESRI and WYDOT worked to align GIS implementation with the strategic direction and needs of WYDOT. Mission statements, organizational goals, and information management objectives helped to define the niche for GIS within WYDOT. In addition, the scope of implementation was determined, and the project team was established.

4.3 GIS Requirements Analysis

Even the most technically elegant GIS solution can fail if it does not meet the needs of its users. ESRI met with representatives of many programs and sections within WYDOT to ensure that GIS development efforts matched staff needs. GIS requirements were summarized into three predominant categories: functionality, data, and organizational support.

4.4 Database Design

Database design tasks focused on the establishment of a shared, integrated geographic database where spatial locations were used to organize seemingly disparate data sets. The design structured data elements efficiently and nonredundantly to support the functional needs of WYDOT staff. It represents a fully scalable solution that accommodates additional data sets as they are identified for inclusion in the GIS.

At the core of the design effort was the integration of tabular records with map-based Federal Aid system route features. ESRI's dynamic segmentation data model was used to aggregate road segments into route features. Milepost locations, defined in the *Wyoming Reference Marker* book, were used to calibrate the route systems with a linear referencing scheme. The linear referencing scheme provided the link between Utility records and geographic data layers to allow spatial queries, analyses, and displays of utility information.

4.5 Hardware, Software, and Network Communication Specifications

System design efforts described the essential hardware, software, and network considerations necessary to support GIS implementation within WYDOT. It began with a review of user needs, continued with a recommended systems configuration, and concluded with sizing specifications for identified hardware components. The derived specifications enabled WYDOT to make informed decisions about their GIS and deploy a system solution that leveraged existing technology and served WYDOT's long-term system objectives.

4.6 Systems Construction

Construction efforts involved the mapping of design specifications to actual system components. The geographic basemap was developed in accordance with ESRI® data models. Applications were coded, tested, and refined based on input from WYDOT staff. GIS hardware, software, and network communications were acquired, installed, integrated, and tested. The result of the systems construction was an operational GIS, where WYDOT users employ GIS application software to create, maintain, query, display, analyze, and output data centrally stored on departmental servers.

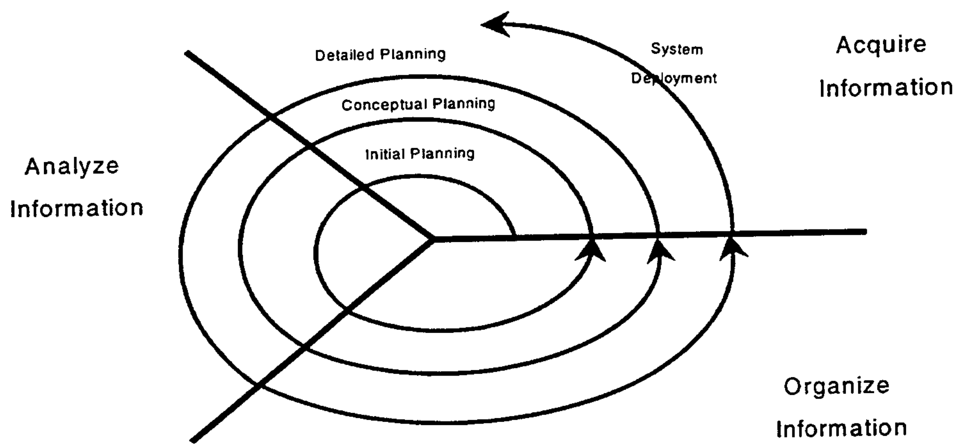
5.0 Findings and Conclusions

5.1 Design Methodology

The design methodology that guided GIS implementation within WYDOT consisted of three distinct, but tightly integrated, planning stages, where a high-level definition of the system provided the foundation for more detailed, technical specifications. The planning activities were followed by system deployment efforts that resulted in an operational GIS. **Figure 3** illustrates the implementation approach.

Figure 3

Design Methodology



Implementation activities began with initial planning efforts that defined organizational goals and objectives for the GIS. Strategy meetings held with WYDOT staff defined the scope of implementation and identified the roles and responsibilities of project team members. The Strategic Plan for GIS report, included in **Appendix A, Strategic Plan,** documented the initial planning activities.

Conceptual planning efforts built upon the conclusions of the initial planning activities to explicitly define functions and products of the geographic information system. GIS requirements were determined from a combination of broad departmentwide interviews and program-specific interviews. The information gathered during the user interviews enabled WYDOT staff to align GIS development with well-defined business and user needs. The Requirements Analysis report, included in **Appendix B, Requirements Analysis** documented conceptual planning activities.

Detailed planning moved from a consideration of what the GIS was to accomplish to an identification of how the system would operate. A database design was developed to identify the relationship between map-based features and tabular data stores. System design activities identified the hardware, software, and networking infrastructure necessary to support GIS. Implementation planning activities prioritized development efforts including the construction of the geographic basemap and customized applications, the integration of system components, training, and staffing. The results of the detailed planning step were documented in three separate reports included in the following appendixes:

- **Appendix C, Database Design**
- **Appendix D, Hardware, Software, and Network Design**
- **Appendix E, Implementation Plan**

Systems deployment efforts represented the transition from GIS planning to GIS integration. The geographic basemap and applications were constructed. System components, including hardware, software, and network communications, were acquired, installed, and integrated with GIS data and applications. The systems deployment activities resulted in an operational GIS delivered to WYDOT on November 15, 1999—six months after the initiation of the project.

The design methodology developed by WYDOT and ESRI guided the successful implementation of GIS within WYDOT. An operational GIS was delivered on time and within budget. The design methodology offered the following strategic benefits for the Wyoming Department of Transportation:

- Implementation took place within a planning environment. Financial commitments to hardware, software, and data were deferred until system requirements were fully understood. The approach ensured that each GIS investment decision met well-defined needs and long-term organizational goals.

- Convenient stopping points enabled WYDOT staff to assess the feasibility of GIS development after each step in the design process. In this manner, WYDOT staff gained confidence in and control of their GIS development decisions.

- Active participation of WYDOT staff resulted in an internal GIS knowledge base that will reduce their reliance on outside consultants and enable them to effectively direct future GIS investment.

5.2 Project Organization

5.2.1 Organizational Goals of GIS

The Wyoming Department of Transportation considered GIS implementation because it enhanced the existing information management capabilities of the department. GIS offered an opportunity to organize data around its inherent spatial context, provided an intuitive map-based interface to existing tabular data stores within WYDOT, and promoted a cross-disciplinary approach to problem solving and policy making. Specifically, WYDOT staff identified the following long-term objectives for GIS technology:

- Data Visualization
- Decision Support
- Integration of Management Systems with the Department
- Data Consistency
- Improved Business Operations

5.2.2 Scope of Implementation

WYDOT developed a phased, multiyear approach to guide GIS implementation. The first phase focused on integrating GIS within the Utilities/Railroad section of the department. The Utilities/Railroad section was chosen to participate in the initial implementation because its records were completely automated in Oracle and those records were widely used throughout WYDOT. The second phase of implementation, currently under development, considers the expansion of GIS into other programs and sections in the department, resulting in stand-alone, operational systems. Phase Three implementation efforts serve to unite the programs and sections into an enterprise GIS solution that integrates management systems, reduces data redundancy, and streamlines operations. WYDOT staff realized the following benefits from their phased implementation strategy:

- The limited scope of Phase One enabled WYDOT to deliver an operational GIS within the given six-month time frame.

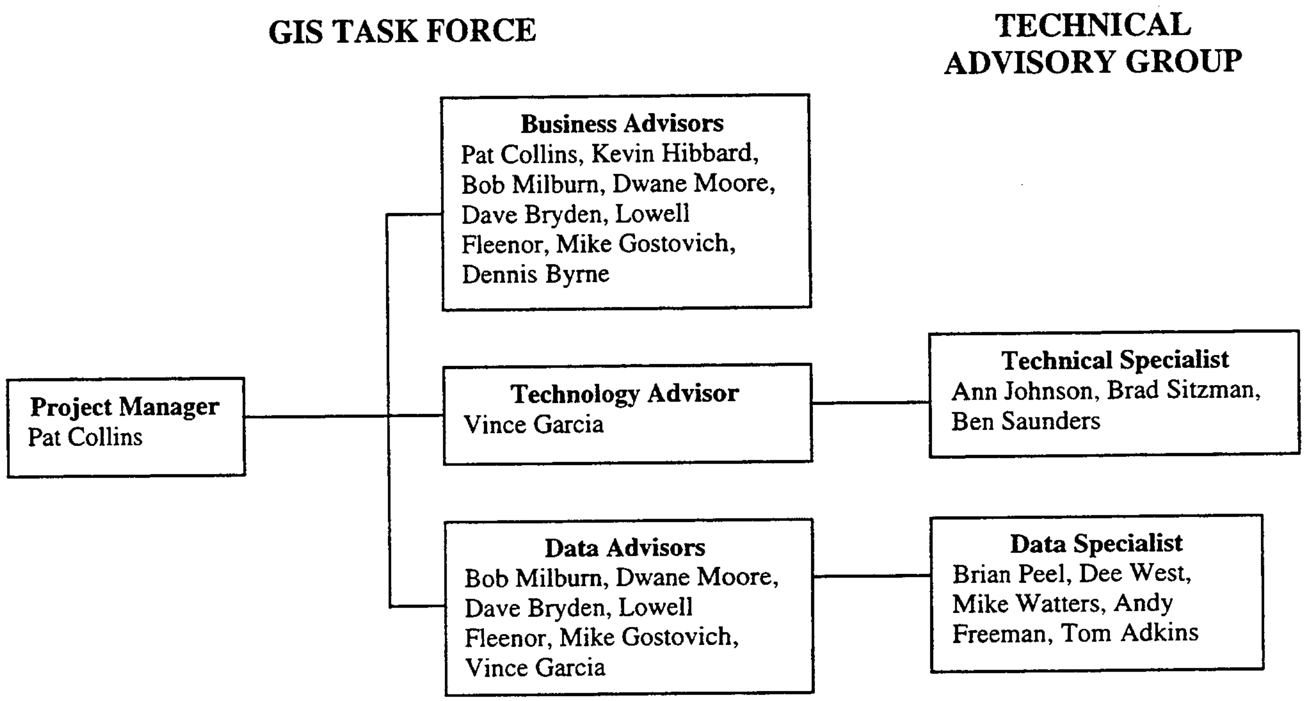
- The timely delivery of GIS enabled WYDOT staff to demonstrate products and functionality that solidified support for ongoing GIS activities.

- GIS implementation methodologies were tested and proven in the initial phase.
- WYDOT staff gained the experience necessary to lead future GIS efforts.

5.2.3 Project Team

Figure 4 illustrates the project team that guided GIS implementation within WYDOT.

Figure 4
WYDOT GIS Implementation Project Team



A project manager who finalized development decisions, coordinated implementation activities, and communicated progress to the executive staff led the GIS task force. The project manager was supported by business advisors that provided an understanding of WYDOT needs, technology advisors that understood the existing systems environment, and data advisors that provided an in-depth knowledge of existing data stores. The GIS task force relied on the Technical Advisory Group for detailed specifications as needed.

Upon the successful completion of Phase One implementation, the GIS task force transitioned to an oversight committee responsible for coordinating ongoing GIS efforts within the department. The Technical Advisory Group transitioned to a user's group responsible for identifying GIS development efforts and providing support for the expanding GIS community at WYDOT.

5.3 GIS Requirements Analysis

GIS requirements were determined from information gathered and analyzed during interviews with WYDOT staff. Requirements were documented in three predominant categories: functions, data, and organizational support.

5.3.1 GIS Functional Requirements

Functional requirements, derived from user interviews, were predominantly planning based, providing a visual inventory of existing data stores and an Intranet map-based forum through which users interact with various spatial and tabular data sets. The implementation of that functionality was addressed by out-of-the-box tools in conjunction with customized applications that enabled WYDOT users to be immediately productive with their GIS.

5.3.2 GIS Data Requirements

The following layers were identified for inclusion in the shared geographic basemap.

On-system Roads
Linear Reference System Routes
Railroads
Airports
Reference Posts
1:100,000 Digital Raster Graphics
1:24,000 Digital Raster Graphics
Statistical Areas
School Districts
Hydrography
County Boundaries
WYDOT Districts
Land Ownership
Cities
Public Land Survey System
Commission Districts
Geographic Places
Highway Patrol Zones
Control
Wells

WYDOT staff concluded that existing, readily available geographic data at a scale of 1:100,000 appropriately served WYDOT users. Data development efforts focused on aggregating road segments into Federal Aid system routes and building a linear referencing system that integrated existing tabular data with map-based features. ESRI's dynamic segmentation data model supported the requisite database relationships.

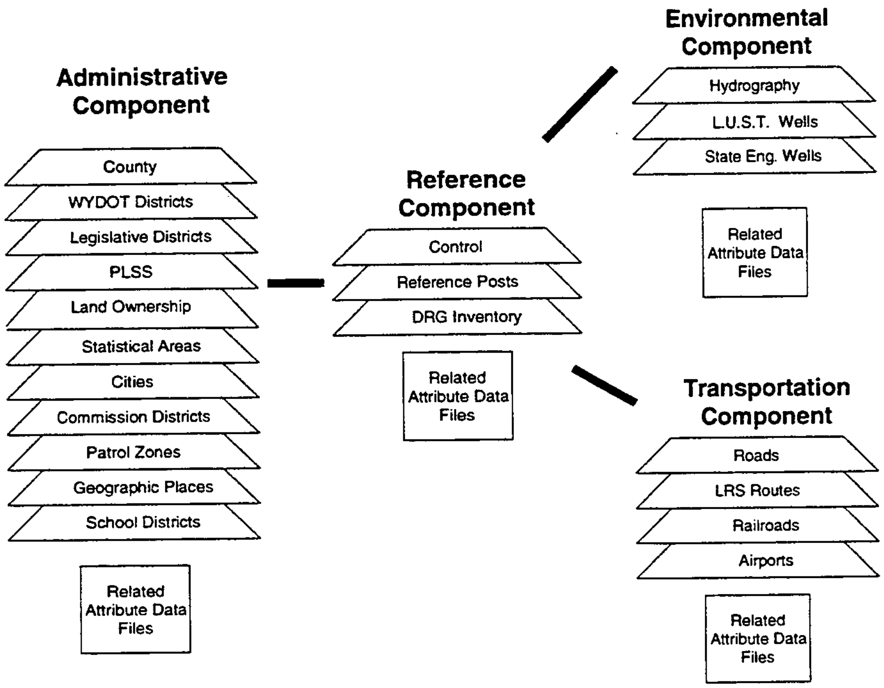
5.3.3 Organizational Support Requirements

The GIS task force provided leadership to ensure the ongoing success of GIS. It devised a multisource funding strategy for GIS that anticipates a changing economic environment. It guided an organizational restructuring that accommodates spatial data maintenance, GIS application development, and GIS systems support. The GIS task force directed resources toward staff development and training and secured membership within the Wyoming Geographic Information Advisory Council to ensure consistency between the GIS efforts of WYDOT and other State agencies. The GIS task force also developed a communication strategy to keep WYDOT staff abreast of GIS activities.

5.4 Database Design

Figure 5 illustrates the concept and components of the shared geographic basemap for WYDOT. It provided a picture of the GIS basemap that enabled GIS task force members to view the database in its entirety and evaluate the interactions of the various aspects of the database in a planning effort before committing time and resources to its actual development.

Figure 5
Shared Geographic Basemap



Specifically, the design of the geographic basemap

- Promoted the integrated activities of WYDOT staff by providing a single, consistent structure for storing and maintaining geographically related information.
- Encouraged a scalable solution where data may be added to support future GIS requirements.
- Organized spatial data by theme to increase the flexibility of data retrieval, analysis, and production operations and facilitate the development of user applications.
- Minimized the redundant storage of geographically related information.
- Reduced the reliance on specialized database management systems and procedures by centrally organizing spatial and attribute data around the GIS database.

- Provided a spatial context for the vast amounts of descriptive data currently maintained by WYDOT. Such descriptive data includes project information, utility data, traffic signal inventories, and congestion and pavement management data.

- Supported data sharing between WYDOT and external agencies by providing data structures that are easily exported into common exchange file formats.

At the core of the database design effort was the need to integrate existing tabular data stores with map-based features. ESRI met with the Technical Advisory Group on June 4, 1999, to develop standards for identifying WYDOT route systems. The standards address Federal Aid system route names because that was the naming convention most widely used within WYDOT. **Table 1** presents the agreed upon standards.

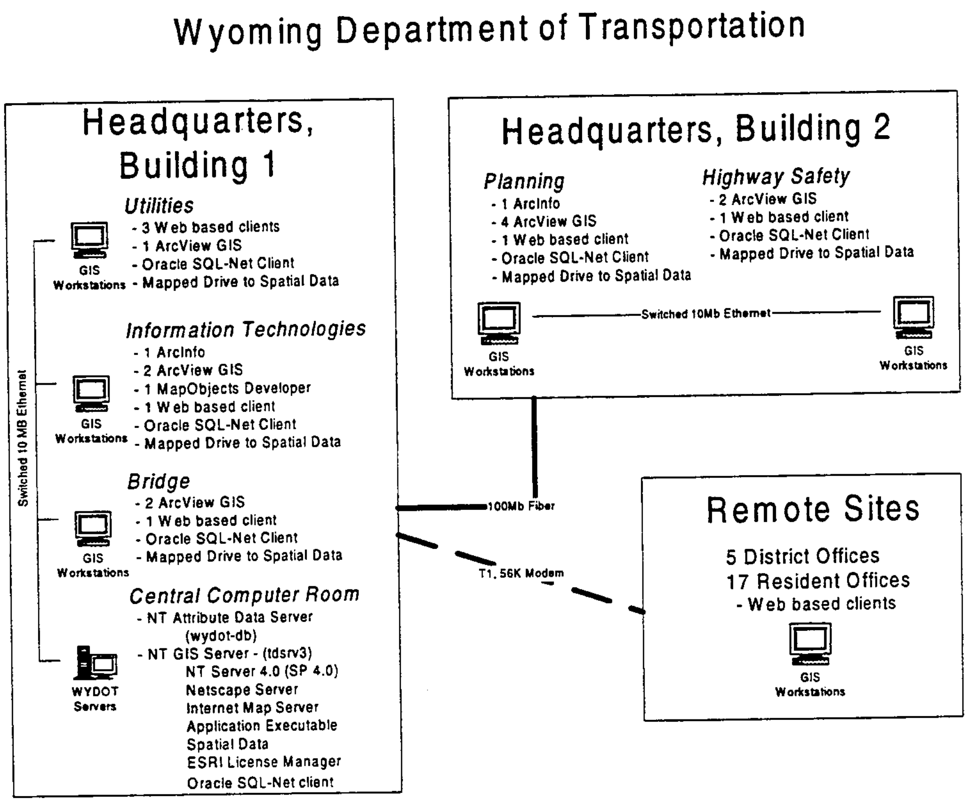
Table 1
Federal Aid System Route Identification Standard

Attribute Item	Item Definition	Valid Values	
System	Character (4)	I—Interstate	SRI—Service Road Interstate
		P—Primary	SRP—Service Road Primary
		S—Secondary	SRS—Service Road Secondary
		U—Urban	SRU—Service Road Urban
		SH—State Highway	SRSH—Service Road State Highway
Route	Number (4)	1–9,999	
Accessory	Character (4)	C—Connector	Y—Y construct
		B—Bypass	1–999—Route Numbers
		ML—Main Line	O—Osage Connector
		S—Spur	
Direction	Character (1)	N—North	S—South
		E—East	W—West
		B—Both	

5.5 Hardware, Software, and Network Communication Design

The GIS task force evaluated user needs to determine the software products required to support GIS activities. Once the software products were identified, hardware and network specifications were derived to take advantage of existing equipment and design the infrastructure necessary to accommodate anticipated system loads. **Figure 6** illustrates the systems design solution.

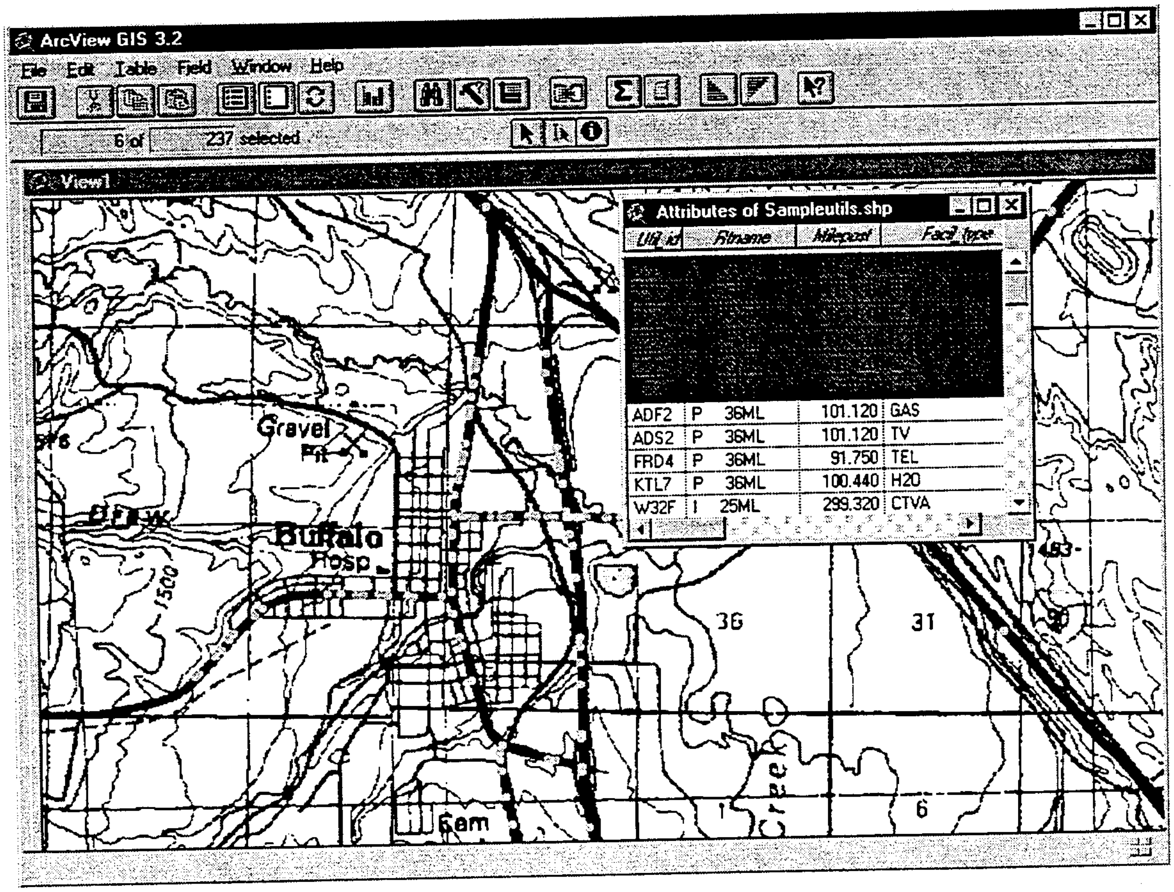
Figure 6
Systems Configuration Solution



5.6 System Construction

GIS implementation activities resulted in the hardware, software, GIS staff, applications and data that make up the operational GIS. **Figures 7** and **8** illustrate the department's GIS.

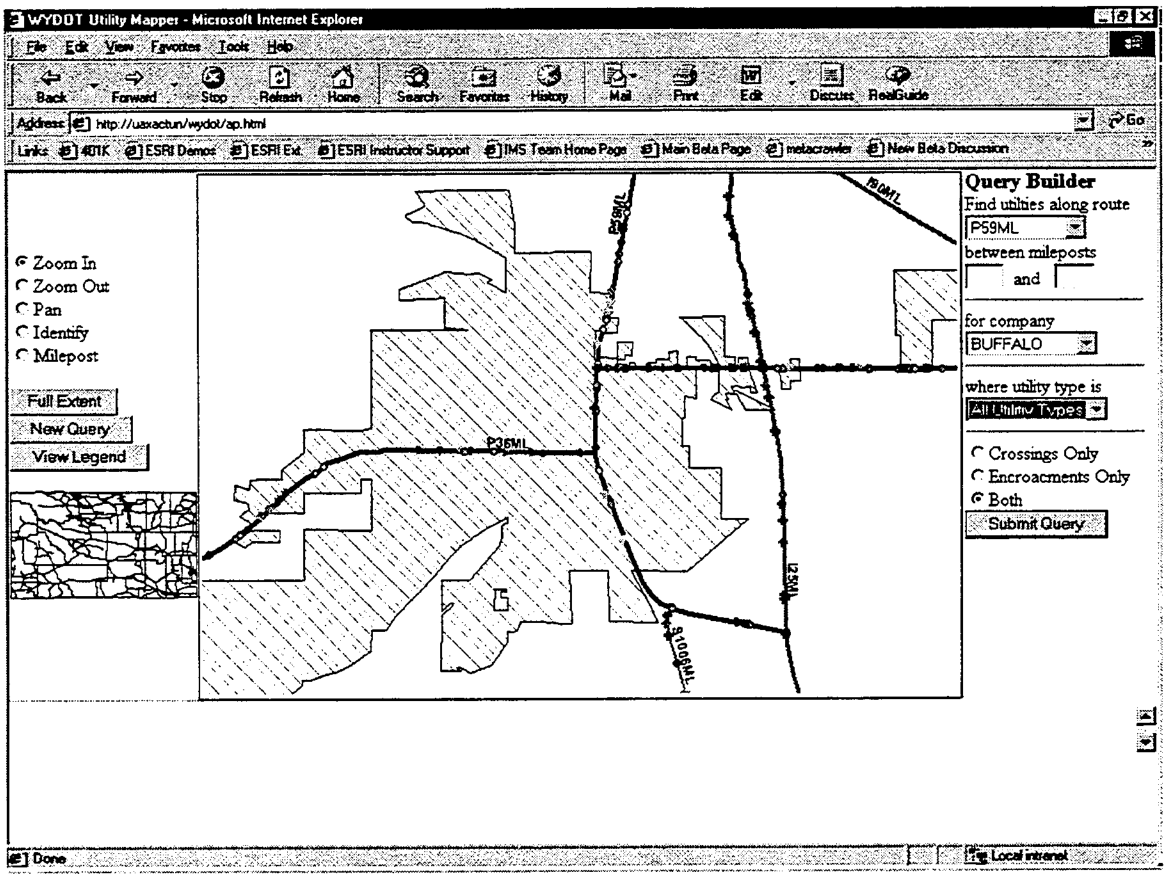
Figure 7
ArcView GIS



ESRI's ArcView GIS, purchased and installed on desktop computers throughout the department, provides an easy-to-use interface that allows WYDOT users to capture, store, analyze, display, and present all types of geographically related information. In the figure above, tabular Utility records, stored in an Oracle database, are related to map-based Federal Aid system routes. Utility locations and Federal Aid system routes are displayed on a 1:100,000-scale digital raster graphic acquired from the United States Geological Survey.

The application allows users to visualize utility information. Spatial relationships such as position, direction, adjacency, and coexistence, are inherently provided in the map display. By providing a spatial context for utility information, GIS users within WYDOT are able to see relationships and patterns in the data beyond those provided in typical tabular representations.

Figure 8
Intranet-based Utility Application



The application shown above provides mapping functionality within standard Web browsers to support the display, query, and analysis of Oracle-based utility information. It was developed using ESRI's MapObjects® and MapObjects Internet Map Server software.

Figures 7 and **8** above demonstrate the integration of WYDOT's GIS components. Data, stored centrally on departmental servers, is distributed to individual user desktops through efficient network connections. GIS functionality is delivered through a combination of ESRI software programs and customized Internet applications to accommodate the wide-ranging needs of WYDOT staff.

The GIS solution implemented within WYDOT offers real promise for being able to help people interrelate and work more closely together. It enables WYDOT staff to see the context as well as the substance of their problems more clearly and perhaps deal with them more effectively.

6.0 GIS Implementation Recommendations

GIS implementation is an arduous task. To realize strategic benefits of efficient data management and effective decision support, GIS must be implemented within a design methodology that ties investment decisions to organizational goals and objectives. WYDOT tailored and utilized such an approach to deliver an operational GIS within the time frame allotted. Based on the experience of the GIS task force within WYDOT, the following implementation recommendations are offered:

- GIS managers must avoid costly commitments to hardware and software by first defining what business processes the GIS serves and then tailoring software and hardware solutions around those needs.

- GIS managers must learn to become GIS experts quickly. They must learn and come up to speed in a number of topical GIS areas.

- GIS managers must accommodate the organizational impact that results from GIS. The integrative nature of GIS technology often affects entire processes that may lead to an element of organizational restructuring to realize the true return on a GIS investment.

- GIS managers must not tie all their GIS funding to a single source. The more successful implementations employ multiple funding sources to more readily adapt to an ever-changing political and economical environment.

- GIS managers must make good on deliverables promised. Failure to adhere to scheduled milestones and deliverables can jeopardize support for the GIS. It is often better to employ a phased implementation, where user expectations and products are more easily managed.

- GIS managers must have executive level support with a long-term vision for GIS development.

- GIS managers must demonstrate benefits. GIS benefits range from reducing costs associated with simple tasks to generating revenue from improved information management and business operations.

Appendix A

Strategic Plan

A.1 Strategic Plan

A.1.1 Introduction

The Wyoming Department of Transportation (WYDOT) is responsible for close to 7,000 miles of on-system roads and interstates. They are concerned with all aspects of the roadway system from safety, closures, and maintenance activities to long-term planning and forecasting. WYDOT relies on vast information stores, collected and updated over the past twenty-five years, to successfully meet the day-to-day obligations of the department. The ability to manage information, in terms of eliminating data redundancies, reducing data inconsistencies, and providing access to data in a timely manner, enables WYDOT to excel in its mandate as a service provider.

Currently, WYDOT maintains information in a multitude of digital and hard-copy formats, as documented by an in-depth data inventory recently completed by WYDOT Information Technology (IT) staff. The majority of that data is spatial in nature. Data records contain descriptive information about a particular location along the roadway infrastructure.

In an attempt to standardize information management within WYDOT, executive staff have directed a departmentwide migration toward an Oracle-based relational database management system (RDBMS). While Oracle offers robust tools to create, store, maintain, and organize descriptive information, Oracle does not have tools readily available to exploit the spatial component of WYDOT data stores. Oracle is built around *tabular relationships,* where common attributes link data records, rather than *spatial relationships,* where an inherent reference to a physical location is used to link data records. Comparing crash records with highway features and vehicle miles, for example, is difficult to do in Oracle because the query language of Oracle does not support concepts of adjacency, coexistence, proximity, and connectivity.

A geographic information system (GIS) is needed by WYDOT to leverage the spatial component of its data. GIS provides intuitive, location-based query and analysis tools that support such geographic considerations as where a feature exists, what else occurs at that location, and what borders it. GIS "*spatially enables*" the data stored and maintained in Oracle. It complements the fundamental data management functions of Oracle to provide powerful spatial analysis, query, and display capabilities.

Perhaps most importantly, GIS technology offers real promise of eliminating data redundancies and reducing data inconsistencies by organizing seemingly disparate data sources around their common reference to a location on the roadway infrastructure. By promoting the integrated activities of many programs and sections, GIS provides the foundation for making policy, planning, and making decisions that enable WYDOT to responsibly serve public interests.

Recently, WYDOT contracted with ESRI to provide planning and implementation services aimed at establishing GIS technology within WYDOT. ESRI is the leader in geographic information systems, with worldwide markets. Founded in 1969, ESRI has fine-tuned a GIS design methodology that considers the unique organizational, financial, and technical considerations that promote successful GIS integration within an organization. ESRI will rely on experience with similar organizations and build upon the past achievements of WYDOT staff to tailor an implementation solution for WYDOT that supports internal needs and complements State-wide GIS efforts.

A.1.2 Background

The utilization of GIS as a planning and analysis tool has become commonplace in transportation departments nationwide. The Bureau of Transportation Statistics, an operating administration of the U.S. Department of Transportation, has surveyed many state departments of transportation (DOTs) to determine the "state of practice" for GIS implementations. Findings from the survey indicate that GIS is used in all aspects of the infrastructure life-cycle, from planning to maintenance and operations.

WYDOT has recognized that GIS can impact many areas of their operations. Utility management, transportation planning, crash records and safety analysis, pavement management, bridge management, sign and signal inventory, traffic capacity modeling, and environmental analysis may all benefit from the introduction of GIS tools and techniques. While no operational GIS is currently in place at WYDOT, considerable effort has been taken to lay the groundwork for GIS implementation. The following reports illustrate WYDOT's achievements:

- WYDOT, Internal Memorandum, August 27, 1993.
- WYDOT, 1994 WYDOT Information Technology Report, 1994.
- WYDOT, Final Report: "Oracle Database User's Group, January 20, 1998.
- Wyoming Geographic Information Advisory Council (WGIAC), Wyoming State-wide GIS Basemap, October 25, 1996.

Outside of WYDOT, many other State agencies have invested in GIS. The State Engineer's Office, State Land and Investments Office, Wyoming Game and Fish, Wyoming Geologic Survey, Wyoming Department of Environmental Quality, and Wyoming Department of Revenue all rely on GIS to support their daily activities. Additionally, the University of Wyoming has a variety of departments that utilize GIS, and the university currently supports the Spatial Data Visualization Center. Governor Jim Geringer has recognized the need for coordinated GIS activities and, on January 20, 1999, the legislature adopted the Spatial Technology and Geographic Information System Policy "to facilitate development of efficient and cost-effective GIS implementation, maximizing system compatibility and interagency sharing and utilization of spatially referenced data."

The success of GIS within DOTs nationwide and within other State agencies has been recognized by WYDOT. A considerable momentum has built up over the last few years for the introduction of GIS within WYDOT. The Governor has identified GIS implementation as a priority for the department and actively supports the Department's GIS design and implementation efforts. WYDOT has solidified contractual arrangements with ESRI–Denver to develop an implementation strategy that addresses internal needs and conforms to State-wide data standards. An operational GIS to support the Utility/Railroad section of the department is scheduled for completion by November 15, 1999.

A.2 GIS as a Strategic Tool

Integrating GIS into an organization is an arduous task. To be successful GIS technology must be aligned with the strategic direction and needs of WYDOT. When integrated in this way, the chances of a successful GIS implementation are greatly increased.

Governing the integration of GIS are the long-term goals and objectives of WYDOT. As defined in the department's mission statement, WYDOT is charged with the public trust for transportation systems. WYDOT staff strive to achieve excellence through innovation and creativity, conduct business in accordance with high ethical standards, work together to formulate policies that respect the opinions and values of others and, perhaps most importantly, act responsively to the needs of the public. By providing tools to capture, manage, display, analyze, and output all types of geographically related information, GIS technology greatly assists WYDOT in achieving its mission statement. The primary role of GIS within WYDOT will be as a planning tool. Accordingly, GIS provides the following strategic benefits:

- **Data Visualization.** The successful integration of GIS depends on its ability to provide a database relationship that links existing tabular records with map elements. Linear referencing systems, employed by many programs and sections within WYDOT, define the spatial context for a myriad of information, from utility locations to crash records to improvement projects. Integrating those referencing schemes with GIS data models allows WYDOT staff to display the information in a more intuitive, map-based form. Displaying information on a map unlocks the inherent spatial relationships of connectivity, adjacency, and proximity that are not readily apparent in typical tabular representations. Maps provide a graphical context for WYDOT data that enhances public forum presentations and supports the effective communication and dissemination of information.

- **Decision Support.** In providing a safe and efficient transportation system, WYDOT staff must solve problems and formulate policy that appropriately serves the public trust. GIS supports the decision making process of WYDOT by providing robust tools that analyze all types of geographically related information. Using GIS, WYDOT staff can combine various data sets (accident locations, pavement conditions, traffic patterns, soil conditions, topography, etc.) to fully appreciate the nature of a problem. GIS tools and techniques support scenario modeling where alternative solutions can be derived and evaluated. With GIS, users can see the context of their problems more clearly and perhaps deal with them more effectively.

- **Crossing Departmental Specialization.** Most institutions are organized into functionally specialized departments. These departments concentrate on their own specialized work and often develop data and procedures to support their particular activities. One of the valuable roles of GIS within WYDOT is to integrate information across the departments so it can be shared, interrelated, and used in common among the different sections and programs. In crossing departmental specialization, GIS encourages a multi department and multi disciplinary approach to problem solving that serves WYDOT mandates.

- **Data Consistency.** WYDOT is responsible for disseminating information to a customer base of public organizations and private agencies. Critical to their provision of service is the need to provide consistent information in a timely manner. GIS technology offers capabilities to store and manage information in a single, standardized environment. Information that is stored redundantly in many sections and programs can be maintained centrally in the GIS to reduce inconsistencies and promote the accurate and timely response to information requests.

- **Improved Business Operations.** As with all organizations, WYDOT is mandated to be fiscally responsible in carrying out its mission. Centralizing procedures and data around a GIS allows WYDOT to make better use of limited resources. For example, database maintenance may be coordinated centrally to prevent two programs from spending time and resources in automating the same data. Additionally, the GIS may capture entire business functions. Utility permitting operations, for example, may be wholly automated around the GIS, thereby reducing the fiscal requirements for the Utilities/Railroad section.

A.2.1 Implementation Strategy

GIS is not a new idea for WYDOT. The need for systems integration was recognized by executive staff in their memo dated August 27, 1993, that stated "while the various divisions and programs have excellent and productive systems, the Department lacks an overall coordinated effort." The memo led to a departmentwide program review that resulted in the 1994 WYDOT Information Technology Report. The report identified the following three goals that govern systems implementation within WYDOT:

1. Systems implementation must take place in a "systematic manner."

2. Systems implementation must focus on "defined needs" and "business processes."

3. Computer management programs must be developed to "ensure that present and future applications will be compatible with all program areas."

These broad goals provide the framework around which ESRI and WYDOT GIS task force members consider GIS integration. Working together, ESRI and task force members have developed a phased implementation that begins with a single section, expands to include other programs or sections that demonstrate an interest and need for GIS, and concludes with a departmentwide installation of GIS. The phased approach limits WYDOT's exposure to large investments in staff, hardware, software, and data by aligning implementation with the needs of identified programs and sections. Experiences gained in each phase are used to guide and control future GIS investments. Each phase represents a stand-alone systems implementation that builds upon previous efforts and results in an operational GIS.

ESRI contributes a proven design methodology, completely described in **Section A.3** below, that ties GIS investment decisions to well-defined business needs and facilitates multidepartmental participation. In addition, the design methodology involves representatives from many sections and programs to ensure that the implementation, to the extent possible, complements existing information and organizational structures and promotes compatibility with all program areas.

A.2.1.1 Phase 1—Initial Implementation

The WYDOT GIS task force has identified the Utilities/Railroad section of the Highway Development program to participate in initial GIS implementation activities. Implementation emphasizes the integration of existing utilities database records with GIS map-based features. Phase 1 implementation activities were completed in November 1999. The Utilities/Railroad section was chosen for the following reasons:

- **Availability.** Utility database records have been completely automated in Oracle. The records contain a linear reference scheme that supports the immediate incorporation of GIS. Due to the aggressive time frame for completion, the utility database represents a straightforward, manageable environment that supports GIS introduction.

- **Customer Oriented.** Utility information supports the broad citizenry of Wyoming. The efficient management and dissemination of utility information enables public organizations such as cities, counties, and the Economic Development Council to support the public interest by making informed decisions and policies. Utility information enables contractors and maintenance crews to support the public interest by proactively identifying service areas and avoiding costly disruptions in service that result from inadvertently cutting utility lines. Railroad crossing information, in conjunction with Emergency Vehicle Services, provides invaluable public benefit as ambulances, fire equipment and police vehicles appropriately respond to urgencies. Implementing GIS within the Utility/Railroad section provides a customer-oriented application that serves the public interest and fosters enthusiasm and support for continued GIS efforts within WYDOT.

- **Cost Savings.** GIS integration within the Utility/Railroad section of WYDOT provides effective information management that reduces the cost of utility operations. Additionally, GIS tools can be used to select access corridors for utilities. By combining various geographic data layers, such as rights-of-way, land ownership, geology, topography and the like, WYDOT will be able to determine the least costly location for the placement of utilities.

- **Knowledge Transfer.** ESRI will involve WYDOT task force members through the GIS planning and implementation activities necessary to integrate GIS within the Utility/Railroad section. Upon completion of Phase 1, task force members will have the knowledge and experience needed to guide future GIS development decisions. They will reduce their reliance on outside consultants and be positioned to provide the high-level direction necessary to support ongoing GIS activities within WYDOT.

A critical component of Phase 1 activities will be the specification and creation of a geographic basemap. Departmentwide interviews, as well as in-depth Utilities/Railroad section interviews, will be conducted to provide the broad perspective of business needs and data requirements necessary to complete the project.

The 1994 WYDOT Information Technology report recommends that "GIS database design, data acquisition, maintenance policies and procedures, and implementation activities should be undertaken as an organization-wide, top-down activity, while applications be developed on the basis of decentralized, bottom-up initiatives." Phase 1 implementation activities serve this recommendation by placing development authority with the GIS task force. That task force is made up of representatives from many programs to ensure that GIS development decisions meet organizational goals and objectives. Focusing implementation activities within the Utilities section enables the task force to consider individual needs and complete the initiative by November 15, 1999.

The 1994 report also recommends that "coordination and cooperation with other outside entities should be an integral part of WYDOT's GIS planning." In meeting this recommendation, implementation activities will solicit input from two principle agencies: the Office of GIS (OGIS) and the WGIAC. Both provide a statewide perspective to ensure that WYDOT implementation efforts do not limit the activities of other state agencies. In addition, by selecting ESRI software programs, WYDOT conforms to State standards, as outlined in the State of Wyoming Information System Architecture Standards: Geographic Information System Standard (1998-03 R). Working from standard data models and formats facilitates the sharing of information and procedures and enables WYDOT to supplement existing data with information developed to support internal WYDOT needs.

A.2.1.2 Phase 2—Expanded Implementation

Upon the successful completion of initial implementation activities, WYDOT task force members will be given an opportunity to direct continued GIS development within WYDOT. It is anticipated that Phase 2 efforts extend the GIS to other sections or programs that demonstrate a need for GIS technology. Phase 2 activities follow a "departmental" approach that is not necessarily linear. Phase 2 may evolve as a series of parallel activities, each program and section introducing GIS to support their daily responsibilities. The GIS task force guides Phase 2 efforts, in terms of funding and organizational leadership, to ensure that individual activities conform to departmentwide goals and objectives. To facilitate the identification of candidate programs and sections, the task force has identified the following criteria that promote inclusion in GIS activities:

- GIS enables the program or section to provide better service to the public.
- GIS enables the program or section to better support internal WYDOT needs.
- The program or section requires the functional capabilities offered by GIS.
- The program or section is enthusiastically interested in GIS technology.
- The capability to support GIS will be evaluated by the task force based on the following considerations:
    - Financial: the task force will evaluate the availability of funds necessary to support investment in GIS.
    - Staff: the task force will evaluate the availability of staff to support GIS activities.
    - Equipment: the task force will evaluate the availability of hardware and software to support GIS.

- Tabular Data: the program or section has followed Department standards and migrated existing data to Oracle.
- Spatial Data: the scale, extents, and content of required data are compatible.

- The program or section has a compatible Linear Referencing System.

As GIS expands throughout WYDOT in Phase 2 of the implementation, it is critically important for the task force to control each investment decision. Uncontrolled, the GIS may expand in Phase 2 to serve the specialized interests of a handful of programs and sections. GIS use will become fragmented and will not serve the broader organizational goals and objectives of the department. To ensure that GIS serves the department appropriately, the authority for GIS development decisions (i.e., funding, systems acquisitions, staff augmentation, etc.) will remain with the GIS task force.

Phase 2 implementation affords GIS task force members an opportunity to consider a third recommendation outlined in the 1994 WYDOT Information Technology report. Namely, "the GIS manager and database manager should establish a set of common linear referencing keys that would be mandatory for all department databases." While mandating uniform referencing keys is not necessary, it is certainly valuable. It would facilitate the integration of multiple departments and would further interdepartmental data sharing.

A.2.1.3 Phase 3—Enterprisewide Implementation

Upon the successful completion of Phase 2 activities, WYDOT GIS task force members may elect to implement GIS throughout WYDOT. Enterprisewide implementation focuses on integrating the individual activities of all programs and sections participating in GIS. It is an aggressive undertaking. Increased investment in data to support varied scale needs, systems to support enterprise file and application servers, and staff to support increased system maintenance tasks is to be expected. Environmental boundaries and organizational support for GIS at all levels must be considered. However, the strategic benefits of GIS in terms of organizational efficiencies, cross-departmental interactions, and State-wide mapping support more than justify the cost of GIS. WYDOT GIS task force members will guide enterprisewide implementation activities in light of the experience gained in previous implementation efforts.

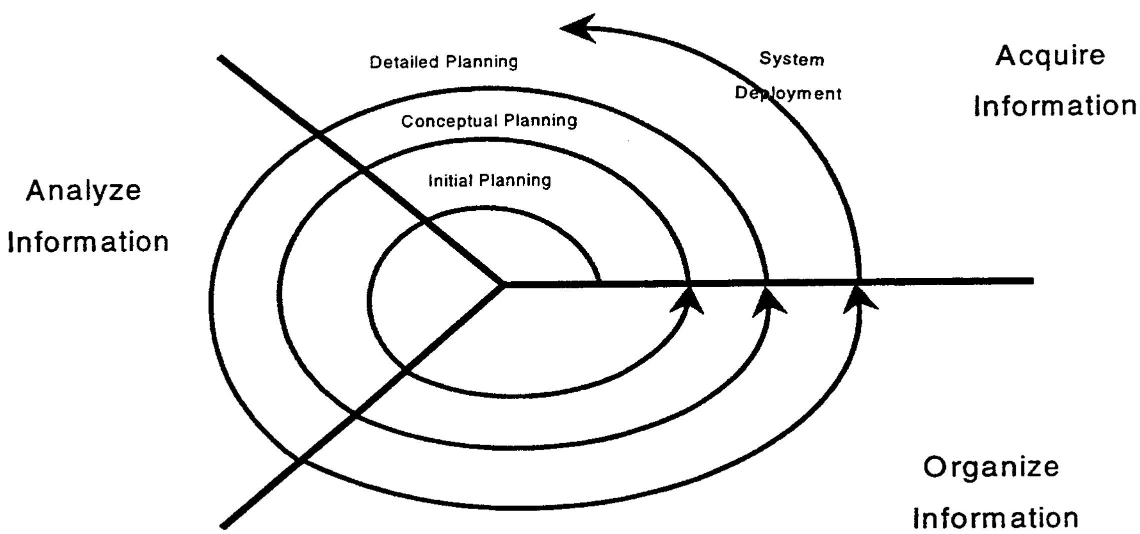
A.3 Project Overview

A.3.1 Design Methodology

ESRI designed a structured, business-need-driven methodology to guide the phased implementation of GIS within WYDOT. Each phase of implementation will follow the steps defined by this methodology. The approach consists of three distinct but tightly integrated steps: an initial plan that identifies organizational goals, information system objectives and a project scope; a conceptual plan that articulates *what* the GIS will do; and a detailed plan that defines *how* the system performs. The planning activities are followed by system deployment that considers the acquisition, installation and integration of system components (i.e., hardware, software, and data). The emphasis of the approach remains on planning; financial commitments to hardware, software, and data are deferred until system requirements are fully defined. This approach ensures that each GIS investment decision is closely tied to well-defined needs and long-term organizational goals. To use an architectural analogy, we work with the architect through preliminary sketches and comprehensive views and then deliver the final plans to the builder. The design methodology is illustrated and described below.

Figure A.1-1

Design Methodology



Step 1: Initial Planning

The initial planning stage of the design process is the most abstract of the three and it involves setting the stage for GIS implementation within WYDOT. ESRI staff meets with WYDOT GIS task force members to review mission statements, organizational goals, and design processes; identify project team members and responsibilities; and define the project scope and determine a preliminary project schedule. The meetings provide a forum through which GIS integration can be framed within the organizational goals and objectives of WYDOT.

The initial planning step results in the Strategic Business Plan document that fully describes the introduction of GIS technology. The conclusions of the Strategic Plan document, reviewed and accepted by WYDOT officials, provide the foundation for continued GIS planning and development.

Step 2: Conceptual Planning

Conceptual planning involves a series of tasks that explicitly define what functions the GIS will perform and what products the GIS will deliver. GIS requirements are determined from a combination of broad organizational interviews and detailed program-specific interviews. The organizational perspective is important to determine a scalable GIS solution, one that not only meets immediate needs but also anticipates future requirements as GIS expands throughout WYDOT.

Task 2.1: Orientation Seminar

Conceptual planning begins with a half-day orientation seminar that describes the GIS project, generates enthusiasm for GIS integration within WYDOT, and introduces WYDOT users to the capabilities and benefits of GIS technology. The seminar includes a general discussion about geographic data concepts, data models, and transportation-oriented demonstrations. The purpose of the seminar is to provide WYDOT staff with a basic understanding of GIS so they are more comfortable with GIS constructs and may offer more valuable input during the user interview process.

Task 2.2: Broad Organizational Interviews

Following the orientation seminar, ESRI meets with program and section representatives to evaluate existing data stores; departmental responsibilities; and procedures for creating, maintaining, and utilizing spatial information. The WYDOT-wide interviews provide the broad perspective necessary to identify the organizational impacts and data sharing opportunities that accompany the introduction of GIS technology. ESRI anticipates interviews with the following programs and sections:

Bridge	Highway Development	Planning and Programming
Highway Safety	Right-of-Way	Environmental Services
Traffic	Communications Support	Construction and Maintenance
Geology	Materials Lab	Photogrammetry/Survey

Task 2.3: Utility Program Interviews

In-depth information regarding utility data stores, reference mechanisms, and procedures will be gathered through interviews with representatives from the Utilities/Railroad section of the Highway Development program. This information provides the detail necessary to compile rigorous design specifications for GIS products.

Task 2.4: Geographic Basemap Development

ESRI compiles information gathered during the user interviews and evaluates existing geographic data sources to develop detailed specifications for the geographic basemap. Specifications for database relationships (i.e., attribute items, logical data linkages, linear referencing schemes, etc.) as well as accuracy requirements are formulated. ESRI uses the specifications as a basis for contacting and selecting vendors capable of providing the basemap data conversion services. ESRI works with WYDOT GIS task force members to evaluate data conversion alternatives and derive a cooperative, cost-effective solution to the organization's data needs.

The conceptual planning step of the design process concludes with the Requirements document, reviewed and accepted by WYDOT project staff, which fully describes GIS users, functions, and products.

Step 3: Detailed Planning

Detailed planning moves from a consideration of what the GIS is to accomplish to an examination of exactly how this is to be done. Detailed planning tasks involve a physical database design, hardware, software and network design, and system implementation planning. In addition, it is appropriate to develop quality assurance/quality control (QA/QC) guidelines that serve to validate data development activities and begin application design activities.

Task 3.1: Physical Database Design

Physical design activities translate the tabular and spatial data relationships, as specified in the Requirements document, into normalized database tables and structures. Coding schemes to support symbolization and labeling are fully specified, and linear referencing schemes are developed in accordance with the chosen GIS and relational database management system. The physical database design is fully described in the Data Design document, which is reviewed and accepted by WYDOT staff.

Task 3.2: Hardware, Software, and Network Design

The existing computer systems within WYDOT are evaluated and recommendations are made that accommodate the introduction of GIS. Server technology, desktop workstations, memory requirements, disk storage, peripheral devices (i.e., digitizers, plotters, scanners, etc.) and networking capabilities will be inventoried. Detailed site plans that fully describe the GIS technological infrastructure will be prepared. To the extent possible, hardware and software will be recommended that complement WYDOT's current computing environment. The design is fully described in the Hardware, Software, and Network Design document that is accepted and reviewed by WYDOT staff.

Task 3.3: QA/QC Plan

Data validation considers four fundamental data errors: referential errors, topological errors, relative errors, and absolute errors. ESRI provides procedures and guidelines to verify data that is identified for inclusion in the GIS. Whether the data currently exists or will be delivered by a third party vendor, ESRI will work with WYDOT to ensure that the data supports the identified needs of WYDOT GIS users.

Task 3.4: Application Development

The majority of GIS users in WYDOT will utilize the standard functionality that comes with the GIS software products. However, selected users may benefit from customized applications that automate repetitive tasks or simply limit functionality. Commonly built applications vary from templates that standardize map products to complicated programming tasks that supplement out-of-the-box GIS functionality. ESRI works with WYDOT through this task to identify, design, and develop an application that integrates utility information with the GIS to support data display, query, and output activities.

Task 3.5: Implementation Planning

Implementation planning considers the physical integration of GIS within an organization. It identifies organizational structures necessary to support the operational GIS as well as staffing and training requirements that enable users to be truly productive with the provided GIS tools. Implementation planning includes a detailed schedule that anticipates system acquisition, installation, and integration; application distribution and training; network security and risk assessments; and deployment throughout WYDOT. ESRI prepares and delivers the Implementation Plan document that guides WYDOT staff through the various implementation activities. WYDOT staff review and accept the findings in the Implementation Plan document.

The detailed planning stage formally describes how the GIS will operate. It proceeds through well-defined tasks that may be undertaken concurrently. Application development may occur while QA/QC procedures are being established or while the hardware, software, and network design is being completed. The detailed planning step results in the following documents, reviewed and accepted by project team members:

- Data Design document
- Hardware, Software, and Network (Systems) Design document
- Implementation Plan document

Step 4: System Deployment

System deployment activities represent the formal transition from GIS planning to GIS installation. Tasks include system acquisition, systems installation, and systems integration. ESRI will assist in the deployment of identified system components, as defined by the Requirements document. ESRI anticipates involvement in the installation and integration of GIS software licenses, data, and application code.

Conclusion

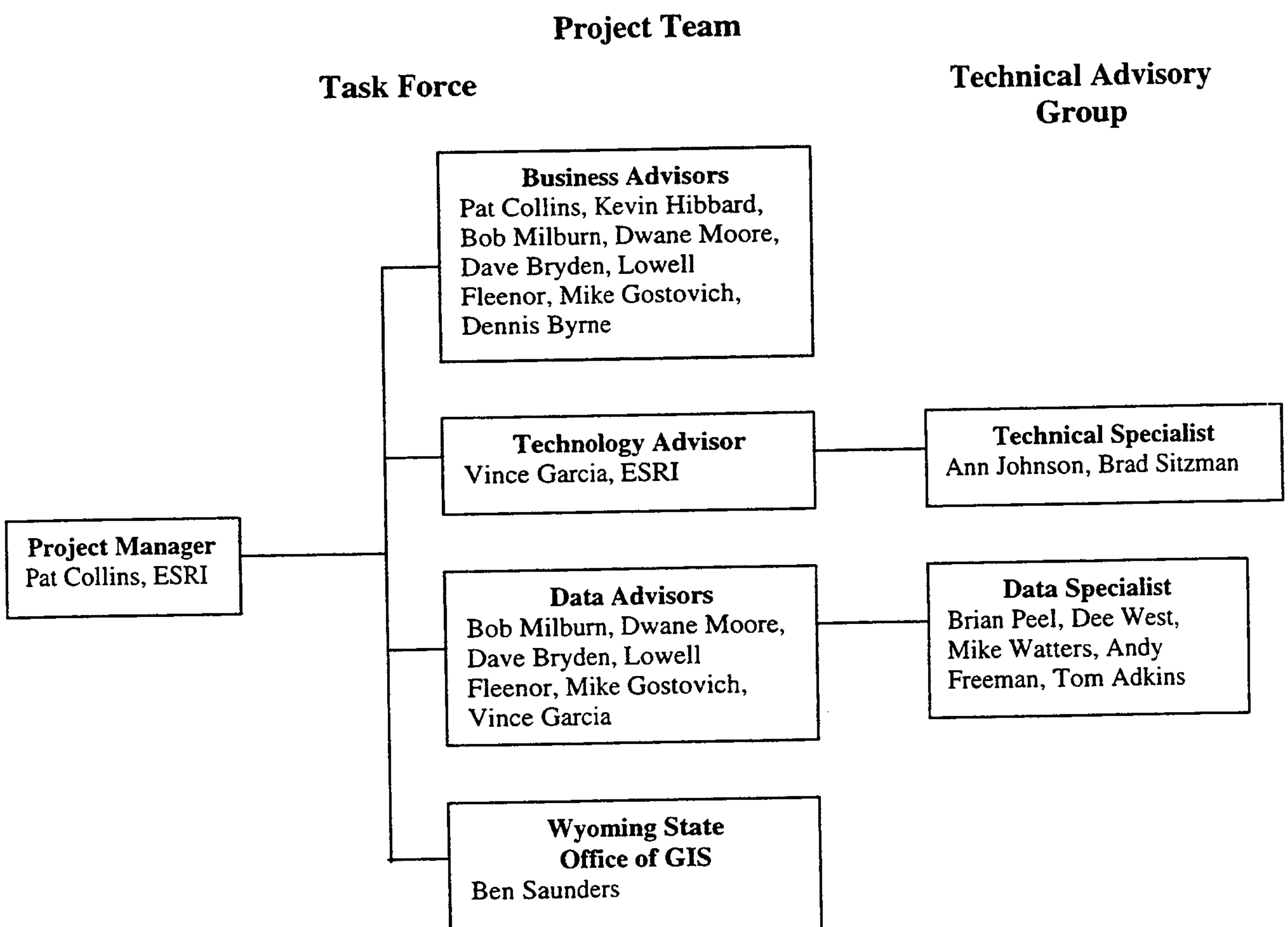
ESRI staff guide WYDOT officials through the design methodology. At the conclusion of each step, WYDOT staff will be given an opportunity to assess the feasibility of the project. They may elect to continue forward, revisit earlier decisions, or stop the project altogether. The built-in checkpoints give WYDOT officials confidence in and control of their GIS investment. The planning framework of the design methodology ensures that GIS development decisions are closely tied to clearly defined business needs, thereby dramatically increasing the probability of a successful GIS implementation.

A.3.2 Project Organization

Successful integration of GIS technology requires a commitment of staff time and expertise to guide the implementation. WYDOT recognized this need and created the GIS task force in January 1999 to oversee the GIS development. They solicited the expertise of ESRI–Denver to participate on the task force, providing in-depth knowledge of design methodologies, GIS data models and GIS functionality.

The task force engages in a number of activities including the preparation of documents that report on the findings and progress of the project. The task force has scheduled regular meetings, convening on the second and fourth Friday of each month to identify and resolve system design problems, focus activities on the critical path to achieve an operational GIS by November 15, 1999, balance workload assignments, and maintain communication with the executive staff. The task force will utilize the monthly WYDOT publication, *The Interchange,* to communicate the status of the project to all WYDOT staff.

The composition of the task force is illustrated and described below.



- **Project Manager.** The project manager is responsible for finalizing design decisions, accepting project documents, coordinating activities of task force members, evaluating the feasibility of continued investment, and communicating progress to the executive staff. The other members of the task force support the project manager in these responsibilities.

- **Business Advisor.** The business advisor provides an understanding of the business needs supported by the GIS. The business advisor ensures that the GIS serves well-defined functional requirements of WYDOT. The most technically elegant GIS solution is meaningless if it does not fully meet business needs.

- **Technology Advisor.** The technology advisors understand networks and the client/server architecture currently employed by WYDOT. They provide knowledge specific to GIS data models and functional capabilities and ensure that applications are developed in accordance with organizational standards.

- **Data Advisor.** The data advisor provides a detailed understanding of the data stores and logical linkages among data elements.

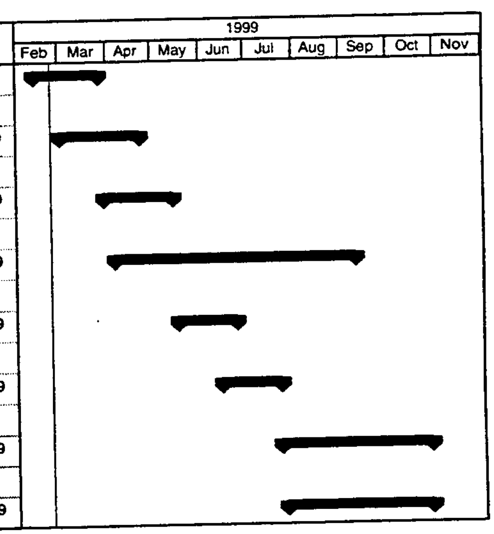
The WYDOT GIS task force is well constructed to consider the various elements of GIS integration. GIS system components of hardware, software, data, personnel, and business practices are fully supported by representatives of the task force. In addition, the advisors may solicit detailed information from the specialists that make up the Technical Advisors Group as that detailed information is required.

A.3.3 Project Schedule

The figure below illustrates the preliminary project schedule for GIS integration within WYDOT.

Figure A.1-2
Phase One Project Schedule

ID	Task Name	Start	Finish
1	Strategic Business Plan	Fri 2/12/99	Fri 3/26/99
9			
10	Requirements Analysis	Mon 3/1/99	Fri 4/23/99
20			
21	Database Design	Mon 3/29/99	Fri 5/14/99
28			
29	Base Map	Mon 4/5/99	Fri 9/10/99
35			
36	Hardware, Software, Network Design	Mon 5/17/99	Fri 6/25/99
43			
44	Implementation Plan Report	Mon 6/14/99	Fri 7/23/99
51			
52	Systems Integration	Fri 7/23/99	Fri 10/29/99
60			
61	Application Development	Mon 7/26/99	Fri 10/29/99



Appendix B

Requirements Analysis

B.1 Requirements Analysis

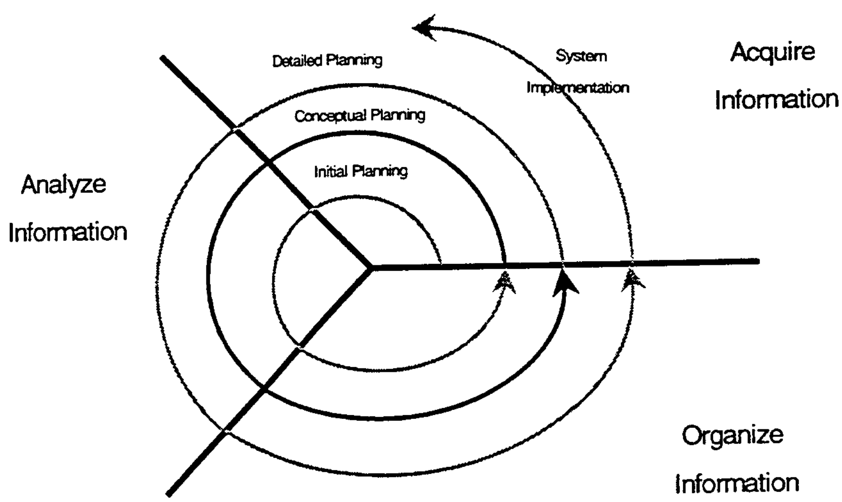
B.1.1 Introduction

The success of the geographic information system (GIS) implementation within the Wyoming Department of Transportation (WYDOT) is ultimately defined by how well it supports staff in accomplishing their daily tasks. To promote success, WYDOT must ensure that GIS investment is driven by well-defined user needs. Assessing and defining those needs for Phase One of the GIS implementation is the objective of this document.

The WYDOT GIS task force completed initial planning activities aimed at defining long-term goals and objectives for the geographic information system. Strategy meetings held during January and February of 1999 concluded that GIS technology complements WYDOT information processing procedures. It offers an opportunity to organize data around its inherent spatial context, provides an intuitive map-based interface to existing data stores, and promotes an intradepartmental and cross-disciplinary approach to problem solving and policy making. The strategy meetings defined the niche for GIS within WYDOT and provided the foundation for subsequent GIS planning and development efforts.

Figure B.1-1, below, illustrates the transition in the design process from initial, strategic planning to the current stage of conceptual planning, where task force members defined GIS system requirements that include organizational support, data and functional needs. It is important to recognize that hardware and software specifications are deferred until the system requirements are fully defined.

Figure B.1-1
Design Methodology



Conceptual planning involved the following tasks:

- **Orientation Seminar.** The orientation seminar was conducted on March 4, 1999 at WYDOT headquarters in Cheyenne, Wyoming. The presentation included lectures and demonstrations that introduced GIS techniques, described the design methodology undertaken by WYDOT GIS task force members, and encouraged the participation of WYDOT staff. Introductory comments from Mr. Gene Roccabruna, Director of WYDOT, reiterated executive staff support for GIS implementation within WYDOT.

- **departmentwide Interviews.** The orientation seminar was followed by interviews with representatives from various programs and sections of WYDOT. The departmentwide interviews provided GIS task force members, with the broad organizational perspective necessary to develop a scalable GIS solution, one that not only serves immediate needs but also anticipates future requirements as the use of GIS expands throughout WYDOT.

- **In-depth Utility/Railroad Section Interviews.** Information gathered through in-depth meetings with staff from the Utility/Railroad section provided GIS task force members with a firm understanding of the data and procedures that currently support the operations of the Utility/Railroad section. System requirements, in terms of data, GIS functionality and organizational support, were developed to meet the identified needs.

- **Geographic Basemap Requirements.** The geographic basemap contains the core data layers that support Phase One mapping needs. Core data layers were determined from user needs. The information gathered and compiled during the interviews with WYDOT staff enabled the GIS task force to consider various alternatives and devise a cost-effective basemap solution that supports identified GIS activities.

Findings from the conceptual planning activities are reported in this Requirements Analysis report. The report is organized into three sections: 1) Interview Summaries, which presents the findings of the departmentwide interviews, (2) System Requirements, which describes the data, functions and organizational support necessary to develop a successful GIS solution, and (3) Basemap Requirements, which details the scale (accuracy), topological constructs, and content for the WYDOT geographic basemap.

B.2 Interview Summaries

Phase One GIS implementation focuses on the Utility/Railroad section of WYDOT. However, in considering system requirements, task force members were encouraged to develop a systems solution that promoted the participation of many programs and sections throughout WYDOT. Accordingly, departmentwide interviews were conducted to meet two goals: 1) develop a broad organizational perspective for GIS and 2) identify candidate programs and sections for Phase Two implementation activities. The departmentwide interviews were not structured to define the in-depth needs of each group; rather the interviews focused on defining geographic layers and linear referencing systems that facilitate the integration of GIS throughout the department. The departmentwide interviews were held in March 1999, and the following programs and sections were represented:

Geology	Materials Lab	Photogrammetry
Project Development	Programming	Planning
Highway Safety	Environmental Services	Highway Patrol
Right-of-Way	Telecommunication	Bridge
Construction/Maintenance	Traffic	Utility/Railroad

Interview participants responded to a series of questions that were structured to define ways in which each group could benefit from the initial implementation activities involving the Utilities/Railroad section. Overwhelmingly, the interviewees identified a need for providing a map-based interface to the system, route, and reference post linear reference system (LRS) maintained by the Planning section as the Wyoming Reference Marker System. Because each program and section relies to some degree on this LRS, building it into the geographic basemap facilitates the inclusion of other programs and sections in GIS activities.

Criteria for a program's involvement in Phase Two GIS development efforts were defined in the Strategic Plan document. Interview summaries were prepared in accordance with those criteria and are presented below. The summaries are fairly subjective but serve to identify the overall environment for GIS that provides task force members with a framework to consider possible Phase Two implementation efforts.

B.2.1 Public Benefit

Program and section roles and responsibilities were discussed to determine the magnitude of public benefit that would be achieved by involving that program or section in GIS. The magnitude is described as HIGH for those groups that interact daily with the public or provide invaluable service of the public trust, MODERATE for those groups that have limited interaction with the public and LOW for those groups whose work predominately supports others in the department in responding to public interests.

Table B.2-1
Program's Public Benefit Summary

Group	Rating	Comments
Geology	Low	Most work supports internal design, construction efforts.
Materials Lab	Moderate	Pavement Management System supports legislative order to maintain health of roads.
Photogrammetry	Moderate	Publicly available photos may support cost recovery options.
Project Development	Moderate	Supports reconnaissance that initiates project development.
Programming	High	Public and legislative interest for improvement projects.
Planning	High	Needs analysis, traffic volumes tied to public interest.
Highway Safety	High	Descriptive and prescriptive solutions for crash prevention.
Environmental Services	Low	Documents filed in support of internal construction work.
Highway Patrol	High	Operations promote public safety.
Right-of-Way	Moderate	Predominately supports internal efforts.
Telecommunication	Moderate	Infrastructure supports public interests.
Bridge	High	Supports load routing, quarterly reporting.
Construction/Maintenance	Moderate	Create informational products for public (i.e., weight and width).
Traffic	Low	Most work supports internal design.
Utilities/Railroad	High	Management of utility infrastructure supports public interest.

B.2.2 Organizational Benefit

Organizational benefit describes the interaction of groups within WYDOT. A HIGH benefit pertains to those groups that maintain data and procedures that support the interests of another group. A MODERATE benefit is for those groups whose data and procedures could be used, if they were widely available. A LOW benefit is for those groups whose day-to-day activities do not impact a large portion of WYDOT.

Table B.2-2
Program's Organizational Benefit Summary

Group	Rating	Comments
Geology	Low	Efforts support specialized departmental needs.
Materials Lab	High	Pavement Management System data supports departmentwide efforts.
Photogrammetry	Moderate	Photos may provide support information for many areas.
Project Development	Moderate	Project reconnaissance supports detailed project designs.
Programming	High	departmentwide activities respond to identified STIPs.
Planning	High	departmentwide activities follow goals of 20 year plan.
Highway Safety	High	Desire to create safe roads drives departmentwide efforts.
Environmental Services	Low	Filed documents are minimally used by other programs.
Highway Patrol	Low	Data supports internal Patrol needs.
Right-of-Way	High	Project construction does not start until ROW is cleared.
Telecommunication	Low	Minimal interaction with other programs.
Bridge	Moderate	Supports inter-departmental planning and reconnaissance.
Construction/Maintenance	Moderate	Could assist their roles as liaisons to district offices.
Traffic	Moderate	Sign/signal inventory located by address and reference post.
Utilities/Railroad	Moderate	Supports inter-departmental planning and reconnaissance.

B.2.3 Functional Needs

GIS offers robust tools to analyze spatial information. A rating of HIGH is reserved for those groups that have difficulty performing their analysis without the techniques of GIS. A MODERATE rating is given for those groups that would employ GIS for graphic queries and display but that could perform those same queries outside of GIS. A LOW rating is given to those groups that could not take advantage of GIS tools; for example detailed design level work is difficult for the WYDOT GIS because of the increased investment in large-scale data needed to support such efforts. Functional needs provide a measure of "bang-for-the-buck" for the GIS investment.

Table B.2-3
Program's Functional Needs Summary

Group	Rating	Comments
Geology	Moderate	GIS to provide display and inventory tool for tabular data.
Materials Lab	Low	Current procedures provide necessary functionality.
Photogrammetry	Moderate	Inventory, registration, transformations supported by GIS.
Project Development	High	Data overlays utilized in project reconnaissance.
Programming	High	Display, query, output, analysis capabilities define projects.
Planning	High	Data overlays, scenario modeling support planning efforts.
Highway Safety	High	Crashes are subjected to in-depth spatial analyses.
Environmental Services	Low	Current procedures provide necessary functionality.
Highway Patrol	High	Vehicle routing, emergency response support patrol efforts.
Right-of-Way	Moderate	Enhanced querying of access, property holdings, etc.
Telecommunication	Low	Current procedures provide necessary functionality.
Bridge	High	GIS could act as front end for BRASS. Optimize routing.
Construction/Maintenance	Moderate	Could take advantage of querying enterprise database.
Traffic	Moderate	Benefits from a visual interface to inventory.
Utilities/Railroad	High	Map-based query/overlay, supports permit processing.

B.2.4 GIS Interest

Enthusiasm for GIS is measured as HIGH, MODERATE, and LOW according to a group's interest in incorporating GIS into their activities.

Table B.2-4
Program's Interest in GIS Summary

Group	Rating	Comments
Geology	High	GIS could speed up data searches.
Material Lab	Low	Staff does not perceive a GIS need or a potential benefit.
Photogrammetry	Moderate	Interested in using GIS to complement other applications.
Project Development	Moderate	GIS supports broad project planning.
Programming	High	Save time, money and provide better service.
Planning	High	Save time, money and provide better service.
Highway Safety	High	Save time, money. Provide more complete crash analyses.
Environmental Services	Moderate	Interested in GIS but does not see immediate benefit.
Highway Patrol	Moderate	Emergency dispatch procedures exist; benefits from data.

Group	Rating	Comments
Right-of-Way	Moderate	Interest in GIS to access data more efficiently.
Telecommunication	Low	No immediate need for GIS, current procedures are adequate. Interested in more detailed digital elevation model data.
Bridge	High	Strong interest in potential benefits of GIS.
Construction/Maintenance	Moderate	Interest in GIS to access data more efficiently.
Traffic	High	GIS organizes large information stores.
Utilities/Railroad	High	Map-based interface complements existing procedures.

B.2.5 Support

Support is a broad criterion that identifies a group's ability to sustain GIS activities. Support considers the following areas:

- **Financial Support.** The GIS task force will secure funding for all interested programs and sections, essentially leveling the playing field for access to GIS. However, the Planning, Programming and Highway Safety sections may take advantage of federal funding sources to invest in GIS. A support level of HIGH is reserved for those programs not solely dependent on internal WYDOT funding. All other programs and sections have a support level of MODERATE to reflect the equitable consideration for GIS investment.

- **Staff Support.** The GIS task force is committed to providing resources in support of staff development. A staff support level of HIGH indicates that GIS expertise exists within that program or section; MODERATE is reserved for those programs and sections that are new to GIS. It is important to note that all users within WYDOT will require formalized training to become productive with GIS.

- **Equipment.** The GIS task force will provide the necessary hardware, software and communications infrastructure necessary to support GIS within each program and section. An equipment level of HIGH indicates that GIS software may be incorporated onto existing machines with minimal modification, and a level of MODERATE identifies those programs and sections that may need to upgrade equipment to support GIS software.

- **Tabular Data.** Departmental standards have directed a migration of existing tabular data stores to an Oracle-based relational database management system (RDBMS). A support capability of HIGH indicates that the program or section has migrated to Oracle, MODERATE refers to the utilization of a compatible database management system, and LOW indicates that the majority of tabular data is in an incompatible or hard-copy form.

- **Spatial Data.** Nearly all programs and sections maintain spatial data. A support capability of HIGH is reserved for those groups that currently maintain spatial data in a format that can be readily incorporated into GIS topological data models. MODERATE indicates digitally available data that does not conform to topological standards. LOW indicates that the majority of spatial data exists as paper maps.

Table B.2-5
Program's Ability to Support GIS Summary

Group	Support					Summary
	Financial	Staff	Equipment	Tabular Data	Spatial Data	
Geology	Moderate	Moderate	Moderate	Low	Low	Low
Material Lab	Moderate	Moderate	High	High	Low	Moderate
Photogrammetry	Moderate	Moderate	High	Moderate	Low	Moderate
Project Development	Moderate	Moderate	Moderate	Moderate	Low	Moderate
Programming	High	High	High	Moderate	Moderate	High
Planning	High	High	High	Moderate	Moderate	High
Highway Safety	High	High	Moderate	High	Moderate	High
Environmental Services	Moderate	Moderate	Moderate	Low	Low	Low
Highway Patrol	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Right-of-Way	Moderate	Moderate	Moderate	Low	Low	Low
Telecommunication	Moderate	High	High	Moderate	High	Moderate
Bridge	Moderate	High	High	High	Low	High
Construction/Maintenance	Moderate	Moderate	Moderate	Low	Low	Low
Traffic	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Utilities/Railroad	High	Moderate	Moderate	High	Low	High

B.2.6 Summary

Table B.2-6
Summary of Selection Criteria

Group	Public Benefit	Dept. Benefit	Functions Needed	Interest	Support	Summary
Geology	Low	Low	Low	High	Low	**Low**
Material Lab	Moderate	High	Low	Low	Moderate	**Moderate**
Photogrammetry	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Project Development	Moderate	Moderate	High	Moderate	Moderate	**Moderate**
Programming	High	High	High	High	High	**High**
Planning	High	High	High	High	High	**High**
Highway Safety	High	High	High	High	High	**High**
Environmental Services	Low	Low	Low	Moderate	Low	**Low**
Highway Patrol	High	Low	High	Moderate	Moderate	**Moderate**
Right-of-Way	Moderate	High	Moderate	Moderate	Low	**Moderate**
Telecommunication	Moderate	Low	High	High	Moderate	**Moderate**
Bridge	High	Moderate	High	High	High	**High**
Construction Maintenance	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Traffic	Low	Moderate	Moderate	High	Moderate	**Moderate**
Utilities Railroad	High	Moderate	High	High	Moderate	**High**

The departmentwide interviews describe, in a broad sense, the organizational perspective that allows GIS task force members to guide Phase One implementation activities and consider candidates for Phase Two efforts. The following conclusions are evident from the interviews:

- The GIS task force is positioned to guide all development efforts to ensure that GIS investment serves broad departmental goals and objectives. Each program and section will have an opportunity to present their case for involvement in subsequent GIS development efforts and each will be considered in accordance with the criteria outlined above. The GIS task force will control investment decisions to limit the potential for specialized implementations that may fragment the department.

- The Planning, Programming, Bridge, and Highway Safety programs are natural candidates for inclusion in Phase Two activities. Each has a demonstrated need for and interest in the spatial tools and techniques offered by GIS.

- The system, route, and reference post referencing scheme is widely used among many programs and sections within WYDOT. Accommodating that referencing scheme into Phase One activities not only supports the immediate needs of the Utilities/Railroad section but also promotes the use of GIS across the department.

B.3 System Requirements

System requirements were derived from information gathered and compiled through interviews with WYDOT staff. Requirements are presented in three broad categories: data, functionality and organizational support.

B.3.1 Data Requirements

Data requirements for the WYDOT stem from the concept of a shared, integrated database where many layers of geographic information are provided to support a variety of users. While the representation of on-system roads is the principal consideration, many other data layers are necessary to support the effective use of a map as a communication and analytical tool. For example, when roads are combined with county and State legislative districts, hydrography, and city locations a more meaningful display is created. During the interviews, WYDOT staff were encouraged to think beyond the traditional roadway infrastructure and identify geographic themes that support all aspects of their planning and reconnaissance efforts. **Table B.3-1** illustrates the identified data layers, organized into four conceptual data components.

- Reference Component
- Administrative Component
- Environmental Component
- Transportation Component

B.3.1.1 Core Data Layers of the Geographic Basemap

The user interviews identified many data layers that are required to support GIS activities within the department. Automating each of the layers is a time consuming, arduous task that may prohibit the completion of Phase One activities on November 15, 1999. The data collection effort is simply too great to accommodate all of the inventoried data elements. Data layers marked with an asterisk (*) on the data inventory are those layers that are necessary to support the required Phase One functionality of the GIS. Accordingly, those data sets comprise the core layers of the geographic basemap. Additional data layers may be identified for inclusion in the geographic basemap as future needs dictate. Phase One efforts will focus on developing the following data layers:

- **Control.** Public Land Survey System (PLSS) section corners and High Accuracy Reference Network (HARN) monuments provide established reference locations to register layers in the WYDOT geographic basemap.

- **Administrative Boundaries.** County, State, WYDOT District, Highway Patrol Zone, School District, State Legislative District, Land Ownership (Indian Reservations, USFS, NPS, BLM), Metropolitan Planning Organization (MPO) Units, Urban Areas, and Cities provide the areal definition that supports planning, forecasting, and maintenance activities as well as statistical reporting.

Table B.3-1
Data Requirements Inventory by Program

↓— Data Users
→—Data Maintainers
☒—External Agency

*—Phase One Core Data

	Geology	Materials Lab	Highway Development	Programming	Planning	Highway Safety	Environmental Services	Highway Patrol	Right-of-Way	Telecommunication	Bridge	Construction/Maintenance	Traffic	Utility/Railroad	External Source
Reference															
Control (HARN and PLSS) *	↓		→		↓		↓		↓			↓		↓	☒
Reference Marker Posts *	↓	↓	↓	↓	→	↓	↓	↓	↓	↓	↓	↓	↓	↓	
Topography	↓		→			↓	↓	↓		→	↓	↓		↓	☒
Wells—State Engineer Office	↓														☒
Roadway Video Logs		→	↓	↓	↓	↓	↓	↓		↓			↓	↓	
Digital Raster Graphic *	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	☒
Aerial Photos	↓		→			↓	↓	↓		↓	↓	↓		↓	
Administrative															
County Boundaries *		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	☒
WYDOT District Boundaries *		↓	↓	↓	→	↓	↓	↓	↓	↓	↓	↓	↓	↓	
Commission Districts *		↓	↓	↓	→	↓	↓	↓	↓	↓	↓	↓	↓	↓	
Highway Patrol Zones *		↓	↓	↓	↓	↓	↓	→	↓	↓	↓	↓	↓	↓	
State Legislative Districts *		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	☒
Federal Land Ownership *	↓		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	☒
Indian Reservations *	↓		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	☒

Table B.3-1 (con't)
Data Requirements Inventory by Program

↓— Data Users
→—Data Maintainers
☒—External Agency

*—Phase One Core Data

	Geology	Materials Lab	Highway Development	Programming	Planning	Highway Safety	Environmental Services	Highway Patrol	Right-of-Way	Telecommunication	Bridge	Construction/Maintenance	Traffic	Utility/Railroad	External Source
MPOs, Urban Areas *			↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	☒
PLSS *	↓		↓		↓		↓		↓			↓		↓	☒
Cities *		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	☒
School Districts *		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	☒
Demographics				↓	↓	↓	↓	↓		↓			↓		☒
Environmental															
Soils			↓	↓	↓	↓	↓							↓	☒
Habitats, Migration Routes			↓	↓	↓	↓	↓							↓	☒
Endangered Species			↓	↓	↓	↓	↓							↓	☒
Geology			↓	↓	↓	↓	↓				↓			↓	☒
Wetlands			↓	↓	↓	↓	→		↓					↓	
Archaeology Sites (SHPO)	↓		↓	↓	↓		↓		↓					↓	☒
Wells—State Engineer Office *	↓														☒
Wells—LUST Monitor Sites *	↓	↓				↓						↓			☒
Groundwater/Hydrography *			↓	↓	↓	↓	↓		↓		↓			↓	☒
Transportation															
On-system Roads *	↓	↓	↓	↓	→	↓	↓	↓	↓	↓	↓	↓	↓	↓	
Off-system Roads	↓	↓	↓	↓	↓	↓	↓	↓		↓	↓		↓	↓	☒
Road Alignments	↓		→						↓		↓	↓		↓	
Vehicle Miles (AADT)		↓	↓	↓	→	↓		↓					↓		
Crash Locations/Images/Data			↓	↓	↓	→		↓				↓	↓		
Railroads *			↓	↓	→	↓		↓	↓		↓	↓	↓	↓	☒
Utility Locations (Permits) *	↓	↓	↓			↓			↓	↓	↓	↓	↓	→	
Improvement Projects	↓	↓	↓	→	↓	↓	↓		↓		↓	↓	↓	↓	
Const./Maint. Projects	↓	↓	→	↓	↓	↓	↓	↓	↓	↓	↓	→	↓	↓	
Travel Demand Models		↓	↓	↓	→	↓							↓		
Traffic Analysis Zones				↓	→	↓							↓		
Bridge Locations	↓		↓	↓	↓	↓		↓			→	↓		↓	
Pavement Conditions		→	↓	↓	↓	↓						↓	↓		
Signs and Signals			↓	↓	↓	↓		↓	↓	↓		↓	→	↓	
Snow Fence			→	↓	↓	↓			↓			→		↓	

Table B.3-1 (con't)
Data Requirements Inventory by Program

☟— Data Users
☛—Data Maintainers
☒—External Agency

*—Phase One Core Data

	Geology	Materials Lab	Highway Development	Programming	Planning	Highway Safety	Environmental Services	Highway Patrol	Right-of-Way	Telecommunication	Bridge	Construction/Maintenance	Traffic	Utility/Railroad	External Source
DOT Real Estate, Capitol Facilities			☟	☟	☟	☟	☟	☟	☛	☟	☟	☟	☟	☟	
Planning LRS *	☟	☟	☟	☟	☛	☟	☟	☟	☟	☟	☟		☟	☟	
Maintenance Data	☟	☟	☟	☟		☟	☟		☟		☟	☛	☟	☟	
Pit Locations	☛	☟	☟				☟		☟			☟			
Bore Hole Locations	☛	☟									☟				
Maintenance Stations			☟	☟	☟	☟		☟	☟		☟	☛	☟	☟	
Telecommunication Facilities			☟	☟	☟	☟				☛				☟	
Drainage Structures		☛	☟	☟	☟	☟	☟				☛	☟		☟	
Land/Rock Slide Locations	☛		☟		☟	☟						☟	☟	☟	
Highway Features Files		☟	☟	☟	☛	☟	☟				☟	☟	☟	☟	
Airports			☟	☟	☟		☟	☟						☟	☒

- **On-system Roads.** Features corresponding to WYDOT's on-system road network provide the map-based representation of the transportation infrastructure necessary to support Phase One display, query, and analysis functionality.

- **Planning Linear Reference System.** The planning linear referencing system provides the database relationship that associates seemingly disparate data sources (i.e., crash records, pavement condition, sign/signal inventories, bridge locations, improvement projects, etc.) to the map based roadway features. The LRS promotes the departmentwide integration of data stores collected and maintained by individual programs and sections.

- **Utility and Railroad Locations.** The representation and presentation of features support Phase One activities.

- **Digital Raster Graphics (DRGs).** Digital raster graphics are scanned images of the 1:100,000-scale map series maintained by the U.S. Geologial Survey. The images are available for Wyoming and contain the pictorial representation of administrative cultural and natural features. Each DRG is registered to real-world coordinates to support a graphic overlay with other data layers in the GIS database.

B.3.1.2 Linear Referencing System

LRSs are used to locate descriptive attribute information that occurs along portions of a road network. For instance, utilities records may reference a pipeline crossing as I80, 65, indicating that it is located on an interstate system of Route 80 at reference post 65. Information gathered and compiled during the interviews with WYDOT staff identified two prominent referencing schemes used within WYDOT: (1) the system, route, and reference post scheme maintained by the planning program and 2) the Maintenance section scheme used by maintenance staff in the district offices.

It is important that the GIS task force understand that the development of a robust on-systems road data layer involves two components. The first is the capturing of the road features as arcs, that is, lines that utilize X and Y coordinate values on a Cartesian plane. The second is developing an LRS on top of the road features. This is performed in two steps: (1) by extending a new geographic feature (i.e., routes) from the underlying arcs and (2) calibrating the routes to account for the actual distance traveled along the route. The accuracy at which the *geographic* features (the first component) are captured determines the relative accuracy of the database (i.e., one geographic feature's relative position to another geographic feature). The accuracy of the calibration points applied to the LRS determines the positional accuracy of events (i.e., crashes, utilities) along the route features.

B.3.1.2.1 Planning System, Route, and Reference Post LRS

The Planning section of the Planning and Programming Division maintains the Wyoming Reference Marker System that "establishes a satisfactory and uniform system of highway identification and designation that is adaptable to all Divisions in the department" (*Wyoming Reference Marker Book*, 1999, page 3). The Reference Marker System is used as a location reference for the traveling public and for locating traffic accidents and other highway incidents. It is also widely used to support the maintenance and administrative functions of the department. The National Highway System functional classification scheme has replaced the Federal-Aid specifications used by WYDOT staff. Because WYDOT has not yet transitioned to the new nomenclature, the Federal Aid specifications, listed below, are commonly used to support current activities.

New Designation	Old Designation
I	Interstate
P	Primary
S	Secondary
U	Urban
SHS (alternately W)	State Highways Only

When two or more routes are coincident along a section of highway, reference posts reflect the distance of the major route. In general, reference post distances commence at the south or west terminus of each route and continue in numerical increments to the north or east terminus with the exception of paper reference posts on service roads. Reference post locations are maintained for "Y" structures on highway ramps.

The Wyoming Reference Marker System provides for the use of equations when necessary. Equations are usually the result of construction or realignment projects. They provide the mechanism for appropriately locating positions along the roadway that have been lengthened, shortened or extended in the process of maintaining the roadway infrastructure.

B.3.1.2.2 Maintenance Sections

The Maintenance Staff Office of the WYDOT creates and updates the *Maintenance Section Reference Book,* 1999, that supplements the Wyoming Reference Marker System with a linear referencing system that supports maintenance staff activities. The Maintenance section referencing scheme serves to delineate maintenance jurisdictions and primarily supports the accounting responsibilities of the maintenance staff.

B.3.1.2.3 LRS Summary

Phase One implementation activities consider the data needs of the Utilities/Railroad section of WYDOT. Information gathered and compiled during interviews with the utilities staff indicated that the majority of their efforts involve locating utility features through the planning system, route, and reference post LRS as defined in the Wyoming Reference Marker System. However, because the utilities staff interact routinely with maintenance staff in the district offices, they have adopted the practice of recording the maintenance section that pertains to utility applications. Utilities staff do not rely on maintenance sections, nor do they utilize equations in referencing utility features.

The Wyoming Reference Marker System must be incorporated into Phase One implementation activities to accommodate the needs of the Utilities/Railroad section. In addition, the data inventory presented in **Table B.3-1** justifies the development of Planning System, Route, and Reference Post LRS. The development effort is validated by the organizational benefit realized by providing a map-based interface to that referencing scheme. The majority of representatives interviewed utilize the Wyoming Reference Marker System.

B.3.1.3 Utility Database Records

The linear referencing scheme of system, route, and reference post provides the database structure to associate tabular information maintained by the Utility/Railroad section with geographic, map-based features. The Utility database is automated in Oracle and contains the following fields:

- **Utility-id.** This four-character field, internally maintained by the utility staff, uniquely identifies Utility features by reference post. It is the only candidate key. The first three characters identify the feature, while the fourth character specifies sections of the feature that fall between a given reference post. For example, the Central Telephone (CENTEL) utility feature between reference posts 113 and 118 on Primary route 11 is specified by six Utility-id values of AQBV, AQBQ, AQBN, AQBO, AQBP, and AQBR, respectively.

- **Company.** This eight-character field uniquely identifies the company that owns and maintains the utility feature.

- **Agreement Number.** This six-number field references the licensed application that describes the design and placement of the utility feature. Agreements are bound in "blue folders" and are maintained by the Records Office of WYDOT.

- **Route.** This eight-character field identifies the system and route where the feature exists. The system and route specification is concatenated into this single field and conforms to the Planning section's classifications. P-11, for example, refers to Federal Primary Route 11.

- **Milepost.** This seven-digit decimal field references the reference post at which the Utility feature exists. Combined with the Route field above, the reference post locates the existence of utility features.

- **Lane.** This four-character field identifies whether the utility crosses the road at the specified route and reference post (XING) or follows the road at that location (ENCR).

- **Maintenance Section.** The maintenance section is an alternative linear referencing scheme that locates utility features. It is used primarily by the maintenance foreman in the district office who responds to and oversees the Utility application. Maintenance sections are stored in a six-character field in the Utility database.

- **Township, Range, Section.** These fields locate the utility feature within the PLSS maintained by the Bureau of Land Management.

- **Facility Type.** This four-character field refers to the type of utility (i.e., telephone, gas, water, fiber-optic, etc.) referenced in the application.

- **Date.** Automatically provided to the database, this field records the date of the license agreement.

- **Remarks.** This multiline, multicharacter field is used by utility staff to record information about the utility feature. Remarks conform to commonly accepted practices of the utility staff, and as such there are no explicit standards for this field. Staff utilize the remarks field to record the length of encroachment-type features (i.e., lane values of ENCR).

- **Company Number.** This thirteen-character field refers to the identifier used by individual utility companies to track their features. WYDOT staff record the information to support crosschecking between internal WYDOT identifiers and external utility company records.

- **District Number.** This eight-character field refers to the unique identifier used by district office staff to record Utility applications. WYDOT staff in the Utility section maintain this information as a cross-checking mechanism for records maintained in the district offices.

B.3.1.4 Utility Database Issues

The Utility database is structured to support queries and sorts by each of the fields. It works well to support the current activities of the Utility/Railroad section. However, with the introduction of GIS, there is an opportunity to restructure the database to provide more efficient data storage and more effective relationships with map-based features. GIS applications do not require a restructuring of the database but will certainly benefit from a more normalized organization of data elements and tables. GIS task force members, in association with utility staff, will evaluate potential modifications to the database. Database design and application development efforts will conform to the recommendations of the GIS task force. The following issues are identified:

- **Location Reference.** The Utility database stores two types of features: (1) those that cross the road at a given point (crossings) and (2) those that follow the road linearly for a specified distance (encroachments). Encroachment distances are referenced in the nonstandard Remarks field and do not readily support inclusion in the GIS. GIS data models typically reference these features by storing a *from* position and *to* position to capture the linear nature of the features. This structure enables users to more effectively display, query, and analyze utility features because the linear representation more closely models the inherent characteristics of the features. It is recommended that the Utility section consider storing utilities features by referencing a from-reference post and a to-reference post. The Remarks field may be manipulated to support an automated procedure that populates the proposed to-reference post filed. Features that are currently maintained as crossings could simply duplicate the existing from-reference post reference to the to-reference post field, essentially storing the point feature as a line with no length.

- **Normalize Data Structures.** Normalization is a database technique that limits the redundant storage of information and efficiently structures database relationships to support update procedures and improve database performance. The Utility database offers many opportunities for normalization, but each would constitute a modification in the way records are currently maintained. For example, the Company field could be stored in a separate database table, along with the agreement number to reduce the redundant reference to company identifiers. This would reduce the potential for inconsistencies because the company identifier would be stored singularly and referenced as needed.

- **Symbology.** GIS relies on symbols and labels to support the effective display of information. Data elements may be added to existing database records to support the automated generation of maps that locate and describe utility features.

- **Feature Representation of Interstates.** The Utilities database does not make reference to the direction of multilane roads (i.e., I-80 West). Thus these features will be represented as single lines that represent the center line between the two lanes.

B.3.2 Functional Requirements

Geographic information systems offer robust tools to capture, store, query, display, analyze, and output all types of geographically related information. Those tools are provided through an easy-to-use graphical interface that may be customized to support more specific functionality as needed.

Interviews conducted with WYDOT staff highlighted broad functional requirements for the system. They can be categorized into two areas: (1) data display, query, and update and (2) data analysis. Functional requirements were derived from user interviews, previous efforts as documented in the 1994 WYDOT Information Technology report, and from the experiences of other State Departments of Transportation.

B.3.2.1 Data Display, Query, and Update

Data display and query operations were by far the most widely recognized functions for the GIS. Spatial queries that define what exists at a particular location as well as attribute queries that describe individual elements are well supported by GIS. Less recognized, perhaps because not all information is automated in a relational database management system, was the opportunity for GIS to support data entry and update operations. Potentially, GIS users may invoke database forms directly from the GIS, or an Internet application, to complement update and maintenance procedures. It is understood that display, query and update requirements pertain to all data layers identified in the data inventory (**Table B.3-1,** above). Common examples include the following:

- Display and query of highway features (on-system roads, pavement conditions, bridges, crash sites, vehicle miles, signs and signal locations, railroad crossings, etc.).
- Display and query of other data layers (districts, county boundaries, municipalities, wetlands, habitats, right-of-ways, etc.)
- Update information from completed applications and licensed permits by identifying the roadway segment and populating a form that automatically updates database tables.

B.3.2.2 Data Analysis

GIS tools provide the means to analyze a myriad of data layers based on their reference to a common location. Analytical functions desired by WYDOT are as follows:

- Overlay highway features to identify priority locations for capital improvements, travel modeling, crash site analysis, and so forth.
- Overlay proposed route alignments on other spatial features (wetlands, historic or archaeological sites, geological conditions, land ownership, construction materials availability, environmental concerns, etc.) to support high-level project reconnaissance.

- Provide map displays over the Internet to serve public interests in areas of traffic congestion, winter road conditions, and construction delays.

- Provide geographic indices to internal WYDOT reference files such as aerial photos, pavement video logs, federally mandated environmental impact assessments, and various other database records.

- Compute and display preferred routes for vehicle movements including oversize/overweight truck routing, hazardous material shipments, and snow removal equipment.

- Report geographically referenced highway statistics to federal and State agencies including capital improvements; crash statistics; pavement condition and travel demands by WYDOT district, legislative district, and municipal jurisdictions.

B.3.2.3 Utility/Railroad Section Functional Requirements

The Utility/Railroad section of WYDOT requires much of the capability described above. However, because initial implementation activities focus on establishing GIS procedures to support their specific operations, it is important to explicitly define functional requirements for the Utility/Railroad section. The identified requirements provide the foundation upon which successive application development efforts are built.

Currently, the Utility section maintains an Intranet application that enables WYDOT staff to query and display utility information. The application supports a query by system, route, and reference post that results in a tabular listing of facilities by location, agreement number, or company. GIS offers the ability to enhance the query by providing a map-based display that allows users to click on a map and retrieve relevant records. The functional requirements below assume an appropriately structured database as described in the data requirement section above.

<u>Data Display and Query</u>

- Select utility features by
  - System, route, and reference post
  - Company name
  - Agreement number
  - Maintenance section
  - Facility type
  - Date
  - Township, range, and section
  - Company number
  - District number

- Select utility features by geographic extent of
  - Administrative boundaries
  - Proposed project boundary
  - Interactive point location specified on a map
  - Interactive area location specified by a bounding rectangle on a map

Symbolize and label utility features by
- Facility type.
- Company name.
- Date.
- Lane (i.e., encroachment versus crossings).
- Render road features by utility density.

Data Analysis

Proactively define suitable locations for utility placement based on
- Topography
- Occurrence of existing features
- Travel demand and vehicle miles information
- Geology
- Soil conditions
- Pavement conditions
- Aerial photos

Spatially compare utilities to provide a measure of existing facilities at a location.
Overlay utility locations with proposed projects to reduce the potential for cut utility lines.
Overlay utility permit applications with existing facilities to avoid duplicated efforts.

Data Update and Maintenance

Streamline the application entry process by automatically populating fields such as
- System, route and reference post
- Township, range and section
- Maintenance section
- District, municipal jurisdiction, as needed

B.3.3 Organizational Requirements

In order to realize the strategic benefits of GIS, the task force understands that GIS investment is not a one-time, static event. Regardless of the scale of GIS implementation, whether it be a single section, multiple sections, or enterprisewide, ongoing commitments to GIS are necessary to support the operational system. Listed below are fundamental organizational considerations that determine the success of GIS investment.

- **Funding.** Many organizations have relied on a single funding strategy to support GIS, only to be forced to limit GIS activities when that funding source is no longer available. The GIS task force has recognized the value of multiple funding strategies and is positioned to guide GIS investment. Each GIS request will be evaluated by the GIS task force in terms of GIS objectives and organizational goals. Upon approval, the GIS task force will submit the request to the Information Technology Committee where it will be considered in terms of departmentwide standards and overall systems compatibility. This approach serves to unite GIS investment with recognized departmental procedures to avoid unwarranted system purchases.

- **Staff Development.** As GIS is implemented within WYDOT, the task force recognizes the need to direct resources toward staff training and development.

- **Data Maintenance.** Geographic data is not static. WYDOT must anticipate the need to update roadway segments, route systems, and associated attribute information. In the short-term individual sections and programs may be identified to maintain elements of the basemap, but as GIS use expands throughout WYDOT there may be a need to centralize geographic updates within a single organizational unit. The task force is positioned to address the need for maintenance operations as the GIS is implemented within WYDOT.

- **Environmental Boundaries.** By nature, GIS is an integrative technology that cuts across organizational boundaries. The GIS task force is positioned to anticipate the organizational impact of GIS and provide leadership to accommodate varying degrees of restructuring that the GIS may promote.

- **External Relationships.** GIS has become commonplace within many agencies throughout Wyoming, including, but not limited to, the Office of GIS, University of Wyoming, State Lands Office, Wyoming Department of Revenue, Wyoming Game and Fish and department of Environmental Quality. Considerable amounts of data are widely available that support Phase One activities within WYDOT. It is critically important for the department to recognize the value of State-wide efforts to reduce the redundant collection and maintenance of GIS data layers. The GIS task force must remain aware of external GIS activities in order to avoid costly expenditures that simply "reinvent the wheel." Involvement in the Wyoming Geographic Information Advisory Council (WGIAC) and other consortiums promote the State-wide perspective necessary to guide GIS implementation efforts within WYDOT.

- **Public Relations.** The orientation seminar and user interviews generated considerable enthusiasm for GIS throughout WYDOT. However, any time technology is incorporated into an organization there is the potential for reservation, as individuals perceive a system that drastically changes the manner in which they tackle their day-to-day responsibilities. The task force will remain in constant communication with all users, from the maintenance staff in the district offices to the executive staff at headquarters, to answer questions, resolve concerns, manage expectations, and keep the development efforts focused on the critical path. The task force will rely on the Public Affairs section of WYDOT to periodically publish articles in the *Interchange* and *Destinations*. In addition, Information Technology staff will develop an internal Web site that enables WYDOT staff to keep abreast of the GIS development. The communication channels, established by the GIS task force, enable WYDOT staff to follow and participate in the GIS implementation efforts.

B.4 Basemap Requirements

Successful implementation of a geographic information system provides users with the data, functionality, and organizational constructs that enable them to become immediately productive with GIS and utilize it to support their daily responsibilities. The design methodology employed by the

GIS task force dictates database requirements that are driven by well-defined user needs. From the information gathered in the user interviews it is clear that the geographic basemap must contain the on-system roadway infrastructure and the system, route, and reference post linear referencing system. However, in order to realize the aforementioned strategic benefits of GIS, the basemap must contain more than just the on-system roads. Supplemental data layers might include administrative boundaries, Public Land Survey System, environmental data layers, highway features, project locations, right-of-way data, and railroads. Recall that the power of GIS is not just to locate an individual geographic theme (i.e., roads) but also to view and analyze a geographic theme's spatial relation to other geographic themes (i.e., roads in conjunction with topography, political and DOT district boundaries).

In devising requirements for the geographic basemap, the GIS task force evaluated four fundamental considerations: accuracy, topological integrity, attribute content, and completeness. Each is described below.

B.4.1 Accuracy

Geographic features, roads, rivers, boundaries, and so forth, are deliberately generalized when presented in map form to communicate spatial relationships without introducing unwanted detail. Accuracy is inherently tied to scale where large scale maps (1:1,200–1:24,000) are typically used for detailed site analysis, and small-scale maps (1:24,000–1:1,000,000) are reserved for broader planning needs that support analysis across a much larger geographic extent (county, state or country). Accuracy and scale together define the ability to reference the absolute position of geographic features represented on the map with their true locations (i.e., submeter GPS data) on the surface of the earth. For example, 7.5-minute quads are generated by the USGS at a scale of 1:24,000. National Map Accuracy Standards dictate that features represented on these maps are within ±40 feet of their real-world location. A scale of 1:100,000 results in the ability to locate features to within ±166 feet of their absolute position, as described by national standards. An important aspect to consider in acquiring and maintaining geographic data is that costs and development efforts increase exponentially as accuracy requirements increase.

In order to avoid unnecessary investment in data, the GIS task force appropriately decided to let user needs dictate the accuracy requirements for the geographic basemap. The predominant use of the geographic basemap by WYDOT users, including the Utilities/Railroad section staff is as a visual interface to existing database records. The system, route and reference post reference scheme provides the database relationship that links map features to tabular records. There is no inherent accuracy requirement associated with this function because WYDOT users are more interested in a pictorial representation rather than an explicit coordinate location. Map scales of 1:100,000, providing an accuracy of ±166 feet, more than adequately support this need.
Many interview participants identified the need for GIS to support broad planning and reconnaissance efforts. These operations involve overlaying many different data layers to determine aggregate conditions. Crash locations may be combined with administrative boundaries to define the jurisdiction in which the crash occurred; project development may combine wetlands, soils, hydrography, and many other data layers to define the scope of a construction project. Often these

planning operations are followed by detailed surveys that are conducted outside the realm of GIS. Consequently, map scales of 1:100,000 sufficiently support these activities.

A more abstract use of the GIS as defined by the GIS task force is to foster an intradepartmental and cross-disciplinary approach to problem solving and policy making. Because the majority of users within WYDOT rely on the system, route, and reference post LRS to locate information along the highway in support of administrative and maintenance operations it is imperative to build that reference scheme into the geographic basemap. Users may share data based on the common reference to a highway location. The calibration of the route systems, rather than the absolute position of the roadway features, defines the accuracy for integrating data across many programs and sections. Therefore, a map of 1:100,000 scale, with properly calibrated reference posts, encourages the participation of departmentwide users in GIS activities.

In accordance with functional requirements, the GIS task force determined that a basemap scale of 1:100,000, with an accuracy of ±166 feet, appropriately serves Phase One GIS data requirements. The department is well served by this specification in that statewide data is readily available. The State Office of GIS currently maintains an inventory of digital data that may be immediately incorporated into the WYDOT geographic basemap. Data development efforts within WYDOT, therefore, focus on building the LRS, rather than embarking on a timely and costly data creation process.

B.4.2 Topological Integrity

The State of Wyoming Information Systems Architecture Standards: Geographic Information System Standard (1998-03 R) identifies ESRI software programs as the State standard for GIS. ESRI's GIS software programs rely on a data model that is topologically structured to support data capture, display, query, analysis, and output operations. In choosing ESRI's software products, the GIS task force recognized the strength of the topological data model and defined a de facto standard for basemap data layers. Namely, linear features must be connected at nodes to support the development of the system, route, reference post referencing scheme. Areal and point features captured in the GIS must also conform to ESRI's topological data model.

B.4.3 Attribute Content

GIS links spatial data with tabular attribute information that describes the map features. Data developed in support of the WYDOT geographic basemap must be rigorously attributed to support display, query, and analysis operations. For example, building the LRS involves selecting all the roadway features that make up a particular route, aggregating those features into a single entity, and calibrating reference post locations along the route. If the roadway feature does not contain an attribute of road name, it will be very difficult to construct the route system. Similarly, an administrative boundary that does not include a reference to the administrative jurisdiction is virtually useless from an operational standpoint.

B.4.4 Completeness

Data layers that are identified for inclusion in the GIS must contain the appropriate geographic features. The transportation data layer that stores on-system roads must contain interstate, federal aid primary, secondary, and urban roads and State highways. Map scale plays an important role in determining which features are represented on a map. Small-scale maps (1:100,000) include many features that are "generalized" and thus do not have the level of detail found in maps at much larger scales (1:200–1:24,000). This is desirable from a storage and performance standpoint. Less detail means fewer coordinate values need to be stored, and thus display and analysis of the features can take place more quickly. Because of the State-wide extent of the WYDOT geographic basemap, such a generalization is appropriate to exclude unnecessary detail. The accuracy specification of 1:100,000, described above, has proven successful in many state-wide agencies including Wyoming Game and Fish Department, Wyoming Geological Survey, and Wyoming Department of Environmental Quality. Likewise, a report by the Bureau of Transportation Statistics www.bts.gov/gis/state/visit.html) shows that other State DOTs have started at this scale and then refine their data over a multiyear period as the GIS evolves.

B.4.5 Cost Basis

The WYDOT GIS task force has two options for obtaining the spatial and attribute data necessary to support GIS activities. They may utilize existing data or they may elect to create their own data.

Existing data is available from many sources; the State Office of GIS, for example, maintains spatial data that includes administrative boundaries, land ownership information, environmental features, transportation-related data, and aerial photos. The data is collected from local, state and federal sources and is typically at a scale of 1:100,000. The role of the State Office of GIS is to foster data sharing among Wyoming GIS users by providing data in standardized formats and to reduce redundant data collection efforts throughout the State. Because the scale of 1:100,000 supports well defined internal needs, WYDOT may elect to utilize that data in developing its geographic basemap.

In choosing to develop their data, WYDOT is afforded the opportunity to create that data at virtually any desired scale. Paper maps, typically at a scale of 1:24,000, may be digitized, aerial photos with map scales of 1:200–1:12,000 may be scanned and ortho-rectified to support heads-up digitizing, and global positioning system (GPS) techniques may capture data at submeter accuracies. Although user needs are well suited by a scale of 1:100,000, it is widely understood that all users benefit from the most accurate data that is possible.

Table B.4-1 below was developed by the GIS task force to illustrate the costs of using existing data versus creating more accurate data layers. The costs are estimated as a rough order of magnitude and are compiled from estimates provided by data conversion specialists at ESRI headquarters in Redlands, California. Estimates for digitizing a single USGS 7.5-minute quadrangle ranged from $1,350.00 to $7,200.00 based on the data content of the quadrangle. Because there are approximately 1,925 quadrangles that cover the state of Wyoming, data development costs range between $2.5 million to $13.8 million. (The $13.8 million estimate is an anomaly. It was derived from a sample project that is not representative of the WYDOT initiative and as such will not be considered realistic.) Data collection efforts to provide data at a more accurate scale than 1:24,000 are difficult to estimate because of the unknown availability of that data.

Table B.4-1
Phase One Data Development Cost Comparisons

Data Requirements	Created Data (<1:24,000)	Existing Data (1:100,000)
On-system roadway infrastructure	$75,000–$450,000	$0–$1000
Supplement existing sources for completeness	$0	$0–$5000
Develop routes to support linear reference system	$0–$10,000	$5000–$15,000
Calibrate routes with reference post measures	$0–$10,000	$5000–$10,000
QA/QC procedures (on-system roads and LRS)	$0–$30,000	$0–$5,000
Automate supplemental data layers (administrative, environmental, engineering, etc.)	$5,000–$2,500,000	$0–$10,000
Populate supplemental data layer attributes (administrative, environmental, engineering, etc.)	$5,000–$100,000	$0–$20,000
QA/QC supplemental data layers	$5,000–$100,000	$ 0–$10,000
Total Phase One Costs	**$ 90,000–$3,200,000**	**$10,000–$76,000**

It is very plausible that future GIS needs may require a greater accuracy than can be derived from 1:100,000 scale. Since WYDOT is at the initial stage of GIS implementation and thus data creation, it may seem to be more fiscally prudent to capture the on-system roads at greater accuracy than what was derived as needed from the interviews. That is, why spend the money twice to capture the same data? However, this overlooks some key points.

One is that it is not just the roads layer that has to be captured at a greater accuracy; all data layers (i.e., hydrography, topography, etc.) would need to meet the minimum accuracy standards. Results from overlaying disparate geographic themes for analysis are no more accurate than the grossest resolution of any of the input data themes. Secondly, WYDOT is to complete Phase One by November 15, 1999; creating data rather than using existing data could jeopardize meeting that time constraint. Lastly, there is an opportunity cost to creating more accurate data before it is needed. That is, why incur the additional costs if the value from that accuracy is not going to be realized until some undetermined point in the future? Indeed, WYDOT may determine after Phase One that GIS did not meet the criteria for success and decide not to continue with any further implementation.

B.5 Conclusion

During March and April of 1999, the GIS task force conducted user interviews and met numerous times to discuss system requirements for the implementation of GIS within WYDOT. According to the design methodology, the task force evaluated user needs to determine the data, functions, and organizational support that promote a successful Phase One implementation of GIS. The GIS task force concluded that existing, readily available data, at a scale of 1:100,000, appropriately serves the needs of WYDOT users. Consequently, data development efforts in support of Phase One focus on building the linear reference system, as defined by the Wyoming Reference Marker System, into existing data sources. This effort offers the following benefits:

- It promotes State-wide interests by supplementing existing data sources with the system, route, and reference post referencing scheme. The linear reference system can be shared among all GIS users based on its inherent reference to roadway features captured and stored in accordance with standard State-wide data formats.

- It supports the identified needs of WYDOT staff. Providing a visual interface to tabular records, performing planning and reconnaissance, and integrating data and procedures across the department rely on building the database relationship that links reference post information with map-based features. The accurate representation of reference post locations relies on route system calibration rather than the absolute specification of spatial coordinates.

- It facilitates more accurate data collection efforts as future needs dictate. Data conversion vendors, as well as WYDOT staff, can utilize features from the Phase One basemap (i.e., reference post calibration points, interchanges, railroads, etc.) as a foundation for more detailed data collection efforts.

- It facilitates the inclusion of spatial data layers that are maintained by other State agencies. The State Office of GIS has compiled an inventory of digital data that, because of the common scale, may be immediately incorporated into the WYDOT geographic basemap. Because other agencies create and update these supplemental data layers, WYDOT's responsibility for maintaining data is reduced.

- It limits WYDOT's exposure to costly investments in data should the initial implementation prove unsuccessful.

- It provides GIS task force members with an opportunity to participate and guide data development procedures. The knowledge and experience gained in Phase One enable task force members to control future GIS investment, reducing their reliance on outside consultants.

Functional requirements, derived from user interviews, are predominantly planning based, providing a visual inventory of existing data stores and an Intranet map-based forum through which users can interact with various spatial and tabular data sets. The implementation of that functionality is addressed by out-of-the-box tools in conjunction with customized procedures that enable WYDOT users to be immediately productive with their GIS.

Finally, the GIS task force is well positioned to provide the organizational leadership necessary to consider geographic information systems implementation. Funding, maintenance, staff development and environmental boundaries are subjected to the greater interest of the department to ensure a GIS solution that not only supports immediate needs but also remains scalable to support the long-term objectives and goals of the department.

Appendix C

Database Design

C.1 Database Design

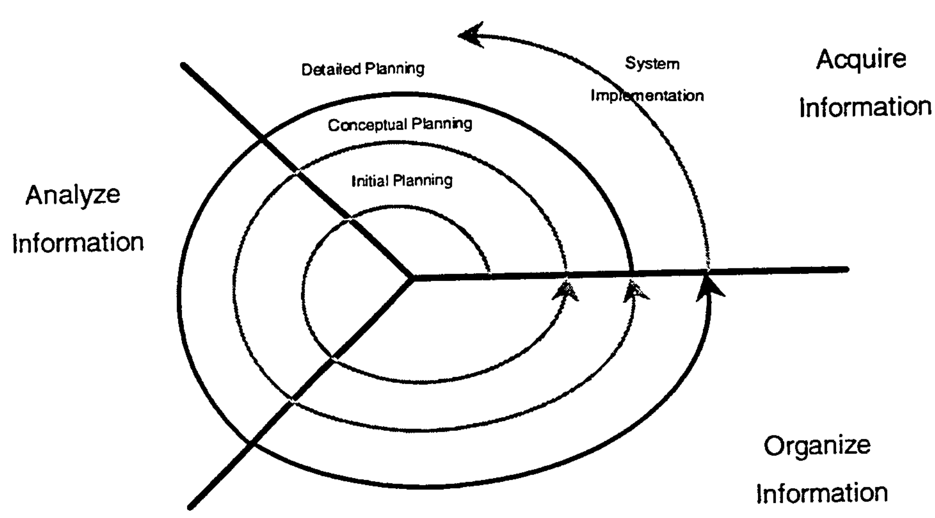
C.1.1 Introduction

A geographic information system (GIS) offers the Wyoming Department of Transportation (WYDOT) the technological means for managing multiple and wide-ranging spatial and attribute information. GIS technology greatly enhances the effective development, maintenance and use of this information to support the planning, forecasting, and policy making responsibilities of WYDOT. However, GIS involves more than just hardware and software. At its core is a database, efficiently and nonredundantly structured to support the wide variety of tasks required by WYDOT.

This report describes the concept and components of the WYDOT geographic database. It provides a "picture" of the geographic information system database by illustrating and describing the spatial and attribute data elements that support Phase One implementation activities. This report enables WYDOT GIS task force members to view the database in its entirety and evaluate the interactions of the various aspects of the database in a planning atmosphere before investing time and money in actual data development efforts.

The database design builds upon findings of the requirements analysis where data layers and functional needs were identified. It marks the transition in the design process from conceptual planning that defines "what" the GIS is to accomplish to detailed planning that defines the spatial and attribute data relationships that support "how" the GIS operates. **Figure C.1-1** illustrates WYDOT's migration through the design methodology.

Figure C.1-1
Design Methodology



Specifically, the design of spatial and attribute information presented in this report serves to

- Promote the integrated activities of WYDOT staff by providing a single, consistent structure for storing and maintaining geographically related information.
- Encourage a scalable solution where data may be added to support future GIS requirements.
- Organize spatial data by theme to increase the flexibility of data retrieval, analysis and production operations and facilitate the development of user applications.
- Minimize the redundant storage of geographically related information.
- Reduce the reliance on specialized database management systems and procedures by centrally organizing spatial and attribute data within the GIS database.
- Provide a spatial context for the vast amounts of descriptive data currently maintained by WYDOT. Such descriptive data includes project information, utility data, traffic signal inventories, and congestion and pavement management data.
- Support data sharing between WYDOT and external agencies by providing data structures that are easily exported into common exchange file formats.

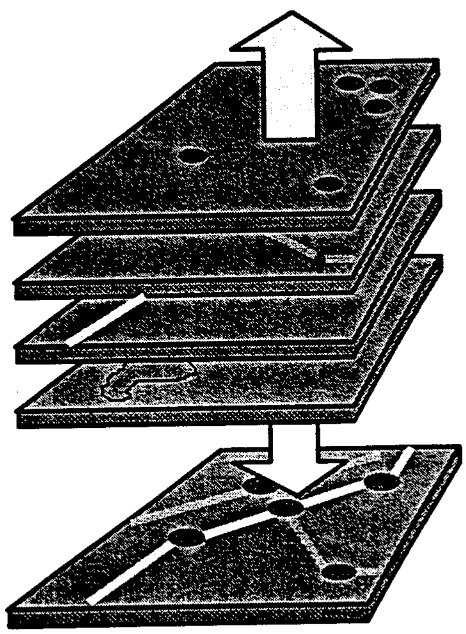
This database design report is organized into the following three sections:

- **Geographic Databases.** Background information regarding spatial data layering and GIS data models is presented to support the development of the database design.
- **Database Design.** Spatial data layers, feature representations, and attribute relationships are designed to meet the functional requirements defined in the conceptual planning activities. Data elements are structured efficiently and nonredundantly to create an integrated, shared geographic database that unifies WYDOT staff around their common information processing needs.
- **Utility Database Design.** Database relationships are presented that serve to link Utility database records with map-based route features. The dynamic segmentation point event model was recommended by the GIS task force and chosen because it complements existing Utility/Railroad section data maintenance and update procedures.

C.2 Geographic Databases

Geographic databases store information for features that exist on or near the surface of the earth. They organize these features by theme into various data layers that are maintained by the GIS. **Figure C.2-1** illustrates the layering concept of a geographic database.

Figure C.2-1
Geographic Database Layers



The individual layers in the geographic database are registered to each other by referencing feature locations in a common coordinate system. Well-known coordinate systems include the State Plane Coordinate System and Universal Transverse Mercator (UTM). Geographic referencing allows data layers to be combined to support selections, symbology, and summary statistics based on multiple, aggregated data relationships. For example, a roads layer may be combined with a county boundary layer to determine the number of road miles per county.

Geographic data layers contain two types of information: spatial data that stores the location of geographic features and attribute data that describes those features. Combined, these two data types enable users to organize information around its inherent spatial context.

C.2.1 Spatial Data

Spatial data is represented in a geographic database as points, lines, or areas. These three fundamental abstractions allow the GIS to model any object that exists in the real world.

- **Points** define discrete locations of geographic features too small to be depicted as lines or areas such as traffic signal locations and accidents. Depending on the scale of a map, a point can also represent locations that have no area such as a mountain peak.

- **Lines** (arcs) represent the shapes of geographic objects too narrow to depict as areas, such as streets, utility lines, and streams, or linear features that have length but no area such as elevation contours.

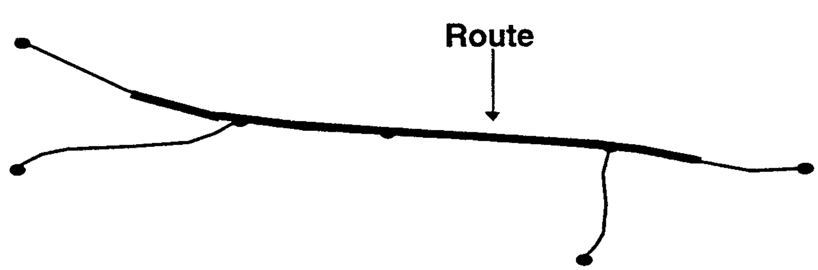
- **Areas** (polygons) are closed figures that represent the shape and location of homogeneous features such as states, counties, parcels of land, ZIP Codes, and statistical areas (Traffic Analysis Zones, census boundaries, etc.).

The dynamic segmentation data model supports users that require more sophisticated spatial data modeling. It is an extended feature type in that it is built from the spatial definition of underlying linear features.

- **Routes and Events.** The dynamic segmentation model consists of routes and events. Linear features (arcs) are selected and aggregated to form routes. Routes contain measures that define distances along them. The spatial reference of the underlying arcs and the measurement system defined for the route are used to spatially locate descriptive, attribute information (i.e., events) occurring along the route. Event database tables contain a route identifier and a measure to specifically locate the event on the route system. Events can be defined for points or by defining a single measure, or they may be defined for a portion of a route by defining the start and end measures of the event.

C.2.1.1 Route

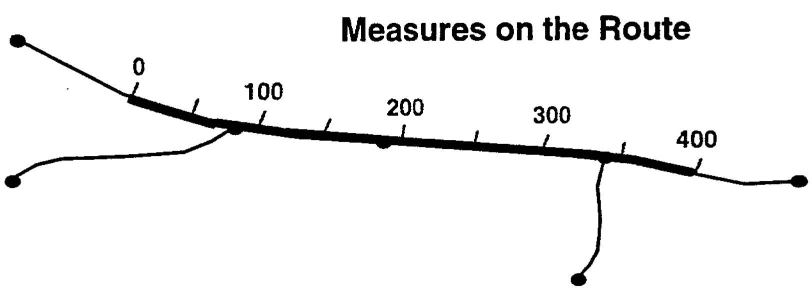
A route is a linear feature on which attributes are defined.



The graphic above shows a route defined on a set of four arcs. The start and endpoints of the route do not have to coincide with the start and endpoints (nodes) of the arcs. Routes of similar thematic type are combined and managed as a group in a route subclass. A single coverage can contain multiple route subclasses. Each route subclass consists of several relational INFO tables that define the route and can house attributes about each route.

C.2.1.2 Measures

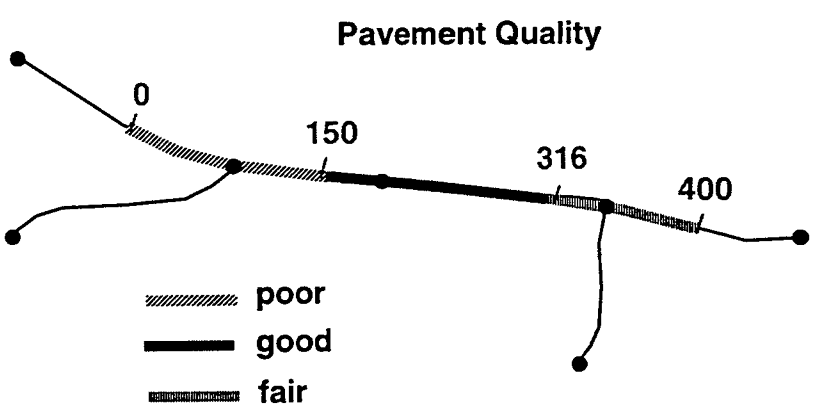
Each route system is associated with a measurement scheme, a linear method consisting of a starting value and other values along the route. The measurement scheme is independent of the underlying coordinate system in which the data was captured. The measurement scheme is user defined and is commonly represented as length (i.e., reference markers) or time. Attributes (or events), such as highway accidents, can be positioned on routes with user-defined measures.



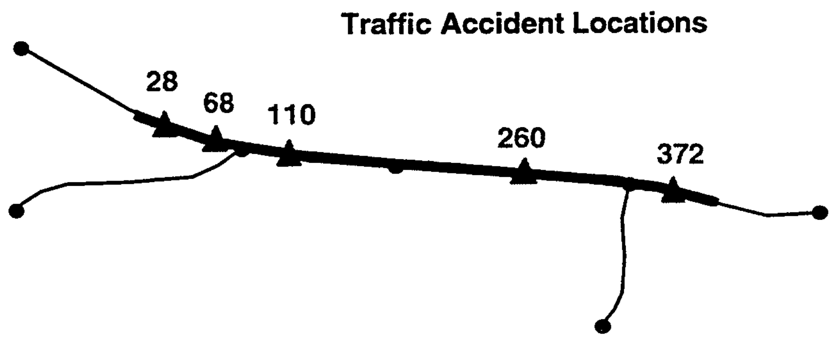
The graphic above shows a system of measures defined along a route.

C.2.1.3 Events

Attributes associated with a route, such as pavement quality, are known as events. In the highway application shown, pavement quality has been labeled according to the measures, poor from 0–150, good from 150–316, and fair from 316–400.



The graphic above illustrates pavement data contained in an event database. The pavement events are defined in terms of a linear measure along the route. Similarly, point events, such as accidents, may be associated with the route at measure locations 28, 68, 110, 260, and 372.



The graphic above shows an event database of traffic accidents on a route. Each event is recorded in terms of a linear measure along the route and graphically represented with a point marker.

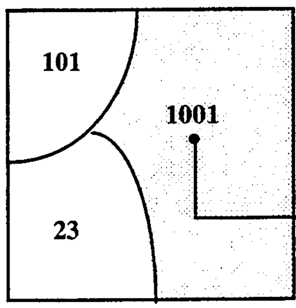
Events are not part of the ARC/INFO® coverage data model. They are stored in INFO data files or any supported relational database management system (RDBMS).

C.2.2 Descriptive (Attribute) Data

In addition to storing feature locations, geographic databases are capable of storing descriptive attribute information that describes the features. Attributes of spatial data features are stored in feature attribute tables (FATs). Each feature attribute table has a set of items that are automatically assigned when spatial data is captured and stored in the geographic database. These items define the topological relationships (i.e., area, adjacency, connectivity, etc.) that exist between spatial data layer features. Additional items can be added to the feature attribute tables, or they may be stored in separate, related attribute tables. Related tables may exist within ARC/INFO, or they may be stored in a separate related database management system (i.e., Oracle, MS SQL Server, etc.). The GIS maintains the necessary linkages between geographic features and descriptive attribute information. **Figure C.2-2** illustrates the relationship between polygon features and their associated attributes. While the example illustrates a natural resource application, the concept can be easily extended to support any polygonal representation. Attributes for point, line, route, and region features are referenced in a similar fashion, each maintaining items specific to the respective feature type.

Figure C.2-2
GIS Attribute Linkages

Polygon layer



Polygon Attribute Table

Item

Area	Perimeter	Cover #	Cover-ID	Stand #
30	21	2	101	I–1604
68	52	3	1001	I–1623
32	19	4	23	I–2004

Record

Related attribute database table

Stand #	Dom. Species	Age
I–1622	S. Spruce	45
I–1623	W. Hemlock	110
J–2000	W. Spruce	60
J–2001	Deciduous	30

As mentioned above, attributes of primary data layer features are stored in feature attribute tables. There are four primary kinds of feature attribute tables:

- **Polygon Attribute Table (PAT):** Contains information pertaining to area features, such as county boundaries, Highway Patrol Zones, WYDOT districts. and so forth. Items automatically generated by ARC/INFO are area, perimeter, *cover#* and *cover*-id, where *cover* is the generic reference to the data layer name.

- **Arc Attribute Table (AAT):** Contains information stored for arcs such as street type, river name, and so forth. Items automatically generated by ARC/INFO are from-node and to-node, used to model connectivity; left-polygon and right-polygon, used to model adjacency; length; *cover#* and *cover*-id.

- **Point Attribute Table (PAT):** Contains information stored for points. Items automatically generated by ARC/INFO are area, perimeter, *cover#*, and *cover*-id. The point attribute table will have the AREA and PERIMETER items set to zero, thereby distinguishing it from the polygon attribute table.

- **Node Attribute Table (NAT):** Contains information stored for nodes. Node information is typically used in network analysis to model transitions between arcs such as travel impedance and flow control. Items automatically generated by ARC/INFO are *cover#* and *cover*-id and arc#, used to uniquely identify an arc connected to the node.

Data layers that require more sophisticated feature types for data modeling may have additional feature attribute tables:

- **Route Attribute Table (RATsubclass):** Contains information stored for route features. Items automatically generated by ARC/INFO are *subclass*# and *subclass*-id, where *subclass* is the unique identifier for a collection of linear features.

- **Section Attribute Table (SECsubclass):** Contains sectional information stored for route features. Items automatically generated by ARC/INFO are routelink#, used to reference the appropriate route feature; arclink#, used to associate each segment with its underlying arc feature; from-measure, to-measure, from-position, and to-position refer to segments of arcs for which the associated attributes occur; and *subclass*# and *subclass*-id, which uniquely identify segments in the section table.

The manner in which descriptive, attribute data is organized in the database has a tremendous impact on the overall performance of the system. Both user response times and data maintenance procedures are optimized by a normalized tabular structure that organizes attribute data into a series of related database tables. Entity-relationship diagrams (ERDs) are included, as the database concept is presented below, to identify the key items and relate structures that support the nonredundant storage of attribute information within the GIS.

C.2.2.1 Entity-Relationship Diagrams

ERDs provide a graphical representation of the relationships that exist among data elements in an information system. They are used in this report to define the logical linkages between spatial, map-based features and descriptive, attribute information existing in related database tables. Entity-relationship diagrams contain the following components:

- **Entity.** Entities are the objects that are being modeled. Entities represent a collection or set of objects (tables) in the system whose individual members (records) can be uniquely identified in some fashion. Feature attribute tables are those created by ARC/INFO as spatial data is collected and related attribute tables are optionally created by users to store descriptive information for the spatial data layer features.

- **Relationships.** Entities are connected to one another by relationships. Relationships conform to rules of cardinality as defined below.

- **Cardinality.** Cardinality represents the number of mappings in which instances of one entity are represented in the related entity. The graphic representation used to describe cardinality in this document is illustrated below.

--+----------+--	One and only one. An instance of the parent entity corresponds to a single instance of the child entity.
--+---------O+	Zero or one. An instance of the parent entity corresponds to zero or one instance of the child entity.
--+---------+<	One or many. An instance of the parent entity corresponds to one or many instances of the child entity.
--+---------O<	Zero, one or many. An instance of the parent entity corresponds to zero, one or many instances of the child entity.

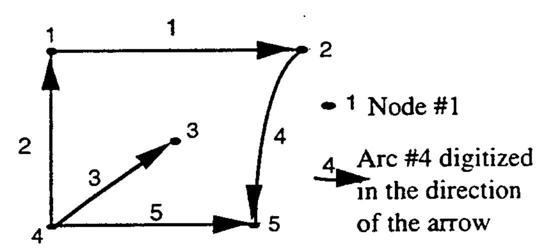
C.2.3 Topology

GIS technology provides a centralized, automated, visual environment that fully supports the information management needs of an organization. But perhaps more importantly, GIS models the spatial relationships that exist among database features. These spatial relationships include:

- **Coexistence**—Features that occupy the same geographic location (i.e., soil conditions of a proposed roadway)
- **Adjacency**—Features that are next to other features (i.e., parcels bordering an improvement project)
- **Proximity**—Features that are near other features (i.e., gas lines near a road intersection)
- **Connectivity**—Features that are connected to other features (i.e., Oak Street connected to Main Street by Third Avenue)
- **Distance, Direction**—Relationships of features to other features
- **Size**—The area and perimeter of a polygonal feature

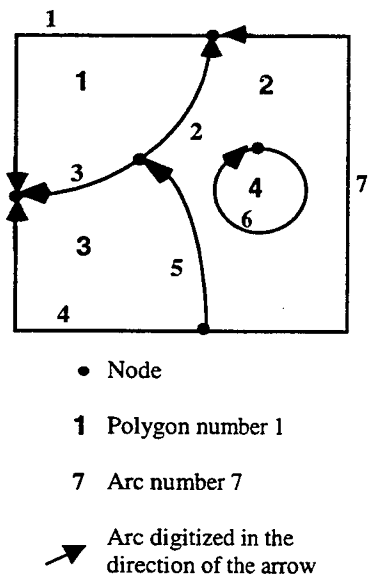
GIS relies on a branch of mathematics known as *topology* to explicitly define these spatial relationships. In practice, topology is nothing more than a series of related lists and attribute tables. For example, each line stored in the GIS includes a reference to the two endpoints (nodes) that make up the line. Lines that share nodes are considered connected. Similarly, spatial relationships of adjacency, size, distance, and direction are modeled within the attribute tables of the GIS database. The figures below illustrate how topology is maintained in a geographic database.

Arc–Node Topology



ARC #	FNODE #	TNODE #
1	1	2
2	4	1
3	4	3
4	2	5
5	4	5

Polygon–Arc Topology



Polygon	No. of Arcs	List of Arcs
1	3	-1, -2, 3
2	4	2, -7, 5, 0, 6
3	3	-3, -5, 4
4	1	6

By managing spatial relationships, GIS technology enables WYDOT to develop comprehensive solutions to problems that are basically spatial in nature. GIS provides users with the capability to answer a variety of questions, such as;

- What utility lines surround a road intersection?
- Where are the State transportation improvement projects planned for 1999?
- How many road miles of an interstate exist within each county in Wyoming?
- What bridges will a truck cross as it travels across Wyoming?
- Where are there poor pavement conditions within a county?

C.2.4 Future Data Models

Descriptions of the data model to this point have been based on ESRI's ARC/INFO 7.x technology. That technology is well proven and is the foundation for Phase One GIS activities within the WYDOT. However, ESRI is developing the next major revision, ArcInfo™ 8 software, to be released later this year. Version 8 introduces the GeoDatabase, which has a new object-oriented data model for the creation of intelligent databases that combines the properties of objects with their behavior. This allows users to treat geographic features as real-world entities rather than having to think about them in primitive geographic terms (e.g., point, lines and polygons). Furthermore, users can create their own object-oriented models that extend this model.

ArcInfo 8 and future releases will be compatible with all of ESRI's existing data formats. What that means for WYDOT is that the route system and basemap developed to support Phase One will remain a viable, ESRI-supported solution. To support subsequent phases of implementation, WYDOT may choose to build on the existing data model or may adopt the new, object-oriented data model. If the new data model is chosen, WYDOT will follow a clear, well-defined migration path that minimizes the impact on existing operations. Implementation of dynamic segmentation functionality in the new data model is planned for ArcInfo 8.1 (release expected summer of 2000). At that time, WYDOT will have the internal GIS knowledge to make an assessment of the new data model and make a decision on its benefits and the costs of migration.

An ESRI white paper that outlines the new functionality for ArcInfo 8 can be found at the following Web site: www.esri.com/library/literature.html.

C.3 Database Design

C.3.1 Shared Geographic Database

The WYDOT database design stems from the concept of a shared, integrated database where spatial locations are used to organize seemingly disparate data stores. The design structures data elements efficiently and nonredundantly to support the functional requirements of WYDOT staff. It represents a fully scalable solution that accommodates additional data layers as they are identified for inclusion.

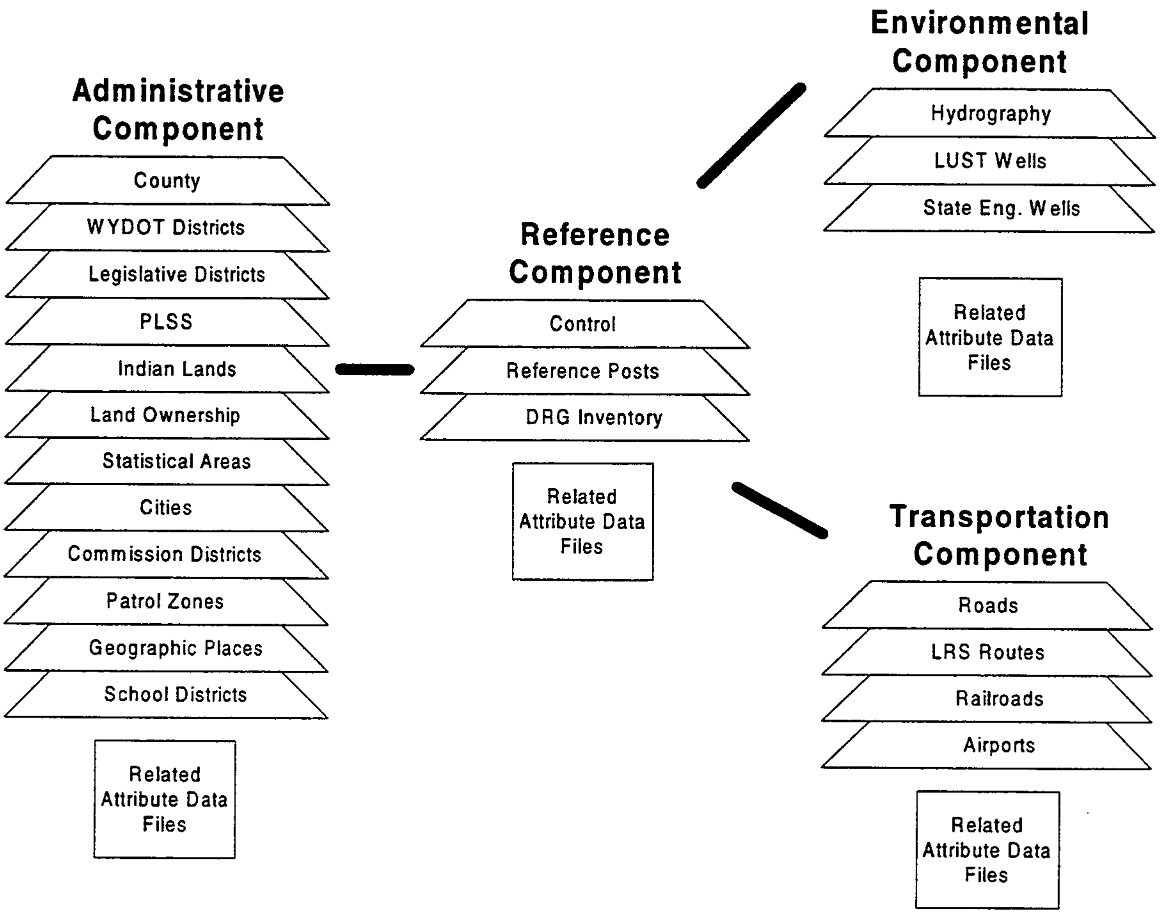
A GIS database registers the various data layers by storing the coordinates for all layers in a common coordinate system. Coordinate systems are typically based on rectangular (Cartesian) coordinate systems that have been projected from the earth's "spherical" shape or other "datum." Data collected and developed in support of Phase One will be stored in geographic (latitude/longitude) coordinates. This specification is the most flexible in that users can choose from a suite of available projections to define coordinate systems that best serve their analytical and presentation needs.

The selection and organization of spatial features within each data layer are dependent upon the operational use of the information. A database that must support a wide variety of user views and queries is most appropriately served by data layers that store features in their most basic, primitive form. Such an organization provides flexibility for users as they may combine many layers to achieve their specialized objectives. On the other hand, data that tends to be used together is often included in the same data layer. For example, transportation-based routes that include interstates and primary and county roads require each of those roadway features to be contained in a single geographic data layer. GIS task force members carefully considered the structure of each data layer to support a flexible, easy-to-use database that minimized the redundant storage of information.

The design organizes geographic data into four types, or components, each of which includes spatial and descriptive tabular data. The four conceptual data components are listed below and illustrated in **Figure C.3-1.**

- Reference Component
- Transportation Component
- Administrative Component
- Environmental Component

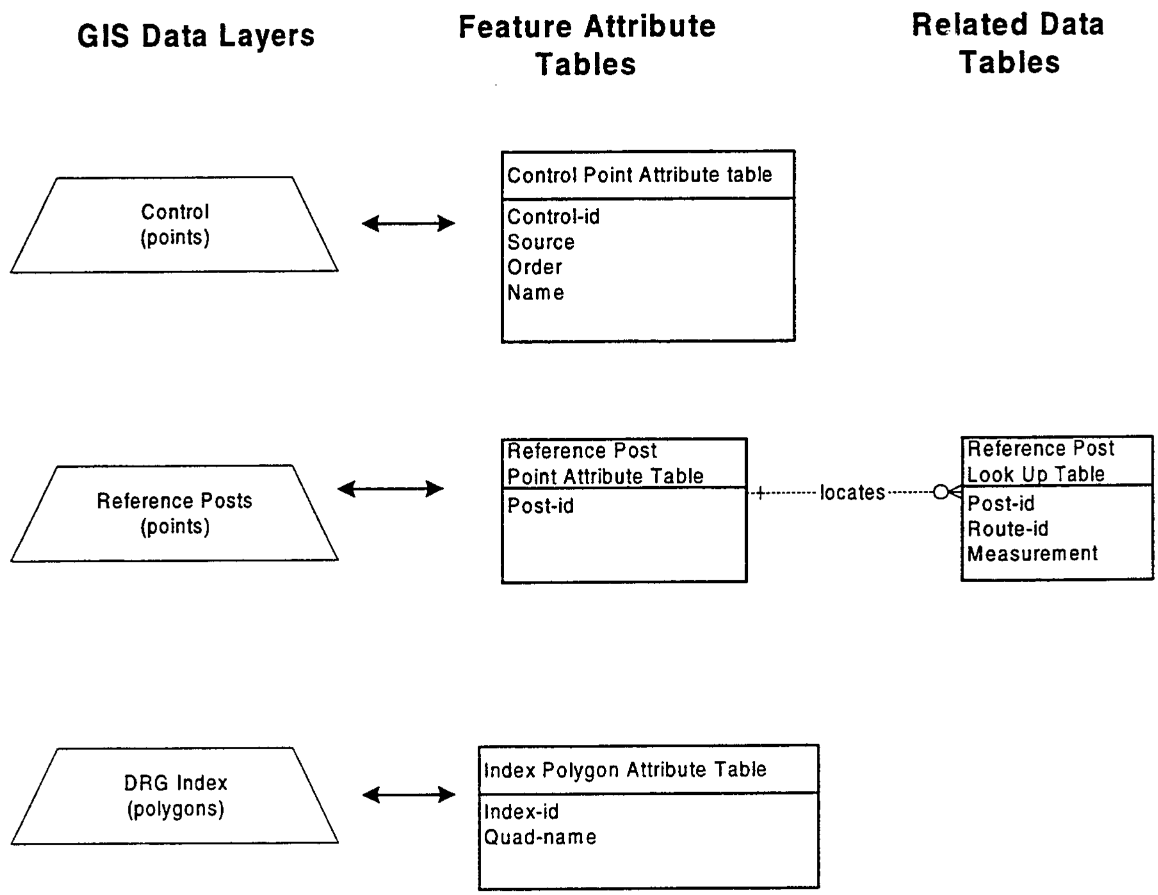
Figure C.3-1
WYDOT Shared Geographic Database



C.3.2 Reference Data Component

Figure C.3-2 illustrates the data layers and related attribute tables that comprise the Reference component of the shared GIS database. These data layers serve to reference and/or identify other database features. Data layers included in this component are the Control layer, Mileposts layer, and an inventory for Digital Raster Graphics (DRGs).

Figure C.3-2
Reference Component



C.3.2.1 Control Layer

Control features are an important part of the shared GIS database. They provide point locations that are used to reference all other spatial data features to a common coordinate system, thereby allowing data layers to be overlaid for graphical and analytical purposes. Public Land Survey System (PLSS) section corners and High Accuracy Reference Network (HARN) monuments are the source for control layer features. They are stored in a single data layer as points in accordance with standard GIS data models.

WYDOT intends to utilize existing data sources to support Phase One activities. Because the existing data will have its own inherent coordinate system and accuracy specification, there may not be an immediate need to develop and maintain a control layer within the shared geographic database. However, as additional data layers are identified for inclusion in the GIS, the well-structured control layer facilitates the integration of that data. Data from various sources is integrated within the shared GIS database by locating control points in the source data and performing a mathematical transformation to convert the coordinate system of the source data into the coordinate system of the control features. The control layer provides the consistent reference for various data sources that may be included in the GIS to support the future needs of WYDOT staff.

Attribute data for the control features should be managed in the feature attribute table associated with the control layer. Attributes of control source (PLSS, HARN), control order (first, second, third order of accuracy), control name (feature name to identify the control point), and sponsor (BLM, WYDOT, private party, etc.) will enable WYDOT users to select, display, and query the control information. Additional attributes describing control features may be added by defining additional columns on the feature attribute table. No related tables are necessary to support the control data layer.

C.3.2.2 Reference Post Layer

The Wyoming Reference Marker System, maintained by the Planning section, contains a geographic reference to the milepost measurement scheme utilized by the majority of WYDOT staff. At a minimum, reference post locations are defined at junctions of intersecting State routes, district boundaries, county lines, State lines, and unincorporated place-names. Those locations will be captured in the GIS as point locations and will serve to calibrate the route system developed in support of Phase One implementation activities.

Storing the reference post locations in a separate data layer provides flexibility in the definition and maintenance of the route system. If, for example, a route is realigned or expanded, WYDOT may simply recalibrate the selected route to reflect the updated measurement scheme. Likewise, if WYDOT acquires more accurate data than that used in the initial implementation, the Reference Post data layer may be used in conjunction with GIS tools to rebuild the routes in an automated batch process. The Reference Post layer builds scalability into the GIS database, which allows it to respond efficiently to changing route system specifications.

Attribute information stored with milepost point locations include the route and measurement that corresponds to the milepost. Reference post attributes are stored in a related database table to accommodate the situation where a single reference post location describes the measurement along two or more route systems. For example, portions of routes that overlap may have two measurement schemes that describe the same location. **Figure C.3-2** illustrates the one-to-one or one-to-many relationship that exists between reference post locations and milepost referencing schemes.

C.3.2.3 Digital Raster Graphic Index Layer

Digital raster graphics are scanned images of the standard 1:100,000 map series produced by the United States Geological Survey. The images are georeferenced and provide a pictorial representation of natural (topography, rivers, etc.) and man-made features (county, State, city boundaries, PLSS boundaries, etc.). The digital raster graphics are available for the State of Wyoming and are included in the WYDOT geographic database to provide supplemental background information requirements. The index layer contains polygons that define the spatial extent of each image. The polygon attribute table stores the name of each quadrangle. Through this structure, WYDOT staff may overlay the index layer with various other data layers to determine the digital raster graphics that correspond to their specific areas of interest. Additionally, the full directory path may be defined as the quadrangle name to allow the direct display of digital imagery from a point and click operation supported by the GIS.

C.3.3 Transportation Data Component

Figure C.3-3 illustrates the data layers and related attribute tables that comprise the transportation component of the shared geographic database. Data layers included in this component are Roads, Roads.LRS routes, railroads, and airports. Conceptually, the Federal Aid system routes may be considered as separate data layers. Physically, in accordance with the dynamic segmentation data model, this route system relies on the spatial definition of features in the Roads data layer. As such, the route system is an extended feature of the Roads data layer. The name Roads.LRS was chosen to reiterate the relationship between the route features and underlying road segments in the Roads data layer.

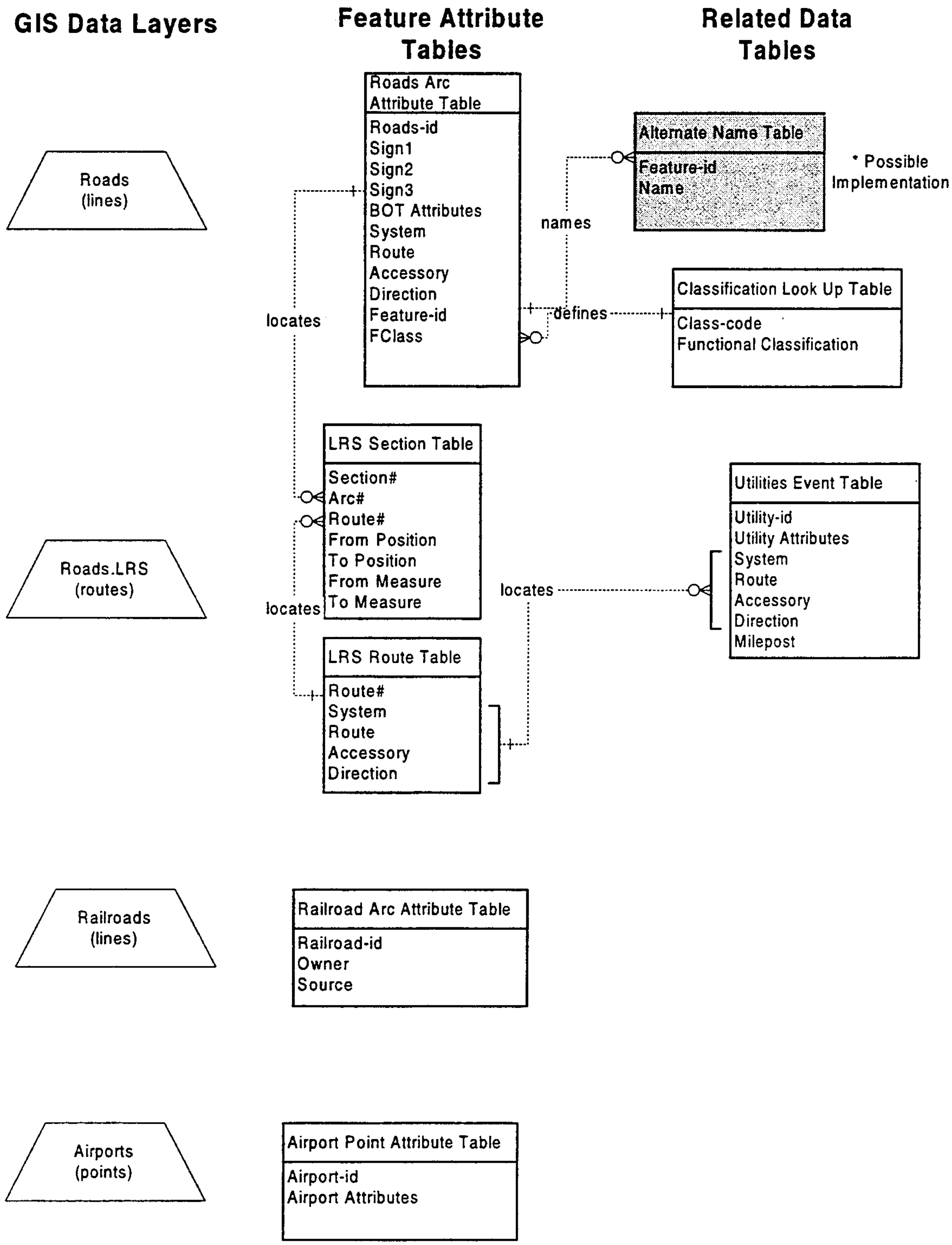
C.3.3.1 Roads Data Layer

The Roads data layer contains line segments that correspond to the "on-system" roadway inventory as defined by WYDOT staff. Cartesian coordinates defining the start, end, and shape of each line are stored to provide the spatial definition of each feature. The majority of features are derived from the Bureau of Transportation Statistics (BTS) National Highway Planning Network (NHPN), Version 2.1. TIGER files, a U.S. Census Bureau data product, Wyoming State Office of GIS and internal WYDOT data sources are used to supplement the NHPN data to ensure a complete representation of the WYDOT "on-system" roadway inventory. In accordance with the findings of the requirement analyses, data is captured at a scale of 1:100,000. Because the Roads data layer is constructed from a variety of public sources, there is no limitation for WYDOT in regards to distributing the data to other State agencies or interested third parties.

The Bureau of Transportation's NHPN 2.1 was chosen because it contains approximately 95 percent of the "on-system" roadway inventory, its features are well attributed (including links to related BTS data files), and it comes with a complete set of metadata that meets Federal Geographic Data Committee (FGDC) standards. The FGDC standards are the same as those adopted by the State of Wyoming and, as part of its data development effort, ESRI will extend the metadata to include information that pertains to any additional attributes added to the Roads data layer and the Roads.LRS route features.

As described in **Section C.2.1** above, line segments in the Roads data layer are aggregated to construct routes. To support the efficient composition of route features, attributes of the Federal Aid system, route, accessory, and direction will be added to each roads feature. Through this specification, routes may be created by the GIS in a bulk process that constructs routes from similarly attributed roads features. Should the situation arise where a single line segment is part of two different Federal- Aid routes, an alternate name table may be implemented in the design to resolve the one-to-many relationship between line segments and route features.

Figure C.3-3
Transportation Component



Features in the Roads data layer also contain attribute items that store "public" names for the roads (i.e., I-25, US287, Wyo. 59, etc.). The identification of "public" names is implemented in the design as three distinct columns on the Roads Attribute Table, Sign1, Sign2 and Sign3, respectively. The redundant storage of road names supports the relationship that a single line segment may have multiple names. It is not a truly normalized database scheme, but it provides for an intuitive, easy-to-use structure that reduces complexity for GIS users.

It is important to recognize that the Federal Aid system, route nomenclature, while widely used internally by WYDOT staff, has been superceded by the National Highway System (NHS) functional classification of roads. The NHS functional classification is implemented in the design by attributing each line segment in the Roads data layer with a code that defines the functional classification. The code is defined in an associated lookup table that stores the code and a textual description of the classification.

Figure C.3-3 above illustrates the attribute items and database relationships that define features in the Roads data layer.

C.3.3.2 Roads.LRS Route Layer

The Roads.LRS route layer represents the seamless aggregation of line segments in the Roads data layer into routes commonly referred to as the Federal Aid system routes. The design of the Roads.LRS data layer conforms to the GIS dynamic segmentation data model. Federal Aid system routes are stored as individual records in the Roads.LRS route table, while measures (roadway miles) for the routes are maintained in the Roads.LRS section table.

In developing the Roads.LRS data layer, there is a subtle consideration to make note of—namely, that the Roads features are stored in three-dimensional (geographic) coordinates, while the milepost measures imply a two-dimensional, rectangular coordinate system. To resolve this discrepancy, the Roads data layer will be projected, using the Albers Equal Area projection, to a Cartesian coordinate system before the routes are calibrated with the reference post locations. The Albers Equal Area projection is well suited for the State-wide extent of the database, and it appropriately addresses the concern.

The Federal Aid system, route, and reference post scheme offers the database structure to integrate seemingly disparate data sets collected and maintained throughout the department. Pavement management, accident information, sign/signal inventories, State transportation improvement project information, utilities data and a myriad of other data sets may be linked with the GIS to support display, query, update, and analysis operations. **Figure C.3-3** illustrates the structure of the Utilities database. Stand-alone database tables that describe events along the route system are linked with map-based features by simply maintaining a route identification and a location reference within the tables.

ESRI–Denver staff met with members of the GIS Technical Advisory Group on June 1, 1999, to define standards for identifying Federal Aid system routes. Discussions focused on defining a primary key that could be implemented within the GIS and could foster consistency throughout the department. The group reached a consensus that the primary key for Federal Aid system routes would be a composite of four database items; System, Route, Accessory, and Direction. The Direction item will not be used in Phase One. It is incorporated to support expansion in Phase Two as bidirectional routes are incorporated into the database design. **Table C.3-1** describes the domain for each of the items.

C.3.3.3 Railroads Data Layer

The Railroads data layer includes linear features that represent the railroad network of Wyoming. Information compiled from user interviews highlighted the importance of railroad features in terms of highway safety, project reconnaissance, and emergency routing. Attribute information that describes railroad features is maintained in the arc attribute table and minimally includes the owner of the rail line. Logical linkages between Utilities/Railroad section databases and the GIS are provided through reference post locations that describe where the railroad crosses "on-system" roads. Federal Crossing Numbers, as well as latitude/longitude coordinates, define railroad locations to support other departmentwide interests.

Table C.3-1
Route Identifier

Attribute Item	Item Definition	Valid	Values
System	Character (4)	I—Interstate	SRI—Service Road Interstate
		P—Primary	SRP—Service Road Primary
		S—Secondary	SRS—Service Road Secondary
		U—Urban	SRU—Service Road Urban
		SH—State Highway	SRSH—Service Road State Highway
Route	Number (4)	1–9999	
Accessory	Character (4)	C—Connector	Y—Y Construct
		B—Bypass	1–999—Route Numbers
		ML—Main Line	
Direction	Character (1)	N—North	S—South
		E—East	W—West
		B—Both	

C.3.3.4 Airports Data Layer

The Airports data layer includes point features that represent locations of airfields within Wyoming. The data was compiled from publicly available sources and contains attributes describing the airport features. **Figure C.3-3** illustrates the attributes maintained in the Airports data layer.

C.3.4 Administrative Component

Figure C.3-4 illustrates the data layers and associated attribute tables that comprise the administrative component of the shared GIS database. Data layers included in this component are

County boundaries, WYDOT Districts, State Legislative Districts, PLSS, Indian Lands (Shoshone–Arapahoe Lands), Metropolitan Statistical Areas and Urban Areas, Cities, Geographic Places, Commission Districts, Patrol Zones, School Districts and Maintenance Districts. The data layers are self-explanatory and each is currently available at a scale of 1:100,000 from the State Office of GIS (OGIS). Most of the data layers contain polygon features that define the extent of the various boundaries. However, point representations for city locations and geographic places are included to provide for scale-dependent displays. For example, at a State-wide scale, cities may be represented as points. As the user zooms to a selected area, the point location is replaced by a polygonal representation of the city. Feature attribute tables associated with each of the data layers store descriptive information that enables WYDOT staff to query, display and analyze the data.

C.3.5 Environmental Component

Figure C.3-5 illustrates the data layers and associated attribute tables that comprise the environmental component of the shared geographic database. Environmental data is those features that pertain to natural phenomena. Data layers included in this component are Hydrography, LUST Monitor Wells, and State Engineer Wells. The Hydrography layer relies on linear features to represent rivers and streams and polygonal features to define water bodies (lakes, reservoirs, etc.).

Figure C.3-4
Administrative Component

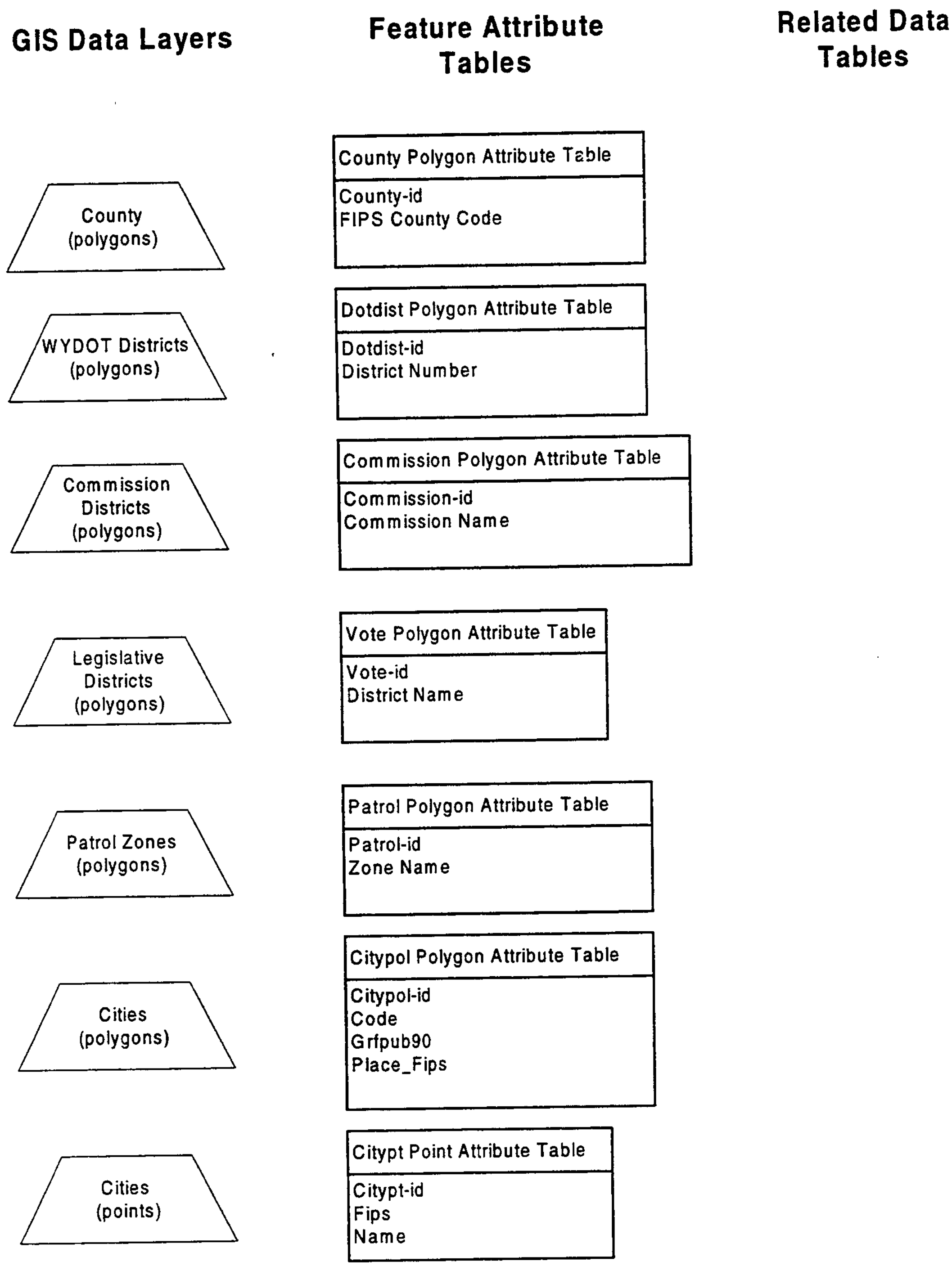


Figure C.3-4
Administrative Component
(Continued)

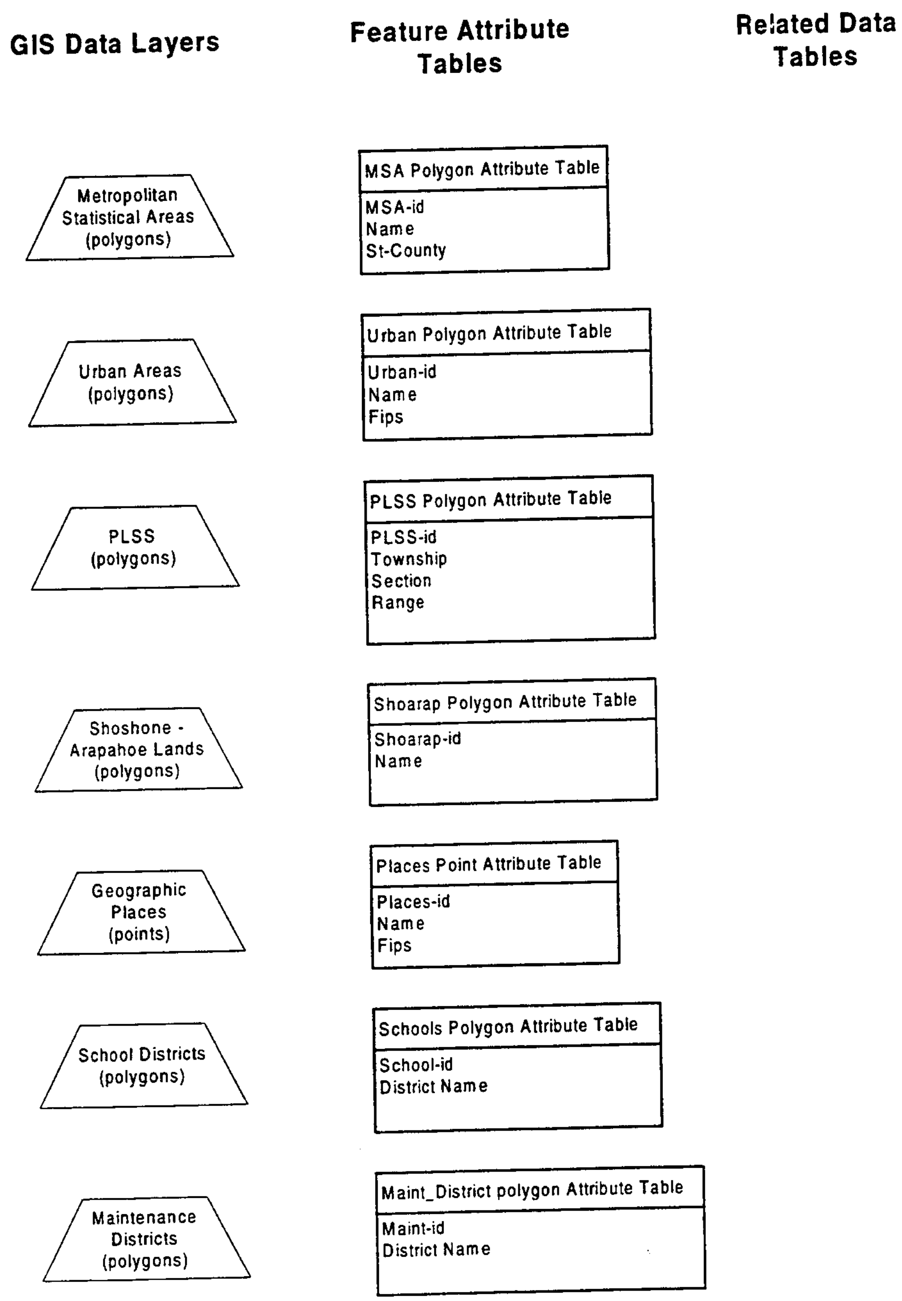


Figure C.3-4
Administrative Component
(Continued)

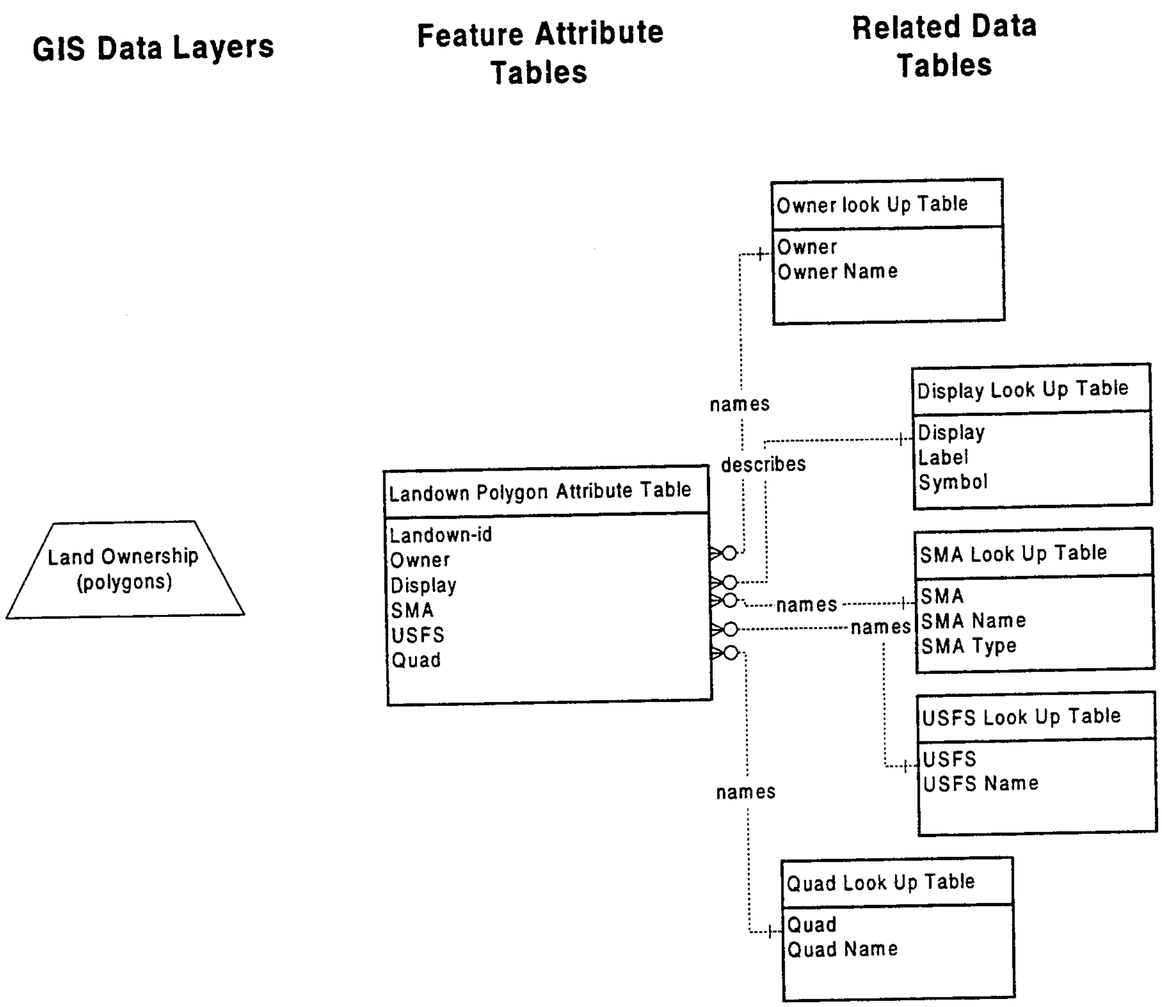
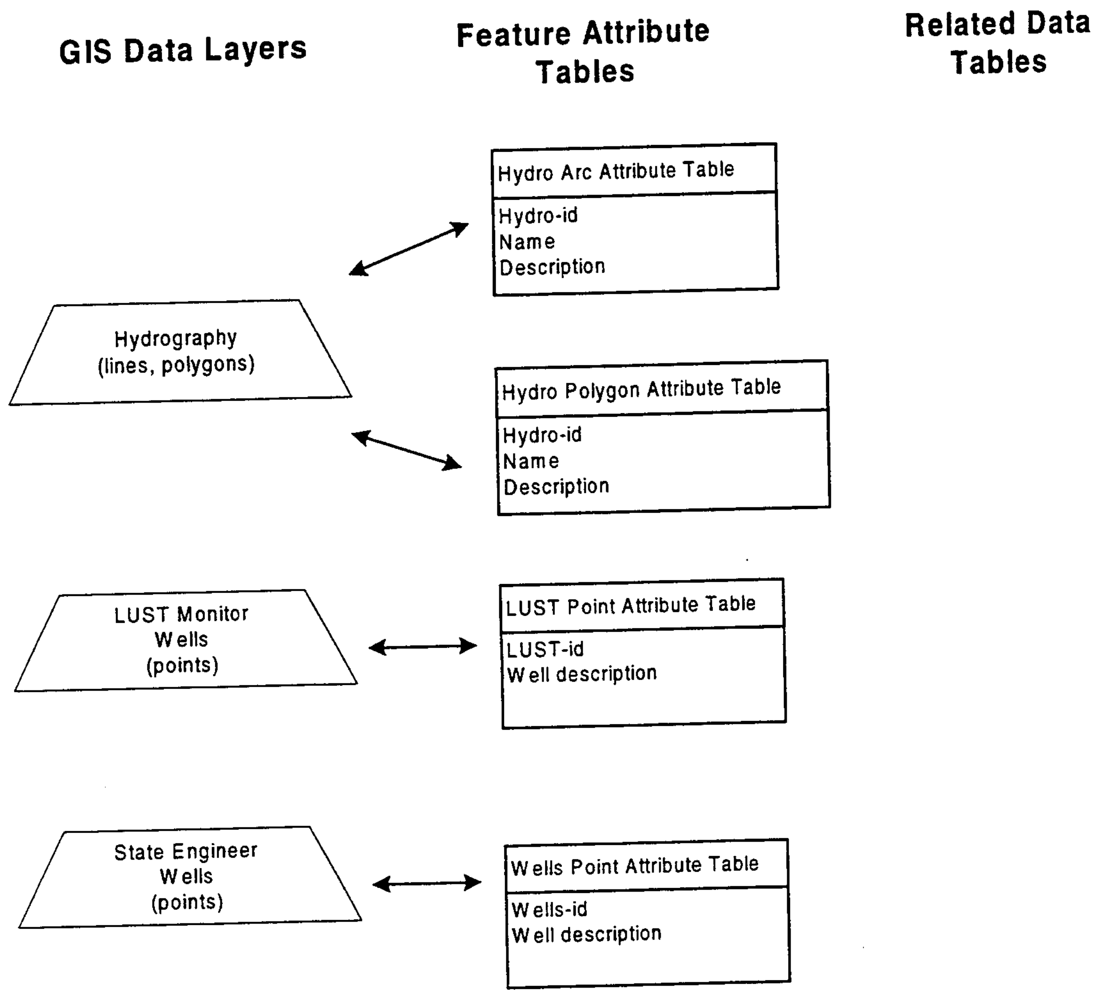


Figure C.3-5
Environmental Data Component



C.4 Utilities Database Design

C.4.1 Introduction

Utility records are stored in an Oracle relational database management system table. The table contains attributes that describe the utility features and support the daily activities of the Utility/Railroad section WYDOT. Attributes of system, route, and reference post provide the spatial context for Utility database records, enabling staff to locate features on the roadway network.

As GIS is developed in Phase One to support the Utilities/Railroad section, it is necessary to link existing database records with map-based roadway features. The dynamic segmentation data model of GIS provides the database relationship that supports this requirement. As described in **Section C.2.1** above, the dynamic segmentation data model consists of routes and events. Routes are the map-based aggregation of roadway segments. Each route system has a defined measurement scheme that uniquely defines positions along the route. Events are the database tables that define attributes occurring along a route. There are point events that store attributes for discrete locations on routes and linear events that rely on from and to measurements to describe portions of routes. Together, routes and events provide the framework that ties existing utility records to GIS data layers.

The dynamic segmentation data model is flexibly structured to accommodate many applications. In designing a database structure that supports the integration of GIS within the Utility/Railroad section, it is important to evaluate current practices and procedures in light of the opportunities that GIS technology presents. As outlined in the Requirements Analysis document, the following issues with respect to the Utilities database were identified:

- **Location Reference.** There are two types of features represented in the Utilities database: (1) features that cross the roadway network (crossings) and (2) features that run along the road network (encroachments). In terms of the GIS, crossing features are considered point events, each crossing occurring at a point on a specified route system, while encroachments are considered linear events, with the from and to locations of the feature constituting a portion of a route system. Currently, the Utility/Railroad section maintains encroachments by storing individual records defining the reference posts that the feature passes.

- **Normalized Data Structures.** Normalization is a technique used to structure data elements in a nonredundant form. A normalized database is beneficial in that it eliminates repeating groups of information, reduces data inconsistencies and promotes efficient maintenance and update procedures. The Utilities database, as currently structured, offers opportunities for normalization.

- **Symbology.** Map displays rely on symbols and labels to communicate information. Symbols have not been necessary to support the traditional database operations, but the introduction of GIS offers an opportunity to define shapes and color schemes that supplement the presentation of Utility information.

- **Feature Representation.** The Utility database does not make reference to the direction of divided roads (i.e., I-80 West, I-80 East). Thus these features will be represented as single lines THAT represent the center line between the two lanes (I-80). Viewing the database record or varying the symbology of the feature may accommodate utility information that defines the side (north, south, east, or west) at which the feature is placed.

The GIS task force, working closely with staff from the Utility/Railroad section, have an opportunity to address all or none of these issues as GIS is developed into support Phase One implementation activities. Accordingly, three alternative approaches have been identified.

C.4.2 Option One: Point Events—Utilize Existing Database Structures

The first option, and by far the least intrusive, is simply to use the Utility database in its current form. Utility features are modeled as point events, where symbols and labels are used to illustrate the existence of features at discrete locations on defined route systems. The benefit of this approach is that it does not require a modification of current procedures. Traditional database queries are complemented by graphical, map-based operations to provide a visual interface to the data records. The drawback to this approach is that the representation does not truly model the inherent linear nature of the encroachment features. Spatial relationships of length and connectivity are undefined when using point events and as such may limit certain analytical capabilities. Additionally, Utility features will be drawn on the map as a series of unconnected points, limiting the cartographic quality of map products. **Figure C.4-1** illustrates the database relationship necessary to support Option One.

C.4.3 Option Two: Linear Events—Modify Existing Database Structures

The second approach involves a development effort aimed at converting the point representation of encroachment features to a linear representation. It is accomplished by redefining the Utility-id field, or adding a new field, that uniquely identifies each encroachment feature. For example, a utility feature that is represented by three rows in the database to represent the reference post that it passes could be given a unique value indicating that it is a single feature. From and to measurement locations could then be easily defined by selecting the unique feature identifier and then querying for the minimum measurement and the maximum measurement. This operation is supported by the "view creation" capabilities of Oracle.

The benefit of this approach is that it fully exposes the capabilities, both analytical and display, of GIS. The drawback is that a development effort is required to identify records in the database that could be aggregated into single features. Additionally, current procedures aimed at capturing and maintaining utility information would need to be slightly modified. A new field may be added to the Utility Inventory Input Form that allows staff to uniquely identify the multiple records that are used to represent encroachment features. Such a modification alleviates the need to describe from and to locations of encroachments in the Remarks field and lessens the potential for inconsistencies in the database. **Figure C.4-2** illustrates the database structure corresponding to Option Two (note the addition of the Feature-id field at the bottom of the Utility database).

Figure C.4-1
Option One: Point Events

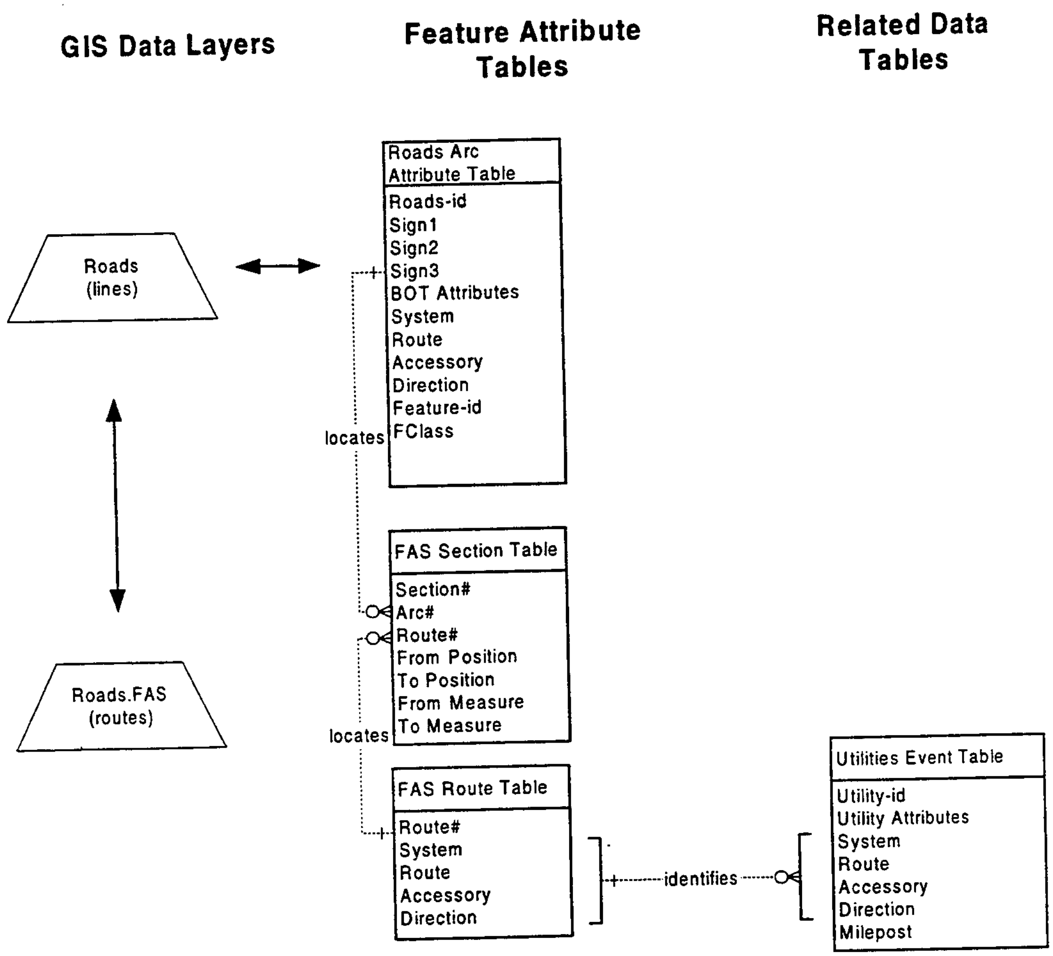
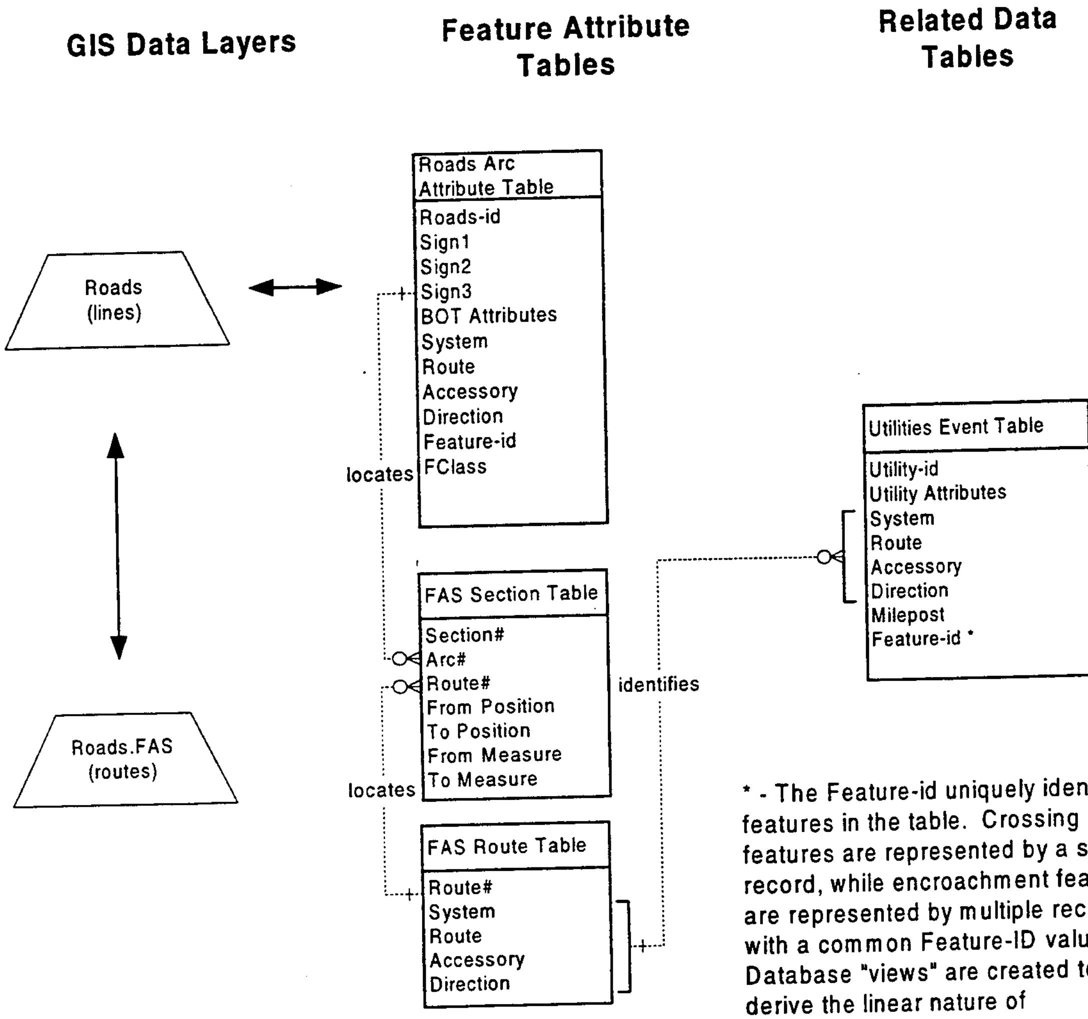


Figure C.4-2
Option Two



* - The Feature-id uniquely identifies features in the table. Crossing features are represented by a single record, while encroachment features are represented by multiple records with a common Feature-ID value. Database "views" are created to derive the linear nature of encroachment features.

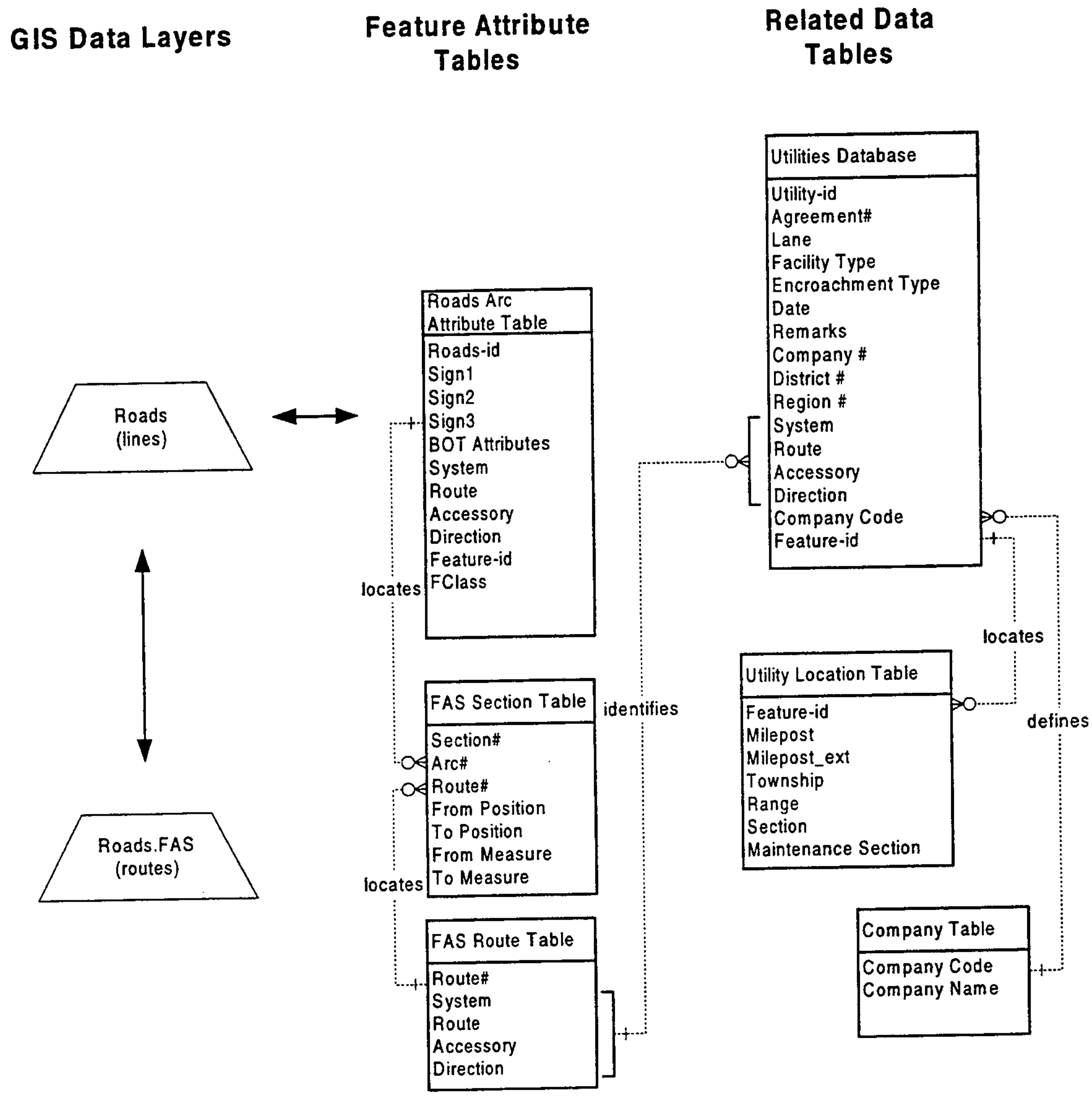
C.4.4 Option Three: Linear Events and Normalized Database Structures

The third option extends the effort in Option Two, above, to include the normalization of the Utility database. Existing items stored in the utility database are evaluated in terms of functional dependencies. Attributes not dependent on the primary key are broken into separate database tables that can be linked together based on the standard Oracle functions. The benefit of this approach is that it takes advantage of GIS while eliminating the redundant storage of information, reducing data inconsistencies, and providing efficient maintenance and update procedures. The drawback is that the approach significantly modifies the way business is currently conducted within the Utility/Railroad section of WYDOT. **Figure C.4-3,** below, illustrates the proposed normalized structure of the Utility database. Note in the diagram how the Utilities database contains fields that are functionally dependent upon the specific features, while the Location table contains fields functionally dependent on the spatial position of the feature. The Feature-id and Milepost form a composite key that uniquely identifies each of the records in the Location table. Also, note how the attribute of company name has been coded to reduce the repetition of company names in the Utility database. Each unique company name is coded and the codes are defined in the Company table.

C.4.5 Recommendations

Option Three represents a long-term strategy for the Utility/Railroad section that is not immediately necessary to support Phase One implementation efforts. The GIS task force is encouraged to consider Option One. The approach meets the strategic objectives for GIS implementation as defined in the Strategy Document and minimizes the impact upon current procedures within the Utility/Railroad section. In choosing Option One, GIS data development efforts focus on the establishment of the system, route, and reference post linear referencing scheme that promotes the integration of various other sections and programs within WYDOT. Once the linear referencing scheme is developed, the GIS task force may evaluate opportunities for supporting Option Two, where linear events for encroachment features are developed. Choosing Option One represents a low-risk solution that can be expanded should time, interests and budgets allow.

Figure C.4-3
Option Three



Appendix D

Hardware, Software, and Network Design

D.1 Hardware, Software, and Network Design

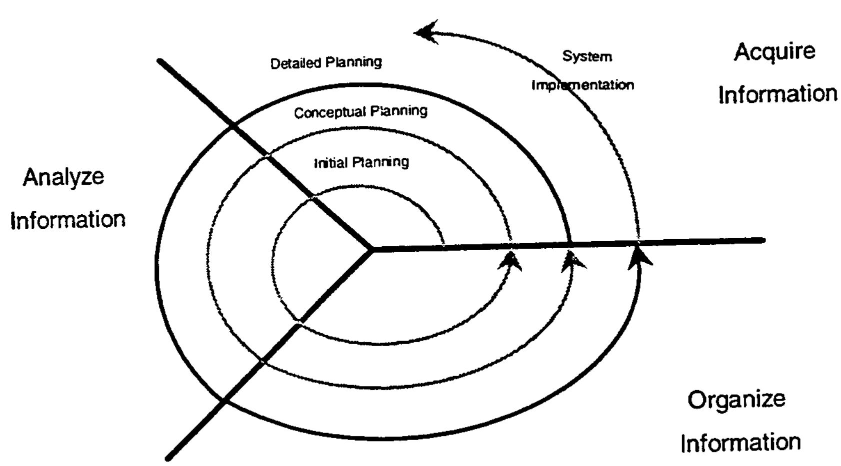
D.1.1 Introduction

ESRI geographic information systems (GISs) continue to support more hardware platforms than any other GIS in the industry. ESRI® software programs use the native operating system of the hardware platform such as Windows or vendor-specific implementation of UNIX. Running ESRI software programs on an unmodified platform gives the Wyoming Department of Transportation (WYDOT) the widest range of choices and tremendous flexibility in implementing their GIS. It also allows the GIS to run in conjunction with numerous other applications that are supported by the native operating system.

This report describes the essential software, hardware, and network considerations necessary to support the implementation of GIS within WYDOT. It begins with a review of user needs, continues with a recommended systems configuration and concludes with sizing specifications for identified hardware components. The information provided herein enables WYDOT to make informed decisions about their GIS implementation and deploy a systems solution that leverages current technology and serves WYDOT's long-term system objectives.

The design methodology employed by the Wyoming Department of Transportation involved discrete planning activities that defined functional requirements for the GIS. Those functional requirements provide the foundation for considering the hardware, software, and network components that support the operational GIS. Tying the systems design to well-defined requirements ensures a system solution that supports the immediate needs of WYDOT GIS users. It gives the GIS task force control of and confidence in their investment because each system component is justified by the anticipated use of GIS. **Figure D.1-1** illustrates the design methodology used by WYDOT. The detailed planning cycle, identified in the figure by the bold black arrow, accommodates systems considerations and reinforces the notion that technology is dependent on user needs.

Figure D.1-1
Design Methodology



D.1.2 Scope of the Report

This report focuses on the systems components necessary to support Phase One implementation activities, where hardware, software and network communications are established to support departmentwide access to the Utilities database. However, due to the increased interest in GIS within the Planning and Programming, Highway Safety, and Bridge sections, this report has been expanded to support GIS users in those areas. The systems design accommodates those users projected to be involved with GIS at the completion of Phase One in November 1999.

D.1.3 Hardware Policies and Standards

WYDOT has identified Dell Computer Corporation as its vendor of choice. WYDOT has standardized on Microsoft's operating system including Windows NT, Windows 98, and Windows 95 on the desktop. WYDOT has also standardized database activities around an Oracle relational database management system solution. WYDOT is currently upgrading their current local area network (LAN) to provide a 100 megabit (MB) fiber backbone with switched 10 Mb Ethernet access to the desktop. WYDOT staff have good experience supporting these environments. As GIS is implemented within WYDOT, it will be considered in light of the existing systems environment to limit the burden of support placed on Information Technology (IT) staff.

D.1.4 Document Organization

This document is divided into the following three sections:

- **Requirements Review.** This section categorizes WYDOT GIS users based on functional requirements. User requirements provide the foundation that supports systems specifications.
- **Systems Configuration.** This section describes the tiered architecture that provides centralized access to spatial data and distributed application processing (ArcInfo™, ArcView® GIS) at the desktop.
- **Systems Sizing.** This section describes recommended sizing for the identified hardware platforms that comprise the Wyoming Department of Transportation GIS.

D.2 Requirements Review

D.2.1 Introduction

Geographic information system technologies provide the means to capture, store, maintain, query, analyze and display all types of geographically related information. The successful systems concept provides GIS users with the products needed to support clearly defined functional requirements. During spring 1999, ESRI conducted in-depth interviews with WYDOT staff to determine the full range of functionality required of the GIS.

From a systems design standpoint those needs may be summarized into categories based on the functions performed. This section of the report defines those categories and describes the software solutions that support the required capabilities. The number of concurrent GIS users, as well as their individual processing needs, support the system design by providing an indication of the number of necessary software licenses and the estimated load placed on system components.

D.2.2 GIS User Types

Wyoming Department of Transportation GIS users may be categorized into four groups as follows:

- **Data Maintainers.** These are the power users of GIS. They rely on GIS tools and techniques to support the creation, maintenance, and distribution of the shared spatial database. Users in this category are predominantly supported by ESRI's flagship software, ArcInfo. ArcInfo provides a full suite of resources to convert and validate spatial data; access attribute data existing in separate relational database management systems (i.e., Oracle); perform spatial analysis that supports planning, forecasting, and management responsibilities; and produce high-quality cartographic output.

- **Data Viewers.** These users rely on GIS to support ad hoc queries of spatial data, simple map production, and general-purpose spatial analysis. Data viewers are supported by ESRI's desktop solution, ArcView GIS, which has an intuitive, easy-to-use graphical user interface that enables users to become immediately productive with GIS.

- **Application Developers.** These users rely on proprietary languages (i.e., ARC Macro Language [AML™], Avenue™, etc.) and nonproprietary languages (i.e., Visual Basic, Java, etc.) to customize user interfaces and automate commonly recurring tasks. Application developers utilize ESRI's ArcInfo, ArcView GIS, and MapObjects® software to embed GIS functionality into new and/or existing applications.

- **Web-based GIS Users.** These users do not require GIS to support their immediate activities. Rather, the Web-based user will view, display, and analyze spatial data through simplified user interfaces and applications tailored for Web browsers. Additionally, WYDOT may choose to utilize ESRI's ArcExplorer™ software to broaden the GIS user base. ArcExplorer is a simplified data viewing tool and is available free of charge.

Table D.2-1 summarizes the GIS user types and software requirements for WYDOT. IMS refers to the ESRI Internet Map Server software, and its requirements are based on the anticipated number of Web-based transactions per hour.

Table D.2-1
GIS User Needs

	ArcInfo		ArcView GIS		MapObjects		IMS
	Total	Peak	Total	Peak	Total	Peak	Hits/hr.
Data Maintainers							
Programming	2	1					5
Data Viewers							
Utilities/Railroad			1	1			100
Programming			10	4			10
Highway Safety			4	2			10
Bridge			4	2			10
Application Developers							
Information Technology	2	1	2	2	2	1	50
Web-based GIS Users							
Planning							10
Programming							10
Highway Safety							10
Bridge							10
Traffic							10
Materials Lab							10
Project Development							10
Right-of-Way							10
Construction/Maintenance							10
Environmental Services							10
Telecommunication							10
Photogrammetry							10
Highway Patrol							10
Geology							10
District Offices (5)							75
Resident Offices (17)							75
TOTALS	4	2	21	11	2	1	475
GIS License Requirements	2		21		1 *		1 **

* Application developers within WYDOT require a single MapObjects Developer's license to support the building and testing of MapObjects applications.

** WYDOT is responsible for a single MapObjects Developer's license that supports the Web-based delivery of applications built with MapObjects.

Table D.2-1 provides valuable information for designing the hardware, software, and network communications necessary to support the initial implementation of GIS within WYDOT. There are four estimated ArcInfo users and twenty-one estimated ArcView GIS users. Two application programmers will be supporting Intranet/Internet Map Server solutions. The estimated peak loads (i.e., concurrent uses) are roughly 50 percent of the total number of users.

The majority of GIS users within WYDOT are expected to interface with the GIS through a series of map products that are made available over the Web. These Web-based users will connect through standard browsers (i.e., Internet Explorer and Netscape) to a map server that delivers specialized products. It is estimated that the map server will handle less than 500 transactions per hour.

D.2.3 Peak Loads

The WYDOT GIS system configuration relies on GIS clients (ArcInfo, ArcView GIS, and browser-based applications) accessing spatial and attribute data existing on centralized data servers located in the computer room at WYDOT headquarters. The peak loads provide an estimate of the "hits" on the data server and support sizing considerations that are fully described in **Section 4.0** of the report.

D.2.4 License Requirements

ESRI's GIS software programs are delivered to WYDOT users through a licensing mechanism that dictates the number of concurrent users of the software. For example, a user in the Planning and Programming section that employs ArcInfo to update routes in the spatial database would require a single license of ArcInfo to perform the task. Another user performing spatial analysis or application development with ArcInfo would require a second license. In the initial implementation, it is anticipated that WYDOT will require two licenses of ArcInfo to support identified activities.

ArcView GIS is ESRI's desktop software program that delivers GIS to individual users within WYDOT. The requirements analysis combined with subsequent interest in GIS indicate that a total of twenty-one users may be involved with GIS by the end of Phase One. In order for WYDOT to support ArcView GIS to support twenty-one individual users, WYDOT is required to purchase twenty-one copies of the software. To limit the number of ArcView GIS purchases, WYDOT may consider dedicating specific machines in various programs and sections as "GIS machines." Users would then share the machines and in essence share the access to ArcView GIS. For example, the Bridge section may load an instance of ArcView GIS on a single machine. Individual staff would share the machine rather than purchasing "personal" copies of the software.

ESRI's MapObjects software enables developers to build custom applications in the nonproprietary language of Visual Basic. Specific GIS functionality is embedded into Visual

Basic source code to support a variety of user needs. The source code is compiled into executables that are distributed throughout an organization. The companion product, MapObjects Internet Map Server (IMS), provides additional resources that enable MapObjects applications to be invoked through standard Web browsers. Phase One GIS activities within the department require a single license to support the development of MapObjects applications and a license to support the deployment of those applications on the WYDOT Intranet.

D.2.5 Software Versioning

GIS implementation within WYDOT involves many software components that work together to deliver GIS functionality throughout the department. Software vendors typically provide periodic updates, also known as versions, to their customers. It is critically important for WYDOT staff to ensure that individual software components are certified to work with one another. The ESRI web site, www.esri.com, contains detailed information regarding the certification of various products and platforms. Information from the web site has been summarized in **Table D.2-2**, below. The check marks illustrate the compatibility of Phase One software components.

Table D.2-2
GIS Software Compatibility

	ArcInfo 7.2.1	ArcView GIS 3.1	MapObjects 2	MapObjects IMS
Microsoft OS				
Windows NT Server 4 (SP4)	√	√	√	√
Windows 95/98		√	√	√
Database Support				
Oracle 8.0.3.0.5	√	√	√	√
Web Server				
Netscape Enterprise Server 3.5.1	N/A	N/A	√	√
Web Browser				
Netscape 4.0.5	N/A	N/A	√	√

In the future, WYDOT staff may be required to update some or all of the software components. ESRI staff, as well as the ESRI Web site, remain available to assist WYDOT staff as they explore updates to their system components.

D.3 Recommended Systems Configuration

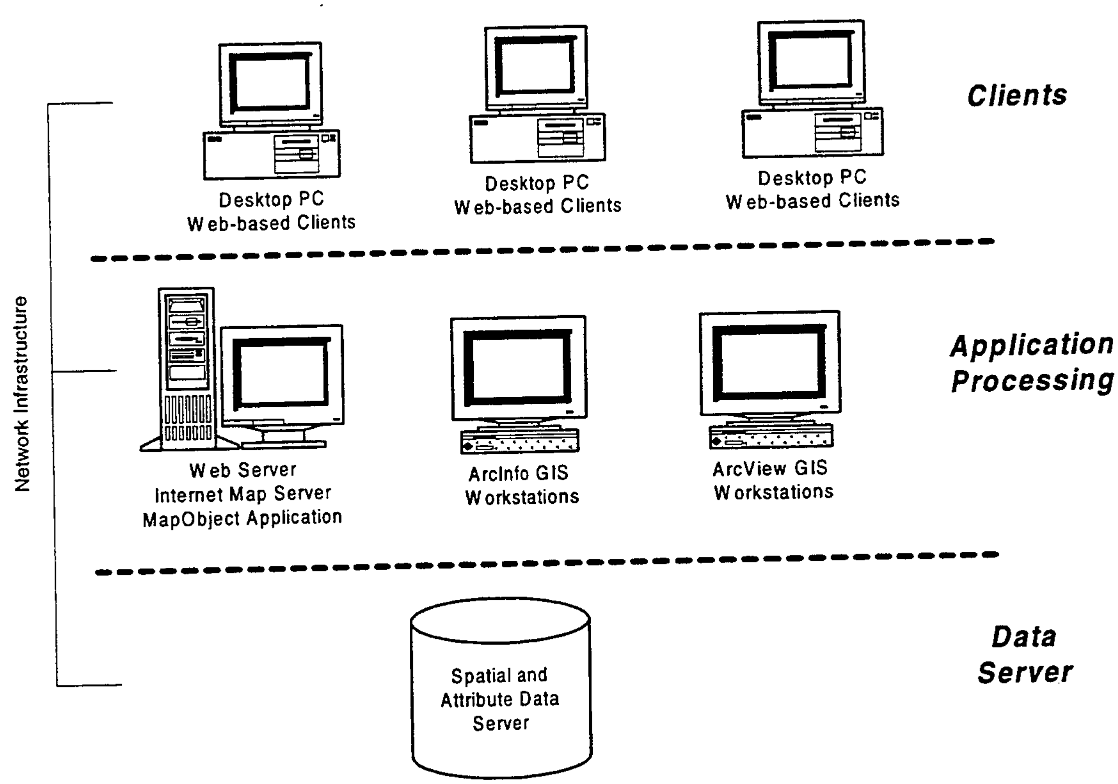
D.3.1 Introduction

The implementation of GIS within the WYDOT supports a variety of users requiring access to shared spatial and attribute data. System components are constructed into a tiered, client/server architecture. A client/server system is a type of network that connects a user's computer (client) to one or more host computers (servers). A client is often a personal computer (PC); it requests services from the server, shares processing tasks with the server and displays the results of processing tasks. Servers can be computers of all sizes; they store both application programs and spatial and attribute data, and are equipped with network operating software to manage the integrated activities of users throughout the network.

D.3.2 System Overview

System design alternatives were discussed during meetings with Information Technology staff and reviews with WYDOT GIS task force members. The general design strategy identifies a tiered, client/server architecture that addresses initial deployment activities and provides a scalable solution that promotes migration toward a departmentwide implementation. **Figure D.3-1** illustrates a functional view of the systems solution.

Figure D.3-1
Functional View of the GIS Components



The design includes three tiers, as follows:

- **Clients.** The majority of WYDOT GIS users will interact with the first tier in the design. Web browsers and ESRI's ArcExplorer software provide generic tools that support users requiring simple display and query functionality from standard map products and data stores.

- **Application Processing.** The second tier accommodates users requiring specialized processing, analysis, and output of geographically related information. Applications running in the second tier include ArcInfo, ArcView GIS, and customized MapObjects routines. The map server, which services requests for MapObjects application software, is located on the existing WYDOT Web server and is also included in the second tier.

- **Data Server.** The third tier of the design is responsible for managing the vast amounts of spatial and attribute data needed to support WYDOT GIS users. In the initial implementation, spatial and attribute data is centrally stored on a single server. The configuration limits network traffic and minimizes the effort required to maintain and back up the information stored on the data server.

D.3.3 Network Communication Requirements

Network communications support a critical component of a distributed GIS client/server environment. GIS applications typically process a relatively large amount of data. Most GIS applications access shared data located on the central GIS data server. The network environment supports communication between the data server and the application workstations. A significant portion of a GIS application response time is determined by how long it takes to access data. GIS applications typically spend about half their time accessing data and the other half in CPU computations. Data access (I/O) is a significant component of overall application performance.

Workstation processing performance (CPU) has improved much faster than data access performance (I/O) over the last five years, increasing the relative importance of I/O in determining overall application performance. The current 10 Mbps network bandwidth was a local area network standard for over ten years, and this bandwidth is becoming a bottleneck for distributed applications. With new high-performance workstations, GIS applications accessing data on a local workstation disk experience much faster performance than when accessing the same data from a remote server. Remote access performance can be improved significantly by increasing network bandwidth to 100 Mbps.

There are two primary communication performance characteristics that impact network design. The first is transaction response, and the second is network collisions.

Transaction Response: Transaction response is the amount of time it takes to transfer requested data over the network. The transaction response time is directly related to the available bandwidth. Current workstations can transfer data to the network much faster than 10 Mbps, and for large file transfers the application may delay further processing until receiving an appropriate response from the server. Response can be noticeably improved when using 100 Mbps Ethernet to the desktop. Currently, only a limited number of GIS users support 100 Mbps to the desktop, but we see this as a trend for future systems.

Network Collisions: Network collisions occur when two clients on the same network segment try to transmit at the same time. Local area networks support only one transmission broadcast at any one time. If two transmissions occur at the same time, a collision is detected and each client must delay and retransmit the same message (no information is passed when a collision occurs). Network collisions are a function of the number of users on the same network segment, the network access frequency of each user, and the transaction response time for each transmission. These factors combine statistically to establish the probability of any two transactions occurring at the same time. Once collisions begin to occur, network traffic will increase exponentially due to retransmission of the same transactions, and network performance will rapidly deteriorate. Network administrators should manage shared network segments to avoid collisions. Dedicated 10 Mbps to the desktop significantly reduces the potential for collision. Increasing the bandwidth to 100 Mbps or 1 Gbps significantly reduces the transaction response time (a primary factor in determining collision probability) since the data is on the broader segment for such a relatively short amount of time.

Figure D.3-2 provides recommended network design guidelines and quantitative decision points for supporting GIS user communications. SDE servers and Windows terminal servers are not necessary to support the initial implementation of GIS within WYDOT but are included here for future reference.

Figure D.3-2
Recommended Network Guidelines

Bandwidth	File Servers	SDE Servers	Windows Terminals
10 Mbps LAN	5-10	10-20	150-300
16 Mbps LAN	8-16	15-30	250-500
100 Mbps LAN	50-100	100-200	1500-3000
1 Gbps LAN	500-1,000	1,000-2,000	1,000-30,000
Wide Area Networks			
Bandwidth	**File Servers**	**SDE Servers**	**Windows Terminals**
56 Kbps Modem	NR	NR	1-2
1.54 Mbps T-1	NR	1-2	25-50
6.16 Mbps T-2	3-6	6-12	100-200
25 Mbps ATM	13-25	25-50	400-800

Network administrators within the Information Technologies section have implemented a suite of robust tools that enable them to monitor network performance. Additionally, IT staff have replaced shared network segments with switched segments to provide more efficient network communications within WYDOT headquarters. As GIS use grows within WYDOT, IT staff have the resources and experience necessary to respond to changing network communication requirements.

D.3.4 Systems Solution

The recommended systems configuration centralizes the storage of spatial and attribute data and distributes application processing to the desktop. **Figure D.3-3** illustrates the system solution for the WYDOT.

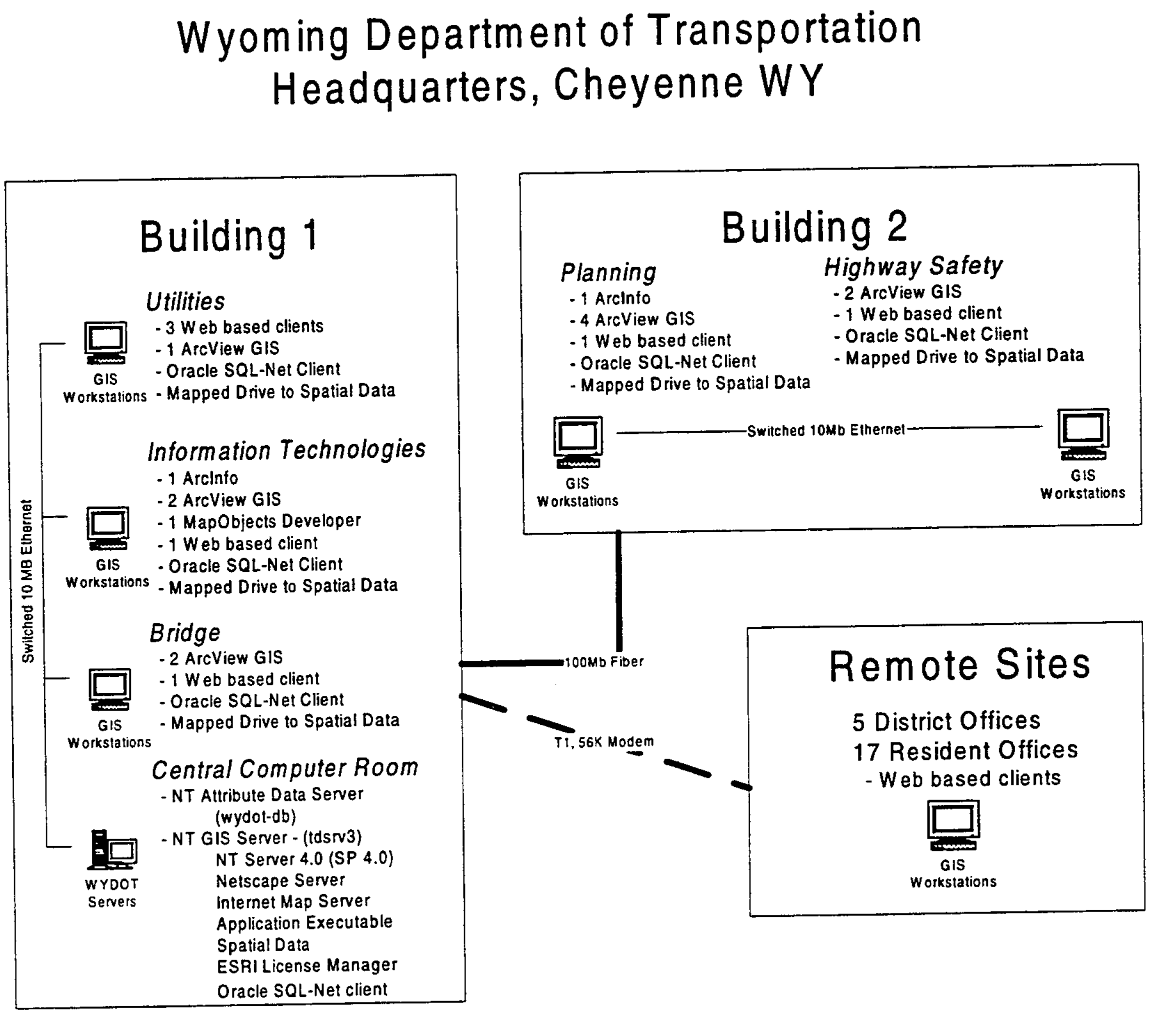
Two servers in the central computer room support the WYDOT geographic information system: an attribute data server that manages Oracle data (WYDOT-DB) and a GIS server (TDSRV3) that supports the ArcInfo license manager, spatial data structures, Internet Map Server and Intranet applications. The two servers are connected via a switched 10 Mbps Ethernet link that supports Internet Map Server access to data stored on the attribute data server.

ArcInfo and ArcView GIS applications are loaded locally onto the desktop computers of WYDOT staff. The distributed application processing enables WYDOT to take advantage of existing hardware resources and tailor machines to meet individual needs. In the distributed configuration,
GIS tasks such as data display and query, map production, and spatial analysis are carried out on local desktop machines. The central data server provides data across the network that supports GIS tasks. WYDOT has installed switched hubs that provide a minimum of 10 Mbps Ethernet connectivity to the desktop machines. The existing network infrastructure appropriately supports the recommended configuration.

Remote GIS users in the district and resident offices and the Web-based GIS users at WYDOT headquarters are supported by an Intranet application that provides Web-based access to GIS data. The application limits network traffic by passing images of standard map products to desktop browsers. The network infrastructure at WYDOT headquarters easily supports the Web-based clients. The existing T1/56K modem connection between WYDOT headquarters and the remote locations, while not adequate for data transfers and remote application processing, is more than sufficient for Web-based interactions with the shared GIS database.

The recommended configuration supports the estimated application processing and data serving needs of WYDOT users that are anticipated to be involved with GIS by November 15, 1999. As needs grow and WYDOT considers migration toward an enterprise solution, the configuration can be scaled to accommodate an increased number of users and increased loads on the system. For example, the spatial data may be migrated from ArcInfo coverages to an Oracle–Arc Spatial Database Engine™ (ArcSDE™) solution. The Oracle–ArcSDE solution is built on a client/server architecture that maximizes the performance of display and query operations. In addition, the Oracle–ArcSDE solution provides robust tools to support the management of spatial data in an enterprise environment. The configuration may also be scaled to support alternatives for application processing. The most likely option involves the deployment of remote solutions where Windows terminal servers centrally store ArcInfo and ArcView GIS applications that are remotely accessed by GIS users within WYDOT headquarters and remote locations alike.

Figure D.3-3


Wyoming Department of Transportation
Headquarters, Cheyenne WY
Building 1
Utilities
- 3 Web based clients
- 1 ArcView GIS
- Oracle SQL-Net Client
- Mapped Drive to Spatial Data
GIS Workstations
Information Technologies
- 1 ArcInfo
- 2 ArcView GIS
- 1 MapObjects Developer
- 1 Web based client
- Oracle SQL-Net Client
- Mapped Drive to Spatial Data
GIS Workstations
Switched 10 MB Ethernet
Bridge
- 2 ArcView GIS
- 1 Web based client
- Oracle SQL-Net Client
- Mapped Drive to Spatial Data
GIS Workstations
Central Computer Room
- NT Attribute Data Server (wydot-db)
- NT GIS Server - (tdsrv3)
NT Server 4.0 (SP 4.0)
Netscape Server
Internet Map Server
Application Executable
Spatial Data
ESRI License Manager
Oracle SQL-Net client
WYDOT Servers
Building 2
Planning
- 1 ArcInfo
- 4 ArcView GIS
- 1 Web based client
- Oracle SQL-Net Client
- Mapped Drive to Spatial Data
Highway Safety
- 2 ArcView GIS
- 1 Web based client
- Oracle SQL-Net Client
- Mapped Drive to Spatial Data
Switched 10Mb Ethernet
GIS Workstations
GIS Workstations
100Mb Fiber
T1, 56K Modem
Remote Sites
5 District Offices
17 Resident Offices
- Web based clients
GIS Workstations

D.4 System Configuration Sizing

D.4.1 Introduction

ESRI's web site, www.esri.com/library/literature.html, provides sizing models that provide standards for selecting and configuring GIS hardware and network solutions. Design models are developed based on actual client configurations and support a distributed system solution based on selected client performance levels.

Distributed computer system environments are established using several platform components. These components include data servers, application servers, client workstations, and network communications. Each must work together to support user performance requirements. The weakest component of the system will limit total performance.

A measure of the relative performance of the various hardware platforms is needed to support platform selection. Standard commercial performance benchmarks are used to measure relative performance. Specific user applications can also be used to measure platform performance. The performance benchmarks published by the Standard Performance Evaluation Corporation (SPEC) have been most useful in supporting the design of ESRI GIS solutions. An introduction of these benchmark suites is provided at www.esri.com/library/literature.html.

D.4.2 User Performance Baselines

Computer platform performance has changed significantly over the past several years. User performance expectations have changed with technology over this same period. User *performance baseline* standards for ArcInfo 7 range from Sun SPARCstation 10 Model 40 (SPECfp95 = 1.3) workstations purchased in 1994, to Pentium III 500 (SPECfp95 = 14.7) workstations purchased in 1999. A similar user performance expectation change has been noticed with ArcView users.

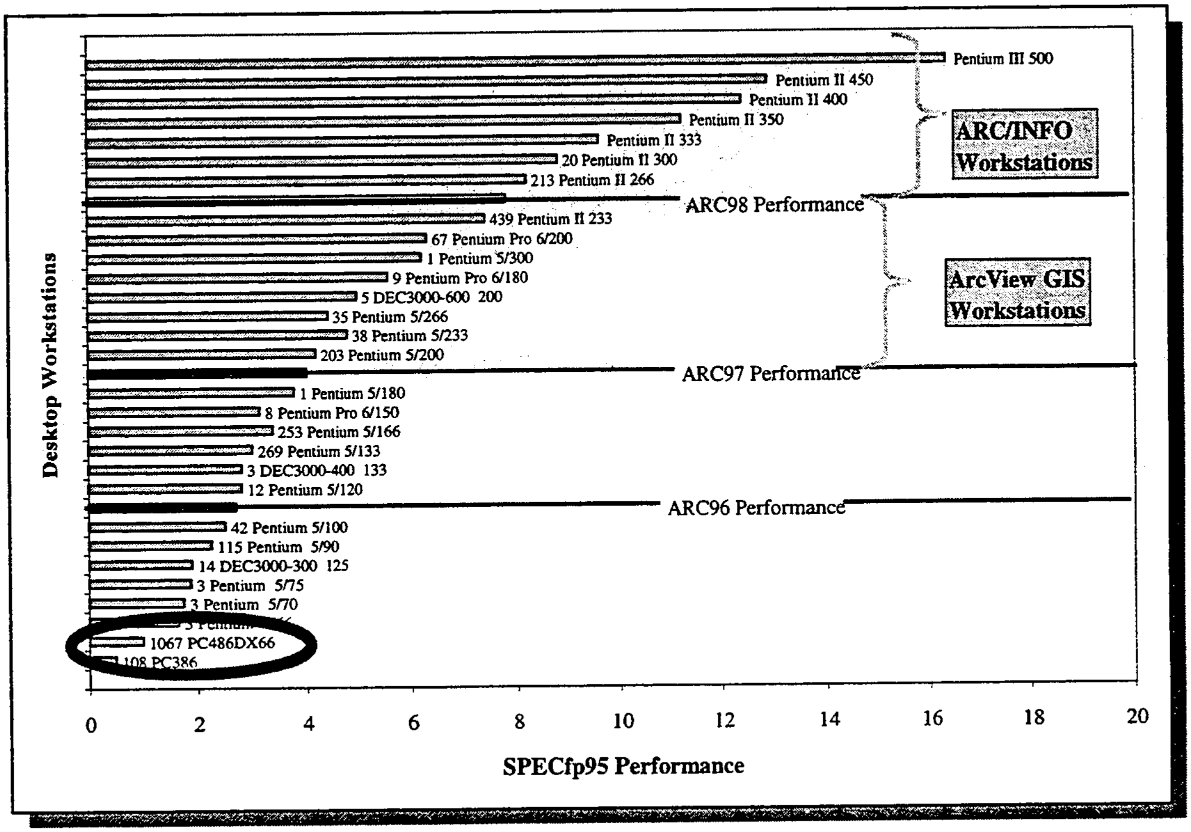
Changes in ArcInfo and ArcView platform performance standards since September 1994 are described in the white paper "Systems Design Strategies" found at www.esri.com/literature." PC platforms today operate over ten times faster than standard UNIX workstations in 1994.

The published baselines are used to identify platform- sizing requirements for the hardware components that comprise the WYDOT GIS. Sizing specifications are provided for three hardware platforms: GIS workstations, GIS spatial data servers, and Intranet Map Servers.

D.4.3 GIS Workstation Guidelines

Workstation performance has changed significantly over the past several years. **Figure D.4-1** illustrates the performance expectations for various workstation platforms. For example, a new ArcInfo user running on a 486DX66 machine would experience performance levels that were typical of users in the mid 1990's. The chart provides a quick indication of performance expectations that enable WYDOT to evaluate the validity of existing platforms that may be used to support GIS.

Figure D.4-1
GIS Workstation Platforms



Recommended GIS workstation base configurations for the WYDOT include the following:

ArcInfo Workstation: Pentium III 500, 256 MB memory (128 MB minimum), 8 MB VRAM (4 MB minimum) high-performance graphics card with 1,280 x 1,024 resolution, 9GB internal UltraSCSI disk drive, 21" color monitor

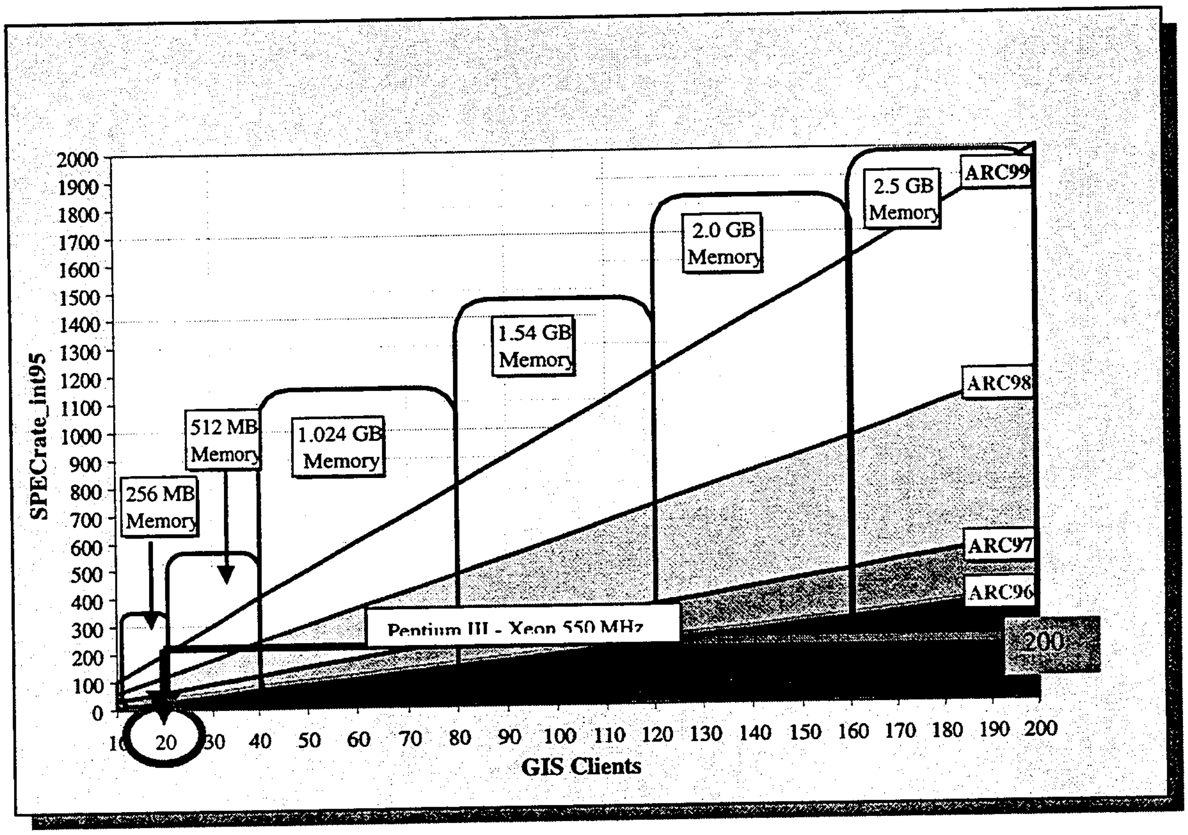
ArcView GIS Workstation: Pentium II 350, 128 MB memory (64 MB minimum), 8 MB VRAM (4 MB minimum) high-performance graphics card with 1,280 x 1,024 resolution, 9 GB internal UltraSCSI disk drive, 17" color monitor

ArcInfo users will require the highest performance platforms with a minimum of 128 MB (256 MB memory may be required if multiple applications remain open on the desktop). ArcView GIS clients can be supported by Pentium II platforms with acceptable levels of performance. Recommended memory for ArcView GIS users is 64 MB (128 MB may be required if multiple applications remain open on the desktop).

D.4.4 GIS Data Server Guidelines

GIS users within the WYDOT are supported by a central data server that houses the shared GIS database and associated attribute data files. The requirements analysis concluded that two ArcInfo users as well as eleven ArcView GIS users might be accessing the data on the server at a given time. In addition, a single MapObjects application process will be competing for file services as well. ArcInfo and ArcView GIS clients are considered equal for data serving sizing purposes; however, research conducted by ESRI has shown that each instance of a MapObjects application is roughly five times that of a normal GIS client. Therefore, for data server sizing purposes, the estimated number of users competing for data services is eighteen. **Figure D.4-2** presents the sizing chart used that supports the recommended configuration for the WYDOT data server.

Figure D.4-2
Data Server Platform Sizing



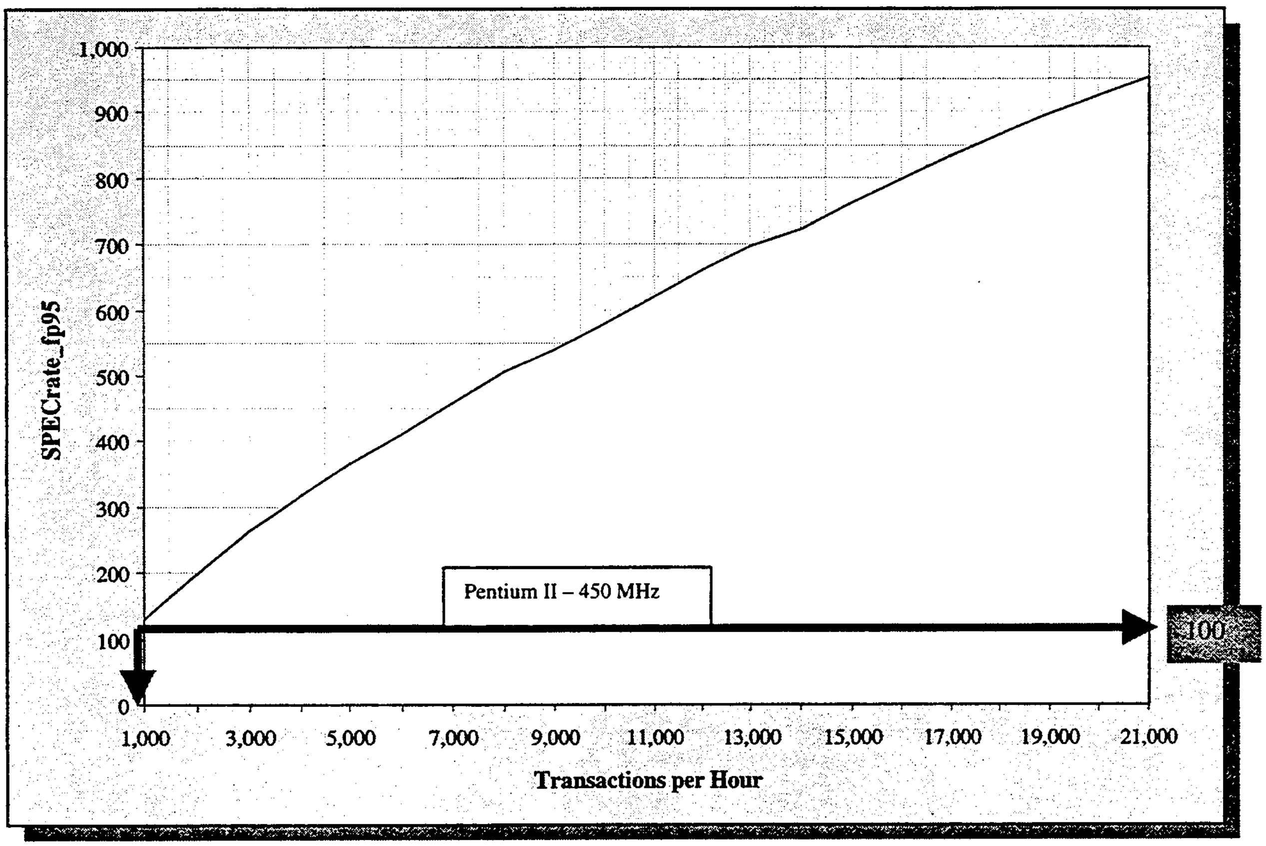
The chart illustrates that eighteen GIS clients require a relative performance specification of approximately 200. In addition, the chart shows that 256 megabytes of RAM are required to support the anticipated number of clients. Published specification rates found at the Web site www.specbench.org/osg/cpu95/results show that a single processor Pentium III Xeon, 550 MHz machine with 256 MB RAM is adequate to support the data serving needs of WYDOT.

D.4.5 Map Server Platform Requirements

ESRI's Internet Map Server software provides web services required to support the casual GIS user within WYDOT. Casual users will interact with the map server through Web browsers (i.e., Internet Explorer, Netscape, etc.) and simplified GIS applications (ArcExplorer) loaded locally on their individual machines. The map server will be located on the same machine that currently supports the internal Web applications of WYDOT.

The requirements analysis identified less than 500 transactions per hour involving the map server. **Figure D.4-3** provides map server performance recommendations based on anticipated transaction loads.

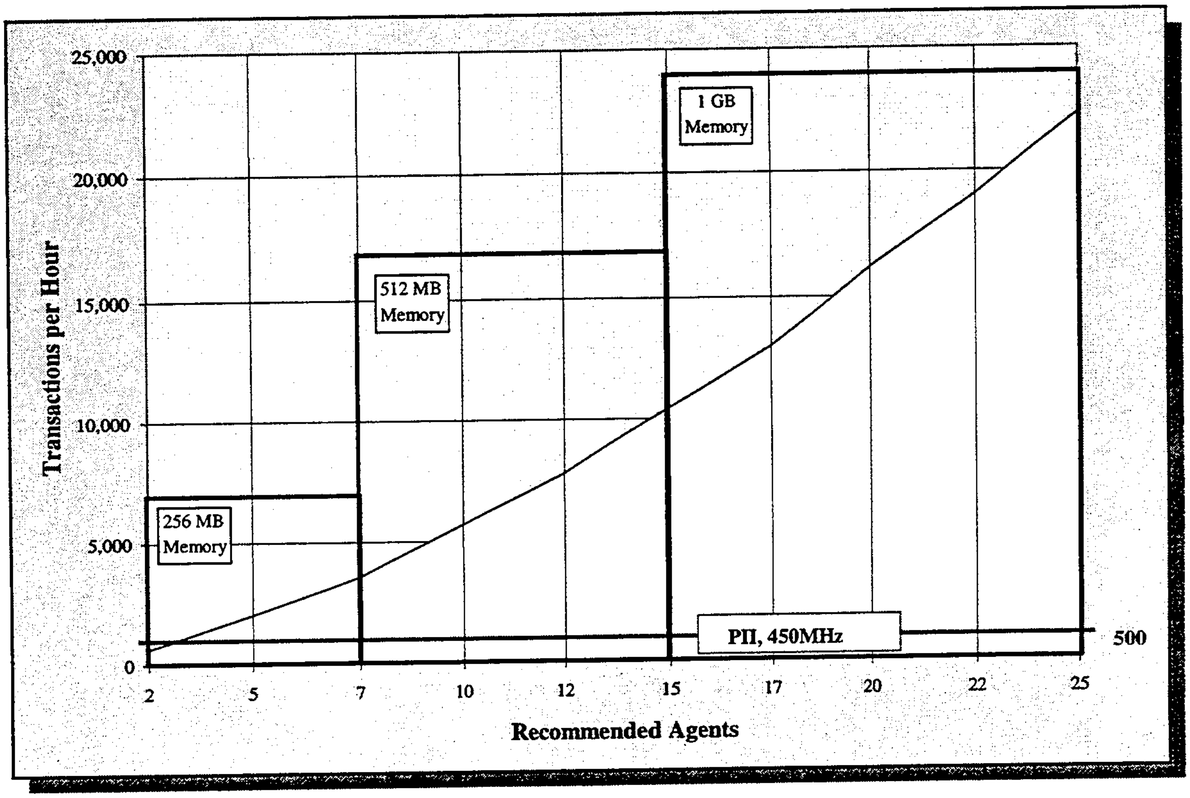
Figure D.4-3
Map Server Platform Sizing



The chart shows that a specification rate of approximately 100 is required to support the estimated transaction load of the map server. Published specification rates found at the Web site www.specbench.org/osg/cpu95/results show that a single processor Pentium II, 450 MHz machine with 256 MB RAM is adequate to support the GIS needs of WYDOT.

Figure D.4-3 above identifies the number of transactions per hour supported by selected platforms. **Figure D.4-4** below is used to identify the recommended number of MapObjects application agents and memory requirements to support the needs of casual GIS users within WYDOT.

Figure D.4-4
Recommended MapObjects Agents



The chart illustrates that a single instance of the MapObjects applications sufficiently handles the estimated number of WYDOT transactions.

D.4.6 Conclusions

Sizing models developed by ESRI provide the foundation for recommended hardware components that support GIS users within WYDOT. The platform recommendations are summarized in **Table D.4-1.**

Table D.4-1
GIS Platform Recommendations

Platform	Peak Usage	Platform Recommendations			
		Qty.	Processor	CPU-MHz	RAM (MG)
Central Data Server	19 clients	1	Pentium III Xeon	550	256
Internet Map Server	<500 transactions/hr.	1	Pentium II	450	256
ArcInfo Workstation	1 *	1	Pentium III	500	128
ArcView GIS Workstation	1 *	1	Pentium II	350	64

* ArcInfo and ArcView GIS applications are distributed to desktop machines that support a single concurrent user. In the distributed configuration there is no sharing of GIS application processing.

Appendix E

Implementation Plan

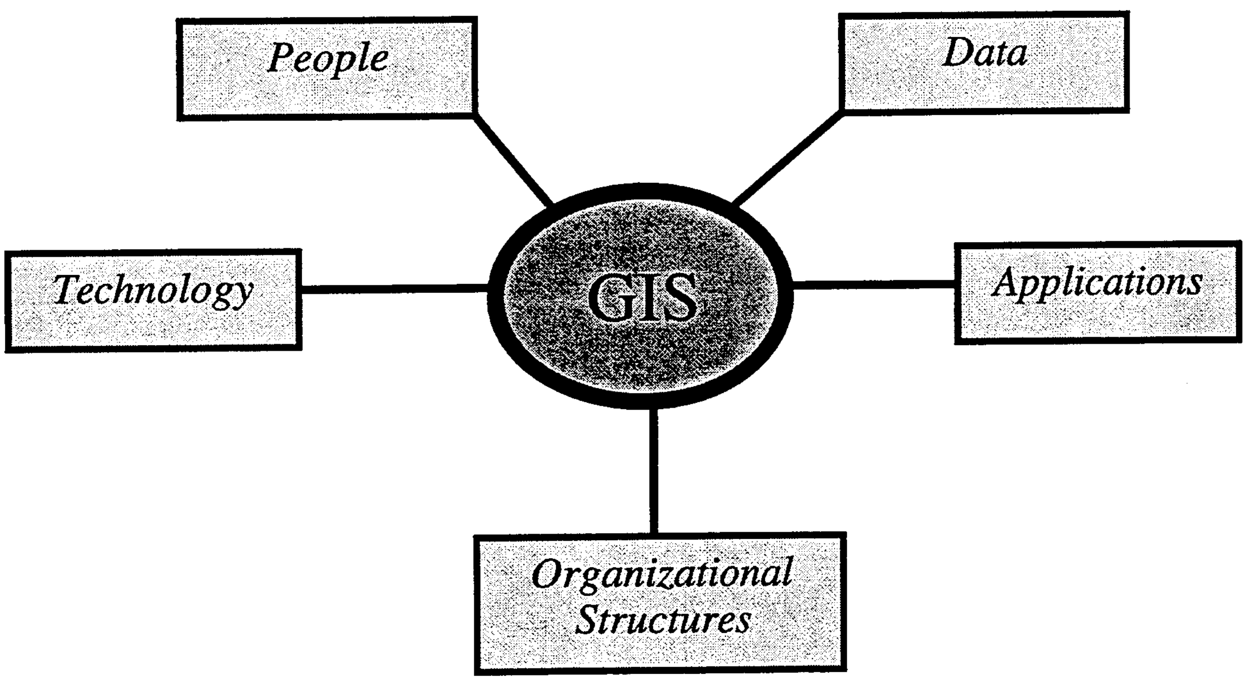
E.1 Implementation Plan

E.1.1 Introduction

Geographic information system (GIS) technology offers robust tools to capture, store, manage, analyze, display, and present all types of geographically related information. By nature, GIS is an integrative technology, uniting people, departments and organizations around their common information processing needs. It offers real promise for being able to help people interrelate and work more closely together. It enables people to see the context as well as the substance of their problems more clearly and perhaps deal with them more effectively.

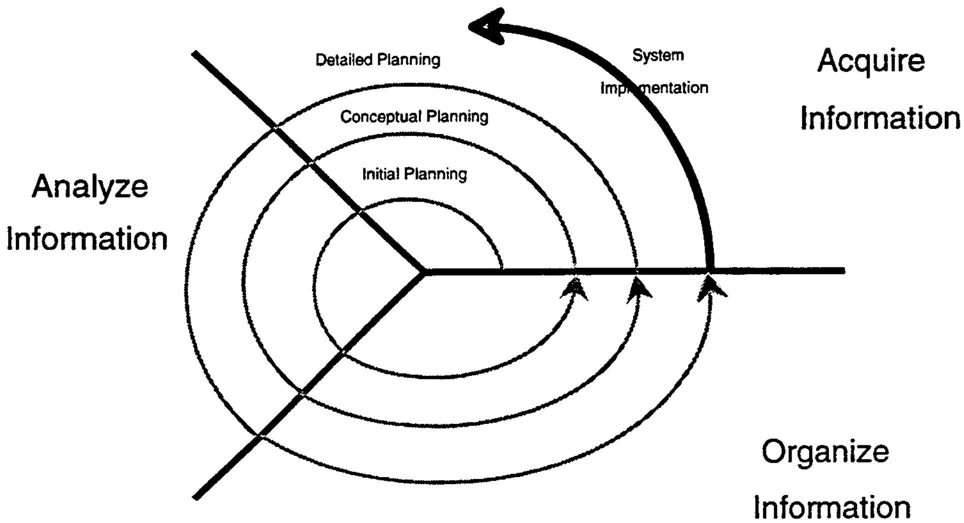
GIS implementation, however, involves more than simply purchasing hardware and software. At its core is a planning process that equally considers five aspects of implementation: people to run the system, data, technology, applications, and organizational structures that support the system. **Figure E.1-1** illustrates the elements of a successful implementation.

Figure E.1-1
Elements of GIS Implementation



The Wyoming Department of Transportation (WYDOT) employed a design methodology that served to align GIS investment decisions with well-defined user needs and long-term organizational goals and objectives. **Figure E.1-2** illustrates WYDOT's progression through the design methodology.

Figure E.1-2
Design Methodology

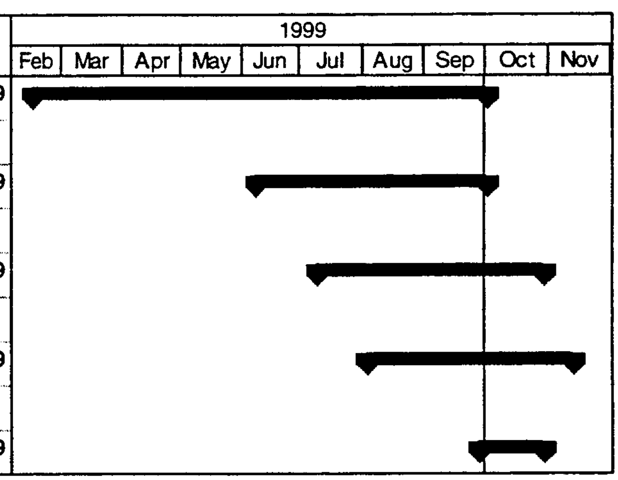


Initial planning activities defined the business need for the use of GIS within WYDOT. Conceptual planning activities built upon the conclusions of the initial planning stage to clearly define the functional requirements for the GIS. Detailed planning transformed ***what*** the system was to accomplish into vendor specific GIS solutions that define ***how*** the system operates.

This report identifies the tasks and considerations necessary to deploy GIS within WYDOT. It describes staffing, training, database and application development, and organizational structures that support Phase One GIS activities. The report concludes with a strategy that secures the niche for GIS within WYDOT. **Figure E.1-3** illustrates the project time line. Individual tasks are presented in detail as the implementation plan is presented in this report.

Figure E.1-3
Project Time Line

Task Name	Start	Finish
Planning Activities	**Fri 2/12/99**	**Fri 10/1/99**
Base Map Development	**Mon 6/7/99**	**Fri 10/1/99**
Systems Integration	**Fri 7/9/99**	**Fri 10/29/99**
Application Development	**Mon 8/2/99**	**Fri 11/12/99**
GIS Training	**Mon 9/27/99**	**Fri 10/29/99**



E.2 Staff Support

E.2.1 Staffing

GIS implementation relies on people to operate and maintain the system. An important aspect of GIS implementation is to understand the potential burdens placed on staff that support the system. There are three major user groups in the department: data maintainers, data viewers and application developers. The responsibilities of these user groups vary and must be supported to ensure the long-term success of GIS.

Data Maintainers. These staff are responsible for integrating, developing, distributing and maintaining the shared spatial database that supports WYDOT users. As road segments are added to or modified within the on-system roadway inventory, the data maintainers will ensure that the appropriate updates are made to the spatial database. In addition, these staff may service ad hoc requests for map layers, provide data conversion services, and develop high-quality map products. These may be time-consuming activities, and WYDOT must be prepared to provide the time and resources necessary to support the activities of the data maintainers.

Data Viewers. Data viewers will use GIS as a tool that supports their current activities. There is no significant burden placed on data viewers, but in the short term they must be allowed time to acquaint themselves with the system.

Application Developers. Application developers within WYDOT will be responsible for maintaining existing applications, supporting Web-based users, and developing scripts and user interfaces that support WYDOT GIS staff. Application development typically follows an iterative cycle that involves designing, building, testing, and deploying the application. As with data maintainers, WYDOT must provide the time and resources necessary to support the activities of the application developers.

The WYDOT GIS task force deliberately chose a phased approach to GIS implementation in order to limit the burden placed on existing staff. The WYDOT GIS task force has done a tremendous job of anticipating initial GIS needs by restructuring programs and sections to accommodate GIS and by hiring an additional staff member to support GIS. However, WYDOT GIS task force members must consider the timing of subsequent deployment activities to ensure that staff are trained and are able to efficiently manage an expanding GIS user base. As GIS use expands throughout the Department, WYDOT task force members may consider staffing full-time positions aimed at supporting GIS in the following areas:

- Database Administrators
- Training/Technical Support Staff
- Systems/Network Administrators

E.2.2 Training

A subtle form of failure that organizations experience with GIS is a system that no one uses. Often people are intimidated by GIS technology, and the tools and techniques of GIS can be overwhelming. In order to increase the acceptance of GIS, WYDOT must be committed to provide training for staff members. During meetings with the GIS task force a three-tier training solution was developed that provides WYDOT staff with the essential skills necessary to operate and maintain the geographic information system. The solution includes formal course work, on-site workshops and specific training that supports the Utilities/Railroad section application.

The training solution that supports WYDOT users was developed with an emphasis on those skills needed to accommodate the initial phase of GIS, scheduled for completion in November 1999. The database delivered in Phase One was developed in accordance with ESRI's dynamic segmentation data model. ESRI–Denver staff utilized the MapObjects® development environment to "spatially enable" the existing Utilities/Railroad section Intranet application. As WYDOT staff will take ownership of the database and application, it is important that they have an understanding of those technologies. The training solution begins with formal course work that provides the skills to create and maintain data and support the MapObjects application.

E.2.2.1 Formal Course Work

Introduction to Workstation ArcInfo. This ESRI training course provides an overview of the general functionality and data structures of ArcInfo™ software. It is presented in a five-day format and is offered in the ESRI–Denver regional office during the week of September 27, 1999. Two staff members, responsible for creating and maintaining data in the spatial database, should be enrolled in the *Introduction to Workstation ArcInfo* course.

Advanced Workstation ArcInfo. This course covers advanced ArcInfo concepts and techniques and is designed for users needing to broaden their skills. The course provides an in-depth presentation of the ESRI® dynamic segmentation data model and is recommended as a follow-up course for those users that maintain the spatial database and have completed the *Introduction to Workstation ArcInfo* course. Additionally, this course is valuable for application developers within WYDOT that would be responsible for automating repetitive tasks and supporting other WYDOT users. The class is provided in a five-day format and is offered at various times throughout the year in the ESRI–Denver regional office. It is also offered at other locations around the country to accommodate more immediate scheduling needs.

Programming MapObjects with Visual Basic. This course provides the foundation for becoming a successful MapObjects developer. It offers an overview of the MapObjects control and hands-on experience using its set of ActiveX automation objects within the Microsoft Visual Basic programming environment. This three-day course is recommended for application developers within WYDOT that will be responsible for developing and supporting MapObjects applications. It is offered at the ESRI-Denver regional office on October 11–13, 1999.

Working with MapObjects Internet Map Server. Topics covered in this two-day course include how to administer a map server site with MapObjects Internet Map Server (IMS) administration components, fundamental Internet concepts and protocols, and client/server design strategies. This course is recommended for Information Technologies staff responsible for maintaining the Web server and associated map server applications. This course is offered at the ESRI-Denver regional office on October 14–15, 1999.

Introduction to ArcView GIS. ArcView® GIS software is designed to be a user-friendly application for displaying, querying, analyzing and presenting geographical and attribute data. This two-day course provides an introduction to the functionality provided by ArcView GIS. It is recommended for WYDOT staff that employ GIS to support general purpose analysis, query and display activities. The course is offered at the ESRI–Denver regional office on October 25–26, 1999. Additionally, WYDOT may consider hosting the course at WYDOT headquarters to provide a cost-effective solution for training a larger number (8 or more) of ArcView GIS users.

E.2.2.2 On-site GIS Workshops

The second tier of the training solution involves on-site GIS workshops that expose GIS functionality to broad user groups. The workshops are developed to meet the specialized needs of WYDOT staff and provide interim training that enables WYDOT users to become immediately productive with their GIS. The workshops are anticipated to be less than two hours long and may address a range of topics. Listed below are a handful of topics that may be of interest to WYDOT users.

ArcInfo

- Introduction to the dynamic segmentation data model
- Managing spatial and attribute data by defining database relationships
- Producing high-quality map products using route model display tools
- Performing spatial analysis
- Automating tasks with ARC Macro Language (AML™) software

ArcView GIS

- Integrating spatial data with Oracle tables using SQL Connect functionality
- Performing general queries and analysis
- Working with layouts and charts to create simple map products

On-site workshops may be supplemented with the unique training opportunity offered by ESRI known as the ESRI Virtual Campus. The ESRI Virtual Campus is an Internet-based training program that allows GIS users to register for specific training courses that are similar to the topics identified in the workshops above. For a cost of $79.95, users may download

GIS modules to their local desktop machine. Modules consist of tutorials and exercises that the student may complete at his/her leisure. The ESRI Virtual Campus is a flexible training opportunity that delivers introductory GIS courses in an efficient, cost-effective manner. The World Wide Web address for the Virtual Campus is www.campus.esri.com/home/home.cfm.

2.2.3 Application Training

The third tier of the training solution involves specific training for the Intranet application that ESRI delivers in fulfillment of Phase One. The application will "spatially enable" the existing Utilities/Railroad section Intranet application by placing a map onto the user interface. WYDOT users will be able to query the database, as before, but will have additional functionality that enables them to construct spatial queries and output standardized map products. The application will include buttons and menus that support user interactions with the shared spatial database. Training is offered to introduce users to the functionality and to demonstrate how the application operates. Because many users of the application will be from remote district offices, ESRI will work with GIS task force members to provide training to accommodate the broadest possible audiences.

The three-tier training solution is a flexible solution that provides WYDOT GIS users with the skills necessary to maintain the geographic information system. It is developed to alleviate the possible tension and reservation that often comes with an introduction of technology. ESRI will work with WYDOT task force members to provide comfortable, well-paced training alternatives that enable WYDOT staff to become immediately productive with their GIS.

Figure E.2-1 identifies the training schedule that accommodates Phase One GIS implementation within WYDOT. Two staff members from the planning program are registered for the *Introduction to Workstation ArcInfo* class, and two members of the Information Technology (IT) staff are registered for the MapObjects courses. Specialized workshops and self-paced training will be scheduled during fall 1999 at the convenience of WYDOT staff.

Figure E.2-1
Training Schedule

			September				October				
Task Name	Start	Finish	9/5	9/12	9/19	9/26	10/3	10/10	10/17	10/24	10/31
GIS Training	**Mon 9/27/99**	**Fri 10/29/99**									
Intro Workstation ArcInfo	Mon 9/27/99	Fri 10/1/99									
Programming MapObjects	Mon 10/11/99	Wed 10/13/99									
MapObjects Internet Map Server	Thu 10/14/99	Fri 10/15/99									
Intro ArcView GIS	Mon 10/25/99	Tue 10/26/99									
GIS Workshops	Mon 9/27/99	Fri 10/29/99									
GIS Self Paced Training	Mon 9/27/99	Fri 10/29/99									

E.3 Database Development

Even the most trained and experienced staff cannot utilize GIS if there is no data to support their planning, forecasting, and management activities. Data is the foundation upon which GISs are built. Working closely with GIS task force members, ESRI developed the following six-step strategy to guide the development of the WYDOT basemap. As additional data layers are identified for inclusion, it is strongly recommended that WYDOT staff follow similar procedures to ensure data quality and consistency.

1. **Identify system outputs.** In GIS there is no such thing as good or bad data; rather; data is either useful or useless. All data development efforts begin with a clear definition of what information products are required of the data. Knowing what comes out of the system helps to define what goes into the system. Data requirements, such as scale, accuracy, projection, and attribution, are determined by the end use of the data. This approach ensures that resources are spent to develop data that meets tangible, well-defined needs. During summer 1999, ESRI staff developed the geographic basemap in accordance with user requirements that were documented in the Requirements Analysis report, reviewed and accepted by GIS task force menders on June 4, 1999.

2. **Develop physical designs for the data.** As spatial and attribute data is captured in the GIS, it is stored in data structures that support query, display, analysis, and presentation operations. Physical design activities undertaken by ESRI served to organize data elements efficiently and nonredundantly to limit inconsistencies in the database and make it easy to use and maintain.

3. **Compile and evaluate existing data sources.** Traditionally, data development has been a bottleneck for GIS implementation, where tremendous amounts of time and resources were spent digitizing information from analog sources. Today, however, there are vast amounts of spatial data available in the public and private domain that can jump-start data development activities. To meet the data requirements for Phase One, ESRI evaluated data from federal, state and local government data sources as well as data from private companies. ESRI combined data from the Bureau of Transportation Statistics National Highway Planning Network, U.S. Census Bureau TIGER files, and the Wyoming Spatial Data Clearinghouse to construct the linear reference system that supports WYDOT GIS users. In addition, a Public Land Survey System data layer was purchased from a private vendor for much less than the cost of developing it internally.

4. **Develop automation procedures to guide data development.** Consistency is the goal of any data development effort. An automation plan guides data development through standardized procedures. In addition, a well-defined automation plan enables managers to track progress and implement quality control procedures that support the on-time delivery of data products. The automation plan used by ESRI is included in **Appendix F.**

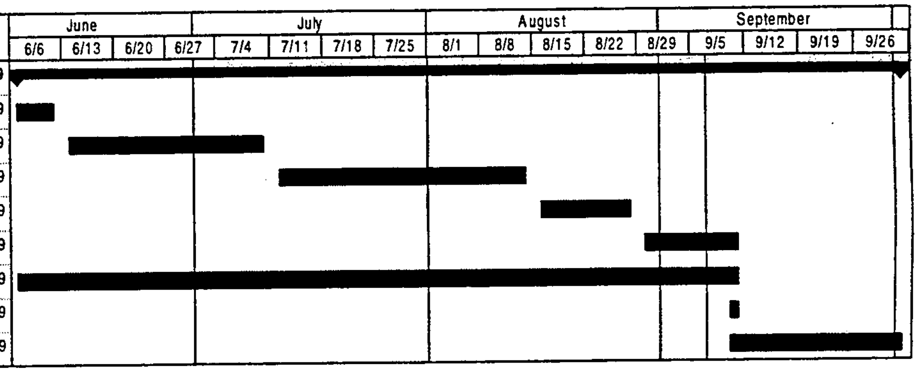
5. **Enter and process the data.** Once the database development procedures have been planned, GIS staff can begin creating the requisite data.

6. **Verify the appropriateness of data through quality control procedures.** ESRI's GIS software programs offer many tools to validate data in terms of referential and topological integrity. The quality control procedures are often automated through scripting languages that implement the tools and output results. The AML programs used by ESRI in developing and validating the linear reference system for Phase One are provided in **Appendix G.**

Figure E.3-1 below, illustrates the time line for database development activities. It may be used as a reference for estimating future data development efforts within WYDOT.

Figure E.3-1
Basemap Development Time Line

Task Name	Start	Finish
Base Map Development	**Mon 6/7/99**	**Fri 10/1/99**
Data Evaluation	Mon 6/7/99	Fri 6/11/99
Attribute Arcs	Mon 6/14/99	Fri 7/9/99
Add Missing Features	Mon 7/12/99	Fri 8/13/99
Aggregate into Routes	Mon 8/16/99	Fri 8/27/99
Calibrate Routes	Mon 8/30/99	Fri 9/10/99
QA/QC	Mon 6/7/99	Fri 9/10/99
Delivery	Fri 9/10/99	Fri 9/10/99
Acceptance	Fri 9/10/99	Fri 10/1/99



E.3.1 Data Security

Studies have shown that the cost of data development can represent as much as 90 percent of the total cost of GIS. It is critically important for WYDOT to consider ways to protect their investment in data. Data may be lost in many ways, ranging from inappropriate employee intervention to hardware disk failures to natural disasters. It is recommended that WYDOT consider establishing system level permissions on core data layers to limit the number of users that have write access to the data. In addition, WYDOT must include the GIS database in its backup procedures and may consider storing GIS archives off-site to protect against natural disasters.

E.3.2 Data Migration

The data developed and delivered in fulfillment of Phase One activities was built upon the ESRI dynamic segmentation data model. Currently, ESRI is developing a new data model called the GeoObject data model that takes advantage of object-oriented technology trends. The functionality offered by the dynamic segmentation data model will not be implemented in the GeoObject data model in time to meet the November 15, 1999 deadline of Phase One. However, as GIS use expands toward an enterprise solution in Phases Two and Three, WYDOT will have an opportunity to explore the GeoObject data model and develop a migration strategy when the time is appropriate.

E.4 Technology

A fundamental component of any GIS implementation is the hardware, software, and network communications that support the operational GIS. The Hardware, Software, and Network Design report, reviewed and accepted by GIS task force members on September 10, 1999, identified the systems components necessary to support Phase One GIS activities. Implementing the systems recommendations involved the following steps:

1. **Hardware, software, and network acquisition.** Existing staff expertise, vendor relationships, and the current systems environment were considered to ensure a systems solution that complements the existing hardware, software, and network infrastructure.

2. **Site planning and preparation.** Accommodating system components requires an element of site preparation—identifying where the system will be located, ensuring adequate power and temperature controls and, potentially, reorganizing office resources (desks, network cables, plotter, digitizers, etc.) to support the system. ESRI staff worked with IT staff to ensure that these considerations were addressed.

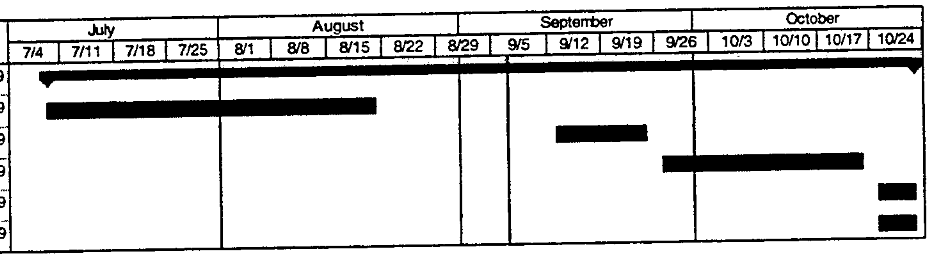
3. **Systems installation.** Installing the system components typically follows a logical process that begins with checking the equipment for physical defects. Once the components are deemed acceptable, the operating system is loaded. Establishing network connectivity with servers and peripheral devices and loading application software completes the installation. ESRI assisted IT staff by providing testing procedures that validate the installation of GIS.

4. **Systems integration.** Systems integration involves loading data and custom applications that support departmentwide users. Integration activities ensure that the system components are working together appropriately. ESRI staff worked closely with IT staff to integrate GIS data and applications.

Figure E.4-1 presents the timetable for systems integration activities. ESRI–Denver staff, in conjunction with IT staff, installed and tested GIS software products, loaded data and applications and integrated the components to ensure an operational GIS. To the extent possible, system integration activities followed the training schedule so that WYDOT staff were able to work with the system after completing their training.

Figure E.4-1
Systems Integration Time Line

Task Name	Start	Finish
Systems Integration	**Fri 7/9/99**	**Fri 10/29/99**
Acquisition	Fri 7/9/99	Fri 8/20/99
HW/SW Installation	Mon 9/13/99	Fri 9/24/99
Data Installation	Mon 9/27/99	Fri 10/22/99
Application Installation	Mon 10/25/99	Fri 10/29/99
Integration Testing	Mon 10/25/99	Fri 10/29/99



ESRI software programs support a large number of complementary technologies including relational database management systems, document imaging systems, and Web-based Internet services. An important aspect to consider when deploying GIS is the versioning of the various products that make up the system. Phase One GIS implementation activities involve ARC/INFO® 7.2.1, ArcView GIS 3.1, MapObjects 2, MapObjects Internet Map Server 2, Microsoft Windows NT Server 4, (with Service Pack 4), Microsoft Internet Information Service (IIS) 4 and Oracle 8.0.3. These technologies are currently certified to work together, but as vendors provide updates to products, WYDOT must pay close attention to the potential impact of implementing new versions of software.

E.5 Applications

Applications are customized procedures and user interfaces that automate repetitive GIS tasks, provide documentation and consistency for GIS processing and enable users to become immediately productive with their GIS. Commonly built applications vary from simple templates that standardize map products to complicated programs that supplement out-of-the-box GIS functionality.

ESRI developed the MapObjects application that supports the Utilities/Railroad section by following the common application development tasks listed below.

1. **Determine application functional requirements.** ESRI staff met with representatives from the Utilities/Railroad section to determine the needs of the application. Discussions focused on identifying data sources and formats, processes and output products that support WYDOT GIS users employing the application. Functional needs for the application were defined in the Requirements Analysis Report prepared in spring 1999.

2. **Develop a system design.** System design activities provided greater detail regarding the application interface (i.e., windows, menus, browsers, etc.), data flows, processes and output products. Program specifications provided ESRI application programmers with details for developing the code.

3. **Application development.** ESRI programmers implemented the system design in the application development environment provided by ESRI's MapObjects and MapObjects Internet Map Server technologies.

4. **Application testing and review.** Iterative builds of the application were developed by ESRI and reviewed by GIS task force members and Utilities/Railroad section staff to evaluate functionality and performance response times.

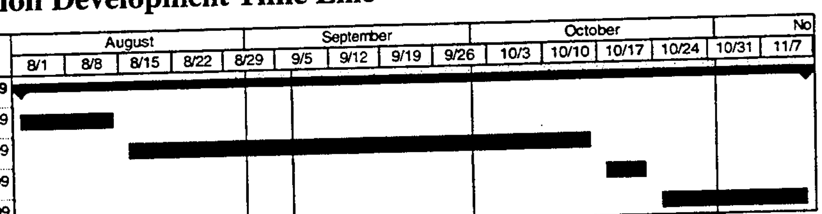
5. **Application installation and training.** Once completed, ESRI staff installed the application onto WYDOT hardware platforms and trained Utilities/Railroad section staff on its functionality.

Applications are a valuable part of any GIS implementation in that they enable GIS to be tailored to support virtually any need. As GIS expands within WYDOT, users may request applications to support their daily GIS activities. Application programmers within WYDOT are encouraged to follow the development steps above to ensure an application that is user-friendly, easy to use and easy to maintain.

Figure E.5-1 illustrates the time line for application development activities.

Figure E.5-1
Application Development Time Line

Task Name	Start	Finish
Application Development	**Mon 8/2/99**	**Fri 11/12/99**
Design	Mon 8/2/99	Fri 8/13/99
Build/Test	Mon 8/16/99	Fri 10/15/99
Deliver	Mon 10/18/99	Fri 10/22/99
Training	Mon 10/25/99	Fri 11/12/99



The WYDOT GIS Task force was established to provide organizational support for the GIS. Task force members developed funding strategies that enable individual programs and sections to petition for budget allocations that support specific GIS needs. The Task force organizes and centralizes funding requests to ensure that GIS investments serve the long-term goals and objectives of WYDOT.

GIS requires support staff to maintain the hardware, software and networking infrastructure. It requires staff to maintain the shared spatial database and requires leadership to manage resources and service requests. The Task force has recognized the organizational impact resulting from Phase One GIS activities and has accommodated this impact by convening a Sub-Committee that offered the following recommendations:

- Staff in the Planning and Programming section of WYDOT would handle spatial data maintenance responsibilities. This section was reorganized to provide the requisite services.

- Staff in the Information Technologies section would handle the systems support and application development responsibilities necessary to support WYDOT GIS users.

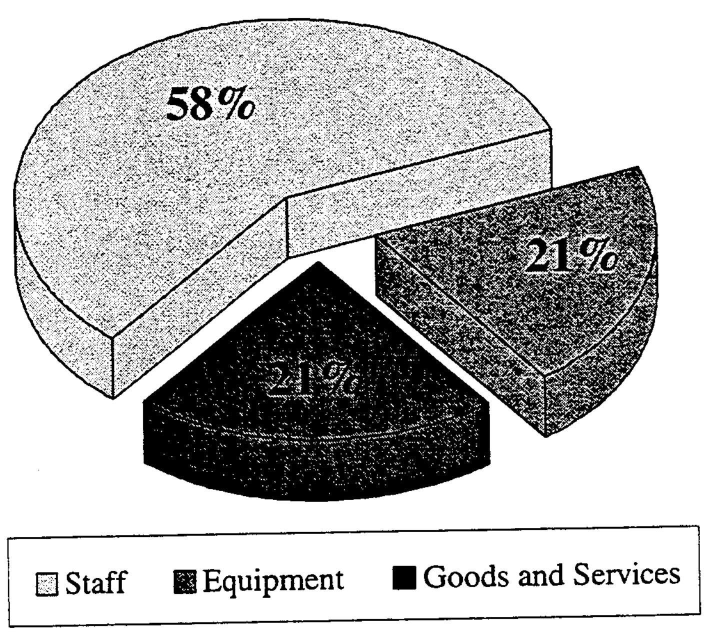
An additional staff member was recently hired to accommodate the increased responsibilities of GIS.

The Task force has been supported in the GIS planning process by a Technical Advisory Group (TAG) that provides assistance in areas of database design, systems design, and spatial data maintenance and processing. As Phase One concludes, it is recommended that the Task force transition the role of the TAG to one that supports the day-to-day operational use of the GIS. A WYDOT users group, consisting of members from the TAG, may be constructed to service WYDOT users, foster cooperation and share GIS experiences throughout the Department. A list server or Internal Web site may be supported so those users in the District Offices have access to the expertise of the WYDOT users group.

E.6 Conclusions

WYDOT has migrated through a design methodology that guides Phase One GIS activities. As Phase One products are delivered, it is important for the task force to remember that GIS implementation is not a static, one-time event. Rather, GIS is dynamic technology that offers the promise of integrating programs and sections within the department around their common information processing needs and providing a spatial perspective that streamlines entire processes. To realize the promise of GIS, it must be continually supported and funded. **Figure E.6-1** illustrates the annual budget allocation of successful implementations.

Figure E.6-1
Annual GIS Expenditures



Note that roughly three-fifths of the annual budget supports the staff that maintain the system. These staff update the database, develop applications, and provide services to the broader WYDOT GIS user community. Notice also that roughly one-fifth of the annual GIS budget is used to upgrade system components and provide system resources for new users. Typically, an organization allocates only 5 percent of the budget for these system considerations. However, because of the rapidly changing nature of technology (i.e., faster processing speeds, increased storage capacities), GIS user performance expectations increase dramatically. WYDOT must support their commitment to GIS by providing hardware platforms that reduce downtime and foster departmentwide enthusiasm for GIS.

Lastly note that one-fifth of the annual budget is reserved for defining new opportunities for the GIS—expanding the user base, achieving customer satisfaction and reducing the cost of doing business. In theory one-day each week could be reserved for thinking about new ways to incorporate GIS activities within the department. New opportunities are considered in light of the long-term goals and objectives of the system that were identified early on in the strategic planning activities of Phase One. Reviewing the strategic plan not only guides future GIS activities but also enables GIS to respond to changing mission statements and new influences on the department, thereby securing the long-term niche for GIS within WYDOT.

Appendix F

Automation Plan

F.1 Automation Plan

This appendix describes the methods and processes used by ESRI–Denver staff in developing the on-system linear referencing scheme for the Wyoming Department of Transportation (WYDOT) in accordance with Phase One GIS implementation activities. It is provided as a guide for WYDOT staff as they develop procedures for the long term maintenance and support of the shared spatial database.

Base map development followed an in-depth requirements analysis that concluded that the majority of WYDOT staff rely on the *Wyoming Reference Marker System* book, published by the Planning and Programming Program, to support their daily planning, forecasting and management responsibilities. It was decided that a department–wide benefit would be realized from a GIS effort that provided a visual, map-based view of the information contained in the *Wyoming Reference Marker System* book.

ESRI's dynamic segmentation data model provided the foundation for creating a route scheme that aggregated spatial features representing roadway segments into WYDOT's on-system routes. In addition, the dynamic segmentation data model provided tools to calibrate the routes at well-defined positions such as county and state boundaries and road intersections. During summer 1999, ESRI–Denver staff evaluated data sets and built a GIS data layer that supports the WYDOT linear referencing system.

ESRI–Denver identified five sequential tasks that guided the development of the route systems: data evaluation, data attribution, digitizing, and calibration. Each of these is described in detail below.

F.2 Data Evaluation

GIS development efforts typically begin with lengthy data creation processes where paper maps and other non-digital information stores are automated for use in a computerized environment. Traditionally, data has been a bottleneck for many GIS implementations. However, as GIS use expanded in the early to mid 1990s a multitude of digital data sources have become freely available. The proliferation of the world wide web has had a tremendous impact on GIS in that organizations are able to publish and distribute their data in a timely and cost efficient manner.

The initial task undertaken by ESRI–Denver was to research and select an appropriate data source that supported GIS implementation efforts within WYDOT. ESRI–Denver found that the National Highway Planning Network, produced by the Bureau of Transportation Statistics (BOTS), provided close to 80 percent of the on-system roads required by WYDOT. ESRI–Denver utilized existing TIGER data from the Census Bureau and data sets from the Wyoming Geographic Information Advisory Council (WGIAC) and the Spatial Data Visualization Center (SDVC) at the University of Wyoming to supplement the Bureau of Transportation Statistics data set. Because of the existing data sets, ESRI–Denver was able to dramatically reduce the data development effort, and rather than focus on creating data, ESRI–Denver concentrated on attributing the data sets to appropriately serve the Wyoming Department of Transportation.

F.3 Data Attribution

Following the selection of the data set, ESRI–Denver attributed each of the road segments with values that identified the Federal Aid system, route and accessory used internally by WYDOT to describe on-system features. ArcView GIS was chosen to support the attribution effort because it offered an intuitive, easy to use interface. ESRI–Denver worked on a county-by-county basis, using the *Wyoming Reference Marker System* book as a guide. The following steps were taken:

- Identify the county to work on
- Select road segments that correspond to the on-system routes represented in the *Wyoming Reference Marker System* book
- Populate database columns of system, route and accessory according to database standards established by the GIS Task Force in association with the Technical Advisory Group.

In addition, ESRI–Denver created simple text files that stored the name of each route as it was attributed. The text files provided a means to validate that each of the routes in the *Wyoming Reference Marker System* book was accounted for in the attribution process.

F.4 Digitizing

As mentioned above, the Bureau of Transportation Statistics data sets provided approximately 80 percent of the on-system roads. Most notably absent from that data set were the service roads, connectors and spurs. ESRI–Denver utilized TIGER, WGIAC and SDVC data sets to provide the spatial representation for the missing features. The copy and paste functionality of ArcView GIS was used to copy features from supplementary sources and paste them into the BOTS data set. To accommodate the situation where no features could be found in any alternate data set, ESRI–Denver digitized the missing features by hand. The digitizing effort accounted for less that 5 percent of the data development effort.

Aggregation of Arcs into Routes

Once each of the road segments was attributed with the appropriate system, route and accessory information, ESRI–Denver used the ArcInfo command *measureroute* to create the Wyoming Linear Reference System. The *measureroute* command gathers similarly attributed arc features into unique route systems and applies a default measurement scheme, based on the length of each constituent arc. The *measureroute* command was applied on a county by county basis; routes were built within each county and quality checks were applied to ensure that the routes were constructed appropriately. The default measurement scheme enabled ESRI–Denver to identify potential problems in the route structure, such as overlaying routes and forks (i.e., measures duplicated along different portions of the same route feature). Routes requiring additional attention were re-visited and fixed by editing the underlying road segments or editing the routes themselves. When all the routes were fixed, ESRI–Denver built the route system for the entire state. The text files created in the attribution step were loaded into the GIS and used as a control mechanism to ensure that each of the routes was constructed.

Calibrate the Routes

ESRI-Denver created a separate point map of surveyed locations that was used to calibrate the routes. The ArcInfo *calibrateroutes* command was used to transfer the measurements from the point map to the route systems. During the calibration process, the default measurement scheme for the routes was replaced with the measurement scheme described in the *Wyoming Reference Marker System* book. Known locations such as county and state boundaries and road intersections were used to recalculate measures along each of the routes in the linear referencing system. The following steps were undertaken to support calibration:

- Construct a point map and attribute each point with a system, route, accessory and milepost location. Repetitive database columns were used to accommodate those points that referenced more than one route.
- Edit the directionality of the route system measurement schemes to control the calibration process. This process involved visiting each of the routes and verifying that the default measurement scheme increased in the same direction as the calibration points. It is a necessary step that is required in the calibration process.
- Manually "remeasuring" routes to accommodate for nuances in the Reference Marker System. For example, many routes had deliberate "jumps" in the measures that could not be addressed by a truly automated method.

F.5 Conclusion

ESRI–Denver constructed a geographic data layer that contains individual road segments aggregated into routes in accordance with the dynamic segmentation data model. As WYDOT staff take ownership of the data layer, the majority of their responsibilities will center on maintaining and updating the on-system routes. ESRI's GIS product ArcInfo contains a full range of tools to realign routes and adjust measurements on a route by route basis. There may not be an immediate need for WYDOT staff to utilize the methods employed by ESRI–Denver, where more of a bulk route creation process was necessary. However, when WYDOT staff consider adding off-system routes to the data layer, the techniques described above may prove valuable.

Appendix G

QA/QC Procedures

G.1 QA/QC Procedures

This appendix describes the quality assurance/quality control procedures used by ESRI–Denver staff during the construction of the linear referencing scheme. The procedures were written in ARC Macro Language (AML) and served to validate the various stages of the data development process. AML code fragments are presented to highlight the essence of the procedures. The following checks are discussed in this appendix:

- Data set descriptions that verify the number of features (arcs, routes), topological integrity and projection information.
- Attribute checks that ensure the standard database columns used to define Wyoming Department of Transportation (WYDOT) routes (i.e., system, route, and accessory) are appropriately populated. Domain values for the database columns were fully described in the database design document.
- During the data development process, control files were created that identify the WYDOT routes within each county. Comparison checks were developed to ensure that each route in the *Wyoming Reference Marker System* book was included in the linear referencing scheme of the GIS data set.
- The ESRI Dynamic Segmentation data model supports overlapping and forked routes. However, the Federal Aid System relies on unique routes and milepost schemes. Procedures were developed that identified potential problems in the route structure by identifying forks and overlaps.
- Route lengths were appended to the control files during the data development process that enabled ESRI–Denver staff to compare the length of each feature in the GIS data set with the identified length in the control file. Large differences in the route lengths highlighted potential problems with the route structure.

1. Data Set Descriptions

```
&if [exists %rpt_dir%\%workname%.txt -file] &then
   &sv del = [delete %rpt_dir%\%workname%.txt -file]

&sv fileunit = [open %rpt_dir%\%workname%.txt openstat -write]
&describe albcov
&sv wstat = [write %fileunit% [quote In Shape File: %shpfile%]]
&sv wstat = [write %fileunit% [quote Cover Name:  [upcase %workname%]]]
&sv wstat = [write %fileunit% [quote Number Arcs:  %dsc$arcs%]]
&sv wstat = [write %fileunit% [quote Precision:  %dsc$precision%]]
&sv wstat = [write %fileunit% [quote Dangle Tolerance:  %dsc$dangle%]]
&sv wstat = [write %fileunit% [quote    Dangle Verified:  %dsc$qdangle_verified%]]
&sv wstat = [write %fileunit% [quote Fuzzy Tolerance:  %dsc$fuzzy%]]
&sv wstat = [write %fileunit% [quote    Fuzzy Verified:  %dsc$qfuzzy_verified%]]
&sv wstat = [write %fileunit% [quote Projection:  %prj$name%]]
&sv wstat = [write %fileunit% [quote Datum:  %prj$datum%]]
&sv wstat = [write %fileunit% [quote Units:  %prj$units%]]
&sv wstat = [write %fileunit% [unquote '']]
```

2. Attribute Checks

```
tables
select albcov.aat
&sv numrecs = [show number select]
reselect sy in {'I','P','S','U','SH','SRI','SRP','SRS','SRU','SRSH'}
&if ( [show number select] ne %numrecs% ) &then
  &do
    &sv wstat = [write %fileunit% [quote Invalid values found for SYSTEM item]]
  &end
&else
  &do
    &sv wstat = [write %fileunit% [quote Valid values found for SYSTEM item]]
  &end
aselect
reselect rt = 0
&if ( [show number select] ne 0 ) &then
  &do
    &sv wstat = [write %fileunit% [quote Null values found for ROUTE item]]
  &end
&else
  &do
    &sv wstat = [write %fileunit% [quote Valid values found for ROUTE item]]
  &end
aselect
reselect ac = [quote [unquote '']]
&if ( [show number select] ne 0 ) &then
  &do
    &sv wstat = [write %fileunit% [quote Null values found for ACCESSORY item]]
  &end
&else
  &do
    &sv wstat = [write %fileunit% [quote Valid values found for ACCESSORY item]]
  &end

quit
```

3. Completeness Checks

```
/* create info file from rt-check.txt control file
&if ^ [exists %in_txt_dir%\%controlfile% -file] &then
 &do
   &ty Acsii file %controlfile% does not exist in %in_txt_dir%
   &call exit
 &end
&if [exists all-rts.dat -info] &then
   &sv d = [delete all-rts.dat -info]
&if [exists rts-control.dat -info] &then
   &sv d = [delete rts-control.dat -info]

tables
define all-rts.dat
sy,4,4,c
rt,4,4,i
ac,4,4,c
len,4,7,F,3
[unquote '']
add from %in_txt_dir%\%controlfile%
redefine
1
rtname
12,12,c
[unquote '']
quit

frequency all-rts.dat rts-control.dat
rtname
[unquote '']
y
y
len
[unquote '']
y
y

/* compare control table with frequency table for identified routes (arcplot)
/* create frequency table for unique occurrences of route name
&if [exists %workname%.frq -info] &then
  &sv d = [delete %workname%.frq -info]
frequency albcov.aat %workname%.frq
rtname
[unquote '']
y
y
[unquote '']
y
y


display 0
arcplot
```

```
&sv wstat = [write %fileunit% [quote Missing Routes]]
&sv wstat = [write %fileunit% [quote ---------------]]
cursor rtcur declare rts-control.dat info ro
cursor rtcur open
&do &while %:rtcur.AML$NEXT%
 reselect %workname%.frq info rtname = [quote %:rtcur.rtname%]
 &if ( [extract 1 [show select %workname%.frq INFO]] = 0 ) &then
  &do
   &sv wstat = [write %fileunit% [quote %:rtcur.rtname%]]
  &end
 &else
  &do
   /*&sv wstat = [write %fileunit% [quote Route identified for [quote %:rtcur.rtname%]]]
  &end
 clearselect %workname%.frq info
 cursor rtcur next
&end
cursor rtcur close
cursor rtcur remove

quit

&sv wstat = [write %fileunit% [unquote '']]
```

4. Route Structure Analysis (Forks and Overlaps)

```
/* identify forks, overlaps in routes by evaluating from/to measures of sections
relate add
secrel
albcov.seclrs
info
lrs#
routelink#
linear
ro
arcrel
albcov.aat
info
arclink#
albcov#
linear
ro
[unquote '']

&sv wstat = [write %fileunit% [quote Route Structure Analysis]]
&sv wstat = [write %fileunit% [quote ---------------------------]]

cursor cur declare albcov route.lrs ro
cursor cur open
&do &while %:cur.AML$NEXT%
  &sv f1 = %:cur.secrel//f-meas%
  &sv t1 = %:cur.secrel//t-meas%
  &sv s1 = %:cur.secrel//lrs#%
  &sv src1 = %:cur.secrel//arcrel//data_sourc%
  cursor cur relate secrel next
  &do  &while %:cur.secrel//AML$NEXT%
    &sv f2 = %:cur.secrel//f-meas%
    &sv t2 = %:cur.secrel//t-meas%
    &sv s2 = %:cur.secrel//lrs#%
    &sv src2 = %:cur.secrel//arcrel//data_sourc%
    &if ( ( %f2% ne %t1% ) and ( %f1% ne %f2% ) ) &then
      &do
        &sv wstat = [write %fileunit% [quote GAP: %:cur.rtname% -- Sections %s1%,%s2% -- Source
 %src1%,%src2%]]
      &end
    &if ( %f1% = %f2% ) &then
      &do
        &sv wstat = [write %fileunit% [quote FORK: %:cur.rtname% -- Sections %s1%,%s2% -- Source
 %src1%,%src2%]]
      &end

    &sv f1 = %f2%
    &sv t1 = %t2%
    &sv s1 = %s2%
    &sv src1 = %src2%
    cursor cur relate secrel next
  &end
  cursor cur next
&end
cursor cur close
cursor cur remove
&sv wstat = [write %fileunit% '']
```

5. Route Length Checks

```
measureroute arc albcov lrs rtname rtname 'length / 5280' # gap # noblank

&if [exists rts.sta -info] &then &sv del = [delete rts.sta -info]
&if [exists sec.sta -info] &then &sv del = [delete sec.sta -info]
routestats albcov lrs rts.sta sec.sta
all
[unquote '']

relate add
rtrel
rts.sta
info
lrs#
lrs#
linear
ro
datrel
rts-control.dat
info
rtname
rtname
linear
ro
[unquote '']

&sv wstat = [write %fileunit% [quote Route Lengths]]
&sv wstat = [write %fileunit% [quote ---------------]]
cursor cur declare albcov route.lrs ro
cursor cur open
&do &while %:cur.aml$next%
  &sv control_len = %:cur.datrel//len%
  &sv diff = [calc %:cur.rtrel//measurelength% - %control_len%]
  &if ( %control_len% > 0.01 ) &then
    &do
      &if ( [calc %diff% / %control_len%] > 0.2 ) &then
        &do
          &sv wstat = [write %fileunit% [quote %:cur.rtname% --- %:cur.rtrel//measurelength% -->  %diff% ]]
        &end
    &end
  &else
    &do
      &sv wstat = [write %fileunit% [quote %:cur.rtname% --- %:cur.rtrel//measurelength% -->  %diff% ]]
    &end
  cursor cur next
&end
cursor cur close
cursor cur remove
&sv wstat = [write %fileunit% '']
```