NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE: ESM 407

COURSE TITLE: GEOGRAPHIC INFORMATION SYSTEMS

MODULE 1 [Introduction to GIS]

Unit 1: Overview

1.0 Introduction

This course is basically aimed at introducing the students to the science, art and technology of Geographic Information Systems (GIS). Some of the basic concepts, components, functions and application of GIS will be introduced in the course. Presented below is a synopsis of the core course contents.

2.0 Objectives

1. To formerly introduce the students to the science and technology of geographical information systems
2. To give a synopsis of the entire course.

3.0 Main Body

Since its inception in the early 1960s, Geographical Information System (GIS), as we know it today, has been growing by leaps and bounds. Originally developed by Geographers, GIS has become a powerful tool useful to all and sundry who handle geospatial data. Traditionally, we have long used maps as a method of storing and disseminating spatial data as well as exploring the earth and locating natural and cultural resources. In fact, the origins of GIS are rooted as far back as several millennia ago, when early man drew cave paintings of the animals they hunted along with crude maps depicting migration trails. While the cave paintings only vaguely resemble today’s advanced geographic information systems they contain the same basic data as modern systems namely, geographic data linked with spatially dependent attribute (descriptive) information.

Modern Geographic Information System (GIS) is a computer based information system used to digitally represent and analyze the geographic features and events on the Earth' surface and the non-spatial attributes linked to the geography under study. This way, the GIS has proved itself as a robust and reliable technology for managing spatial data and as a decision support tool. Indeed GIS is rather revolutionizing the way we collect, store, visualize, analyze and use geographical data.

Owing to its versatility, many disciplines can benefit from GIS technology. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS. These developments will, in turn, result in a much wider use of the technology throughout science, government, business, and industry, with applications including real estate, public health, crime mapping, national defense, sustainable development, natural resources, landscape architecture, archaeology, regional and community planning, transportation and logistics. GIS is also diverging into location-based services (LBS). LBS allows GPS enabled mobile devices to display their location in relation to fixed assets (nearest restaurant, gas station, fire hydrant), mobile assets (friends, children, police car) or to relay their position back to a central server for display or other processing. These services continue to develop with the increased integration of Global Positioning System (GPS) functionality with increasingly powerful mobile electronics (cell phones, PDAs, laptops) coupled with and Web-enabled operations.

This course is designed to be an introductory lesson on GIS. The primal aim is to equip the student with basic knowledge of the technology. At the end of the course the student would have sufficiently learnt a lot of things about GIS, including:

- Definitions of GIS
- Historical development of GIS
- The value of Geographical data
- Other technologies related to GIS
- The components of GIS (hardware, software, data, personnel, and procedure)
- The various functions of GIS
- Database models (spatial and non-spatial)
- Applications of GIS
- Issues in the implementation of GIS.

It should be noted that the Course is structured in modular format; hence the entire Course is divided into five (5) modules. Each module treats a particular theme associated with GIS. Furthermore, each module is sub-divided into Units; there are five (5) Units in each module. The discussions in each Unit are not exhaustive. Consequently, some reference materials as well as other resources for further reading are provided at the end of each Unit.

4.0 Conclusion

GIS is a relatively new technology, at least within the Nigerian context. The student should, therefore, be ready to learn some new terminologies, concepts and methods of managing spatial data in a computer environment. Importantly, the student should pay particular attention to the peculiarities and potentialities and, hence, practical applications of the powerful GIS technology.

5.0 Summary

This course is all about introducing the student to the GIS technology. The course has been organised in a somewhat logical manner. There are all together five (5) modules; each module, in turn, contains five (5) related units. To fully understand and appreciate the GIS technology the student needs to have and use a rich library, which will include manuals of some GIS software packages. By and large, learning GIS becomes more interesting and quicker if the student has a desktop or laptop with GIS software installed on it – after all the taste of the pudding is in the eating!

6.0 References/Further Reading

Bolstad, P. (2005). **GIS Fundamentals: A First Text on Geographic Information Systems**, 2nd. ed. White Bear Lake, MN: Eider Press.

Chang, K. (2006) **Introduction to Geographic Information Systems**, Boston: McGraw Hill Higher Education, Third Edition.

Clarke, K. C. (1995). **Getting Started with Geographic Information Systems**, New Jersey: Prentice Hall, 3rd Edition.

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

http://www.gisdevelopment.net/tutorials/tuman006.htm (Accessed 23/12/10)

Unit 2: Defining GIS

1.0 Introduction

There are several definitions of GIS in existence. However, none of such definitions is universally accepted. It is difficult to agree on a single definition for GIS for the simple reason that various kinds of GISs exist, each made for different purposes and for different types of decision making. As we will see shortly in the range of definitions presented below, people offer definitions of GIS with different emphases on various aspects of GIS.

2.0 Objectives

1. To formerly define or describe GIS
2. To highlight the essential features of GIS
3. To highlight some of the spatial questions that GIS can help us answer easily

3.0 Main Body

3.1 Definition of GIS

Geographic Information System (GIS) has been defined in various ways by different authorities. A typical GIS can be understood by looking at its various definitions. In this section, therefore, we present a selection of the numerous definitions (or descriptions) of GIS that have been offered by people.

GIS is a "Set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes" (Burrough, 1986).

GIS is "a computer based system that provides four sets of capabilities to handle geo-referenced data : data input, data management (data storage and retrieval), manipulation and analysis, and data output. " (Arnoff, 1989).

". . . The purpose of a traditional GIS is first and foremost spatial analysis. Therefore, capabilities may have limited data capture and cartographic output. Capabilities of analyses typically support decision making for specific projects and/or limited geographic areas. The map data-base characteristics (accuracy, continuity, completeness, etc) are typically appropriate for small-scale map output. Vector and raster data interfaces may be available. However, topology is usually the sole underlying data structure for spatial analyses." (Huxhold, 1991 p27).

"A geographic information system is a facility for preparing, presenting, and interpreting facts that pertain to the surface of the earth. This is a broad definition . . . a considerably narrower definition, however, is more often employed. In common parlance, a geographic information system or GIS is a configuration of computer hardware and software specifically designed for the acquisition, maintenance, and use of cartographic data." (Tomlin, 1990 p xi).

"A geographic information system (GIS) is an information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-reference data, as well [as] a set of operations for working with data . . . In a sense, a GIS may be thought of as a higher-order map." (Star and Estes, 1990, pp2-3).

A GIS is "an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information." (ESRI, 1990, p1.2).

"A Geographic Information System (GIS) is a collection of computer hardware, software and geographic data used to analyse and display geographically referenced information." (http://www.bestpricecomputers.co.uk/glossary/geographic-information-system.htm).

"A GIS is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location. Practitioners also define a GIS as including the procedures, operating personnel, and spatial data that go into the system." (http://egsc.usgs.gov/isb/pubs/gis_poster/).

"In the strictest sense, a GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations. Practitioners also regard the total GIS as including operating personnel and the data that go into the system." (http://egsc.usgs.gov/isb/pubs/gis_poster).

"GIS is an integrated system of computer hardware, software, and trained personnel linking topographic, demographic, utility, facility, image and other resource data that is geographically referenced." (http://gis-www.larc.nasa.gov/qat/gisdefinition.html).

A list of additional definitions of GIS can be found in Longley et al (2001).

3.2 Essential features of GIS

From the foregoing it is obvious that a geographic information system (GIS) is a computer-based tool that combines the visual appeal of conventional maps with database operations and statistical analysis. It is used for mapping and analyzing things that exist and happen on the surface of the Earth by classifying the information into "layers", making it easy for users to distinguish each element separately. The speed and accuracy of a GIS provide an invaluable service to organizations, by explaining events, predicting outcomes and planning future strategies. Irrespective of the definition one is giving or adopting, it must be realized that GIS is a peculiar technology with the essential features of spatial references and data analysis. Hence, the true power of GIS lies in its ability to integrate information and to help in making decisions. A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts.

GIS is a technological field that incorporates geographical features with tabular data in order to map, analyze, and assess real-world problems. The key word to this technology is Geography – this means that the data (or at least some portion of the data) is spatial, in other words, data that is in some way referenced to locations on the earth. Coupled with this data is usually tabular data known as attribute data. Attribute data can be generally defined as additional information about each of the spatial features. An example of this would be schools. The actual location of the schools is the spatial data. Additional data such as the school name, level of education taught, student capacity would make up the attribute data. It is the partnership of these two data types that enables GIS to be such an effective problem solving tool through spatial analysis.
GIS operates on many levels. On the most basic level, GIS is used as computer cartography, i.e. mapping. The real power in GIS is through using spatial and statistical methods to analyze attribute and geographic information. The end result of the analysis can be derivative information, interpolated information or prioritized information.

A GIS is an information system designed to work with data referenced by spatial / geographical coordinates. In other words, GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data. It may also be considered as a higher order map. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. (ESRI)

"A geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps." (ESRI).

Many professionals, such as foresters, urban planners, and geologists, have recognized the importance of spatial dimensions in organising & analysing information. Whether a discipline is concerned with the very practical aspects of business, or is concerned with purely academic research, geographic information system can introduce a perspective, which can provide valuable insights as

- 70% of the information has geographic location as its denominator making spatial analysis an essential tool.
- Ability to assimilate divergent sources of data both spatial and non-spatial (attribute data).
- Visualization Impact
- Analytical Capability
- Sharing of Information

In a nutshell, GIS is a special-purpose digital database in which a common spatial coordinate system is the primary means of reference. A full-fledged, comprehensive GIS has dedicated facilities or subsystems for:

- Data input, from maps, aerial photos, satellites, surveys, and other sources
- Data storage, retrieval, and query

- Data transformation, analysis, and modeling, including spatial statistics
- Data reporting, such as maps, reports, and plans

3.3 Questions that GIS can answer

We can gain a deeper understanding of GIS by looking at the type of questions the technology can (or should be able to) answer. GIS can be used to address concerns relating to location, condition, trends, patterns, modelling, spatial questions, as well as aspatial (non-spatial) questions. Basically, we can identify five broad types of questions that a sophisticated GIS can answer (http://www.gisdevelopment.net/tutorials/tuman006.htm).

Location: What is at………….?
This question seeks to find out what exists at a particular location. A location can be described in many ways, using, for example place name, post code, or geographic reference such as longitude/latitude or x/y.

Condition: Where is it………….?
In this question, instead of seeking to identify what exists at a given location, one may wish to find location(s) where certain conditions are satisfied (e.g., all rentable 3-bed room apartments in a neighbourhood, sites suitable for the construction of a cement industry, an unforested section of at-least 2000 square meters in size, within 100 meters of road, and with soils suitable for supporting buildings)

Trends: What has changed since…………..?
This question involves seeking to know what has changed over a given period of time, as well as the magnitude and spatial pattern of such a change (e.g. change in land use or elevation over time).

Patterns: What spatial patterns exist…………..?
This question is more sophisticated. One might ask this question to determine whether, for instance, landslides are mostly occurring near streams. It might be just as important to know how many anomalies there are that do not fit the pattern and where they are located.

Modelling: What if……………..?
"What if…" questions are posed to determine what happens, for example, if a new road is added to a network or if a toxic substance seeps into the local ground water supply. Answering this type of question requires both geographic and other information (as well as specific models). GIS permits spatial operations.

Aspatial Questions
"What's the average number of people working as Estate Surveyors and Agents in each location?" is an aspatial question - the answer to which does not require the stored value of latitude and longitude; nor does it describe where the places are in relation with each other.

Spatial Questions
"How many people work with Estate Firms in the major urban centres of Lagos Metropolis?" OR " Which centres lie within 10 Kms. of each other? ", OR " What is the shortest route passing

through all these centres". These are spatial questions that can only be answered using latitude and longitude data and other information such as the radius of earth. Geographic Information Systems can answer such questions.

4.0 Conclusion

GIS is basically a computer-based system for comprising hardware, software, geographically-referenced data, people and procedures logically arranged to store, retrieve, manipulate, analyze, update and output data (as information), for decision making. This way, GIS should be rightly seen as a powerful decision support system (DSS).

5.0 Summary

Modern computer-based GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data. It may also be considered as a higher order map. GIS can be used to address concerns relating to location, condition, trends, patterns, modelling, spatial questions, as well as aspatial (non-spatial) questions. GIS is a digital technology that combines the visual appeal of conventional maps with database operations and statistical analysis.

6.0 References/Further Reading

Arnoff, (1989).

Burrough, P. A. (1986) **Principles of Geographical Information Systems for Land Resources Assessment**, New York: Oxford University Press.

ESRI (1990). **Understanding GIS: The ARC/INFO Method,** Redlands, CA: Environmental System Research Institute.

http://www.rockvillemd.gov/gis/ (Retrieved 23/12/10)

http://www.gisdevelopment.net/tutorials/tuman006.htm (Retrieved 23/12/10)

http://gislounge.com/what-is-gis/ (Retrieved 22/12/10)

http://www.bestpricecomputers.co.uk/glossary/geographic-information-system.htm (Retrieved 23/12/10)

http://www.gis.com/content/what-gis

Huxhold, W. (1991). **Introduction to Urban Geographic Information Systems**. New York: Oxford University Press.

Longley, P. A., Goodchild, M. F., Maguire, D. J. and Rhind, D. W. (2001). **Geographic Information Systems and Science**, New York: John Wiley & Sons, Inc.

Maguire, D.J. (1991) *An Overview and Definitions of GIS*, in Maguire, D. J., Goodchild, M. F., and Rhind, D. W. (eds) **Geographical Information Systems: Principles and Applications**, London: Longman, Vol. 1, pp. 9-20.

Star, J. and Estes, J. (1990). **Geographic Information Systems: An Introduction,** New Jersey: Prentice-Hall.

Tomlin, C. D. (1990). **Geographic Information Systems and Cartographic Modeling,** New Jersey: Prentice-Hall.

Unit 3 History of GIS development

1.0 Introduction

Man has always used geographical information. Geographical features and data describing them form part of our everyday lives. Indeed most of the decisions we make on a daily basis are influenced by some aspect of Geography. Hence one would be right to say that, generally speaking geographical information system is as old as man himself. However, in this unit our focus is on modern geographical information system. We will briefly look at the emergence and growth of GIS as well as the underlying factors.

2.0 Objectives

1. To trace the historical evolution of GIS
2. To highlight the factors responsible for the growth of GIS

3.0 Main body

3.1 History of development

It is commonly believed that the more sophisticated modern GIS can be traced back to John Snow's 1854 map of the distribution of incidences of cholera in 19th century London. While it is only a fairly basic 2-dimensional rendering, Snow's map is a useful tool to demonstrate the data analysis possibilities of GIS. When viewed in isolation, a list of cholera cases suggests nothing as to the origin of the outbreak. When that same data is translated into a GIS map the data takes on new meaning, allowing the analyst to track down the outbreak to an infected water pump (the Broad Street Pump) in the centre of a cluster. When the pump's handle was disconnected the outbreak was terminated, giving the authorities the opportunity to curtail the cholera outbreak and save lives.

While the basic elements of topography and theme existed previously in cartography, the John Snow map was unique, using cartographic methods not only to depict but also to analyze clusters of geographically dependent phenomena for the first time.

The early 20th century saw the development of photolithography, by which maps were separated into layers. Computer hardware development led to general-purpose computer "mapping" applications by the early 1960s.

Work on GIS began in late 1950s. Canada was the pioneer in the development of GIS as a result of innovations dating back to late 1950s and early 1960s. Much of the credit for the early development of GIS goes to Dr. Roger Tomlinson. The year 1962 saw the development of the world's first true operational GIS in Ottawa, Ontario, Canada by the Federal Department of Forestry and Rural Development. Developed by Tomlinson and his team, it was called the "Canada Geographic Information System" (CGIS) and was used to store, analyze, and manipulate data collected for the Canada Land Inventory (CLI) – an effort to determine the land capability for rural Canada by mapping information about soils, agriculture, recreation, wildlife, waterfowl, forestry, and land use at a scale of 1:50,000. A rating classification factor was also added to permit analysis.

CGIS was the world's first such system and an improvement over "mapping" applications as it provided capabilities for overlay, measurement, and digitizing/scanning. It supported a national coordinate system that spanned the North American continent, coded lines as "arcs" having a true embedded topology, and it stored the attribute and locational information in separate files. As a result of this, Tomlinson has become known as the "father of GIS," particularly for his use of overlays in promoting the spatial analysis of convergent geographic data. CGIS lasted into the 1990s and built a large digital land resource database in Canada. It was developed as a mainframe computer based system in support of federal and provincial resource planning and management. Its strength was continent-wide analysis of complex datasets. The CGIS, however, was never available in a commercial form.

In 1964, Howard T. Fisher formed the Laboratory for Computer Graphics and Spatial Analysis at the Harvard Graduate School of Design (LCGSA 1965-1991), where a number of important theoretical concepts in spatial data handling were developed, and which by the 1970s had distributed seminal software code and systems, such as 'SYMAP', 'GRID', and 'ODYSSEY' -- which served as literal and inspirational sources for subsequent commercial development—to universities, research centers, and corporations worldwide.

By the early 1980s, M&S Computing (later Intergraph), Environmental Systems Research Institute (ESRI), CARIS (Computer Aided Resource Information System) and ERDAS emerged as commercial vendors of GIS software, successfully incorporating many of the CGIS features, combining the first generation approach to separation of spatial and attribute information with a second generation approach to organizing attribute data into database structures. In parallel, the development of two public domain systems began in the late 1970s and early 1980s. The Map Overlay and Statistical System (MOSS) project started in 1977 in Fort Collins, Colorado under the auspices of the Western Energy and Land Use Team (WELUT) and the U.S. Fish and Wildlife Service. GRASS GIS was begun in 1982 by the U.S. Army Corps of Engineering Research Laboratory (USA-CERL) in Champaign, Illinois, a branch of the U.S. Army Corps of Engineers to meet the need of the U.S. military for software for land management and environmental planning.

The later 1980s and 1990s industry growth were spurred on by the growing use of GIS on Unix workstations and the personal computer. By the end of the 20th century, the rapid growth in various systems had been consolidated and standardized on relatively few platforms, and users were beginning to export the concept of viewing GIS data over the Internet, requiring data format and transfer standards. More recently, a growing number of free, open source GIS packages run on a range of operating systems and can be customized to perform specific tasks. Increasingly geospatial data and mapping applications are being made available via the World Wide Web.

Computerized mapping and spatial analysis have been developed simultaneously in several related fields. The present status of GIS would not have been achieved without close interaction between various fields such as utility networks, cadastral mapping, topographic mapping, thematic cartography, surveying and photogrammetry remote sensing, image processing, computer science, rural and urban planning, earth science, and geography.

3.2 Factors Aiding the rise of GIS.

Certain developments over the centuries have been cumulatively instrumental to the emergence and subsequent growth of the GIS technology. Such factors include:

- Revolution in Information Technology.
    - Computer Technology.
    - Remote Sensing.
    - Global Positioning System.
- Communication Technology.
- Rapidly declining cost of Computer Hardware, and at the same time, exponential growth of operational speed of computers.
- Enhanced functionality of software and their user-friendliness.
- Visualizing impact of GIS corroborating the Chinese proverb "a picture is worth a thousand words."

4.0 Conclusion

The management of geographical data has a long and rich history. Modern sophisticated computer-based GIS, however, is a relatively new innovation. Nonetheless, since its formal inception in the early 1960s the GIS industry has been growing by leaps and bounds. Advancements in the field of GIS have been taking place faster than anticipated. The technology is steadily making great inroads into virtually every facet of human endeavour.

5.0 Summary

Present day GIS technology made its debut in the second half of the 20^{th} cc. Over the years, however, this technology has witnessing tremendous transformations in hardware and software engineering, as well as in the manner in which geospatial data are acquired, processed and used. Basically GIS is a contemporary technology for digitally handling the data acquisition, manipulation and analytical operations commonly associated with traditional geography. This technology has been experiencing unprecedented growth, which is encouraged by developments in allied fields (especially ICT) as well as the new impetus given to information (particularly geo-referenced information) as a key infrastructure for sustainable socio-economic development and environmental management.

6.0 References/Further Reading

Chang, K. (2006). **Introduction to Geographic Information Systems**, Boston: McGraw-Hill Companies, Inc. 3^{rd} Edition.

http://www.gisdevelopment.net/tutorials/tuman006.htm (Retrieved 23/12/10) http://www.bestpricecomputers.co.uk/glossary/geographic-information-system.htm (Retrieved 23/12/10)

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

Unit 4: Understanding Geographical Data

1.0 Introduction

GIS is used to manage data. In fact, the ultimate essence of using a GIS is to provide the user with information that can be used to make sound decision and solve some real-world problems. But our concern here is primarily with geographical data or geographical information. Hence, to properly understand and appreciate the workings of GIS and how it is used to handle data, there is need for us to first comprehend the nature and importance of that data.

2.0 Objectives

1. To define geographical data
2. To understand the nature/characteristics of geographical data
3. To identify the types/classes of geographical data
4. To highlight the value of geographical data

3.0 Main Body

3.1 What is Geographical Data?

Geographical data (also known as spatial data) can be defined as any data that has locational or positional identity with respect to the surface of the earth. In other words, geographical data gives us some information about a geographical object or event. Simply put, a geographical object or feature is anything, anywhere. Anything that exists on or in relation to the Earth's surface is a geographical object; similarly, any event that takes place on or in relation to the Earth's surface is a geographical event. So, facts and figures that help us to identify the location and other spatial dimensions of any geographical phenomenon are geographical data.

3.2 Characteristics of Geographical Features

Geographical features have some characteristics which the GIS technology uses to manipulate geographical data. The major characteristics are:

- *Location*: Every geographical phenomenon has a locational or positional identity which can be used to know exactly where it is on or in relation to the surface of the Earth. The relative location of an object can be defined using geographical coordinates (latitude and longitude) or some other form of position identification.
- *Size*: There is a great variety in the magnitude of geographical phenomena. Some are small in size e.g. insects, rats, etc., while some are quite gigantic e.g. mountains, oceans, settlements etc.
- *Dimensions*: Every geographical feature has some geometric dimension(s). Hence each feature can be identified as a point, linear, areal, or volumetric feature. (See the sub-section on types/classes of geographical objects below).
- *Shape*: Geographical objects have shape. Natural features commonly have irregular shapes while most of the man-made features have regular shapes.

- *Distributed*: Geographical phenomena are distributed over space. Some features are highly dispersed while some are clustered together. Similarly, while some features, especially natural features, are more randomly distributed, some others, especially man-made features, tend to be more evenly or regularly distributed. Some geographical objects are considered to be discrete in their distribution; they are not found everywhere, instead they exist at distinct locations e.g. bus stops, boreholes, lakes, etc. On the other hand, some other geographical features are ubiquitous in their distribution; they cover a vast area at varying degrees, e.g. population, temperature, rainfall, soil, etc.
- *Relationship*: No geographical feature exists in isolation; in various ways and degrees they relate and interact with one another. A geographical feature can be located close to or far away from another feature. Also a feature can be locate to the north, east, south, or west of another; just as it could be on the left or right side of another feature. Features could be adjacent to each other; they could also be contiguous to one another in which case they share common boundaries; they can also be widely separated. Similarly features could intersect, just as one feature could lie completely inside another feature. The spatial relationships mentioned above are the key to all GIS-based analysis.

3.3 Types/Classes of Geographical Features

There is a wide range of geographical features in existence. Traditionally, however, all geographical features are grouped into four namely, point, linear, areal (polygon), and volumetric features. This grouping is done based on the geometric dimensions of the features.

- *Point features*: These are features that exist at a single spot without appreciable length and breadth. Hence, point features are considered to be zero dimensional (0-dimensional or 0-D) in nature. Examples include boreholes, bus stops, electrical transformers, etc.
- *Line or linear features*: They are considered to be one dimensional (1-dimensional or 1-D) in nature; it is the length of such features that is usually taken into account. Examples are roads, rivers, railways, etc.
- *Areal or polygonal features*: These are features that occupy a considerably large expanse of space. Both the length and breadth dimensions of such features are usually considered in their measurement; hence they are treated as two dimensional (2-dimensional or 2-D) features. Examples are lakes, farmlands, local government areas, etc.
- *Volumetric features*: these are three dimensional (3-dimensional or 3-D) features. Their length, breadth and height (or depth, or quantity as the case may be) are usually measured. Examples include mountains, population, vehicular traffic, and air mass.

3.4 The value of Geographical data

About 80% or more of the data man uses on a daily basis is geographical in nature. In other words, the decisions and actions we take daily are largely based on information that has geographical content. This should not really be quite surprising, especially when we realize that virtually every activity of man takes place in geographical space. Geographical data or information helps us to understand our environment and, hence, to exploit the available resources in the most productive, sustainable and beneficial manner. More so, geographical information enables us to navigate our environment in an intelligent way. Questions relating to the spatial location, distribution, relationship and accessibility of various phenomena are best answered using geographical information. In other words, geographical knowledge helps us erase locational ignorance by affording us the opportunity of identifying events and features within a spatial frame. Geographical features and data describing them are part of our everyday lives. Most of our daily decisions are influenced by some aspect of Geography.

4.0 Conclusion

GIS makes use of geo-referenced data to function. An understanding of the peculiar nature of geographical data, therefore, is critical to proper handling of the data in a GIS environment. Before entering a piece of geo-data into a GIS environment, the type or class of the data has to be defined; similarly, the type of analysis it would be used for has to be known. Unless a piece of data is given a geographical identity in a GIS environment it will be almost impossible to process the data to yield the desired result. It therefore behoves a potential user of the GIS technology to sufficiently understand the true nature of geographical data; this will help the user in knowing how to handle the data in GIS.

5.0 Summary

Geographical data are facts about geographical features. A geographical feature is anything anywhere. Geographical features could be classified as point, line, areal, or volumetric. The locational, geometric and relational facts, figures, or statistics relating to geographical features are captured and communicated as geographical data. Geographical data/information are quite essential to the everyday intelligent functioning and decision-making of man.

6.0 References/Further Reading

Balogun, O. Y. (2001) *Representation of Geographical Data*, in Uluocha, N. O. and Nsofor, G. N. (eds.) **Cartography and GIS in Nation Building**, Lagos: Nigerian Cartographic Association, pp25-47.

DeMers, M.N. (2000) **Fundamentals of Geographic Information Systems**, New York: John Wiley & Sons.

Jones, C. (1997) **Geographical Information Systems and Computer Cartography**, Essex: Addison Wesley Longman Limited.

Robinson, A. H., Morrison, J. L., Muehrcke, P. C., Kimerling, A. J. and Guptill, S. C. (1995) **Elements of Cartography**, New York: John Wiley & Sons, 6th Edition.

Unit 5 GIS versus Allied Technologies

1.0 Introduction

There are so many terms and technologies that are related to GIS. The use of so many acronyms, synonyms, and terms with related meaning to GIS can actually cause some confusion. This Unit is therefore aimed at assisting the student to know some of the various terms and technologies that are allied to GIS and to know the similarities and dissimilarities between GIS and those other technologies.

2.0 Objectives

1. To highlight some acronyms, synonyms and terms related to GIS.
2. To identify some information technologies that are related to GIS.
3. To differentiate between GIS and other related technologies.

3.0 Main Body

3.1 Related Terms: Acronyms, Synonyms, and More

As noted earlier one reason why it can be difficult to agree on a single definition for GIS is that various kinds of GIS exist, each made for different purposes and for different types of decision making. A variety of names have been applied to different types of GIS to distinguish their functions and roles.

Some of the most widely used related terms include:

- AGIS (Automated Geographic Information System)
- AM/FM (Automated Mapping and Facilities Management): AM/FM is designed specifically for infrastructure management. Automated mapping by itself allows storage and manipulation of map information. AM/FM systems add the ability to link stores of information about the features mapped. However, AM/FM is not used for spatial analysis, and it lacks the topological data structures of GIS.
- CAD (Computer-Assisted Drafting): These systems were designed for drafting and design. They handle spatial data as graphics rather than as information. While they can produce high-quality maps, generally they are less able to perform complex spatial analyses.
- CAM (Computer-Assisted Mapping, or Manufacturing)
- Computerized GIS
- Environmental Information System
- GIS (Geographic Information System)
- Geographically Referenced Information System
- Geo-Information System
- Image-Based Information System
- LIS (Land Information System)
- Land Management System

- Land Record System
- Land Resources Information System
- Multipurpose Cadastre:
- Multipurpose Geographic Data System
- Multipurpose Land Record System
- Natural Resources Inventory System
- Natural Resources Management Information System
- Planning Information System
- Resource Information System
- Spatial Data Handling System
- Spatial Database
- Spatial Information System

3.2 GIS and Related Systems

There are some systems that are similar in both function and name to GIS. Nevertheless such systems are not really geographic information systems as defined above. Broadly, these similar systems do not share GIS's ability to perform complex analysis. Computer-Aided Drafting (CAD) systems, for example, are sometimes confused with GIS. Not long ago, a major distinction existed between GIS and CAD, but their differences are beginning to disappear. CAD systems, used mainly for the precise drafting required by engineers and architects, they are also capable of producing maps though not designed for that purpose. However, CAD originally lacked coordinate systems and did not provide for map projections. Nor were CAD systems linked to data bases, an essential feature of GIS. These features have been added to recent CAD systems, but geographic information systems still offer a richer array of geographic functions.

Uluocha (2007) has identified the similarities and differences between GIS and CAD. Such similarities and differences are discussed below.

Similarities between GIS and CAD

1. Both systems have similar requirements for capturing, storing and displaying graphic images interactively.

2. Interactive commands for entering lines or symbols and for editing, moving, modifying and deleting features are required for both applications.

3. Existing (analogue) maps (in the case of GIS) and drawings (in the case of CAD), must be digitised.

4. Both applications require capabilities for operations such as annotation, labelling, calculation of length, distance and area.

5. Both types of systems require similar computer hardware devices such as processor, disk, tape, workstation, digitizer, scanner, and plotter.

6. Both have requirements for the linking of attribute data with their graphic entities.

Differences between GIS and CAD

1. GIS makes use of maps ranging from large to small scales whereas engineering drawings used in CAD applications usually have very large scales.

2. GIS applications unlike their CAD counterpart, generally require complex and large volume of attribute data.

3. Whereas GIS operations involve complex geographic analysis and modelling of geographic features, CAD applications deal with sophisticated engineering calculations and modelling of engineering structures.

4. GIS makes use of standard map projections while CAD does not. Simple local plane coordinates are usually enough for engineering drawings.

5. GIS has powerful facilities for numerous attribute data processing operations; CAD, on the other hand, has more limited attribute processing capabilities.

6. GIS handles many spatial features such as soil, vegetation, elevation, boundaries, population and infrastructural facilities like roads, sewers, electricity, water, and so on; and also covers a wide geographic area like city, local government, state, country or even the entire earth. On the other hand, CAD applications deal with a specific or single project like the engineering design of a road segment, water or sewer line, electrical wiring, and so on. Such designs are usually done at a very large scale hence they cover very small geographic area.

7. GIS applications use topological data structure that allows for the geographic analysis of the data based on the spatial relationships among map elements. CAD applications do not require a topological data structure.

8. A GIS can be used to perform geographic analytical tasks such as polygon overlay analysis, network tracing and routing, buffering and delineation of service area, district, ecological zone, and so on. A CAD on the other hand, is used for carrying out engineering analysis and calculation functions.

9. GIS is usually used for constant updating of map features, which are known to change frequently. On the other hand, engineering drawings (and structures) hardly change. However, if a major change should occur which may necessitate altering the original concept or structure, an entirely new drawing is produced rather than updating the original drawing.

4.0 Conclusion

There are many digital data processing systems that use geo-referenced data. However, it is not every computer-based system that utilizes geospatial data that can be considered to be a geographical information system. There are notable similarities as well as differences between

GIS and some allied technologies. What distinguish the GIS system from other information systems are its spatial analysis functions. The analysis functions in GIS use the spatial and non-spatial attributes in the database to answer questions about the real world.

5.0 Summary

GIS is used to manage spatial data. Other information systems that can be used to handle spatial data equally exist. However, there are clear similarities and differences between GIS and other related information systems. Unlike most other systems, a typical GIS is a combination of database management system, mapping or graphics system and geostatistical processing/analysis; no other system can boast of such a robust combination. Moreover, whereas other systems are tailored towards handling certain specific and limited tasks, the GIS technology is quite versatile, multifunctional and multipurpose in nature.

6.0 References/Further Reading

Cowen, D.J. (1990) *GIS versus CAD versus DBMS: what are the differences?* in Peuquet, D.J. and Marble, D.F. (eds.) **Introductory Readings in Geographic Information Systems**, New York: Taylor & Francis, pp 52-61.

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

Wise, S. (2002). **GIS Basics**. London: Taylor & Francis.

MODULE 2 [Components of GIS]

Unit 1 GIS Hardware

1.0 Introduction

There are many specialized hardware associated with GIS operations. Hardware comprises the physical electronic equipment needed to support the many activities of GIS ranging from data collection to data analysis and output. In this Unit we will look at the computer, data input devices, data storage devices, data output devices, and other related hardware devices.

2.0 Objectives

1. To identify the hardware components of a typical GIS.
2. To discuss the functions of each of the hardware devices.

3.0 Main Body

3.1 Computer

It consists of the computer system on which the GIS software will run. The computer forms the backbone of the GIS hardware. The central piece of equipment is the workstation, which runs the GIS software and is the attachment point for ancillary equipment. The choice of hardware system ranges from 300MHz personal computers (PCs) to multi-user supercomputers having capability in Tera FLOPS. The computer contains the processor, which is used to manage and manipulate the database based on certain rules and commands.

3.2 Input Devices

The input devices are used to capture or enter data into the computer. There are two broad categories that are usually handled in a GIS environment namely, spatial data and aspatial (attribute or descriptive) data. The spatial data can be entered into the computer with the aid of a digitizer or a scanner. A digitizer is a flat electronic board used for vectorisation of a given map objects. In other words, a digitizer is used for conversion of the drawings on an analogue or hard copy map to digital data. On the other hand, a scanner converts an analogue image or picture into a digital image for further processing. The image data acquired via a scanner can be stored in many formats e.g. TIFF, BMP, JPG etc. The use of handheld field technology is also becoming an important data collection tool in GIS. For instance, data collection efforts can also require the use of a Global Positioning System (GPS) data logger to collect data in the field (Fig. XXXX). The attribute (statistical or non-spatial data) used in GIS are keyed into the computer using the keyboard.

Fig. XXXX A Trimble handheld GPS receiver

3.3 Storage devices

The storage devices include various media such as optical hard disk, magnetic tape, CD, Flash drive.

3.4 Output devices

Output devices are used to obtain the hardcopy versions of processed data. Printers and plotters are the most common output devices for a GIS hardware setup. Presently, printers can only be used to obtain print-outs on paper as large as A3, whereas there are plotters that can draft on paper as large as A0.

3.5 Others

With the advent of web-enabled GIS, web servers have also become an important piece of equipment for GIS.

4.0 Conclusion

In a typical GIS environment various digital hardware devices are used. Some of the devices such as GPS, digitizer, and plotter are rather peculiar to GIS and similar systems, which handle geographical data. The capabilities of these devices can make or mar the success of GIS operations.

5.0 Summary

The hardware components of GIS are the physical electronic devices used in performing GIS operations. The hardware devices include the CPU and allied accessories used in various data handling functions such as data capture/entry, storage, manipulation, output, and distribution. The devices are usually of varying capacities; however, owing to the characteristically voluminous and largely graphic nature of geospatial data, robust and high calibre devices are often preferably required for their handling. In a nutshell, the major hardware-related elements essential for effective GIS operations could be summarized as follows (Burrough, 1986):

- The presence of a processor with sufficient power to run the software;
- Sufficient memory for the storage of large volumes of data;
- A good quality, high-resolution colour graphics screen; and
- Data input and output devices (for example, digitizers, scanners, keyboard, printers and plotters).

6.0 References/Further Reading

Burrough, P. A. (1986) **Principles of Geographical Information Systems for Land Resources Assessment**, New York: Oxford University Press.

Burrogh, P.A. and McDonnell, R.A. (1998). **Principles of Geographical Information Systems**, Oxford University Press.

Clarke, K. C. (1995). **Getting Started with Geographic Information Systems**, New Jersey: Prentice Hall, 3rd Edition.

Heywood, I., Cornelius, S. and Carver, S. (1998). **An Introduction to Geographical Information Systems**, New York: Addison Wesley Longman Limited.

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

Unit 2 GIS Software

1.0 Introduction

In computing, the software is the component that drives the hardware and data using certain methods and rules. There are a number of software packages that are used in GIS operations. GIS software packages are designed to handle geographical or spatial data. In this Unit we will learn about the nature as well as types of GIS software.

2.0 Objectives

1. To understand what a GIS software is.
2. To identify different types /makers of GIS software.

3.0 Main Body

3.1 What is a GIS software?

Generally, software is a digital language comprising of a set(s) of rules, commands, algorithms or programs, logically and systematically written to perform certain tasks. The software elements allow the user to input, store, manage, transform, analyse and output data (Heywood, Cornelius, and Carver, 1998).

Basically, a GIS software is a package of programs, rules or commands used to perform certain GIS operations such as the input, storage, retrieval, editing, querying, analysis, manipulation, update, display and output of geographic data, in a computer environment (Uluocha, 2007). GIS software encompasses a broad range of applications, all of which involve the use of some combination of digital maps and georeferenced data. In the main, GIS software provides the functions and tools needed to store, analyze, and display geographic information. Different software packages are important for GIS. Central to this is the GIS application package. Such software is essential for creating, editing and analyzing spatial and attributes data; therefore these packages contain a myriad of GIS functions inherent to them. Extensions or add-ons are software that extends the capabilities of the GIS software package. Component GIS software is the opposite of application software. Component GIS seeks to build software applications that meet a specific purpose and thus are limited in their spatial analysis capabilities. Utilities are stand-alone programs that perform a specific function. For example, a file format utility that converts from one type of GIS file to another. There is also web GIS software that helps serve data through Internet browsers.

Typical GIS software consists of four distinct but interrelated subsystems or modules. These are:

- Data input software subsystem (used for e.g. digitising or scanning, checking, editing, topology building, etc).
- Data storage and retrieval software subsystem.
- Data manipulation and analysis software subsystem (e.g. for querying, sorting or indexing, overlay operations, buffer creation, etc.)

- Data output software subsystem (e.g. for screen display, page set-up formatting, hard copy generation, etc.)

3.2 Types of GIS software

Numerous GIS software packages are nowadays available which cover all sectors of geospatial data handling. However, the GIS software systems can be sorted into different categories. (See, for example, the Wikipedia Web link listed in the references section of this Unit). Presented below is a list of some notable GIS software packages. It should be noted that some of the packages mentioned are also used for digital cartographic (map-making), CAD, and remote sensing (image processing) operations. (For more details on GIS software packages and their manufacturers, see Uluocha, 2007).

- GRASS GIS – Originally developed by the U.S. Army Corps of Engineers, open source: a complete GIS
- SAGA GIS – System for Automated Geoscientific Analysis- a hybrid GIS software. SAGA has a unique Application Programming Interface (API) and a fast growing set of geoscientific methods, bundled in exchangeable Module Libraries.
- Quantum GIS – QGIS is an Open Source GIS that runs on Linux, Unix, Mac OS X, and Windows.
- MapWindow GIS – Free, open source GIS desktop application and programming component.
- ILWIS – ILWIS (Integrated Land and Water Information System) integrates image, vector and thematic data.
- gvSIG – Open source GIS written in Java.
- JUMP GIS / OpenJUMP – (Open) Java Unified Mapping Platform (the desktop GIS OpenJUMP, SkyJUMP, deeJUMP and Kosmo emerged from JUMP; see [3])
- Whitebox GAT – Open source and transparent GIS software
- Kalypso (software) – Kalypso is an Open Source GIS (Java, GML3) and focuses mainly on numerical simulations in water management.
- TerraView – GIS desktop that handles vector and raster data stored in a relational or geo-relational database, i.e. a frontend for TerraLib.
- Capaware – Capaware is also an Open Source GIS, an incredible fast C++ 3D GIS Framework with a multiple plugin architecture for geographic graphical analysis and visualization.
- FalconView – FalconView is a mapping system created by the Georgia Tech Research Institute for the Windows family of operating systems. A free, open source version is available.
- PostGIS – Spatial extensions for the open source PostgreSQL database, allowing geospatial queries.
- MySQL Spatial
- TerraLib is a spatial DBMS and also provides advanced functions for GIS analysis.
- Spatialite – Spatial extensions for the open source SQLite database, allowing geospatial queries.

- GeoNetwork opensource – A catalog application to manage spatially referenced resources
- Chameleon – Environments for building applications with MapServer.
- MapPoint, a technology ("MapPoint Web Service," previously known as MapPoint .NET) and a specific software program created by Microsoft that allows users to view, edit and integrate maps.
- Autodesk – Products include Map 3D, Topobase, MapGuide and other products that interface with its flagship AutoCAD software package.
- Bentley Systems – Products include Bentley Map, Bentley PowerMap and other products that interface with its flagship MicroStation software package.
- ERDAS IMAGINE by ERDAS Inc; products include Leica Photogrammetry Suite, ERDAS ER Mapper, and ERDAS ECW JPEG2000 SDK (ECW (file format))are used throughout the entire mapping community (GIS, Remote Sensing, Photogrammetry, and image compression).
- ESRI – Products include ArcView 3.x, ArcGIS, ArcSDE, ArcIMS, ArcWeb services and ArcGIS Server.
- Intergraph – Products include GeoMedia, GeoMedia Professional, GeoMedia WebMap, and add-on products for industry sectors, as well as photogrammetry.
- MapInfo by Pitney Bowes – Products include MapInfo Professional and MapXtreme.
- Smallworld – developed in Cambridge, England (Smallworld, Inc.) and purchased by General Electric and used primarily by public utilities.
- Cadcorp – Products include Cadcorp SIS, GeognoSIS, mSIS and developer kits
- Caliper – Products include Maptitude, TransModeler and TransCAD
- ENVI - Utilized for image analysis, exploitation, and hyperspectral analysis.
- Manifold System – GIS software package.
- Netcad – Desktop and web based GIS products developed by Ulusal CAD ve GIS Çözümleri A.Ş.
- Dragon/ips – Remote sensing software with some GIS capabilities.
- Field-Map : GIS tool designed for computer aided field data collection, used mainly for mapping of forest ecosystems.
- VISIONLABS – Products - VISION Enterprise GIS Suite earlier named VISION MapMaker, Complete 2D/3D mapping - Installations in Indian Govt and Defence
- RegioGraph by GfK GeoMarketing; GIS software for business planning and analyses; company also provides compatible maps and market data.
- IDRISI – GIS and Image Processing product developed by Clark Labs at Clark University. Affordable and robust, it is used for both operations and education.
- Boeing's Spatial Query Server spatially enables Sybase ASE.
- DB2 – Allows spatial querying and storing of most spatial data types.
- Informix – Allows spatial querying and storing of most spatial data types.
- Microsoft SQL Server 2008 – The latest player in the market of storing and querying spatial data. At this stage only some GIS products such as MapInfo and Cadcorp SIS can read and edit this data while ESRI and others are expected to be able to read and edit this data within the next few months

- Oracle Spatial – Product allows users to perform complex geographic operations and store common spatial data types in a native Oracle environment. Most commercial GIS packages can read and edit spatial data stored in this way.
- PostGIS – a spatial database based on the free PostgreSQL database
- Safe Software – Spatial ETL products including FME Desktop, FME Server and the ArcGIS Data Interoperability Extension.
- Mapnik - C++/Python library for rendering - used by OpenStreetMap
- GeoServer
- MapGuide Open Source – Web-based mapping server.
- MapServer – Web-based mapping server, developed by the University of Minnesota.
- MapLarge – Web-based mapping server for large datasets.

Software Development Frameworks and Libraries (for web applications)

- OpenLayers – open source AJAX library for accessing geographic data layers of all kinds, originally developed and sponsored by MetaCarta.
- MapFish
- GeoBase (Telogis GIS software) - Geospatial mapping software available as a Software development kit, which performs various functions including address lookup, mapping, routing, reverse geocoding, and navigation. Suited for high transaction enterprise environments.

4.0 Conclusion

Not all that are called GIS software actually have the full range of GIS functionalities. Whereas some packages are general-purpose in nature, some others are thematic or dedicated to performing some specific, usually limited, tasks. Full-fledged GIS software are relatively few.

5.0 Summary

The GIS technology runs on software – a set of logically related rules, commands, algorithm and programs. Some of the software elements are designed to perform a single broad task while some are multi-purpose and multi-functional. The choice of software to install and run on a GIS platform, therefore, depends on the intended use of such a system. By and large, care must be taken to select a software that can conveniently perform any of the four major tasks of GIS software identified above.

6.0 References/Further Reading

Heywood, I., Cornelius, S. and Carver, S. (1998). **An Introduction to Geographical Information Systems**, New York: Addison Wesley Longman Limited.

Steiniger, S. and Weibel R. *"GIS Software - A description in 1000 words"*, http://www.geo.unizh.ch/publications/sstein/gissoftware_steiniger2008.pdf

Steiniger, S. and Bocher, "An Overview on Current Free and Open Source Desktop GIS Developments - Steiniger and Bocher". http://www.spatialserver.net/osgis. (Retrieved 20/7/11)

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

http://en.wikipedia.org/wiki/List_of_geographic_information_systems_software (Retrieved 28/5/11).

Unit 3 Data

1.0 Introduction

Data is the core of any GIS. There are two primary types of data that are used in GIS namely, spatial (or geographic) data and aspatial (attribute or descriptive) data. Documentation of GIS datasets is known as metadata. Metadata contains such information as the coordinate system, when the data was created, when it was last updated, who created it and how to contact them and definitions for any of the code attribute data. Geographic data and related tabular data can be collected in-house or purchased from a commercial data provider. A GIS will integrate spatial data with other data resources and can even use a DBMS, used by most organization to maintain their data, to manage spatial data. This lesson aims at introducing both spatial and attribute data.

2.0 Objectives

1. To introduce spatial data
2. To introduce attribute data

3.0 Main Body

3.1 Spatial data

Spatial data are used to graphically represent some real world features. The features could be material (visible), e.g. road, building, water body; or they could also be abstract (invisible) e.g. geopolitical boundaries, language, temperature. Similarly, spatial data can be obtained from primary or secondary sources. The primary data are obtained first-hand by the user while secondary data are obtained from already existing sources.

The digital map forms the basic data input for GIS. The map is an abstraction or model of some aspect of reality. As shown in Fig. GGG and Table GGG geographical features are abstracted into four spatial entities namely *point* (0-dimensional), *line* (1-dimensional), *area* (2-dimensional), and *volume* (3-dimensional). (See Unit 4 of Module 1). In practice, however, the first three entities (point, line and area) are commonly used.

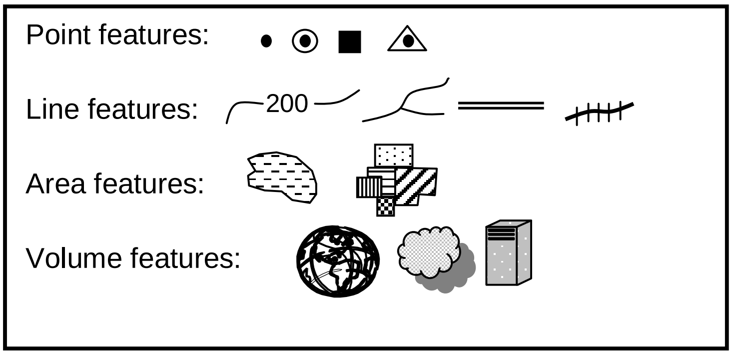

Fig. GGG Categories of Geographic Data (Uluocha, 2007)

Table GGG Geographical Feature Categories and Examples.

FEATURE CATEGORY	EXAMPLES
Point	Borehole, benchmark, Bus Stop
Line	Road, river, railway, coastline
Area	Farmland, lake, forest reserve, boundary
Volume	Population, traffic, air mass

Spatial data in GIS are usually held in a database. A geodatabase is a database that is in some way referenced to locations on the earth. Geodatabases are grouped into two different types: vector and raster. Vector data is spatial data represented as points, lines and polygons. Raster data is cell-based data such as aerial imagery and digital elevation models. The vector and raster models are discussed in greater detail in Unit 2, Module 4.

3.2 Aspatial (attribute) data

Coupled with geographic data is usually data known as aspatial or attribute data. Attribute data is generally defined as additional information about each spatial feature. An attribute data gives descriptive information about some aspect of a geographical entity. Every geographical feature has some attributes. For example, a person is a geographical object located somewhere and occupying space. However, this person also has some attributes with which they can be identified e.g. name, age, complexion, height, tribal/ethnic affiliation, religion, occupation, educational level, hobby, etc. Similarly, a school is a geographical entity having various attributes such as name, address, year of establishment, owner, facilities available (e.g. classrooms, playground, library, laboratory, weather station, hostels), etc.

In a GIS environment attribute data is usually housed in tabular format. This tabular database related to the map objects can also be attached or linked to the digital spatial database (Fig. DDD).

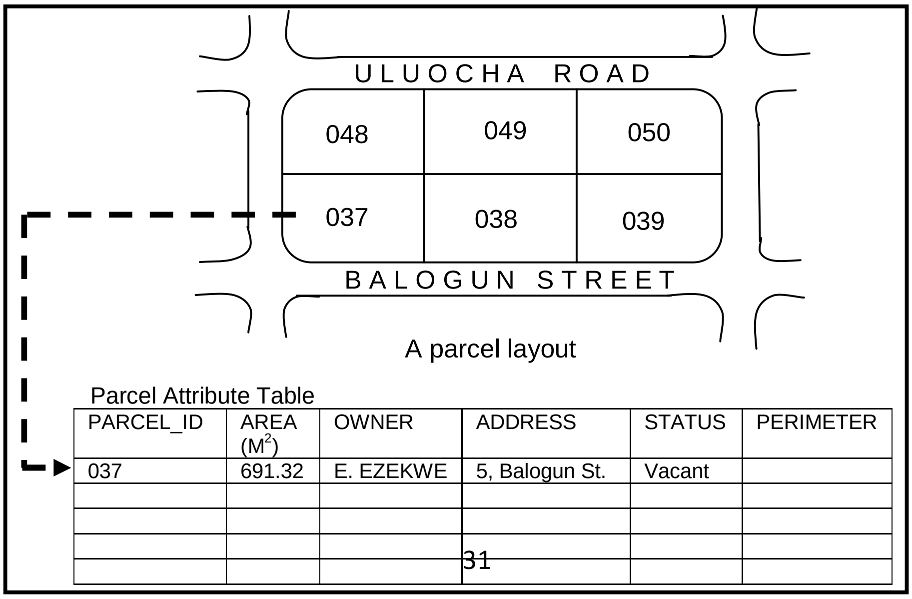

Fig. DDD Linking a geographic file with an attribute table (Uluocha, 2007)

4.0 Conclusion

To successfully implement GIS data is a critical element. Data is the raw material that GIS processes to yield a highly sort after product namely, information. In a sense, data is the element that keeps the engine of GIS running. However, care must always be taken to ensure that the right data is fed into the system. Creating GIS databases could be herculean; yet once in place and routinely updated, the databases are an invaluable asset to the users.

5.0 Summary

Data is a major component of GIS. However, the data to be used for GIS operations must be geographically or spatially referenced. In other words, operating GIS presupposes the availability of a reliable and comprehensive geospatial database coupled with an equally robust attribute database. Without data the GIS cannot work. But before entering any piece of spatial data into GIS it has to be properly classified as either point, linear or areal data. Besides, the attribute database should be properly linked with the spatial database.

6.0 References/Further Reading

Balogun, O. Y. (2001) *Representation of Geographical Data*, in Uluocha, N. O. and Nsofor, G. N. (eds.) **Cartography and GIS in Nation Building**, Lagos: Nigerian Cartographic Association, pp25-47.

ESRI (1991) *A Glossary of GIS and ARC/INFO Terms*, Redlands: Environmental Systems Research Institute, Inc.

Heywood, I., Cornelius, S. and Carver, S. (1998). **An Introduction to Geographical Information Systems**, New York: Addison Wesley Longman Limited.

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

Unit 4 Personnel

1.0 Introduction

Effective development and use of the GIS technology requires the involvement of a number of people performing different tasks. In a GIS environment the people are fittingly referred to as the ***humanware*** or ***liveware***. Well-trained people knowledgeable in spatial analysis and skilled in using GIS software are essential to the GIS process. The humanware coordinates and controls all the other components of GIS. GIS personnel range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work. There are three factors to the people component: education, career path, and networking. The right education is key; taking the right combination of classes. Selecting the right type of GIS job is important. A person highly skilled in GIS analysis should not seek a job as a GIS developer if they haven't taken the necessary programming classes. Finally, continuous networking with other GIS professionals is essential for the exchange of ideas as well as a support community.

2.0 Objectives

1. To identify the various groups of GIS personnel.
2. To identify the functions of GIS personnel.

3.0 Main Body

3.1 Engineers (hardware and software)

This has to with crop of technical specialists who design and maintain the system. They include the hardware engineers who fashion various GIS hardware such as the computers (CPU) and accessories like visual display units (VDUs), digitizers, scanners, disk drives, tape drives, plotters, printers and other hardware components associated with the GIS technology. On the other hand, GIS software engineers specialize in churning out computer programs and programming languages containing a set of rules (or algorithms) for solving certain spatially defined problems.

3.2 Data providers

Data providers are those who collect and/or market spatial/non-spatial data for GIS operations. The data could be acquired through field observation, land survey, GPS, aerial photography, remote sensing technique, socio-economic surveys, and so on. In Nigeria, some of the vendors of data that could be used in GIS projects are the Federal and State Survey Departments; the National Space Research and Development Agency (NASRDA); the Federal Office of Statistics (FOS); the Nigerian Meteorological Agency (NIMET); private surveying/mapping outfits; the Ministry of Environment; Geological Surveys of Nigeria; the National Population Commission (NPC); Centre for Satellite Technology Development, Abuja; National Centre for Remote Sensing, Jos; and so on.

3.3 Digitizers

These are the CAD/GIS operators whose work is to create the database; they vectorise the map objects. In other words, they are those who capture or key in or convert the data from analogue to digital or from binary to image and vector.

3.4 Programmers and Analysts

These are the GIS experts who use of the vectorised data to perform query, analysis or any other work. Their ultimate task is to generate information useful for decision making.

3.5 Managers

The GIS managers undertake administrative functions necessary for the successful implementation of the GIS technology in an organisation. They also make useful decisions based on the available geo-referenced information.

4.0 Conclusion

A team of experts is usually required to successfully install and run a GIS outfit. The quality of personnel involved in the implementation of a GIS project can make or mar the initiative. Hence, concerted effort should be made to ensure that the right calibres of personnel are used. Personnel is the most valuable asset required in the implementation of any GIS programme.

5.0 Summary

GIS personnel are those involved in the provision of the hardware and software, acquisition and handling of data, as well as decision making and implementation.

6.0 References/Further Reading

Adeoye, A.A. (2001) **Geographic Information Systems: Operations and Management**, Lagos: Information Management Consultants.

Aronoff, S. (1995) **Geographic Information Systems: A Management Perspective**, Ottawa: WDL Publications, 4th Print.

Burrogh, P.A. and McDonnell, R.A. (1998). **Principles of Geographical Information Systems**, Oxford University Press.

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

Unit 5 Method

1.0 Introduction

Every task follows some laid down procedure or method; and GIS tasks are no exceptions. But the method of doing things may vary from one task to another and also from one organization to another. In any case, it is always imperative to understand the peculiar method that applies in any given situation. Unless a good understanding of the working procedure in an organization is attained, implementing GIS in that organization may as well be an exercise in futility. Hence, in this Unit we will examine the concept of *method* as an element of GIS.

2.0 Objectives

1. To underscore the need of understanding method or procedure as a major component of GIS.
2. To highlight the need to link GIS procedure with the general business of the company

3.0 Main Body

Simply put, procedure or method has to do with the ways of getting a job done in an organization. But with particular reference to GIS, method could be understood to include a well-designed GIS implementation plan in addition to business rules, which are the models and operating practices unique to each organization (Buckley, *URL*). Method may vary from one organization to another, depending on the objectives as well as *modus operandi* of each individual organization (Uluocha, 2007). The way an estate surveyor/valuer would use the GIS facility, for instance, will differ from how a geologist would use it – since their goals and functions also differ.

The essence of adopting the GIS technology in any organization is to assist the organization to attain its goals. GIS is normally used to meet the information need of an organization, which is quite crucial to decision-making. But for GIS to successfully operate in an organization it has to be appropriately integrated into the business strategy and operations of that organization. Thus, GIS should be a functional part of the entire method of data acquisition, input, storage, sorting, indexing, retrieval, analysis, output and updating, along with the process of decision-making.

GIS could be implemented to simply automate (fully or partially) the methods of executing certain jobs, which hitherto were manually done. This may not involve any major change in procedure except that the job is now done digitally instead of manually. Nonetheless, the adoption of GIS in an organization may necessitate a significant shift in procedure, which could see the organization adopting some entirely new methods of executing some conventional jobs (Uluocha, 2007). For instance, in a GIS environment there are various techniques used for map creation and further usage for any project. The map creation can either be done through automated raster-to-vector conversion or it can be manually vectorised on-screen using the scanned images. The source of these digital maps can be either map prepared by any survey agency or satellite imagery. An organization should be able to decide on which suitable procedure of GIS operations to adopt.

Method or procedure is usually tied to the business of the company. This means before recommending and implementing GIS in a company, the various units of the establishment and the linkages amongst them coupled with the operations/tasks that are carried out must be properly understood. In other words, the method of GIS operation in a company should be dependent on the components of the company, tasks executed, the type of data/information used the pattern of information flow, the information output (product) required, and the general modus operandi of the company.

In discussing or determining the GIS procedure in any organization the following should be taken into consideration:

- The nature of the company's business (what does the company do?)
- Spatial data requirements of the company.
- The types of geospatial data used by the company for its various activity modules.
- How the company collects, converts, stores, and processes its spatial database.
- The pattern of information flow in the company.
- Data accessibility policy of the company.
- Geospatial data handling facilities available.
- The cartographic (map) and allied products (outputs) required by the company.

4.0 Conclusion

Before implementing a GIS in an organization the procedure for the use of the technology should be clearly defined in line with the aim and aspirations of the organization. A successful GIS operates according to a well-designed plan and business rules.

5.0 Summary

Method or procedure is one of the five major components of GIS. It has to do with the way data (geo-referenced data, that is), is managed and used in an organization, in a GIS environment. The process of data handling varies from one organization to another. It is, therefore, important that before introducing GIS into the business of an organization, its general modus operandi, spatial data needs, method of data processing, pattern of information flow, and the use of geo-information in the decision-making process must all be properly understood and incorporated in the GIS implementation programme.

6.0 References/Further Reading

Buckley, *URL*

Uluocha, N. O. (2007). **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

MODULE 3 [Functions of GIS]

Unit 1: Data Input

1.0 Introduction

Data input is a critical aspect of GIS operations. The quality of the output data is largely dependent on the quality of the underlying database. Creating a GIS database could be quite demanding; careful and rigorous planning and execution is usually required. In this Unit we will focus on such data input operations as geographical referencing, digital data conversion/data capture, data checking/editing, and data integration.

2.0 Objectives

1. To discuss the concept of geo-referencing.
2. To examine the processes of spatial and attribute data input.
3. To discuss the issues of data checking and editing.

3.0 Main Body

3.1 Projection

Projection is a key component of map making. A projection is a mathematical means of transferring information from a model of the Earth, which represents a three-dimensional curved surface, to a two-dimensional medium—paper or a computer screen. Different projections are used for different types of maps because each projection particularly suits specific uses. For example, a projection that accurately represents the shapes of the continents will distort their relative sizes.

Since much of the information in a GIS comes from existing maps, a GIS uses the processing power of the computer to transform digital information, gathered from sources with different projections and/or different coordinate systems, to a common projection and coordinate system.

3.2 Geo-referencing

"Every object present on the Earth can be geo-referenced", is the fundamental key of associating any database to GIS. Before using any data in a GIS environment the data should be geo-referenced (Uluocha 2007). Geo-referencing (also known as geo-rectification, geolocating, geocoding or registering) is the process of assigning spatial location identity to pieces of information. In other words, it is the process of giving a cartographic material such as a digital satellite imagery, aerial photograph, map, or statistical data a real world coordinate system and map projection. Or, as Kasianchuk and Taggart (2004) simply put it, "Georeferencing is the process of establishing a relation between the data displayed in your GIS software and its real-world location."

Geo-referencing enables us to know exactly where things are positioned on or in relation to the earth's surface. The geo-referencing process is normally used to relate or link cartographic data to the specific portions on the earth's surface that they represent or pertain to. Besides, geo-referencing enables one to accurately measure distances, directions, sizes (areas) and shapes of features on cartographic base material. In a GIS environment, unless a piece of data is geo-referenced, it would be impossible to undertake certain spatial analysis operations using the data. Georeferencing is commonly achieved by using a coordinate system.

There are various spatial referencing systems in use, some of which are rather crude and simple while some are sophisticated and complex. Nevertheless, it has become somewhat customary to classify geo-referencing systems into two broad groups namely, coordinate systems and non-coordinate systems. Examples of coordinate systems are the spherical (geographic) coordinate system and the rectangular coordinate system. Non-coordinate systems include Postal Addresses and Postal Codes (or ZIP codes in USA), telephone codes, placenames, Enumeration Areas (EAs), House Numberings or Street Addresses, etc. Some common geo-coding systems are shown in Table 3.1. It should be noted, though, that some of the non-coordinate systems, e.g. telephone area codes and postal zip codes, exhibit only rudimentary metric properties and do not give information about direction or size of objects (Fabiyi, 2001, p62).

For large areas such as states, countries, regions, or continents, the spherical (or geographic) grid coordinate system of latitude and longitude is more useful for geo-referencing. Conversely, the plane rectangular grid coordinate system, which makes use of *x*,*y* coordinates (or Eastings and Northings) is more suited to geo-referencing small areas like a school compound, census enumeration area, electoral district, village, ward and township.

The spherical coordinate system is composed of a network of infinite number of latitudes and longitudes. The latitudes and longitudes are usually numbered or identified with angular values in degrees, minutes and seconds, e.g. $4^{o}23'14''$N, $15^{o}07'25''$E. The point of intersection between the Greenwich Meridian and the Equator forms the origin (0) in the spherical coordinate system. In the spherical grid system, the value of latitude is usually given before that of longitude.

Table 3.1 Some commonly used systems of georeferencing

System	**Domain of uniqueness**	**Metric?**	**Example**	**Spatial resolution**
Place-name	Varies	No	Abuja, Ekenobizi, Ghana	Varies by feature type
Postal address	Global	No, but ordered along streets in most countries	21, Abayomi Street, Akoka, Lagos, Nigeria	Size of one mailbox
Postal code	Country	No	101017 (University of Lagos, Akoka, Nigeria)	Area occupied by a defined number of mailboxes
Telephone calling area	Country	No	234 (Nigeria)	Varies

Cadastral system	Local authority	Yes	10m x 30m (Dimensions of a land parcel)	Area occupied by a single parcel of land
Public Land Survey System	Western USA only, unique to Prime Meridian	Yes	Sec 5, Township 6E, Range 4N	Defined by level of subdivision
Latitude/ longitude	Global	Yes	$6^{o}23'15''$N, $10^{o}18'42''$E	Infinitely fine
Universal Transverse Mercator	Zones six degrees of longitude wide, and N or S hemisphere	Yes	542500E, 327638N	Infinitely fine
State Plane Coordinates	Unique to state and to zone within state	Yes	55086.34E, 75210.76N	Infinitely fine

Source: Modified from Longley, et al (2001)

3.3 Spatial Data capture

How can a GIS use the information in a map? If the spatial or cartographic data to be used are not already in digital form, that is, in a form the computer can recognize, various techniques can capture the information. Data capture or conversion is the technical process of entering or putting information into the computer system. Data capture involves identifying the objects on the map, their absolute location on the Earth's surface, and their spatial relationships. This process consumes much of the time of GIS practitioners. Nevertheless, software tools that automatically extract features from satellite images or aerial photographs are now gradually replacing what has traditionally been a time-consuming capture process. There are a variety of methods used to enter spatial data into a GIS where it is stored in a digital format.

Existing spatial data printed on paper or PET film maps can be digitized or scanned to produce digital data. As earlier noted, a digitizer produces vector data as an operator traces points, lines, and polygon (areal) boundaries from a map. Maps can be digitized by hand-tracing with a computer mouse on the screen or on a digitizing tablet to collect the coordinates of features. Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map, survey plan or chart is transferred into a digital medium through the use of a computer-aided design (CAD) program, and geo-referencing capabilities. With the wide availability of ortho-rectified imagery (both from satellite and aerial sources), heads-up digitizing is becoming the main avenue through which geographic data is extracted. Heads-up digitizing involves the tracing of geographic data directly on top of the aerial imagery instead of by the traditional method of tracing the geographic form on a separate digitizing tablet (heads-down digitizing).

Digitization or conversion of existing paper based records, plans, maps and charts to digital using any of the three established and tested methods:

- Using the Digitizing tablet manually.
- Using the semi-automatic raster chasing method
- Using the Bundle (Fully automatic) method.

Electronic scanners can also convert maps to digits. Scanning a map results in raster data, which could be further processed to produce vector data through a process known as vectorization. Table XXXX shows the comparative advantages and disadvantages of the manual digitising process to the automatic scanning technique.

Survey data can also be directly entered into a GIS from digital data collection systems on survey instruments using a technique called Coordinate Geometry (COGO). Positions from a Global Navigation Satellite System (GNSS) like Global Positioning System (GPS), another survey tool, can also be directly entered into a GIS. Coordinates from GPS receivers can be uploaded into a GIS. Current trend is data collection and field mapping carried out directly with field computers (position from GPS and/or laser rangefinder). New technologies allow for the creation of maps as well as data analysis directly in the field; this makes mapping projects efficient and accurate.

Remotely sensed data also plays an important role in spatial data collection. This consists of sensors attached to a platform such as an aircraft or spacecraft (satellite). Sensors include cameras, digital scanners and LIDAR. Here satellites use different sensor packages to passively measure the reflectance from parts of the electromagnetic spectrum or radio waves that were sent out from an active sensor such as radar. Remote sensing collects raster data that can be further processed using different bands to identify objects and classes of interest, such as land cover.

The majority of digital spatial data currently comes from photo interpretation of aerial photographs. Soft copy workstations are used to digitize features directly from stereo pairs of digital photographs. These systems allow data to be captured in two and three dimensions, with elevations measured directly from a stereo pair using principles of photogrammetry. Currently, analog aerial photos are scanned before being entered into a soft copy system, but as high quality digital cameras become cheaper this step will be skipped.

Table XXXX: Digitizing and Scanning Techniques Compared.

Manual digitizing	Automatic Scanning
▪ A time-consuming procedure. ▪ The spatial (map) data is recorded in vector format. ▪ Can be used to selectively capture map data (the operator digitizes only the required features). This reduces the amount of time spent on cleaning and editing the data. ▪ The procedure requires a lot of human input (labour-intensive). ▪ The captured linework often has a high resolution, hence suitable for map production. ▪ The source material to be digitized can easily be geo-referenced. ▪ Suitable for small mapping projects, which involve very few map sheets.	▪ Less time-consuming ▪ The spatial data is recorded in raster (grid cell) format. ▪ Automatically captures every feature on the source document (e.g. map, aerial photograph, orthophoto map, satellite imagery). This creates additional editing problem. ▪ Requires less human input. ▪ Resolutions of lineworks are not often high, hence not quite suitable for map production. ▪ The process of geo-referencing source material is usually extensive. ▪ Suitable for very large mapping and geographical analysis projects requiring the digital conversion of several map sheets, aerial photos or satellite imagery.

Source: Uluocha (2007)

Data restructuring can be performed by a GIS to convert data into different formats. Since digital data is collected and stored in various ways, the data sources may not be entirely compatible. Some of the data may be in vector format while some may be in raster format. So a GIS must be able to convert geographic data from one structure to another. For example, a GIS may be used to convert a satellite image (raster) map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion; this process is known as raster-to-vector conversion.

3.4 Attribute Data Capture

In addition to collecting and entering spatial data, attribute data is also entered into a GIS. For vector data, this includes additional information about the map objects represented in the system. A typical attribute data consists of statistical facts and figures which are usually presented in tabular form. Hence, the keyboard is the device normally used to put attribute data into the computer. If the data already exists as an electronic file, for example as a spreadsheet, it can be simply downloaded into the GIS.

3.5 Checking and Editing

The data capture process is never error-free. Hence, after capturing the geographical data or keying in the statistical (attribute) data into a GIS, the data usually requires checking and editing, to identify and remove any errors, or further processing. For vector data it must be made "topologically correct" before it can be used for some advanced analysis. For example, in a road network, lines must connect with nodes at an intersection. Errors such as undershoots and overshoots must also be removed. For scanned maps, blemishes on the source map may need to be removed from the resulting raster. For example, a fleck of dirt might connect two lines that should not be connected.

The possible errors that could occur in a digitized map include (See Fig XXXX):

- *Pseudo nodes (unwanted nodes)*
- *Overshoots and undershoots (unwanted dangling arcs/nodes)*
- *Sliver polygons (unwanted overlapping polygons)*

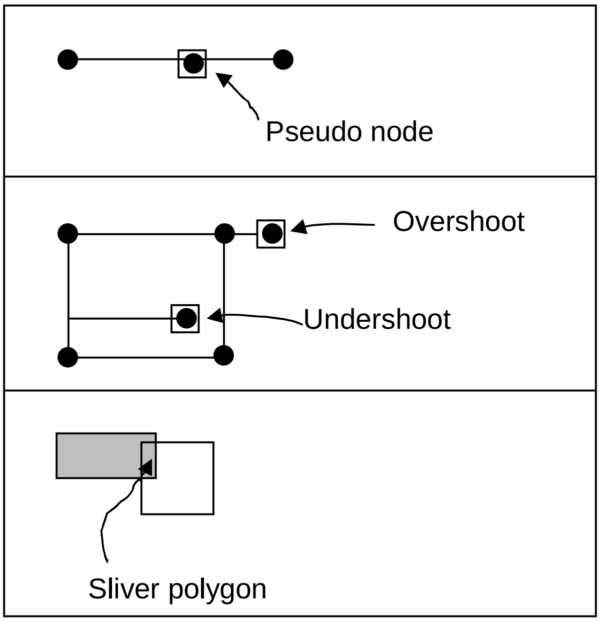

Fig. XXXX Common errors in digitized map data

The possible attribute data entry errors include the following:

- *Spelling errors.*
- *Entering of wrong digits (numerical figures).*
- *Wrong field naming (e.g. designating a field as "character" instead of "numeric", and vice versa).*
- *Too long or too short field width (size).*
- *Omission of some data items.*
- *Inclusion of unwanted data items.*

3.6 Data Integration

A GIS makes it possible to link, or integrate, information that is difficult to associate through any other means. In other words, GIS is effectively used to relate information from different sources. Thus, a GIS can use combinations of mapped variables to build and analyze new variables (Fig. XXXX). For example, using GIS technology, it is possible to combine agricultural records with hydrography data to determine which streams will carry certain levels of fertilizer runoff. Agricultural records can indicate how much pesticide has been applied to a parcel of land. By locating these parcels and intersecting them with streams, the GIS can be used to predict the amount of nutrient runoff in each stream. Then as streams converge, the total loads can be calculated downstream where the stream enters a lake.

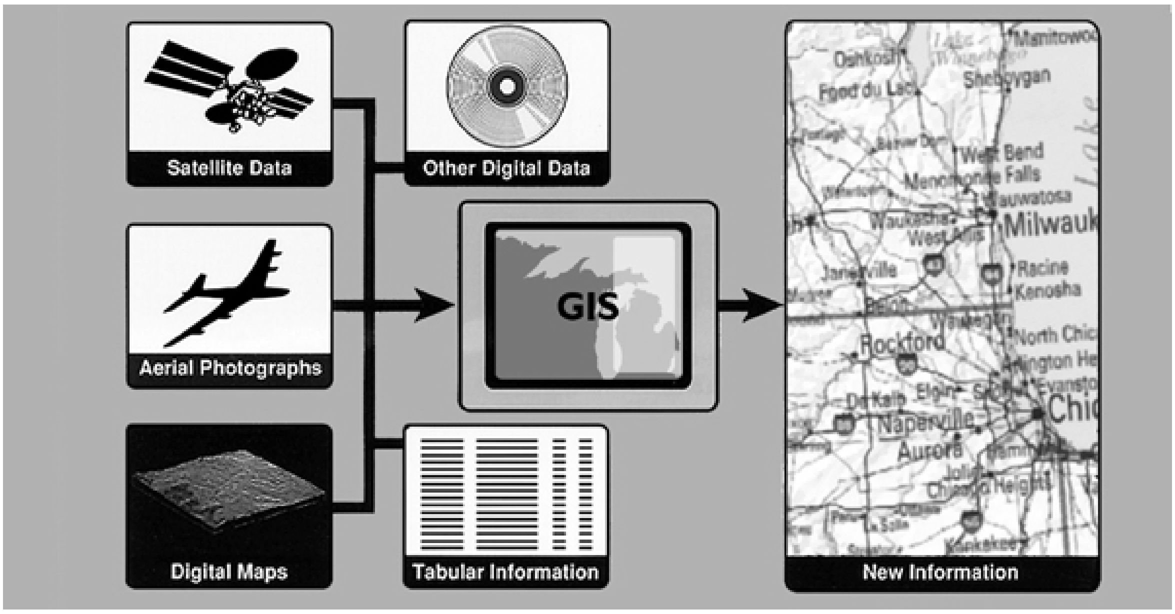

Figure XXXX. Data integration is the linking of information in different forms through a GIS.

The power of a GIS comes from the ability to relate different information in a spatial context and to reach a conclusion about this relationship. Most of the information we have about our world contains a location reference, placing that information at some point on the globe. For instance, when rainfall information is collected, it is important to know where the rainfall is located. This is done by using a location reference system, such as longitude and latitude, and perhaps elevation. Comparing the rainfall information with other information, such as the location of marshes across the landscape, may show that certain marshes receive little rainfall. This fact may indicate that these marshes are likely to dry up, and this inference can help us make the most appropriate decisions about how humans should interact with the marsh. A GIS, therefore, can reveal important new information that leads to better decision-making.

4 Conclusion

Data input is a major function of GIS; it is one of the most critical and cumbersome aspects of the system. Creating a robust, reliable and comprehensive database is crucial to the success of GIS operations. The quality of the outcome obtainable from GIS cannot be different from the quality of the underlying database – it's still a case of "garbage in, garbage out". Thus in any GIS project the data input operation should be properly planned and meticulously executed.

5 Summary

Data is the raw material that GIS processes to produce the much desired information. But before this data can be processed it has to be entered into the system through a process known as data input. The spatial data, which could be in form of a map, aerial photo or satellite image, has to be captured into the system. If the data source is in analogue form (hardcopy) it can be digitized directly into the system or scanned before digitizing it on-screen. The relevant attribute or non-spatial data are usually entered into the system via the computer keyboard. After inputting the data it has to be cleaned up by carefully checking for and correcting any possible errors. The edited data is then stored in any suitable electronic storage medium, for further use.

6 References/Further Reading

Fabiyi, S. (2001). **Geographic Information Systems: techniques and methods**, Ibadan: Research Support Services.
Kasianchuk, P. and Taggart, M. (2004). **Introduction to ArcGIS I**, Redlands: Environmental Systems Research Institute (ESRI).

Longley, P. A., Goodchild, M. F., Maguire, D. J. and Rhind, D. W. (2001). **Geographic Information Systems and Science**, New York: John Wiley & Sons, Inc.

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

Unit 2: Data storage

1.0 Introduction

Perhaps data maintenance in a GIS environment starts with having in place a good data storage system. Once a database has been created it needs to be properly stored for safe-keeping and easy access. There are various digital data storage devices available today. In this Unit we will take a quick look not only at the available devices but also the peculiar requirements and qualities of devices for the storage and handling of geospatial data.

2.0 Objectives

1. To identify the various electronic data storage devices used in GIS
2. To discuss the qualities of good storage devices.

3.0 Main Body

3.1 Data storage

It's not just enough to digitally compile data; once compiled, the digital map files and the related attributes data files in the GIS should be stored on magnetic or other digital media. In a GIS environment data storage is based on a *Generic Data Model* that is used to *convert map data into a digital form*. As already identified, the two most common types of spatial data models are ***Raster*** and ***Vector***. Both types are used to simplify the data shown on a map into a more basic form that can be easily and efficiently stored in the computer. On the other hand, the tabular *Relational* data model is commonly used to store attribute data.

It is instructive to note that the particular model – raster or vector -- used to store spatial data matters a whole lot. As we have already discussed, comparatively speaking, each of the models has its own merits and demerits. Hence, in deciding on which model to choose for data storage, the intended application of the database and the expected output (end product) should be taken into consideration. Moreover, it must be borne in mind that certain operations are more efficiently executed using one type of data model than the other.

3.2 Storage devices

Various data storage devices exist for GIS configurations. These devices are commercially available in varying physical dimensions and storage densities. Conventionally, the magnetic tape and the optical disk are the two types of storage devices used in GIS. However, not too long ago the Zip Drive, compact disk (CD) and FlashDisk joined the family of computer storage media. Diskettes, which were once in vogue, are hardly in use nowadays.

Usually, large storage capacities are required for GIS applications. This should be so because GIS databases apart from being traditionally large often include graphic data, which normally make high demand on computer storage space (Uluocha, 2007). Presently, optical disks with a capacity of several terabytes exist. Such very high storage capacity media can conveniently be used to handle large geographic databases. It should also be noted that for efficient and effective GIS operations, a storage device with an efficient read/write mechanism, hence a fast input/output (I/O) rate, is most desirable. Ordinarily, owing to the large volume of a typical geographic database coupled with the graphic component, it took a while to retrieve and view data in a GIS environment. However "with more efficient read/write mechanisms, higher capacity I/O channels, and intelligent disk controlling devices" (Croswell and Stephen, 1988), it is now a lot faster to retrieve, view, query and manipulate geographical databases.

3.3 Qualities of a good storage device

Owing to the fact that geospatial data are characteristically voluminous coupled with the peculiar nature of some GIS operations, a storage device that meets certain qualities is usually desirable. Fast access rate to data, which allows for real-time processing. For a storage device to be considered good enough for data storage in a GIS environment it should have the following qualities:

- Very high storage density, which can conveniently support the often large volume of geographic databases.
- Efficient read/write mechanism,
- Fast input/output (I/O) rate
- Cost effective.
- Durable
- Less prone to virus attack

4.0 Conclusion

Once the data have been digitally compiled, digital map files and the associated attributes data files in the GIS are stored on magnetic or other digital media. For smooth operations and to obtain good results, appropriate data model and robust devices must be chosen, for data storage.

5.0 Summary

Data storage is an important aspect of every GIS operation. Both the spatial and non-spatial data captured must be properly stored. In storing the data files, an appropriate data storage model should be used; for spatial data this could either be raster model or vector model, while the relational structure is mostly used for non-spatial data. There are many electronic data storage devices. However, given the oft voluminous nature of the data used in GIS, a storage device that is robust, efficient, durable, resilient, and with very high storage density is most preferable.

6.0 References/Further Reading

Croswell, P.L. and Clark, S.R. (1988). Trends in Automated mapping and Geographic Information System Hardware, ***Photogrammetric Engineering and Remote Sensing***, Vol. 54, No. 11, pp. 1571-1576.

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

Unit 3: Data Manipulation and Analysis

1.0 Introduction

Spatial analysis is one of the major a GIS performs. There is a vast range of spatial analysis techniques that have been developed over the past half century. The subject of spatial analysis is a rapidly changing field, and GIS packages are increasingly including analytical tools as standard built-in facilities or as optional toolsets, add-ins or 'analysts'. In many instances such facilities are provided by the original software suppliers (commercial vendors or collaborative non commercial development teams), whilst in other cases facilities have been developed and are provided by third parties. Furthermore, many products offer software development kits (SDKs), programming languages and language support, scripting facilities and/or special interfaces for developing one's own analytical tools or variants. In this session we will look at some of the spatial analytical operations that can be carried out using GIS.

2.0 Objectives

1. To identify some of the major data manipulation and analysis operations carried out in GIS.
2. To discuss in detail some of the geographical analysis procedures.

3.0 Main Body

3.1 Data manipulation/analysis operations

Although the data input is, in general, the most time consuming part, it is for data analysis that GIS is used. What distinguish the GIS system from other information system are its spatial analysis functions. The heart of GIS is the analytical capabilities of the system. The analysis functions use the spatial and non-spatial attributes in the database to answer questions about the real world. Geographic analysis facilitates the study of real-world processes by developing and applying models. Such models illuminate the underlying trends in geographic data and thus make new information available. The objective of geographical analysis is to transform data into useful information to satisfy the requirements or objectives of decision-makers at all levels in terms of detail. Results of geographical analysis are mostly communicated with the help of maps, and/or graphs (charts).

GIS offers the user several data manipulation and analysis options. The facilities available in GIS for data processing functions are known as "*Toolkits*." A toolkit is a set of generic functions that a GIS user can utilize to manipulate and analyze geographic and attribute data. Toolkits provide processing functions such as data retrieval, query, measuring area and perimeter, overlaying maps, performing map algebra, and reclassifying map data. Data manipulation tools include:

- Coordinate change (for changing from one geographical coordinate system to another),
- Projections (for changing from one map projection to another),
- Rescaling (for changing map scale), and
- Edge matching (or rubber sheeting), which allows a GIS to reconcile irregularities between map layers or adjacent map sheets called Tiles.

Similarly, GIS is usually equipped with a number of analytical tools for conducting various kind of geographical analysis. Among the broad range of major geographical analysis procedures in GIS are:

- Database query
- Map overlay
- Proximity analysis
- Network analysis
- Digital Terrain Modeling (DTM)
- Statistical and Tabular Analysis.

3.2 Some geographical analysis procedures

This subsection looks briefly at some of the geographical analysis functions carried out using GIS.

3.2.1 Slope and Aspect

Slope, aspect and surface curvature in terrain analysis are all derived from neighbourhood operations using elevation values of a cell's adjacent neighbours. There are various techniques for calculating slope and aspect. Slope is a function of resolution, and the spatial resolution used to calculate slope and aspect should always be specified.

3.2.2 Data modeling

A GIS, however, can be used to depict two- and three-dimensional characteristics of the Earth's surface, subsurface, and atmosphere from information points. For example, a GIS can quickly generate a map with isopleth or contour lines that indicate differing amounts of rainfall. Such a map can be thought of as a rainfall contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. A two-dimensional contour map created from the surface modeling of rainfall point measurements may be overlaid and analyzed with any other map in a GIS covering the same area. For example, with a GIS one can easily relate wetlands maps to rainfall amounts recorded at different points such as airports, television stations, and high schools.
Additionally, from a series of three-dimensional points, or digital elevation model, isopleth lines representing elevation contours can be generated, along with slope analysis, shaded relief, and other elevation products. Watersheds can be easily defined and delineated for any given reach, by computing all of the areas contiguous and uphill from any given point of interest.

3.2.3 Topological modeling

A GIS can recognize and analyze the spatial relationships that exist within digitally stored spatial data. These topological relationships allow complex spatial modelling and analysis to be performed. Topological relationships between geometric entities traditionally include adjacency (what adjoins what), containment (what encloses what), and proximity (how close something is to something else).

3.2.4 Network Analysis

The GIS can be used to undertake various network analyses. With the GIS, for instance, one can study the network density, network characteristics, network behavior, and network function. The flow of materials and energy in a network can be modelled using GIS. Similarly, the potential impacts of a given network can equally be examined using GIS. For instance, if all the factories near a wetland were accidentally to release chemicals into the river at the same time, how long would it take for a damaging amount of pollutant to enter a recipient wetland reserve? A GIS can simulate the routing of materials along a linear network. Values such as slope, speed limit, or pipe diameter can be incorporated into network modeling to represent the flow of the phenomenon more accurately. Network modelling is commonly employed in transportation planning, hydrology modelling, and infrastructure (utility) modelling.

3.2.5 Hydrological Modeling

GIS hydrological models can provide a spatial element that other hydrological models lack, with the analysis of variables such as slope, aspect and watershed or catchment area. Terrain analysis is fundamental to hydrology, since water always flows down a slope. As basic terrain analysis of a Digital Elevation Model (DEM) involves calculation of slope and aspect, DEMs are very useful for hydrological analysis. Slope and aspect can then be used to determine direction of surface runoff, and hence flow accumulation for the formation of streams, rivers and lakes. Areas of divergent flow can also give a clear indication of the boundaries of a catchment. Once a flow direction and accumulation matrix has been created, queries can be performed that show contributing or dispersal areas at a certain point. More detail can be added to the model, such as terrain roughness, vegetation types and soil types, which can influence infiltration and evapotranspiration rates, and hence influencing surface flow. These extra layers of detail ensure a more accurate model.

3.2.6 Cartographic modeling

The term "cartographic modeling" refers to a process where several thematic layers of the same area are produced, processed, and analyzed to obtain a composite map. The map overlay (or simply overlay) method is generally used to achieve this. Map overlay (Fig. CCCC) involves the combination of several vector spatial datasets (points, lines or polygons) to create a new output vector dataset, visually similar to stacking several maps of the same region. These overlays are similar to mathematical *Venn diagram* overlays. A *union* overlay combines the geographic features and attribute tables of both inputs into a single new output. An *intersect* overlay defines the area where both inputs overlap and retains a set of attribute fields for each. A *symmetric difference* overlay defines an output area that includes the total area of both inputs except for the overlapping area.

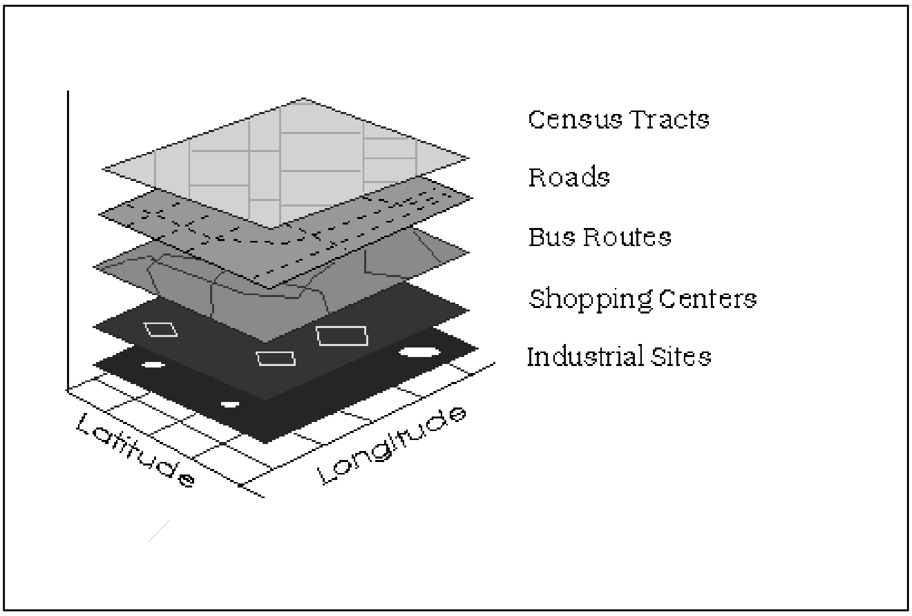

Fig. CCCC The concept of map overlay

3.2.7 Geostatistics

Geostatistics is a point-pattern analysis that produces field predictions from sample data points. It is a way of looking at the statistical properties of those special data. It is different from general applications of statistics because it employs the use of graph theory and matrix algebra to reduce the number of parameters in the data.

When phenomena are measured, the observation methods dictate the accuracy of any subsequent analysis. Due to the nature of the data (e.g. traffic patterns in an urban environment; weather patterns across Nigeria), a constant or dynamic degree of precision is always lost in the measurement. This loss of precision is determined from the scale and distribution of the data collection. Usually the larger the sample size the more accurate will the result of the analysis be. To determine the statistical relevance of the analysis, an average is determined so that points (gradients) outside of any immediate measurement can be included to determine their predicted behavior. This is due to the limitations of the applied statistic and data collection methods, and interpolation is required to predict the behavior of particles, points, and locations that are not directly measurable.

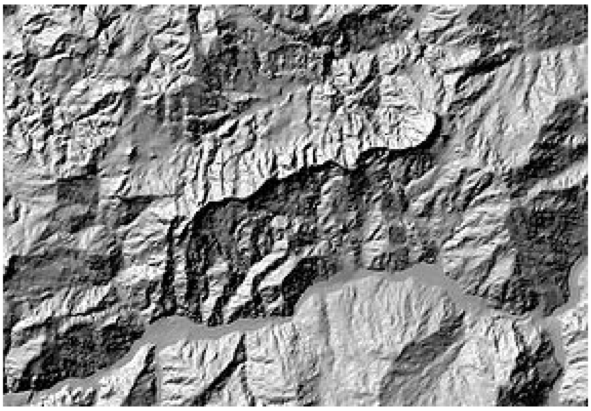

Fig. JJJJ Hillshade model derived from a Digital Elevation Model (DEM)

Interpolation is the process by which a surface is created (Fig. JJJJ), usually a raster dataset, through the input of data collected at a number of sample points. There are several forms of interpolation, each of which treats the data differently, depending on the properties of the data set. In comparing interpolation methods, the first consideration should be whether or not the source data will change (exact or approximate). Next is whether the method is subjective, a human interpretation, or objective. Then there is the nature of transitions between points: are they abrupt or gradual. Finally, there is whether a method is global (it uses the entire data set to form the model), or local where an algorithm is repeated for a small section of terrain.

Digital elevation models (DEM), triangulated irregular networks (TIN), edge finding algorithms, Thiessen polygons, Fourier analysis, (weighted) moving averages, inverse distance weighting, kriging, spline, and trend surface analysis are all mathematical methods to produce interpolative data.

3.2.8 Address geocoding

Geocoding is interpolating spatial locations (X,Y coordinates) from street addresses (i.e. street names and house numbering), or any other spatially referenced data such as Postcodes or ZIP Codes, parcel lots and address locations. A reference theme is required to geocode individual addresses, such as a road centerline file with address ranges. The individual address locations have historically been interpolated, or estimated, by examining address ranges along a road or street segment. These are usually provided in the form of a table or database. The GIS will then place a dot approximately where that address belongs along the segment of centerline. For example, an address point of 50 will be at the midpoint of a line segment that starts with address 1 and ends with address 100. Geocoding can also be applied against actual parcel data, typically from municipal tax maps (cadastral maps). In this case, the result of the geocoding will be an actually positioned space as opposed to an interpolated point. This approach is being increasingly used to provide more precise location information.

There are several potentially dangerous caveats that are often overlooked when using interpolation. Various algorithms are used to help with address matching when the spellings of addresses differ. Address information that a particular entity or organization has data on, such as the post office, may not entirely match the reference theme. There could be variations in street name spelling, community name, etc. Consequently, the user generally has the ability to make matching criteria more stringent, or to relax those parameters so that more addresses will be mapped. Care must be taken to review the results so as not to map addresses incorrectly due to overzealous matching parameters.

4.0 Conclusion

What distinguish the GIS system from other information system are its spatial analysis functions. As a matter of fact, the heart of GIS is the analytical capabilities of the system; it is for data analysis that GIS is used.

5.0 Summary

Once data are stored in a GIS, many manipulation options are available to users. The analysis functions use the spatial and non-spatial attributes in the database to answer questions about the real world. The objective of geographic analysis is to transform data into useful information to satisfy the requirements or objectives of decision-makers at all levels in terms of detail.

6.0 References/Further Reading

GIS Primer, *http://gis.nic.in/gisprimer/analysis3.html* (Retrieved 27/7/11).

http://en.wikipedia.org/wiki/File:Dem.jpg

Unit 4: Data Output

1.0 Introduction

A critical component of a GIS is its ability to produce graphics on the screen or on paper to convey the results of analyses to the people who make decisions about resources. Wall maps, Internet-ready maps, interactive maps, and other graphics can be generated, allowing the decision-makers to visualize and thereby understand the results of analyses or simulations of potential events.

2.0 Objectives

1. To examine the issue of data display in a GIS environment
2. To discuss document and printing formatting
3. To look at the issue of final data output.

3.0 Main Body

3.1 Data Display

Data display is a form of data output – softcopy output. To work interactively with the computer system the data has to be displayed. The VDU (visual display unit) also known as monitor or screen, is usually the medium of data display. Both the graphic (map and chart) and textual (attribute) data can be displayed. The attribute data is usually displayed in tabular format. The spatial data is commonly displayed in map form. Most GIS operations involve a lot of graphics; consequently, a high-resolution VDU with a powerful GUI (graphical user interface) is often desirable.

There are various graphic display techniques. The VDU can be used to present spatial (map) data as a planimetric (2-D) or altrimetric (3-D) displayed, depending on the nature of the data. Traditional maps are abstractions of the real world, a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Topographic maps show the shape of land surface with contour lines or with shaded relief. Today, graphic display techniques such as shading based on altitude in a GIS can make relationships among map elements visible, heightening one's ability to extract and analyze information. For example, two types of data could be combined in a GIS to produce a perspective view of a portion of an area. This can be done by using the digital elevation model, consisting of surface elevations and a satellite image for the same coordinate points, pixel by pixel, as the elevation information.

3.2 Document Formatting

Before the hardcopy of a document is printed (or plotted) some form of formatting may be required. Formatting involves preparing and presenting the document in the desired final output form. This is a form of customizing the document. Thus, document formatting may involve defining certain specifications or settings relating to the document to be produced. Formatting applies to both the graphics and texts. It equally involves defining printing or plotting options. The graphics, texts and printing formatting exercises are discussed below.

Graphics (map) formatting: This relates to the modifications made on the map to enhance its aesthetics and communication efficiency. The formatting exercise may include:

- Modifying feature colour (gray tone (black & white), or coloured).
- Modifying symbols.
- Inserting neatlines (borderlines) around the map.
- Choosing North Arrow symbol.
- Adding/modifying graticules (lines of latitude and longitude), legend and scale bar.
- Adding inset map.
- Adding/editing labels (map lettering).
- Proper positioning of map elements (e.g. map area, scale bar, legend box, north arrow, title, source, disclaimer, copyright, etc.), to achieve balance.
- Map embellishment.

Text formatting: This has to do with certain modifications that could be applied to the text and font. This may involve specifying font:

- Type (e.g. Arial, Times New Roman, Tahoma, etc.)
- Colour
- Size (e.g. 8, 12, 36, 72 point size)
- Style (e.g. normal, italics, bold)
- Underlining
- Effects (e.g. shadow, panels, balloons)
- Orientation (horizontal, vertical, diagonal)
- Etc.

Paper/Printing formatting:

- Selection of paper size (Letter, A4, A3, A2, A1, A0)
- Indicating paper orientation (portrait, landscape)
- Setting page margins
- Inserting page number
- Inserting date and other special remarks, symbols/logos, watermarks
- Defining printing options (e.g. gray scale, colour, number of copies, etc.)
- Print quality (usually specified as number of dots per inch (dpi) e.g. 300dpi, 600dpi, 1200dpi)
- Specifying page range to print (all, current page, pages – to -)
- Selection of printer or plotter type.

3.3 Data Output

Cartographic data output is quite crucial in GIS operations. Visualization or cartographic display of spatial data in a GIS environment is a key component of GIS analytical operations. Cartography is the design and production of maps, or visual representation and communication of spatial data. The vast majority of modern cartography is done with the help of computers, usually using a GIS. Most GIS software gives the user substantial control over the appearance of the data. Cartographic work serves two major functions: First, it produces graphics on the screen or on paper that convey the results of analysis to the people who make decisions about resources. Web Map Servers facilitate distribution of generated maps through web browsers using various implementations of web-based application programming interfaces (AJAX, Java, Flash, etc.). Second, other database information can be generated for further analysis or use. An example would be a list of all building addresses within one mile (1.6 km) radius of a toxic spill.

The hardcopy (paper) data output can be obtained using a printer or a plotter. Printers are used for producing relatively small size papers. Currently, the largest paper size a wide carriage printer can print on is A3. To obtain hardcopy outputs on paper sizes larger than A3 a plotter is commonly used.

4.0 Conclusion

Data manipulation and analysis operations often yield some output. This output could be in soft or hard copy version. The data output subsystem of GIS offers tools that can be used to format and package an output as may be desired.

5.0 Summary

The data output function of GIS involves displaying the result(s) of data processing and obtaining an analogue version of it. Usually, to obtain a softcopy the data is visualized on the screen of the workstation. Permanent or hardcopies are produced on paper (or some other printing media) using a printer or a plotter. The output, whether softcopy or hardcopy, could be a draft or final version. But before obtaining the output, the document should be properly formatted.

6.0 References/Further Reading

Clarke, K. C. (1995). **Getting Started with Geographic Information Systems**, New Jersey: Prentice Hall, 3rd Edition.

Jones, C. (1997). **Geographical Information Systems and Computer Cartography**, Essex: Addison Wesley Longman Limited.

Kraak, M. and Ormeling, F. (1996). **Cartographic Visualization of Spatial Data**, Essex: Addison Wesley Longman Limited.

Longley, P. A., Goodchild, M. F., Maguire, D. J. and Rhind, D. W. (2001). **Geographic Information Systems and Science**, New York: John Wiley & Sons, Inc.

Unit 5: Data Updating

1.0 Introduction

There is always the need to keep the data items in a GIS database as current as possible. Both the spatial and attribute databases should be periodically updated, as the need arises. Hence in this Unit our focus is on issues relating to the update of data entries in a GIS environment. It should be noted that in GIS there are two broad categories of data we deal with namely *graphics* (point, line, polygon) and *text* (alphanumeric and numeric). In other words, GIS data updating involves revising both spatial and non-spatial (attribute) data.

2.0 Objectives

1. To introduce the concept of data updating.
2. To discuss the process of spatial data updating.
3. To discuss the process of attribute (non-spatial) data updating.

3.0 Main Body

3.1 Concept of Data Updating

Basically, data updating is the process of bringing an already existing piece of data up to date. This process may demand deleting an obsolete data item and replacing it with a more recent one. It may also involve simply adding a freshly acquired data to an existing body of related data, without necessarily deleting any existing data.

It should be noted that the decision to update a database as well as the format and extent of the update depends on the intended application. For instance, if a database is to be used for some historical studies or time-series analysis, both the old and contemporary data items alike will be very much needed. If, for example, a land-use/land-cover study of a place is to be carried out for, say, between 1960 and 2010, then maps, aerial photographs, and/or satellite images of different time periods in-between the two time segments will be needed. This, of course, is in spite of the fact that, for instance, a 1960 topographic map of an area will be considered obsolete when compared to a 2010 edition of the same area.

Whatever the reason or nature of any data updating exercise, it requires undertaking some form of data upgrade or modification. The whole idea is to keep the database as timely, relevant, useful and accessible as possible.

The general procedure for updating data in a database can be summarized thus:

- Locate and retrieve file containing database to be updated.
- Open and display the database
- Make required modification to data (e.g. adding new data items, deleting obsolete data items, etc.) using the appropriate software tools.

- Validate data (attempting to update a database can result in some errors. Hence after modifying the database, edit it by checking for possible any errors; correct any identified errors).
- Save the updated database.

Reasons for data updating:

- To make the data up-to-date.
- To improve on the accuracy of the data.
- To enhance the use value and hence of the data.
- To increase data accessibility (for authorized users).

3.2 Spatial data updating

Spatial data updating largely involves updating the vector map database; the essence is to improve on the quality of the database. In other words, a major goal of a map updating program is to ensure that revised graphics meet the accuracy specifications for the intended use. Updating becomes necessary if certain errors are noticed in the data. The updating process can also be used to capture and reflect recent changes that have taken place in the area covered by the map. Owing to the dynamics of land-use/land-cover change, it often becomes necessary to update maps held in a GIS in order to better fit the current landscape.

Updating spatial or cartographic data involves improving the geometric and horizontal (positional) accuracy of features represented on the old map. Usually, current data are more accurate than older map bases and can therefore be used to improve the accuracy of the map data.

Map or spatial data updating is mostly done using data from primary and secondary data sources, including the following:

- Existing maps and atlases
- Aerial photographs
- Satellite imagery
- Orthophotos
- Stereophotographs
- Gazetteer of Place-names
- GPS data
- Direct field measurements
- In-situ personal field observations (ground truthing).
- Geographically-referenced databases from Federal, State and Local Government agencies.

In updating a map digital or scanned map, aerial photograph, orthophoto (orthorectified), or satellite image could be used as a back-drop raster image. The vector map to be updated is displayed as an overlay on the raster image. GIS image warping methods can be used to adjust an old map base to newer, more accurate control. This is done to ensure that the map to be updated aligns or registers perfectly well with the scanned image. For proper registration, the digital image and the map to be updated should be consistent with each other; this can be achieved by making them to be of the same projection and scale. The image rubber sheeting facility available in most commercial GIS has greatly improved the accuracy of some maps and improved the consistency of clusters of maps. Once the vector map and the raster image are properly aligned new objects can be traced (on-screen) from the image and added to existing objects on the map. On the other hand, obsolete, unwanted, or no-longer-existing objects on the map could be deleted. Similarly, in updating/editing a GIS map lines can, for example, be moved, rotated, intersected, or joined. More so, points of lines can be added, deleted, or moved. GPS readings can also be downloaded and used in updating map data in a GIS environment.

It should be noted that in using remote sensing imagery (aerial photographs, orthophotos and satellite images) to update cartographic data some sort of quality control should be conducted. The quality of the imagery can be checked visually on a workstation. In doing this the radiometry, geometry, histogram, brightness and contrast properties of the image should be properly checked.

3.3 Attribute data updating

As already noted, the spatial data in a GIS works in conjunction with the associated attribute data. Hence, just as it often becomes necessary to update the spatial data, it is equally imperative to update the attribute database. As a matter of fact, certain data items in an attribute database are automatically updated as certain properties of map features in a spatial database are modified. This is so because in reality attribute data updating involves adding, changing or deleting attributes of map objects.

The attribute database is commonly held in tabular form. One important operation in maintaining tables is the ability to update the data contained in the table. Most commercial GIS have features or commands that allow one to perform various data updating functions. The rows (records) as well as the columns (fields) of tables can be updated. You can update all the rows in a table or a selection of rows. Also you can update a single column or a group of columns. Some of the commands used in modifying an attribute table are INSERT, UPDATE, or DELETE.

Some of the attribute table modifications that can be carried out in a GIS environment include:

- Add a temporary column or update an existing column with data from another table
- Update a table
- Place graphic information into visible columns
- Add a new column
- Modify data in a cell (entering new values that will replace the current ones)
- Edit/Update data in an existing column
- Delete column
- Change column name
- Delete data in a column
- Change column type (e.g. from alphanumeric to numeric)
- Increase/Reduce column size

The process of updating an attribute data may involve bringing data from one table into another. In doing this, you can either add a temporary column or you can update an existing column, depending on the flexibility and requirements of the GIS software in use. Depending on the magnitude of the modification to be made, the attribute data may be updated directly in the GIS environment, or the table could be created in another GIS-compatible database management system such as Access, Oracle or Microsoft Excel and later imported into GIS. Many contemporary GIS software offer tremendous flexibility with how information is imported and what information is transferred. However, in using another software to create a new tabular data that will be used to update an existing GIS attribute database, care must be taken to ensure that the format of the new database is consistent with the format of the already existing.

4.0 Conclusion

The credibility of GIS hinges so much on the quality and currency of the database. The need for constant updating of GIS data, therefore, cannot be overemphasized. Having current and useable data is essential to maximising the potential of GIS. Hence, a well thought out plan for periodic data upgrading should form a key component of every GIS implementation programme.

5.0 Summary

The ultimate goal of adopting and operating the GIS technology is to provide reliable, useful and timely information for decision making. The success or otherwise of any GIS scheme hinges largely on the quality and dependability of its database. To keep the data 'fit-for-use' at any time there is need to regularly update the data. Data updating involves upgrading the quality of an existing piece of data in order to bring it up to date. Doing this may take the form of adding fresh items to the database and/or deleting certain obsolete ones.

6.0 References/Further Reading

Cheng, H., Li, Y., and Lin, Y. (2008). *A study on multi-agent spatial database update mechanism based on Wiki idea*, in Liu, L., Li, X., Liu, K., Zhang, X. and Chen, A. (Eds.) **Geo-Simulation and Virtual GIS Environments, Proceedings of the SPIE Geoinformatics 2008 and Joint Conference on GIS and Built Environment.** Volume 7143, pp. 71431K-71431K-9.

Martin Scheu, Wolfgang Effenberg and Ian Williamson **Incremental update and upgrade of Spatial Data** citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.6.5286&rep=rep1&type=pdf

MODULE 4 [Database Structures]

Unit 1: Database Structures

1.0 Introduction

The data used in GIS operations are usually organized in form of databases. A database, in turn, is typically organized according to general data models or structures. Understanding the nature of databases and database management systems is, therefore, crucial to understanding the creation and handling of data in a GIS environment. In this Unit we will be looking at both spatial and non-spatial databases.

2.0 Objectives

1. To take a general look at the concept of database (DB) and database management system (DBMS).
2. To understand the nature, content, and functions of spatial database systems.
3. To identify non-spatial database structures.

3.0 Main Body

3.1 The concept of database

In a GIS environment the data used for operations is usually organized in database form. Generally speaking, the term 'database' refers to a collection of information about things and their relationship to each other. A database model is a theory of how a database is supposed to look like. Put differently, a database is an integrated collection of data records, files, and other database objects needed by an application. A database could be in analogue or digital format. Here, our concern is with digital database. Hence, a database is an organized collection of data for one or more purposes, usually in digital form. A database (often abbreviated *DB), is normally* organized in such a way that a computer program can quickly select desired pieces of data. We can therefore think of a database as an electronic filing system.

Traditional databases are organized by *fields*, *records*, and *files*. A field is a single piece of information; a record is one complete set of fields; and a file is a collection of records. For example, a telephone book is similar to a file. It contains a list of records, each of which consists of three fields: name, address, and telephone number.

The data are typically organized to model relevant aspects of reality (for example, the number of flats in a residential apartment building), in a way that supports processes requiring this information (for example, finding a building with a vacant flat for rental). The term "database" refers both to the way its users view it, and to the logical and physical materialization of its data, content, in files, computer memory, and computer data storage. Moreover, the term database implies that the data is managed to some level of quality (measured in terms of accuracy, availability, usability, and resilience) and this in turn often implies the use of a general-purpose Database management system (DBMS).

To access information from a database, you need a *Database Management System (DBMS).* A DBMS is a software package with a collection of computer programs that controls the creation, organization, maintenance, selection and the use of data in a database. The term database is correctly applied to the data and data structures themselves, and is different from the DBMS which is a software system that allows to store and change the database (i.e., the data), as well as retrieve information from it.

A few examples of commercially available DBMSs include Gemstone, O_2, Versant, Mattise, Codasyl, Sybase, Oracle, DB2, Access, dBase, SQL Server from Microsoft, DB2 from IBM and the Open source DBMS MySQL..

The database concept has evolved since the 1960s to ease increasing difficulties in designing, building, and maintaining complex information systems (typically with many concurrent end-users, and with a large amount of data). It has evolved together with the evolvement of Database management systems (DBMSs) which enable the effective handling of databases. Though the terms database and DBMS define different entities, they are inseparable: A database's properties are determined by its supporting DBMS and vice-versa. The major purpose of a database is to provide the information system (in its broadest sense) that utilizes it with the information the system needs.

3.2 Spatial database

The GIS technology operates on spatial databases. Spatial databases store information related to objects in space. A spatial database is a collection of spatially referenced data that acts as a model of reality. In other words, a spatial database is a database that is optimized to store and query data that is related to objects in space, including points, lines and polygons. Furthermore, a spatial database system is a database system that offers spatial data types in its data model and query language, and supports spatial data types in its implementation, providing at least spatial indexing and spatial join methods. Spatial database systems offer the underlying database technology for geographic information systems and other applications (Güting, 1994).

As noted by Güting (1994):
(1) A spatial database system is a database system.
(2) It offers spatial data types (SDTs) in its data model and query language.
(3) It supports spatial data types in its implementation, providing at least spatial indexing and efficient algorithms for spatial join.

While typical databases can understand various numeric and character types of data, additional functionality needs to be added for databases to process spatial data types. These are typically called *geometry* or *feature*. Generally, database systems use indexes to quickly look up values. However, the way that most databases index data is not optimal for spatial queries. Indexes used by non-spatial databases cannot effectively handle features such as how far two points differ and whether points fall within a spatial area of interest. Consequently, spatial databases use a spatial index to speed up database operations.

3.3 Contents of spatial database

The contents of a spatial database depend on its intended purpose, which in turn is dependent on the organization using it. We can briefly illustrate this with two simple examples namely, transportation and wetland.

Example 1: Transportation

Consider the use of highway data from the different points of view of two agencies namely a natural resources organization and a highway transportation organization. The natural resource organization might only need information on logging routes and the connecting access to secondary or state highways. On the other hand, the transportation organization's main interest is in characterizing highways used by the public. The database might also be used to store detailed highway condition and maintenance information. We would, therefore, expect the transportation organization's need for highway data to be more detailed than would the natural resource organization's need.

Example 2: Wetlands

Let us also consider the need for wetlands data from the different points of view of two agencies namely an ecological organization and a taxing authority. The ecological organization might define wetlands as a natural resource to be preserved and restricted from development. Thus, that perspective might require considerable detail for describing the wetland's biology and physical resources. On the other hand, the taxing authority might define a wetland to be a "wasteland" and of very little value to society. Thus, that description might require only the boundary of the "wasteland" to be included in the database.

3.4 Basic characteristics of spatial database

A typical spatial database should possess certain characteristics. Such a database should be:

- Contemporaneous - should contain information of the same time period for all its measured variables.
- As detailed as necessary for the intended applications.
- Positionaly accurate.
- Exactly compatible with other information that may be overlain with it.
- Internally accurate, portraying the nature of phenomena without error - requires clear definitions of phenomena that are included.
- Easily updated on a regular schedule.
- Accessible to whoever needs it and is authorized to use it.

3.5 Functions of spatial databases

Spatial databases can perform a wide variety of spatial operations. To perform its functions spatial databases make use of spatial query languages. A spatial query is a special type of database query supported by geodatabases and spatial databases. The spatial queries differ from

SQL queries in that they allow for the use of geometry data types such as points, lines and polygons and that they consider the spatial relationship between these geometries.

The following query types and many more are supported by many spatial databases especially the Open Geospatial Consortium (see http://en.wikipedia.org/wiki/Spatial_database):

- *Spatial Measurements*: Finds the distance between points, polygon area, etc.
- *Spatial Functions*: Modify existing features to create new ones, for example by providing a buffer around them, intersecting features, etc.
- *Spatial Predicates*: Allows true/false queries such as 'is there a residence located within a mile of the area we are planning to build the landfill?'
- *Constructor Functions*: Creates new features with an SQL query specifying the vertices (points of nodes) which can make up lines. If the first and last vertexes of a line are identical the feature can also be of the type polygon (a closed line).
- *Observer Functions*: Queries which return specific information about a feature such as the location of the center of a circle

3.6 Non-spatial database

As already noted, GIS uses raster or vector representations to model location. It is equally important to consider how GIS must also record information about the real-world phenomena positioned at each location and the attributes of these phenomena. That is, the GIS must provide a linkage between spatial and non-spatial data. The linkage between symbol (map feature) and meaning is established by giving every geographic feature at least one unique means of identification, a name or number usually just called its ID. Non-spatial attributes of the feature are then stored, usually in one or more separate files, under this ID number. In other words, graphic or locational information is linked to specific non-graphic or attribute information in a database.

Non-spatial data (also called *attribute* or *characteristic* data) is that information which is independent of all geometric considerations. It is the set of data that tells more about what geographic features are like. In other words, whereas spatial data gives us information about *where* (location) things are, non-spatial data gives us information on *what* they are like irrespective of their location. For example, a tree is a geographic feature, but the type, height, and age of the tree are non-spatial data because they are independent of the tree's location.

The non-spatial data associated with spatial features can be filed away in several different forms depending on how it needs to be used and accessed. There are numerous types of database models today. These models not only represent how a database looks like but also what kind of operations that can be used to manipulate the data within. Some of the commonly used attribute database models include:

- Hierarchical model
- Network model
- Relational model
- Entity-relationship model
- Object model
- Object/relational database management systems (ORDBMSs)

- Object-oriented database (OODB) model.

In this Unit we will briefly describe the three commonest database models namely hierarchical, network and relational. For more detailed discussion on each of the data models, the interested reader can consult the sources listed in the References section below.

Hierarchical database model

The hierarchical data model organizes data in a tree structure. There is a hierarchy of parent and child data segments. In other words, to create links between record types, the hierarchical model uses Parent-Child Relationships. For example, an organization might store information about an employee, such as name, employee number, department, salary. The organization might also store information about an employee's children, such as name and date of birth. The employee and children data forms a hierarchy, where the employee data represents the parent segment and the children data represents the child segment. If an employee has three children, then there would be three child segments associated with one employee segment. In a hierarchical database the parent-child relationship is one-to-many.

In a hierarchical database model data is stored in more than one type of record. One field is usually recognized as key to all records, but data in one record does not have to be repeated in another. This system allows records with similar attributes to be associated together. The records are linked to each other by a key field in a hierarchy of files. Each record, except for the master record, has a higher level record file linked by a key field "pointer". In other words, one record may lead to another and so on in a relatively descending pattern.

Network Model

The network model uses records and sets, which are its two basic structures, when organizing data. Record contains the fields, while the set is the one defining the relationship existing between the records. Unlike what obtains in the hierarchical data structure, data in network structure are modeled with more than one parent per child. So, the network model permits the modeling of many-to-many relationships in data. The basic data modeling construct in the network model is the set construct. A set consists of an owner record type, a set name, and a member record type. A member record type can have that role in more than one set; hence the multi-parent concept is supported. An owner record type can also be a member or owner in another set. The data model is a simple network, and link and intersection record types (called junction records by IDMS) may exist, as well as sets between them.

Relational database model

A relational database allows the definition of data structures, storage and retrieval operations and integrity constraints. In such a database the data and relations between them are organised in tables. A table is a collection of records and each record in a table contains the same fields. **A** common link of data is used to join or associate records. The link is not hierarchical. A "matrices of tables" is used to store the information. As long as the tables have a common link they may be combined by the user to form new inquires and data output. This is the most flexible system and is particularly suited to SQL (structured query language). Queries are not limited by a hierarchy of files, but instead are based on relationships from one type of record to another that the user establishes.

Perhaps this is the simplest method, where each geographic feature is matched to one row of data. All records in this kind of database have the same number of "fields". Individual records have different data in each field with one field serving as a key to locate a particular record. For example, as a person your national ID card number may be the key field in a record of your name, address, phone number, sex, ethnicity, place of birth, date of birth, religion, and so on. Similarly, for a plot of land there could be hundreds of fields associated with the record (plot), such as owner, address, size, usage, etc. Because of its flexibility this system is the most popular database model for GIS (Foote and Huebner, 2000). The relational database structure is further discussed in Unit 3 of this Module.

4.0 Conclusion

Every GIS has a database management system (DBMS), which is used to create and handle the datasets used for various operations.

5.0 Summary

Data items used in GIS operations are usually arranged and stored in database format. A database, which is normally held in digital form, is an organized collection of data records, files, and other database objects needed by an application, for one or more purposes. We have the spatial database as well as the attribute (non-spatial) database. A spatial database is a collection of geographically-referenced data that acts as a model of reality. On the other hand, an attribute database is used to hold descriptive information about the geographical features represented in a spatial database.

6.0 References/Further Reading

http://www.webopedia.com/TERM/D/database.html

http://en.wikipedia.org/wiki/Database

Date, C.J. (1994). **An Introduction to Database Systems**. Addison-Wesley Publishing Co., New York.

Foote, K. E. and Huebner, D. J. (2000). *Database Concepts*, The Geographer's Craft Project, Department of Geography, The University of Colorado at Boulder. *http://www.colorado.edu/geography/gcraft/notes/datacon/datacon_f.html* (Accessed 22/6/11).

Güting, (1994)

Ralf Hartmut Güting (1994), An Introduction to Spatial Database Systems**,** *The International Journal on Very Large Data Bases*, Vol. 3, No. 4, October 1994.

Yeung, A.K.W. and Hall, G.B. (2007). **Spatial Database Systems: design, implementation and project management**, New York: Springer Science+Business Media.

Unit 2: Spatial data models

1.0 Introduction

Real world features are represented in GIS using a spatial data model. Simply put, a data model is an abstract structure that provides the means to effectively describe specific data structures needed to model an application. GIS data represents real objects (such as roads, land use, elevation, trees, waterways, etc.). Real objects can be divided into two abstractions: discrete objects (e.g., a house, a roundabout, or a borehole) and continuous fields (such as rainfall amount, vegetation, or elevations). Traditionally, there are two broad methods or models used to store spatial data in a GIS: *raster images* and *vector*. In this Unit we will closely look at each of the models.

2.0 Objectives

1. To identify and discuss the two spatial data models commonly used in GIS: vector and raster.
2. To compare and contrast the models
3. To examine the conversion from one model format to another.

3.0 Main Body

3.1 Vector Structure

In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes. Different geographical features are expressed by different types of geometry: Vector digital data have been captured as points, lines (a series of point coordinates), or areas (shapes bounded by lines) (Fig. XXXX a and b). An example of data typically held in a vector file would be the property boundaries for a particular housing subdivision.

Points

Zero-dimensional points are used for geographical features that can best be expressed by a single point reference — in other words, by simple location. Examples include wells, peaks, features of interest, and trailheads. Points convey the least amount of information of these file types. Points can also be used to represent areas when displayed at a small scale. For example, cities on a map of the world might be represented by points rather than polygons. No measurements are possible with point features.

Lines or polylines

One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines. Again, as with point features, linear features displayed at a small scale will be represented as linear features rather than as a polygon. Line features can measure distance.

Polygons

Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types. Polygon features can measure perimeter and area.

Each of the above geometries is linked to a row in a database that describes their attributes. For example, a database that describes lakes may contain a lake's depth, water quality, pollution level. This information can be used to make a map to describe a particular attribute of the dataset. For example, lakes could be coloured depending on level of pollution. Different geometries can also be compared. For example, the GIS could be used to identify all wells (point geometry) that are within one kilometre of a lake (polygon geometry) that has a high level of pollution.

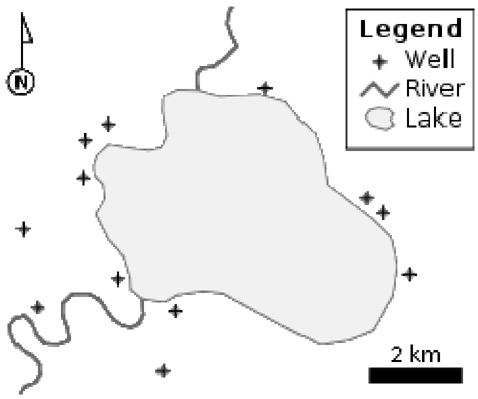

Fig. XXXXa A simple vector map, using each of the vector elements: points for wells, lines for rivers, and a polygon for the lake.

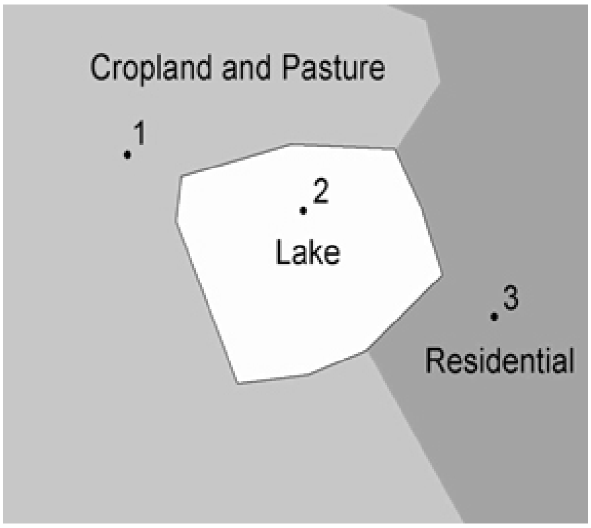

Fig. XXXXb. Example of the vector data model.

3.2 Raster Structure

A raster data type is, in essence, any type of digital image represented by reducible and enlargeable grids. Anyone who is familiar with digital photography will recognize the Raster graphics pixel as the smallest individual grid unit building block of an image, usually not readily identified as an artifact shape until an image is produced on a very large scale. A combination of the pixels making up an image color formation scheme will compose details of an image, as is distinct from the commonly used points, lines, and polygon area location symbols of scalable vector graphics as the basis of the vector model of area attribute rendering. While a digital image is concerned with its output blending together its grid based details as an identifiable representation of reality, in a photograph or art image transferred into a computer, the raster data type will reflect a digitized abstraction of reality dealt with by grid populating tones or objects, quantities, co-joined or open boundaries, and map relief schemas. Aerial photos are one commonly used form of raster data, with one primary purpose in mind: to display a detailed image on a map area, or for the purposes of rendering its identifiable objects by digitization. Additional raster data sets used by a GIS will contain information regarding elevation, a digital elevation model, or reflectance of a particular wavelength of light, Landsat, or other electromagnetic spectrum indicators.

Raster data type consists of rows and columns of cells, with each cell storing a single value. Raster data can be images (raster images) with each pixel (or cell) containing a color value. Additional values recorded for each cell may be a discrete value, such as land use, a continuous value, such as temperature, or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB (red, green, blue) colors, colormaps (a mapping between a thematic code and RGB value), or an extended attribute table with one row for each unique cell value. The resolution of the raster data set is its cell width in ground units.

Raster data is stored in various formats; from a standard file-based structure of TIF, JPEG, etc. to binary large object (BLOB) data stored directly in a relational database management system (RDBMS) similar to other vector-based feature classes. Database storage, when properly indexed, typically allows for quicker retrieval of the raster data but can require storage of millions of significantly sized records.

Typically, raster data files consist of rows of uniform cells coded according to data values. An example is land cover classification (Fig. XXXXX). Raster files can be manipulated quickly by the computer, but they are often less detailed and may be less visually appealing than vector data files, which can approximate the appearance of more traditional hand-drafted maps.

1	1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	3	3	3	3
1	1	1	2	2	2	2	3	3	3
1	1	1	2	2	2	2	3	3	3
1	1	1	2	2	2	2	3	3	3
1	1	1	1	2	2	2	3	3	3
1	1	1	1	1	1	3	3	3	3
1	1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	1	1	3	3

Fig. XXXXX. Example of the raster data model.

3.3 Comparison of Raster to Vector models

There are some important advantages and disadvantages to using a raster or vector data model to represent reality:

- Raster datasets record a value for all points in the area covered which may require more storage space than representing data in a vector format that can store data only where needed.
- Raster data allows easy implementation of overlay operations, which are more difficult with vector data.
- Vector data can be displayed as vector graphics used on traditional maps, whereas raster data will appear as an image that may have a blocky appearance for object boundaries. (depending on the resolution of the raster file)

- Vector data can be easier to register, scale, and re-project, which can simplify combining vector layers from different sources.
- Vector data is more compatible with relational database environments, where they can be part of a relational table as a normal column and processed using a multitude of operators.
- Vector file sizes are usually smaller than raster data, which can be 10 to 100 times larger than vector data (depending on resolution).
- Vector data is simpler to update and maintain, whereas a raster image will have to be completely reproduced. (Example: a new road is added).
- Vector data allows much more analysis capability, especially for "networks" such as roads, power, rail, telecommunications, etc. (Examples: Best route, largest port, airfields connected to two-lane highways). Raster data will not have all the characteristics of the features it displays.
- Raster files can be manipulated quickly by the computer, but they are often less detailed and may be less visually appealing than vector data files, which can approximate the appearance of more traditional hand-drafted maps.

3.4 Data model conversion

From the foregoing it is obvious that digital spatial data are collected and stored in different ways, vector or raster. The two data models are not entirely compatible. Therefore, a GIS must be able to convert data from one structure to another. Data restructuring or conversion can be performed by a GIS to convert data between different formats. For example, a GIS can be used to convert a satellite image map (raster data) to a vector structure by generating lines around all cells with the same classification, while determining the spatial relationships of the cell, such as adjacency or inclusion (Fig. XXXXXa and b).

Fig. XXXXXa. Magnified view of the same GIS data file, shown in raster format.

Fig. XXXXXb. Magnified views of the same GIS data file. converted into vector format.

Vector to Raster Conversion

Converting vector data to raster involves using grid cells to define or represent the location of a point, line or polygon (area) feature held in vector format. To rasterize a vector map an artificial matrix of cells is first imposed on the map. With the fine mesh of grid lines now covering the map features it becomes easy to identify which pixels (cells) lie on or within the boundaries of the features. With the aid of a suitable rasterization algorithm the cells accommodating the particular spatial object(s) of interest can be identified and assigned a value or shaded in a chosen pattern to represent that object type. Figures XXXXXXa, b and c illustrate the rasterization of point, linear and areal features respectively.

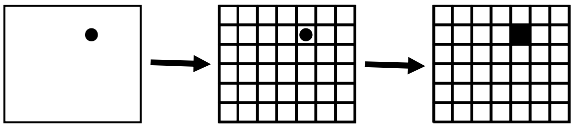

Fig. XXXXXXa Point feature rasterization (Uluocha, 2007).

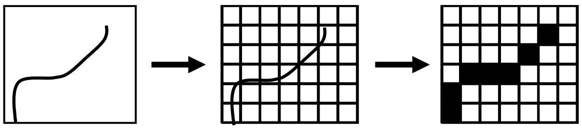

Fig. XXXXXXb Rasterizing a

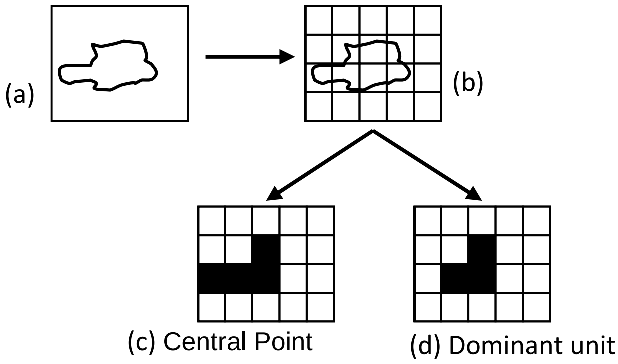

Fig. XXXXXXc Polygon rasterization

4 Conclusion

There are two main spatial data models used in storing geographically-referenced data in GIS. These are the vector model and the raster model. The selection of a particular data model, vector or raster, is dependent on the source and type of data, as well as the intended use of the data. Whereas certain analytical procedures require raster data others are better suited to vector data.

5 Summary

Traditionally geospatial data has been stored and presented in the form of a map. However, various types of spatial data models have been developed for storing geographic data digitally. The two models mostly used are raster and vector. The raster model makes use of a matrix of cells to represent and store data while vector uses the more familiar cartographic symbols (points, lines, and polygons). Each of the spatial data models has its own merits and demerits. It is possible to convert from one data model to the other.

6 References/Further Reading

GIS Primer, *http://gis.nic.in/gisprimer/analysis3.html* (Retrieved 27/7/11).

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications

Unit 3: Attribute data models

1.0 Introduction

Additional non-spatial (also known as aspatial or *attribute*) data can also be stored along with the spatial data represented by the coordinates of a vector geometry or the position of a raster cell. Software is currently being developed to support spatial and non-spatial decision-making, with the solutions to spatial problems being integrated with solutions to non-spatial problems. The end result with these Flexible Spatial Decision-Making Support Systems (FSDSS) is expected to be that non-experts will be able to use GIS, along with spatial criteria, and simply integrate their non-spatial criteria to view solutions to multi-criteria problems. This system is intended to assist decision-making.

2.0 Objectives

1. To discuss the major attribute data model used in GIS.
2. To identify the errors commonly made during attribute database creation.

3.0 Main Body

In a GIS environment attribute data are commonly stored in a tabular form. As earlier mentioned in Unit 1 there are various data structures or models that could be used for attribute data files, including hierarchical structure, network structure and relational structure. However, the relational model is the most commonly used type.

3.1 Relational Database Model

A *relational database structure* is simply a two-dimensional table made up of rows (also known as *tuples* or records) and columns (also known as *domains*, fields, or attributes). Each row contains a single record representing an entity or object, while a column contains an attribute or characteristic of the entity. In vector data, the additional data contains attributes of the feature. For example, as illustrated in Fig. X, a building polygon may also have an identifier (ID) value and other information about it such as the name of the owner, the type of building, street address, number of floors (if storey building), number of flats, colour, age (year built), etc. In raster data the cell value can store attribute information, but it can also be used as an identifier that can relate to records in another table.

In a GIS-based relational attribute table, the fields could be of different types. The field type affects the way GIS will recognize and process the data contained in the field. For instance, if the values (statistical figures) in a field are meant for some arithmetic or mathematical calculations, GIS will not be to use the figures for such operations if the field was not created as a 'numeric' field. Hence, it becomes quite imperative to accurately define the type of each field in an attribute database during the creation of the database.

The fields in an attribute database can be defined as:

- Alphanumeric

- Numeric
- Date
- Logic

Fig. X Sample of a relational table

ID	Address	Owner	Type	No_Floors	No_Flats	Occupier	....	....
001	5, Ulo Close, Eluigwe	Chief B.C Dede	Duplex	2	4	Owner		
....								
....								

Presently, the relational DBMS is the most widely used commercial data management tool in GIS implementation and application. The relational DBMS is attractive to GIS users for a number of reasons, including its:

- *Simplicity* in organization and data modeling.
- *Flexibility* - data can be manipulated in an ad hoc manner by joining tables.
- *Efficiency* of storage – proper design of data tables can reduce redundancy.
- *Queries* do not need to take into account the internal organization of data.

3.2 Data Editing

The accuracy and precision of the attribute data to be used for GIS operations should be ensured. Hence, after creating the database effort should be made to check through the data for possible errors. Any errors detected should be promptly rectified. The common errors which one can possibly make during the creation of an attribute data file include:

- Wrong spelling
- Improper definition of a field
- Omission of some vital details
- Wrong entry (e.g. keying in 17,018 instead of 17,108)

4.0 Conclusion

In GIS a separate data model is used to store and maintain attribute data. These data models may exist internally within the GIS software, or may be reflected in external commercial Database Management Software (DBMS). A variety of different data models exist for the storage and management of attribute data. However, the most widely used attribute data model in GIS is the *relational database model.*

5.0 Summary

Like the spatial data, the non-spatial or attribute datasets used in GIS are usually designed, created and maintained using a certain database model. There are different data structures or models that can be used for attribute data files, such as hierarchical structure, network structure and relational structure. However, the most widely accepted for managing the attributes of geographic data. The relational database organizes data in *tables*. Each table, is identified by a unique table name, and is organized by *rows* (records) and *columns* (fields). Each column within a table also has a unique name. Columns store the values for a specific attribute, e.g. tree age, tree height, etc. Rows represent one record in the table. In a GIS each row is usually linked to a separate spatial feature, e.g. a building. Accordingly, each row would be comprised of several columns, each column containing a specific value for that geographic feature. Good practice demands that after creating a database and keying in the data items it should be edited, to identify and correct any existing errors.

6.0 References/Further Reading

GIS Primer, *http://gis.nic.in/gisprimer/analysis3.html* (Retrieved 27/7/11).

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications

Unit 4: Data Quality

1.0 Introduction

Data quality has to do with usefulness of a set of data vis-a-vis the intended use. It is a measure of the level of the fitness-for-use of the data. It is often necessary to ascertain the quality of data before using it for a GIS operation. One should always bear in mind the popular slogan: garbage in, garbage out. The quality of the data used in a GIS project goes a long way to determining the success or otherwise, of the project. In this Unit we will focus attention on examining the factors for evaluating or measuring the quality of geospatial as well as attribute data.

2.0 Objectives

1. To discuss the parameters for assessing spatial data.
2. To highlight the qualities of attribute data.

3.0 Main Body

3.1 Lineage: This gives account of the origin or source of the data, the date of collecting the data, and the methods adopted in data collection/database creation. Knowing the source of data helps one in determining whether or not the data is reliable.

3.2 Logical consistency: This is a measure of the degree of conformity of internal data structures to specified data modelling rules. This measure of data accuracy and quality is normally applied to spatial data; it is used to establish the authenticity (or otherwise) of the data structure created for a data set. Hence, the logical consistency search is carried out to identify any spatial or topological errors in a spatial data structure such as incorrect line intersections, duplication of lines or boundaries, gaps in lines (discontinuity), and so on.

3.3 Completeness: Measures the extent to which the data cover the population of items of interest. For instance, if there are 15,000 rateable properties in a Local Government Area (LGA) and the database holds records for only 9,000, the database is obviously incomplete.

3.4 Positional accuracy and precision: This index is used to determine the difference between measured (or observed or computed) locational values (coordinates and altitude) and their true values. In other words, positional accuracy and precision is an index that gives one an idea of how close a recorded positional value is to its true or generally accepted value.

3.5 Attribute accuracy and precision: The extent to which recorded attribute values correspond to their true or real world or generally accepted values.

3.6 Currency: This is a measure of the obsoleteness or up-to-datedness of data. By considering or assessing data currency, one would be able to know whether or not the data are recent and timely (up-to-date) in relation to the intended application. (It should be noted that, that a piece of data is out of date does not mean it is no longer useful. Such data are often essential to time-series or temporal analysis).

3.7 Scale and spatial resolution: This deals with the degree of graphic representation of details about real world features. Various GIS applications require mapped data at various scales and hence spatial resolutions. Thus effort should be made to ascertain if the available maps, air-photos, or satellite imagery (paper or digital) are at a scale suitable for the task at hand. For instance, a 1:50,000 topographical map may not be ideal for undertaking detailed site analysis and landscaping for the purpose of constructing a petrol station; a larger scale map, say 1:500, would be needed for such a purpose.

4.0 Conclusion

Data quality refers to the appropriateness of a set of data for an intended use. Data that is appropriate for use with one application may not be fit for use with another. The quality of any data set must be ensured before using it in GIS.

5.0 Summary

Data quality is an important aspect of any piece of data to be used in GIS. Quality here can simply be defined as the fitness for use for a specific data set. It is fully dependant on certain parameters such as the source, scale, accuracy, currency, completeness and extent of the data set.

6.0 References/Further Reading

Faiz, S. and Boursier, P. (1996) *Geographic Data Quality: from Assessment to Exploitation*, Cartographica, Vol. 33, No.1, pp33-40.

Uluocha, N. O. (2007). **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications

Unit 5: Sources of data

1.0 Introduction

Data is critical to the successful execution of any GIS project. The data must not only be available, but also accessible. Moreover, the available data must be relevant, reliable and usable. Sourcing and obtaining useful data is often a major task. Various sources of data exist. However, one must be careful to properly assess the reliability of any source before making use of it. In this Unit we will try to identify the various sources and techniques of spatial and attribute data acquisition, for GIS operations.

2.0 Objectives

1. To identify sources of spatial data
2. To identify sources of attribute data.

3.0 Main Body

3.1 Sources of data

Generally, the data for GIS projects can be got from primary and/or secondary sources. Primary data are basically the set of data collected originally by the user. On other hand, secondary data is an already existing data.

In Nigeria there are a number of government agencies as well as private enterprises that collect and/or retail spatial and statistical data that could be used for GIS projects. Some of such sources of data include:

- Federal Surveys Department (now Office of the Surveyor-General of the Federation (OSGF)).
- Various State Survey Departments.
- National Population Commission (NPC).
- Nigerian Meteorological Agency (NIMET).
- Abuja Geographical Information System (AGIS).
- Nigerian Geological Surveys.
- National Space Research and Development Agency (NASRDA).
- Statistical Department of various ministries.
- Various private Geoinformation Service providers.
- Research Institutes.

3.2 Sources of spatial data

Geospatial data can be generated from the following sources/techniques:

- Land or terrestrial surveys.
- Photogrammetric surveys.
- Satellite imagery.
- Aerial photographs (see Fig. GGG).
- Global Positioning System (GPS) readings.

- Existing maps (analogue or digital).
- Existing digital boundary files, which usually contain geometric description of administrative units.
- Geophysical data files.
- Digital environmental data files.
- Digital elevation model (DEM)
- Gazetteer of Geographical names (Place-names)
- Postcode Directory
- Google Earth

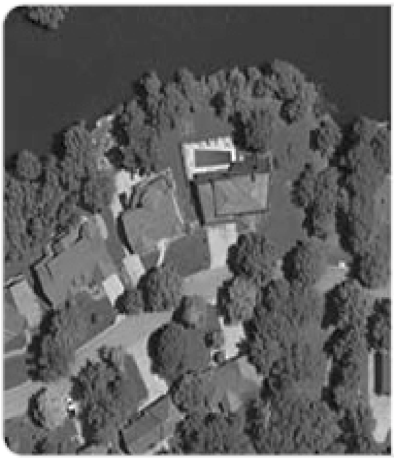

Fig. GGG: A gray-tone aerial photograph

3.3 Sources of non-spatial (attribute) data

- Socio-economic statistical records.
- Questionnaire surveys.
- Census (demographic and housing) surveys
- Market (customer) survey

4.0 Conclusion

To a large extent the source of data determines the quality of that data. Given that there are several possible sources of both spatial and attribute data for GIS operations, effort should be made to acquire data only from authentic and reliable sources.

5.0 Summary

The spatial and non-spatial data used in GIS are usually acquired from different sources and using different techniques. The data could be obtained first-hand as primary data by the user, or it can be obtained as secondary data from already existing sources. Maps, aerial photographs, satellite imagery, surveys, and official statistical records are some of the major sources of GIS data.

6.0 References/Further Reading

Uluocha, N. O. (2007). **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.

MODULE 5 [Applications of GIS]

GIS technology can be used for: earth surface based scientific investigations; resource management, reference, and projections of a geospatial nature—both manmade and natural; asset management and location planning; archaeology; environmental impact study; infrastructure assessment and development; urban planning; cartography, for a thematic and/or time based purpose; criminology; GIS data development geographic history; marketing; logistics; population and demographic studies; prospectivity mapping; location attributes applied statistical analysis; warfare assessments; and other purposes. Examples of use are: GIS may allow emergency planners to easily calculate emergency response times and the movement of response resources (for logistics) in the case of a natural disaster; GIS might be used to find wetlands that need protection strategies regarding pollution; or GIS can be used by a company to site a new business location to take advantage of GIS data identified trends to respond to a previously under-served market. Most city and transportation systems planning offices have GIS sections.

Many disciplines can benefit from GIS technology. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS. These developments will, in turn, result in a much wider use of the technology throughout science, government, business, and industry, with applications including real estate, public health, crime mapping, national defense, sustainable development, natural resources, landscape architecture, archaeology, regional and community planning, transportation and logistics. GIS is also diverging into location-based services (LBS). LBS allows GPS enabled mobile devices to display their location in relation to fixed assets (nearest restaurant, gas station, fire hydrant), mobile assets (friends, children, police car) or to relay their position back to a central server for display or other processing. These services continue to develop with the increased integration of GPS functionality with increasingly powerful mobile electronics (cell phones, PDAs, laptops).

The GIS technology is rapidly becoming a standard tool for management of natural resources. The effective use of large spatial data volumes is dependent upon the existence of an efficient geographic handling and processing system to transform this data into usable information.

The GIS technology is used to assist decision-makers by indicating various alternatives in development and conservation planning and by modelling the potential outcomes of a series of scenarios. It should be noted that any task begins and ends with the real world. Data are collected about the real world. Of necessity, the product is an abstraction; it is not possible (and not desired) to handle every last detail. After the data are analysed, information is compiled for decision-makers. Based on this information, actions are taken and plans implemented in the real world.

Geographic information system (GIS) technology can be used for scientific investigations, resource management, and development planning. GIS are now used extensively in government, business, and research for a wide range of applications including environmental resource analysis, landuse planning, locational analysis, tax appraisal, utility and infrastructure planning, real estate analysis, marketing and demographic analysis, habitat studies, and archaeological analysis.

Unit 1: Cartographic applications

1.0 Introduction

The field of cartography (map making) was the foremost area that GIS readily found applications. In fact, the earliest GIS software packages were mostly used for map visualization and analysis. Many consider GIS to be an advanced form of digital cartography. Today the use of GIS in undertaking various cartographic activities is increasingly becoming quite fashionable. Some of the cartographic functions of GIS are discussed below.

2.0 Objectives

1. To briefly discuss the concept of visualization.
2. To identify the major cartographic uses of GIS.
3. To highlight the advantages of GIS over paper maps.

3.0 Main Body

3.1 The concept of visualization

Maps have traditionally been used to explore the Earth. GIS technology has enhanced the efficiency and analytical power of traditional cartography. GIS have advanced tools for map layout, placement of labels, large symbol and font libraries, and interfaces for high quality output devices. As the scientific community recognizes the environmental consequences of human activity, GIS technology is becoming an essential tool in the effort to understand the process of global change. Map and satellite information sources can be combined in models that simulate the interactions of complex natural systems.

Through a process known as *visualization*, a GIS can be used to produce images— not just maps, but drawings, animations, and other cartographic products. These hot-linked images allow researchers to display and view their subjects in ways that they never could before. The visualized images often are helpful in conveying the technical concepts of a GIS to nonscientists.

3.2 Map production

Researchers are working to fully incorporate the mapmaking processes of traditional cartographers into GIS technology for the automated production of maps. One of the most common products of a GIS is a map. Maps are generally easy to make using a GIS and they are often the most effective means of communicating the results of the GIS process. Therefore, the GIS is usually a prolific producer of maps. The users of a GIS must be concerned with the quality of the maps produced because the GIS normally does not regulate common cartographic principles. One of these principles is the concept of generalization, which deals with the content and detail of information at various scales. The GIS user can change scale at the push of a button, but controlling content and detail is often not so easy. Mapmakers have long recognized that content and detail need to change as the scale of the map changes.

Another important aspect of GIS application in map making is seen in the ability of GIS to combine maps with some other means of communication. This is known as multimedia cartography, and by extension, multisensory cartography. In multimedia cartography the map is hot-linked with some relevant pictures, videos, text and soundtracks relating to some of the mapped features. The hot-linked items are usually not permanently visible on the map; in other words, one can hide and unhide them. Usually, by pointing or clicking the mouse on a feature shown on the map, the hot-linked items will automatically pop up and then perceived.

3.3 3-D Cartographic modelling

To more realistically analyze the effect of the Earth's terrain, we use three-dimensional models within a GIS. A GIS can display the Earth in realistic, three-dimensional perspective views and animations that convey information more effectively and to wider audiences than traditional, two-dimensional, static maps. For example, if a mining company seeks development rights to a mineral deposit in a place, GIS can be used to cartographically model the post-mining landscape impact by creating perspective views of the area to depict the terrain as it would appear after mining. The resulting model can guide the regulatory or approving agency in deciding on whether or not to grant the approval.

3.4 Web Mapping

GIS is equally powering Web mapping. This involves using GIS and Web-enabled facilities to create and distribute both static and editable (smart) maps via the Internet. Web Map Servers facilitate distribution of generated maps through web browsers using various implementations of web-based application programming interfaces (AJAX, Java, Flash, etc.).

3.5 Advantages of GIS map over paper map

Electronic map display in a GIS environment offers significant advantages over the paper map, such as:

- ability to browse across an area without interruption by map sheet boundaries;
- ability to zoom and change scale freely;
- ability to apply a filter to isolate a particular type of data and refresh to display only the selected data.
- large amounts of cartographic data can be processed quickly and displayed in different ways.
- potential for the animation of time dependent data;
- display in "3 dimensions" (perspective views), with "real-time" rotation of viewing angle;
- potential for continuous scales of intensity and the use of color and shading independent of the constraints of the printing process, ability to change colors as required for interpretation.

4.0 Conclusion

Traditionally map-making is a cumbersome, technically demanding task. The application of GIS in cartography has, however, now makes map production a much easier enterprise while at the same time introducing unprecedented flexibility and economy. The advent of digital mapping, powered by the GIS technology has widened the scope of map making and map use.

5.0 Summary

Cartography is the art, science and technology of map-making, map analysis and map use. The GIS technology now makes it easier to produce more accurate maps at a cheaper and faster rate. The compilation and creation of maps are greatly facilitated by GIS. Moreover, GIS also provides a robust means for visualizing and exploring cartographic data. Web-enabled GIS equally makes it possible to create and distribute maps via the Internet. With the aid of GIS maps can be hot-linked with pictures, videos and soundtracks; this has given rise to what is contemporarily known as multimedia and multisensory cartography.

6.0 References/Further Reading

Cartwright, W. (2005). *Maps on the Web*, in Peterson, M. (ed.) **Maps and the Internet**, New York: Elsevier Publications, pp35-56.

Fu, P. and Sun, J. (2010). **Web GIS: Principles and Applications**. Redlands: ESRI Press.

Kraak, M. and Ormeling, F. (1996). **Cartographic Visualization of Spatial Data**, Essex: Addison Wesley Longman Limited.

http://www.gisdevelopment.net/tutorials/tuman006.htm (Accessed 23/12/10)

Rhind, D. ***Maps and map analysis***, *http://www.geog.ubc.ca/courses/klink/gis.notes/ncgia/u02.html* (Retrieved 26/7/11).

Ufuah, M. E. (2006). **Contemporary Methods in Cartography**, Benin City: Ever-Blessed Publishers.

Uluocha, N. O. (2001). *GIS and Cartographic Visualization: opportunities and challenges***,** in Uluocha, N. O. and Nsofor, G. N. (eds.), **Cartography and GIS in Nation Building,** A Special Publication of the Nigerian Cartographic Association. Pp 61-75.

Unit 2: Socio-economic Applications

1.0 Introduction

All socio-economic activities of man take place over geographical space. In other words, every socio-economic activity of man requires the use of some form of geographical data. This explains why GIS easily finds application in every conceivable socio-economic endeavour. Some examples are used in this Unit to illustrate the utility of GIS in socio-economic activities.

2.0 Objectives

1. To highlight some areas of GIS application in managing social amenities.
2. To identify some application of GIS economic activities

3.0 Main Body

3.1 Transportation: A list of application areas of GIS to transport management may include the following items:

- Naming streets.
- House numbering.
- Street network analysis.
- Managing mailing lists.
- Vehicle routing and scheduling.
- Traffic congestion analysis and control.
- Development of evacuation plans.
- Address matching.
- Highway and other routes planning and design.
- Monitoring highway condition.
- Road maintenance.

- Road mapping.
- Accident analysis.
- Transport facilities inventory and management.
- Assessment of environmental impact of transportation.
- Air traffic control.
- Airport facilities mapping, monitoring and maintenance.
- Production of navigational and bathymetric charts.
- Planning and management of inland waterways.
- Monitoring rail systems.
- Siting of terminals (e.g. bus stops, motor parks, railway stations, etc.).

3.2 Agriculture: The following are some of the specific agricultural projects for which the powerful GIS technology could be efficiently and economically used.

- Inventory, mapping and management of agricultural land parcels (field units) and records.
- Mapping and management of agricultural biodiversity.
- Provision of field-specific condition information for precision agriculture (farming).
- Mapping of crop patterns.
- Crop area identification and delineating crop-soil relation.
- Estimating crop yield.
- Provision of accurate, relevant and timely information for effective agro extension services.
- Monitoring of crop health and growth conditions.
- Identifying the presence of pests and diseases.
- Monitoring effects of pesticides and herbicides.
- Agro-risk assessment and management (for Insurance Companies, agro managers and agribusiness entrepreneurs).
- Planning and implementation of mitigation measures.
- Inventory of crops and livestock.
- Agricultural land evaluation and classification.
- Management of grazing fields.
- Assessment of environmental impacts of existing agro projects, or the likely impacts of proposed ones.
- Monitoring crop and livestock production.
- Measuring crop hectareage.
- Determining harvesting system options.
- Mapping soil characteristics.
- Site selection for locating agricultural projects and infrastructural facilities.
- Assessment of the impacts of changes in crop and livestock management practices.
- Delineation of agro-climatic/ecological zones.
- Valuation of agricultural land.
- Soil suitability analysis.
- Effective and efficient maintenance of crop calendar.

- Assessment of the environmental impact of various cropping techniques and other agricultural activities.

3.3 Health: Some of the areas of GIS application in health management are:

- Mapping of disease locations and spread.
- Location of health facilities.
- Public health planning.
- Health services delivery.
- Planning/monitoring sanitary inspection.
- Street cleaning.
- Hazardous (toxic) facility siting.
- Solid waste management and preparation of waste disposal routes.
- Selection of solid waste disposal sites.
- Monitoring atmospheric pollution.
- Mapping water pollution.
- Air pollution monitoring/control.
- Wastewater management and disposal.
- Water quality monitoring and management.
- Sewage network design and tracking.
- Analysis of access to health care providers and facilities.
- Spatial analysis of environmental, economic, political and socio-cultural causes of health problems.
- Assessment of spatial and temporal distribution of epidemiology.
- Mapping and management of healthcare facilities.

3.4 Mining and Minerals Production*:* some of the key roles GIS plays in mineral production are:

- Geological mapping.
- Geological survey and analysis.
- Mine planning and development
- Planning for mineral resources exploration.
- Map integration of geophysical and geochemical surveys.
- Analysis of seismic data.
- Locating oil wells (identifying suitable sites for drilling oil wells).
- Inventory/Monitor oil wells/facilities.
- Simulation and analysis of exploitation scenarios in view of environmental acceptability and economic viability.
- Interpretation of subsurface data from boreholes.
- Designing cost-effective and stable routes for oil and gas pipelines.
- Siting a refinery.
- Siting fuel/gas stations.
- Managing leases, wells, pipelines, facilities, retail outlets, etc.

- Mapping and management of health, safety and environmental concerns.
- Mapping the distribution of oil, gas and solid mineral resources.

3.5 Business Management: The GIS technology can be used to accomplish the following activities in business management:

- Investment analysis.
- Locating businesses (e.g. shops and supermarkets) close to customers.
- Siting of industries.
- Selection of shortest path (i.e. the best route for the quick delivery of goods and services).
- Travelling salesman scheduling/routing.
- Inventory/monitoring business outlets.
- Market survey and business investment analysis.
- Spatial analysis/simulation of consumer behaviour.
- Analysis of customer population and distribution.
- Customer services.
- Managing mailing lists (addresses of customers).
- Defining service boundary or sales territory.
- Advertising.

3.6 Education: The application areas of GIS in education include, but not limited to, the following:

- Research and training.
- Teaching and learning.
- Career outlet for graduates.
- Geographical analysis and simulation modelling.
- Mapping and management of school facilities.
- Library management.
- Mapping and analysis of the distribution of the categories and population of teachers and students.
- Illustrating/reporting results of research works.
- Consultancy services.

3.7 Population and Housing Census: Some of the possible areas of GIS application to pre- and post-census activities and census data handling include:

- Assessment of total workload.
- Estimation of the amount of human and material resources needed for a survey.
- Delineation of Enumeration Areas (EAs).
- Distribution of enumerators' and supervisors' workload.
- Census database management.
- Spatial and aspatial census data querying and retrieval.
- Spatial aggregation and cross-area referencing of census data.

- Integration or spatial overlay of census data with some other relevant geo-referenced data layers.
- Geostatistical analysis of demographic variables.
- Three-dimensional modeling of census results.
- Production of thematic maps of census variables.
- Publication of population atlas.
- Updating of census data.
- Inter-censal population estimation.

3.8 Electoral Administration: Some of the more specific tasks that could be accomplished using the GIS technology before, during and after an election include the following:

- Locating polling places.
- Tracking voter turnout, voting methods, as well as analyzing election results.
- Assigning polling staff to polling places.
- Thematic mapping of real-time election results.
- Voter education (GIS allows registered voters to access information such as their assigned district, polling location, and election results from a computer linked to the Internet).
- Delimiting boundaries of electoral districts as well as redistricting and re-zoning.
- Maintaining voter registration files
- Mapping voters' locations.
- Relaying of information on the collection, distribution and verification of ballot boxes and other voting materials.
- Post-election creation of an electoral atlas.
- Updating voter registration files.

3.9 Tourism: The GIS can be very useful in the following broad thematic areas of tourism development and management:

- Conservation of endangered species.
- Wild and scenic rivers preservation.
- Park and recreation planning/management.
- Wildlife habitat and migration route management.
- Monitoring and forecasting natural disasters.
- Assessment of tourism-induced environmental problems.
- Management of tourist site records.
- Production of tourist Guide maps.
- Mapping tourism facilities.
- Tourism land allocation/zoning.
- Modelling the capacity of individual tourism sites to attract tourists.

4.0 Conclusion

There is geography in every human cultural, socio-political and economic activity. Consequently, the GIS technology has found usefulness in the conduct and management of daily activities of man taking place within any given geographical space. GIS provides the much needed geospatial information for sound decision making in the planning, execution and monitoring and evaluation of socio-economic activities.

5.0 Summary

GIS is a powerful tool for managing human socio-economic activities such as tourism, agriculture, mining, mineral exploration and extraction, population census, electioneering, provision of social amenities, education, transportation, business administration, and so on. The mapping, modelling, allocation, development and management of every space-based activity of man require up-to-date, accurate and relevant geo-referenced information. GIS makes it possible to obtain and use such information as quickly as possible.

6.0 References/Further Reading

Martin, D. (1996). **Geographic Information Systems: Socioeconomic Applications**, London: Routledge, 2nd Edition.

Peters, A. and MacDonald, H. (2005). **Unlocking the Census with GIS**, Redlands: ESRI Press.

Uluocha, N. O. (2007). **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications

Unit 3: Environmental and Natural Resources Management

1.0 Introduction

Issues relating to environmental challenges and natural resources analysis and management are increasingly being put on the front burner. The power of GIS as a veritable tool for environmental and natural resources management has long been recognized. Hence, many agencies involved with environmental management, emergency and disaster management as well as those engaged in natural resources planning, development and management are turning to GIS for assistance.

2.0 Objectives

1. To discuss the application of GIS in the management of environmental challenges.
2. To highlight the usefulness of GIS in natural resources management.
3. To identify the role of GIS in disaster management.

3.0 Main Body

3.1 Emergency response planning: In particular, GIS can assist emergency handlers in:

- Planning emergency evacuation routes.
- Determining possible areas of influence of an anticipated imminent natural disaster.
- Provision of Early Warning information about an impending disaster.
- Selecting suitable site for relocating evacuees.
- Search and rescue operations.
- Design and development of emergency and safety plans.
- Prompt and effective allocation and distribution of resources (relief materials).
- Estimating emergency response times.
- Fire prevention systems.
- Natural hazard monitoring.

- Estimation of damages.

3.2 Natural Resource Based Application

One of the major areas of application of GIS is natural resources management and environmental impact analysis in relation to:

- wildlife habitat,
- wild and scenic rivers,
- recreation resources,
- floodplains,
- aquifers.
- Wetlands preservation.
- Natural resources inventory/monitoring.
- Desert encroachment control.
- Erosion and flood control.
- Conservation of endangered species.

Today, biologists use collar transmitters and satellite receivers to track the migration routes of caribou and polar bears to help design programs to protect the animals. In a GIS, the migration routes were indicated by different colors for each month for 21 months. Researchers then used the GIS to superimpose the migration routes on maps of oil development plans to determine the potential for interference with the animals.

3.3 Environmental Management: Some of the areas of GIS application in environmental management include:

- Mapping ecological disasters (e.g. soil erosion, flooding, desertification, landslide, bush fire, etc.)
- Hazardous (toxic) facility siting.
- Solid waste management and preparation of waste disposal routes.
- Selection of solid waste disposal sites.
- Monitoring atmospheric pollution.
- Mapping water pollution.
- Air pollution monitoring/control.
- Wastewater management and disposal.
- Water quality monitoring and management.
- Sewage network design and tracking.
- Identifying deforestation and its effects.
- Mapping the distribution of Green house gases.
- Assessment of environmental quality.
- Environmental modelling.
- Environmental impact assessment (EIA).
- Formulation of environmental regulations.
- Environmental auditing.

4.0 Conclusion

The management of the physical environment and natural resources is crucial to the survival of man. The timely availability of useful geo-referenced information makes it possible to intelligently manage our environment and resources. The GIS, coupled with other geoinformation technologies such as digital cartography, remote sensing, and GPS, can be used to equip management with valuable information, thus acting as a decision support system in handling environmental and resource management issues.

5.0 Summary

There is a wide range of GIS applications in handling environmental issues including environmental resource analysis, planning, allocation, development and management. Also GIS is a very potent tool for environmental impact study. GIS can be used to find sensitive environments that need protection strategies regarding pollution or any other form of degradation. In another development, GIS may allow emergency planners and managers to easily handle search and rescue operation. For instance GIS can be used to quickly calculate emergency response times and the movement of response resources (for logistics) in the case of a natural disaster.

6.0 References/Further Reading

Tomlinson, R.F. and Boyle, A.R. (1981). *The State of Development of Systems for Handling Natural Resources Inventory Data*, **Cartographica**, 18(4), pp. 65-95.

Uluocha, N. O. (2007). **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications

Unit 4: Facilities and Land Management applications

1.0 Introduction

Arguably, one of the most popular uses of the GIS technology is the management of land and physical infrastructural facilities. Many land administrators as well as facility managers have found in GIS a worthy tool for the effective and efficient discharge of their responsibilities. With some examples, we will highlight in this Unit the role of GIS in facilities and land management.

2.0 Objectives

1. To discuss the role of GIS in physical facilities mapping and management.
2. To highlight the applications of GIS in handling street network information.
3. To identify possible land use management applications of GIS.

3.0 Main Body

3.1 Facilities Mapping and Management

One of the largest areas of GIS application has been in facilities mapping and management. Uses for GIS in this area have included:

- Mapping the locations and distribution of facilities
- Locating underground pipes and cables for maintenance,
- Balancing loads in electrical networks,
- Planning facility maintenance,
- Tracking energy use.

3.2 Street Network Based Applications

GIS has been found to be particularly useful in handling information based on street-networks for different purposes such as:

- Address matching,
- Vehicle routing and scheduling,
- Location analysis or site selection,
- Development of evacuation plans,
- Disaster management.

3.3 Land-use Planning and Management

Local, state, and federal governments have found GIS particularly useful in land management. GIS has been commonly applied in areas like:

- Zoning,
- Subdivision planning and review,
- Land acquisition,
- Create and update land-use maps.
- Display vacant or marginal lands.
- Analyze land accessibility.
- Identify areas of land dereliction.
- Inventory present land uses.
- Monitor and analyse changing patterns of land-use.
- Assess suitability of land for different forms of use.
- Manage records of land ownership.
- Facilitate land-use analysis, planning and allocation.
- Identify areas suitable for further physical development.

4.0 Conclusion

Proper management of land and infrastructural facilities requires the availability of timely, accurate and location-specific information. The GIS, more than any other technology, helps land and facility managers to promptly obtain useful information for quick decision making and project execution.

5.0 Summary

Land administrators and facilities management companies rely heavily on geographically-referenced data to effectively carry out their duties. Hence, they are increasingly turning to GIS to meet their informational needs. With the GIS various operations relating to land resources mapping, analysis, planning, allocation and development can easily be carried out. Similarly, the GIS greatly facilitates the mapping and management of various physical infrastructural facilities.

6.0 References/Further Reading

Dale, P.F. and McLaughlin, J.D. (1990) **Land Information Management: An Introduction with Special Reference to Cadastral Problems in Third World Countries**, Oxford: Oxford University Press.

Nappi, M.F. (1990) *Growth of Geographical Information System Applications in Developing Countries*, in Scholten, H.J. and Stillwell, J.C.H. (eds.) **Geographical Information Systems for urban and Regional Planning**, Dordrecht: Kluwer Academic Publishers, pp.69-76.

Uluocha, N. O. (1998). *Mapping for Utility Management in Nigeria*, in Balogun, O. Y. and Uluocha, N. O. (eds.) **Cartography and the Challenges of the 21st Century in Nigeria,** A Special Publication of the Nigerian Cartographic Association.

Uluocha, N. O. (2007). **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications

Unit 5: GIS Implementation Issues

1.0 Introduction

As already noted, GIS is a multi-faceted system comprising hardware, software, data, people, and methods. For GIS to be used it has to be first implemented. Implementation has been described as the act of combining the technology with people and methods (http://lagic.lsu.edu/gisprimer/phased_implementation.asp).

The key to developing an effective Geographic Information System (GIS) solution is taking the time to develop a plan that fully meets the business needs of the prospective user. Full GIS database development should follow a proven, formal design process to identify the end-user's requirements. This among other things, requires calculating and comparing the value of alternative options, define the detailed specifications of the database, and set up the progress measurement tools, quality control procedures and delivery activities to meet the user's needs.

There are often challenges associated with building a successful GIS. This makes it quite imperative engaging the services of experts who have sufficient experience in GIS design and data conversion and who can also provide assistance throughout the implementation process. Moreover, expert assistance will be required in providing all the necessary training and technology transfer to help the organization maximize their investment in GIS.

This unit provides an overview that explains the steps and activities involved in developing, building, and managing a GIS. The issues discussed include: planning a GIS program or project, requirements analysis, system and database design, determining and specifying system components, determining resource requirements, developing an implementation plan, managing GIS implementation, procuring GIS products and services, data development, system installation, and GIS operations management. GIS implementation success factors, trends, and challenges are also discussed.

2.0 Objectives

1. To highlight the requirements for effective GIS implementation.
2. To identify the potential general problems of GIS implementation.
3. To discuss some specific challenges of GIS implementation in Nigeria.
4. To examine strategies for improving GIS implementation.

3.0 Main Body

3.1 Requirements for GIS implementation

In a nutshell, the GIS implementation process can be said to involve the following:

- Functional Requirements Analysis
- Feasibility Studies
- Database Modeling
- Implementation Planning
- Data Migration Planning
- Application Design and Development
- Systems Integration Design
- Project Management
- Implementation and User Training

The implementation of GIS in an organization is done in phases. On the basis of the above listed activities, the technical approach to GIS implementation could be divided into three broad phases namely, *Planning*, *Design*, and *Operational* (Installation and Execution). Phasing the implementation process allows for all aspects of the project to be thoroughly accounted for. The overall technical approach is shown in Fig. GGGG.

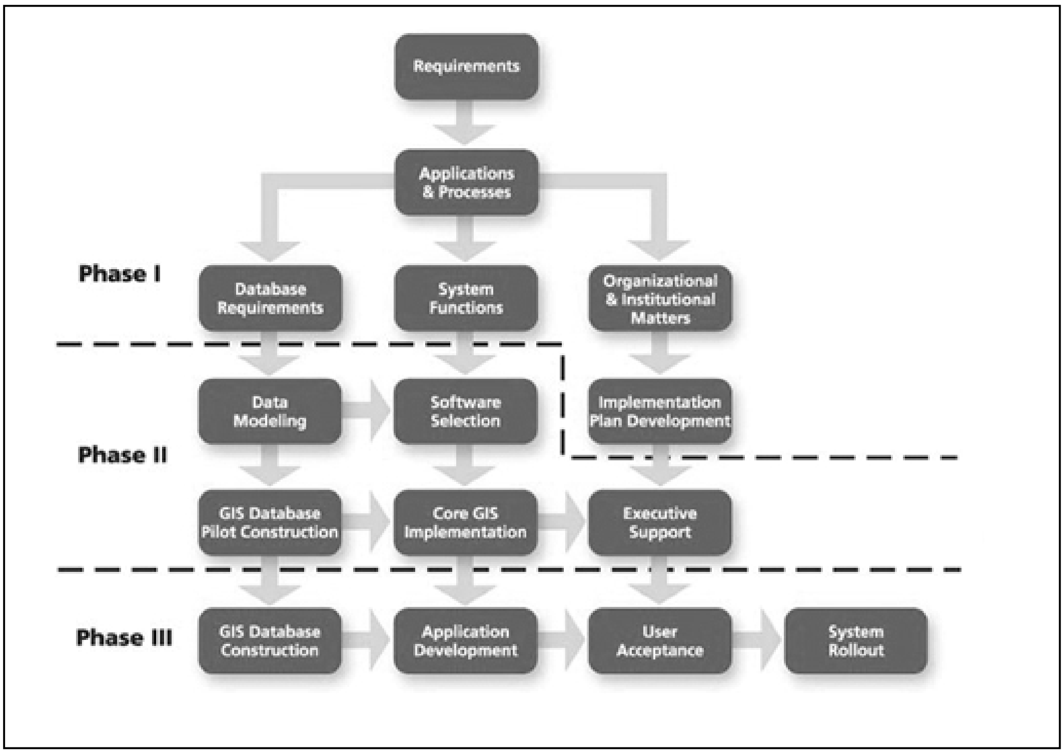

Fig. GGGG Phases of the GIS Implementation process (*Modified from* MJ

GIS Implementation Planning: The Planning Phase is a feasibility study and decision-making stage. Activities that could be undertaking at this phase include:

- Development of a strategic plan
- Identification of goals and objectives
- Appraisal of current situation: tasks, users, data, and data flow
- Review of the experience of others
- Identification of user requirements
- Assessments, e.g. cost-benefit analyses and pilot project
- Choice of implementation strategy

Awareness - this involves:

- Introducing/sensitizing/selling the GIS to the organization
- Reasons for considering a GIS?
  - Data management issues
  - Data retrieval & manipulation issues
- Obtaining the support of management and staff for your GIS proposal

System Requirements:

- Identify components of your organization
  - Data Input and Output
  - Procedures and Policies
  - Applications
  - Users
- Functional Requirements
  - Identify Current Technology
  - Identify Current Users
  - Identify Current Tasks
- Current System Analysis
  - Data quality and completeness
  - Hardware scalable?
  - Recommendations

Perform User Requirements and Needs Analysis:

- Study – written survey, interviews, document review, map utilization cross-reference chart, review of existing information system
- recording organizational goals, objectives, and functions

- identifying facilities and entities
- Data Source
- Primary Applications
- Identify Users
- Deadlines

Situational analysis:

- This involves a study of organizational internal relationships and atmosphere, positions and attitudes of potential users and influential stakeholders

Strategic Planning:

- Method of introduction
- What is to be automated and when
- Level of investment, budget, financing
- Data flow and policies
- Project organization
- Personnel and training

Establishing Long-range Planning Objectives:

- Potential applications -prioritized for implementation
- Max organization-wide benefits
- Resources

Cost-Benefit Analysis:

- Purpose: Improve the basis for decision, increase profit, increase economy consciousness, improve planning
- Impact on: ranking of projects, further considerations/planning, adaptations for increased benefits, ranking of solutions internally, final decision
- Costs: planning, establishment, operations and maintenance
- Benefits: resources, products and services, effect (communication, less work); intangible benefits
- System Cost / Expense Analysis
    - What to Purchase? (Hardware, Software, Data, and Staff Training)
    - When to Purchase?
    - What are the costs?
    - Hardware Conversion
    - Software Conversion & Training
    - Data Conversion
    - Where is the funding source?

Design and Development Phase:

- Database design
- Selection of hardware and software
- Application Design and Development

- Data conversion and
- Technology upgrades
- Systems Integration Design
- Application Development
    - Purpose
    - Goals
    - Methods
    - Procedures
    - Instructions
- Data Conversion / Development
    - Quality Assurance/Quality Control (QA/QC)
    - Accuracy Issues
    - Metadata (information about database and data items)
- Specify System Maintenance
    - Technical Support
    - Product Upgrades
    - Application trouble-shooting

Operational Phase:

Implementation Approaches: Define & Implement Procedures taking into consideration the following:

- Updates/Upgrades
    - Hardware Upgrades
    - Software Updates
    - Training
    - Data Management
- Actively Promote GIS to remind all of benefits. This ensures organization is constantly aware of budgetary needs
- Establish Security & Accountability
    - Develop information distribution and accessibility policies, taking into consideration the technical, legal, economic, and political implications of distribution.
- Decide on Method of Introduction/ Implementation of system
    - Pilot project followed by main project
    - Massive introduction in one main project
    - Gradual introduction in defined phases

It should be noted that before finally installing, integrating and operating the GIS in the organization it is usually advisable to test-run the system through a pilot project application. To run a pilot project:

- Develop complete dataset for small study area.
- Test feasibility of applications
- Refine cost/benefit estimates
- Demonstrate system capabilities
- Determine user acceptance

- Select implementation methods
- Spark users' imagination
- Evaluate the system
- Report Results. (Here details of failures and corrections are necessary)

3.2 GIS Implementation Problems

Certain problems can actually challenge the successful adoption and implementation of the GIS technology in an organization. Such problems must, therefore, be identified and thoroughly addressed before attempting to fully introduce GIS into the business of an organization. Some of such problems are presented below; additional issues can be sourced at Uluocha (2007) and *http://dusk.geo.orst.edu/buffgis/imp.html*.

- Resistance to Change
  - many organizations are conservative
  - resistance to change has always been a problem in technological innovation
  - change requires leadership
  - initial followers of the proposed system are required within an existing department
  - commitment of top management, and individuals within departments is also required.
  - despite economic, operational, even political advantages of GIS, the technology is new and *outside the experience* of many senior managers
  - leaders take great personal risk
  - ample evidence of past failure of GIS projects
  - initial missionary is an obvious scapegoat for failure

- Over-Emphasis on Technology
  - planning teams made up of technical staff will emphasize technical issues in planning
  - perhaps they will ignore managerial issues
  - planning teams often forced to deal with short-term issues
  - perhaps no time to address longer-term management issues

- Rigid Work Patterns
  - it may be difficult for the planning team to foresee necessary changes in work patterns
  - a formerly stable workforce may be disrupted e.g., some jobs may disappear!
  - or some jobs may be redefined, e.g., drafting staff reassigned to digitizing
  - some staff may find their new jobs too demanding e.g., former keyboard operators may now need to do database query operations.
  - drafting staff may need computing skills people comfortable in their roles will not seek change e.g., people must be persuaded of benefits of change through education/training.

- Organizational Inflexibility
  - planning team must foresee necessary changes in organization hierarchy, organizations wiring diagram
  - departments that are expected to interact and exchange data must be willing to do so!

- Decision-Making Procedures
  - many GIS projects are initiated by an advisory group drawn from different depts.
  - adequate for early phases of acquisition but must be replaced by a group with a more well-defined decision-making responsibility
  - usually painful to give a single department authority (funds must be reassigned to that department), but this usually assures a higher rate of success.

- Decision-Making Procedures
  - e.g., many states have assigned responsibility for GIS operation to a dept. of natural resources
  - consulting is then mandated from related user departments through committees
  - project may be derailed if any important or influential individuals are left out of the planning process!

- Assignment of Responsibilities
  - subtle mixture of technical, political, and organizational issues
  - typically made on technical grounds
  - then modified to meet pressing political, organizational issues

- System Support Staffing: at a minimum, a multi-user GIS requires:
  - a system manager responsible for day-to-day operation, staffing, financing, meeting of user requests
  - a database manager responsible for database design, planning data input, data security, database integrity
  - staff for data input, report production, applications programming staff for initial development, although these may be supplied by the GIS vendor. Management may be tempted to fill these positions from existing staff without adequate attention to qualifications. However, the personnel department might be unfamiliar with the nature of positions, qualifications, and salaries of the required GIS personnel.

3.3 Challenges of GIS implementation in Nigeria

Within the Nigerian context, there are particular challenges that often affect the smooth implementation of GIS. Issues in the implementation of GIS in Nigeria have received some measure of attention (see, for example, Balogun and Uluocha, 1998; Uluocha, 1999, Etc.).

- *Low awareness*: Despite the fact that GIS has been in use in Nigeria for more than three decades, the general level of awareness of the technology in the country is still relatively low when compared to what obtains in some other African countries. Many government officials, politicians, captains of industries, and other top-notch decision-makers are either totally ignorant of the existence of this technology or are not sufficiently aware of what the technology is all about and what it can actually do. This general low level of awareness of the GIS technology within the Nigerian society has equally meant low degree of adoption and implementation of the technology throughout the country.

Currently, only a handful of government ministries/parastatals could be said to be GIS compliant. The use of GIS is more in the private domain where we have a sizeable number of individuals, educational and research institutes, as well as corporate organizations using the technology in their various businesses.

- *Data issues*: The country is lacking in geo-referenced data. Most of the existing analogue National map series are significantly outdated. For instance, most of the existing copies of the Nigeria 1:50,000 topographic map series, which is the most commonly used map in the country, were produced more than three decades ago. One attempting to use available mapped data in this country for GIS operations would soon be disappointed to find out that much of the data fall short of the positional, attribute and temporal accuracy, just as a significant portion of the data items lack completeness (Uluocha, 1997 and 2000). For now, one can only hope that with the country embracing the space technology, following the launch of the country's first remote sensing satellite Nigeria-Sat1 in 2003 and the proposed launch of Nigeria-Sat2 and Nigeria-SatX sometime in 2011, that the problem of shortage of geospatial data for GIS operations in the country will be significantly addressed.
- *Lack of a functional National Geospatial Data Infrastructure (NGDI).* This problem is further worsened by the non-existence of an operational Freedom of Information (FoI) law. A robust FoI will greatly enhance access to relevant, timely and useful data for executing GIS projects.
- *Economic consideration*: The implementation and maintenance of a GIS is usually an expensive venture. Thus, given the economic realities of a developing country such as Nigeria, cost consideration becomes a critical factor when contemplating large-scale implementation of GIS (Balogun and Uluocha, 1998). Presently, the cost of spatial data acquisition and automation in the country is rather prohibitively high.

3.4 Strategies for Enhancing Successful GIS Implementation

To ensure the success of any GIS implementation project certain factors or conditions are required. Foley (1988), Forrest et al (1990), as well as Croswell (1991) have all identified certain critical factors that can facilitate GIS implementation success. The success factors are summarized below.

- Involve the management
  - management must take a more active role than just providing money & resources
  - support implementation of multi-disciplinary GIS teams
  - help to develop organizational strategies for crossing internal political boundaries
  - support interagency agreements to assist in data sharing & data acquisition

- Training and education
  - staff and management must be kept current in the technology and applications

short courses conferences trade & academic journals

- Continued promotion
  - project staff must continue to promote the benefits of GIS, even after it has been adopted

- ensures continued financial & political support
- projects should be of high quality and value
- high profile projects often gain public support

- Responsiveness
  - project must be seen to be responsive to user's needs
  - continue to explore ways to make GIS quick and efficient to use user interfaces task automation

- Implementation and follow-up plans
  - carefully developed implementation plans
  - plans for checking on progress
  - both necessary to ensure controlled management and continued support
  - follow-up plans must assess progress
  - need check points for assessing this. . .
  - audits of productivity
  - perhaps study of costs and benefits

4.0 Conclusion

Successful implementation of GIS requires planning the project before its actual implementation. Planning leads to a better structured and organized system. More so, the system should be designed to meet the informational needs of the user. Once in place, the system should be regularly maintained.

5.0 Summary

The life cycle of a typical GIS is composed of four main phases namely planning, design, installation/implementation and maintenance. A planning process is the first stage in the life cycle. This phase involves a systematic review of users, their data, and their information needs. The design phase matches user needs to GIS functionality. Design includes not only selection of hardware and software, but also the design of the GIS spatial and attribute database. During the implementation phase, attention to all user needs must be provided through training and education. Finally, a GIS application must be maintained and kept current in terms of data and user support. In Nigeria large-scale adoption and implementation of the GIS technology is often characterized by certain challenges. Such challenges include low awareness, shortage of data, and shortage of funds.

6.0 References/Further Reading

Balogun, O. Y. and Uluocha, N. O. (1998). ***Fundamental Issues in Sustainable GIS Implementation in Nigeria***, in Balogun, O. Y. and Uluocha, N. O. (eds.) **Cartography and the Challenges of the 21st Century in Nigeria,** A Special Publication of the Nigerian Cartographic Association.

Chrisman, N.R., 1988. "The risks of software innovation: a case study of the Harvard lab," The American Cartographer 15:291-300.

Croswell, P., 1991. "Obstacles to GIS implementation and guidelines to increase the opportunity for success," Journal of the Urban and Regional Information Systems Association, 3(1):43-56.

Fabiyi, S. (2001). **Geographic Information Systems: techniques and methods**, Ibadan: Research Support Services.

Foley, M.E., 1988. "*Beyond the bits, bytes and black boxes: institutional issues in successful LIS/GIS management*," Proceedings, GIS/LIS 88, ASPRS/ACSM, Falls Church, VA, pp. 608-617.

Forrest, E., G.E. Montgomery, G.M. Juhl, 1990. ***Intelligent Infrastructure Workbook: A Management-Level Primer on GIS***, A-E-C Automation Newsletter, PO BOX 18418, Fountain Hills, AZ 85269-8418. Describes issues in developing management support during project planning and suggests strategies for successful adoption of a project.

GIS Implementation Issues, http://dusk.geo.orst.edu/buffgis/imp.html

GIS *Primer: Phased* Implementation, http://lagic.lsu.edu/gisprimer/phased_implementation.asp

M.J. Harden Consultants, *GIS Consulting and Implementation*
http://www2.mjharden.com/GIS_Consulting_and_Implementation.aspx (Retrieved 22/7/2011).

Smith, T. R., Menon, S., Star, J. L. and Estes, J. E. (1987). Requirements and Principles for the Implementation and Construction of Large-scale Geographical Information Systems, **International Journal of Geographic Information Systems**, 1(1), pp13-32.

Somers, R. (2001). **Quick Guide to GIS Implementation and Management**, The Urban and Regional Information Systems Association (URISA), Park Ridge, IL.

Uluocha, N. O. (1997). **The Development and Application of Geographical Information Systems (GIS) for Property Tax Administration: Experiences from Nigeria**, in *Computers in Urban Planning and Urban Management*, Vol. 2, Narosa Publishing House, New Delhi, India.

Uluocha, N. O. (1999). **Issues in the Development of GIS Databases for Urban Mapping in Nigeria**, in P. Rizzi (ed.) *Proceedings of the 6th International Conference in Computers in Urban Planning and Urban Management*, Franco Angeli, Milano, Italy, 1999.

Uluocha, N. O. (2000). **Optimizing the GIS Technology for Sustainable National Development**, in *ASUU-UNILAG Journal of Contemporary Studies*, Vol. 1, No. 1.

Uluocha, N. O. (2007) **Elements of Geographic Information Systems**, Lagos: Sam Iroanusi Publications.