# THE APPLICATION OF STRUCTURED SYSTEMS ANALYSIS TO THE SPECIFICATION OF GEOGRAPHIC INFORMATION SYSTEMS



by

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## ABSTRACT

A Geographic Information System (GIS) can be defined as an automated system which stores a digital version of the analogue map, adding a topologically indexed attribute data base, spatial analysis, and modelling capabilities. The hope for the GIS tool is that it will be used to increase understanding in many diverse disciplines. However, if application scientists in different disciplines can not specify what they want a GIS to do, then user expectations in these disciplines will not be met. When this happens a costly communications failure has occured.

Techniques, such as structured systems analysis, have been successfully applied to this type of specification problem in other areas. Indeed, many GIS researchers have requested that such techniques be applied to GIS specification. However, the literature surrounding the application of structured systems analysis techniques to GIS specification is not particularly forthcoming with 'nuts and bolts' methodologies as to how this might be accomplished.

Based on techniques of structured systems analysis, a model is developed that places GIS requirement specification into a framework with other aspects of GIS implementation. This model builds on accepted structured analysis theory, but divides the model into logical and physical interfaces. GIS specification is the focus of the logical interface. All aspects of this interface are completely developed. The result is a fully explained theoretical model that can be applied by application scientists to GIS specification problems.

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# CHAPTER ONE
# INTRODUCTION

## 1.0 INTRODUCTION

In 1989 Jack Dangermond wrote in the forward to *Geographic Information Systems: A Management Perspective* (Aronoff, 1989) that he believes

> ". . . that Geographic Information System (GIS) technology is important today because it offers an important - perhaps even a critically important - means of understanding some of the most pressing problems of our times; problems like tropical deforestation, the future of global climate, the need for the ecologically sensitive development of global natural resources, acid rain, and rapid urbanization, to name but a few."

In this statement he has touched on expertise from many different academic disciplines, not the least of which is geography.

With the separation of academia, each of these disciplines has its own descriptive language. Yet the hope for the GIS tool is that it will be used to increase understanding in many diverse disciplines. How will this tool be developed such that it will function as well for a climatologist as for an ecologist? The two disciplines seem so disparate - scientists from each do not have a common professional lexicon. Moreover, the scientists from application disciplines dealing with spatial information must communicate effectively with computer scientists who deal with the hardware and software behind a GIS.

Effective communication between the vendors of GIS and prospective GIS purchasers can also be a problem. Although not documented in the literature, each year there are numerous organizations that purchase a GIS that does not meet their needs (Keller, 1991). If the GIS needs of an organization are not met, it is unlikely that the expectations of the GIS users within the organization will be met. When this happens, the GIS in question will not be used as the effective tool that it can be; in a worst-case-scenario it can become nothing more than an expensive "paper-weight".

The costs that this type of mis-communication can generate are staggering. Indeed, it is difficult to get accurate figures on exactly how much is spent every year on GIS installations that do not meet the requirements of the GIS users; no one likes to admit mistakes, especially costly ones. However, such honest appraisals of GIS failures would greatly benefit the rest of the GIS community.

This thesis contends that when a GIS does not meet user expectations, a failure in communication between the various groups who will be involved in GIS implementation has occured. The realization of this condition has been noted by several authors (see for example De Man, 1984; Burrough, 1986; Coppock & Anderson, 1987; Tomlinson, 1987; Aronoff, 1989). Examples of real-life GIS implementation are given by authors such as Linden (1987), Huntley (1987), and Crain (1987). All three of these authors discuss the problems and possibilities involved with acquiring, developing, implementing, and operating a GIS within an organization. Huntley and Linden give examples of GIS implementation in real organizations. Both authors note the problems and pitfalls that their organizations went through in implementing one or more GIS.

Linden (1987), in speaking about the Netherlands, feels that GIS applications for Dutch municipalities will need to take a long term approach that meets the capabilities and needs of the various municipalities. Huntley (1987) speaks about some of the administrative difficulties that were encountered by the City of Toronto in deciding on a GIS. He offers some solutions for these types of problems through on-site testing and evaluation of competing systems.

Crain (1987) does not give any specific GIS examples, but outlines GIS implementation issues that are non-technical in nature, but equally important in the successful implementation of a GIS. These non-technical concerns are institutional, organizational, and interactional in nature. The organizational factors relate to the placement of a GIS within the organization; the ownership and management responsibility for the GIS. The organizational factors include deciding on who will supply geographic data, who will own the data, and how will the users of the GIS be serviced with regard to training, maintenance, and GIS consulting. The interactional issues relate to questions of data standards, quality, formats, access, and quality control.

Unfortunately, in all of the above cases, the 'nuts and bolts' methodologies on how to accomplish the integration of expertise necessary to specify what should occur within a GIS appears to be lacking. It is, therefore, the purpose of this thesis to explore the problems surrounding GIS specification, and to suggest a method which will facilitate the creation of GIS specifications.

## 1.1 THE STUDY OVERVIEW

In order to fully explore this topic, background work needs to be undertaken in several different areas. These include areas of GIS research, systems analysis, and systems analysis as it has been used in geography. Concepts from all of these areas will be required to develop a model within which GIS specification can be undertaken.

Chapter 2 begins with a brief history of GIS and reviews the components of a typical GIS. It outlines some of the GIS applications available today, and points out some of the problems surrounding unfulfilled GIS expectations.

Chapter 3 reviews some of the methods of systems analysis used in specifying complex computer-based systems. It focuses on the use of one successful specification method, that of structured systems analysis. Several tools are associated with this method, and they are fully discussed in this chapter.

Chapter 4 examines some of the different methods of systems analysis that are used in geographical research. Commonalities between some geographic research in GIS and techniques of structured systems analysis are explored.

Chapter 5 puts together several of the components of the first four chapters to form a GIS analysis model that places geographic requirement specification into a framework with other parts of a GIS model. Chapter 6 further discusses this model, but with specific emphasis on the requirement specification process.

Chapter 7 summarizes the study, comments on the outcome of the work and presents implications for further research.

## 1.2 THE OBJECTIVES OF THE STUDY

The chapters noted above may appear to be covering some disparate material, but that is because this study requires some synthesis between techniques and methods common to geography, and computer science. Thus, each of the first four chapters provides background for the communication method proposed in Chapters 5 and 6.

The object of this study is to explore the possibility of using techniques of systems analysis, to provide a framework in which application specialists with an interest in spatial data can communicate their GIS needs and functions in such a way as to be understandable by system developers, computer scientists, and hardware engineers. Research into determining GIS specifications has been called for in the GIS literature. Coppock and Anderson (1987) in the first academic journal dedicated to GIS research note that defining GIS needs often is driven by the hardware and software components of the GIS rather than by an analysis of what type of question the potential GIS user wishes to ask of the geographic data.

Tomlinson (1987) notes that the future of GIS will depend to a large extent on the degree to which application needs for GIS can be specified. Indeed, he is looking for ways in which the requirements of various applications can be integrated into one type of product.

Trenholm (1987) proposes that more emphasis be placed on geographic information management systems, rather than on the hardware and software components of the traditional GIS. He suggests this course of action, because software and hardware concerns would be one component of the bigger information management system. In a short, but to-the-point paper he notes:

> In the developing world, both urban and rural, the need for timely, spatially accurate information both for present management and for future planning is paramount. Resources are scarce and must be used and consumed wisely. The environment must be assessed, understood and preserved or enhanced. A systems approach to present management and for future development must be employed.
>
> (Trenholm, 1987)

This leads to the question: "What have other disciplines used to specify complex system requirements?" In computer science the sub-field of requirements engineering addresses the questions surrounding how to determine system requirements. Many types of analysis tools exist to help determine system requirements. They range from structured design techniques that focus on the description of the physical components of the system, through Object Oriented Analysis (OOA) techniques that treat a system as a group of objects with inherited structures. Other forms of analysis include Rapid Prototyping of systems. This approach focuses on getting a prototype of the proposed new system up and running relatively quickly. This allows the members of the analysis team to detect problems early in the life-cycle of the proposed system. As well, it allows uses to "exercise" the prototype of the system early in the design phase, thus contributing their recommendations for system change early in the design period.

Davis, (1990) provides a good overview of the various tools used in system specification. One of the tools that facilitates communication is structured systems analysis (Davis, 1990). Developed by DeMarco in 1978 (DeMarco, 1979), it represents systems in a top-down manner, such that the system under examination is repeatedly refined in context diagrams.

This study shows that the techniques of structured systems analysis can be used to specify the analysis, data, and organizational components of a GIS. As well, it will be shown that this technique will provide a method to specify requirements such that all those involved with the acquisition and/or development of a GIS will be able to understand and comment on them.

There is, however, a question that must be explored before the techniques of structured analysis are applied to GIS specification; that is "How familiar are geographers with the techniques of systems analysis in geographic enquiry?" This is an important question because synthesis, if it occurs, does not mean taking the stamp of one discipline and pushing it down over another. Synthesis of knowledge implies melding salient points from two or more areas together so that the whole is greater than the sum of its parts. Often finding some similarities, even if they are metaphorical, between two supposedly different areas of knowledge, can provide a starting place for synthesis. Therefore, this study chooses to look at some of the techniques of systems analysis and systems thinking as it has been used in geography to see if there is some common ground between geography and methods of analysing system requirements.

As presented in Chapter 4, there does appear to be a good deal of common ground between these two areas. These commonalities are exploited when the GIS specification model is described. The model, which is developed for use as a communication medium, is the final result of this study.

In summary there are four major reasons behind this research. Briefly, they are as follows:

1). The GIS research calls for more understanding of GIS requirements on the part of those who will use the tool.

2). To gain an understanding of the complex interconnection of data, analysis, and organization components that underlie a successful GIS.

3). To synthesize some analysis techniques from computer science with some geographic analysis techniques.

4). To provide a method of communication between geographers and other scientists involved in the design, implementation, and use of GIS.

# CHAPTER TWO

# GIS: AN INTRODUCTION

## 2.0 INTRODUCTION

The collection, display, and analysis of spatially referenced data about the earth's surface and humanity's activities upon it, has long played an important part in the practice of geography as an academic discipline. Indeed, collation of this type of information was important long before the formalization of geography as a scholarly pursuit (Coffey, 1981). The display of spatial information often takes the form of a map.

Maps, which may be considered as models of the real world (Robinson *et al.,* 1984), have for centuries guided humanity across the oceans and continents of the earth. In fact, the desire to make maps (i.e., to discover and relate new spatial data) has been the impetus behind some of humanity's boldest adventures (Wilford, 1981). Since the turn of the century paper maps have become common-place, at least to the western nations; consider how lost humanity would be without them.

Most human activity depends on geographic information: on knowing where things are and understanding how they relate to each other (Chorley, 1987). Many aspects of decision-making by governments and the commercial world depend on it. Typically paper maps have stored and displayed this information. As Parker (1988) says "Before the day of computers, the map was the spatial database." The day of the computer is now at hand, and the more traditional treatment of spatial data has been augmented, and in some cases replaced, by computer-based storage, manipulation, and display.

Today, more than ever, spatial data about the earth, its resources and people are necessary to assist in the management of everything from sound land use to efficient political campaigns. Computers, with the capacity to store large amounts of data and transmit data at high speeds, can be useful tools to the decision-makers.

One of the latest media through which such data can be effectively collected, displayed and analyzed is a computer-based Geographic Information System (GIS). Chorley (1987), as Chairman of a Committee of Enquiry into the Handling of Geographic Information, has cited three main benefits to be derived from the use of Geographic Information Systems:

1). Quick and easy access to large volumes of data;

2). The ability to select detail by area or theme; to link or merge one data set with another; to analyze spatial characteristics or features in an area; to update data quickly and cheaply; to model data and assess alternatives;

3). New and flexible forms of output - such as maps, graphs, address lists and summary statistics - tailored to meet particular needs.

These benefits, and the perception of timely information as a vital corporate or departmental resource, have led to the success of Geographic Information Systems in government and the private sector.

This chapter provides an overview of such systems. To begin, a brief history of GIS is provided. Then the problem of defining what, exactly, GIS are and what they aim to do is addressed. A brief outline of the components of a generic GIS is then presented. With the above sections serving as background, various applications of GIS are discussed. As the goal of this thesis is to suggest a possible approach for specifying GIS tasks, the final section overviews the problems surrounding GIS design and GIS user expectations.

## 2.1 HISTORY OF GIS DEVELOPMENT

The first stage of GIS development began in the early 1960s and ended in the early 1970s (Crain and MacDonald, 1983). This period was characterized by governmental rather than industry sponsorship. The costs of GIS development were large and applications to which a GIS could be put were, for the most part, specific and selective (Tomlinson, 1984b). The GIS research problems posed and answered in this period do, however, form the underpinnings of today's Geographic Information Systems. These problems included how best to enter spatial data into a computer and how to edit, retrieve and generate reports about the data.

This initial era in GIS development occurred at a time when the technical constraints of small storage capacities within computers and slow processing speeds were major obstacles to be overcome. It was, primarily, a time of specialized hardware development in response to governmental data handling needs (Tomlinson, 1984b).

Once these first hurdles were overcome, GIS development crossed into phase two. Although no firm date has been fixed for the beginning and end of this phase, several authors feel that it stretched from the mid 1970s to the early 1980s (Crain and MacDonald, 1983; Tomlinson, 1984a; Dangermond, 1986). The second phase was characterized by an increased interest in the types of analysis that could be performed on the data (i.e. interactive query - response questions), better output formats (i.e. maps instead of tables), and tremendous growth in the number of actors involved in the GIS arena (Crain and MacDonald, 1983; Tomlinson, 1984a; Coppock and Anderson, 1987). At the same time, computer technology made tremendous advances in increasing memory capability and processing speed.

Interactive computing capabilities were also being developed to allow the user to interact with the process of data input and data manipulation (Berger, 1986, p. 7). The advent of powerful mini and micro computers and lower hardware costs put a GIS within reach of many smaller government agencies, as well as moving them into university departments, research groups, and small commercial firms.

It was during this phase of development that a GIS definitional problem first began to surface. Tomlinson (1984a) feels that there are three main reasons behind this concern.

1). Duplication of Effort. Many small Geographic Information Systems were being developed and distributed with little innovation in development.

2). Management Problems with regard to staffing, training, allocation of company/department resources to GIS concerns and user interaction with a GIS.

3). Lack of any Agreed upon Standards for all aspects of a GIS which, when combined with numerous systems being developed, led to a vested interest in preserving incompatibility.

These problems prompted Tomlinson (1984a), and others (Marble, 1983; de Man, 1984; Goodchild, 1985) working in the GIS field to argue that a start to the search for solutions to these problems would lie in properly defining what a GIS is. Putting historical developments into perspective, it would appear that three major trends have brought GIS into its present phase. These are as follows:

1). The move from large mainframe computer supported GIS to smaller mini and/or micro supported GIS has paralleled developments within the computer industry itself. This allowed government agencies, commercial firms and the individual to have access to machines that could hold over twice the operating and memory capacity of a 1960s mainframe, at a fraction of the cost.

2). Given that computing power has become relatively inexpensive, and given that the expertise to implement applications has become wide spread, current GIS developments are increasingly local or regional in scope.

3). The original impetus for GIS, that of organizing, storing, and displaying data on a particular topic for large areas, often national in scope (Environment Canada, 1973), has been overtaken by the impetus for a more localized or regional type of GIS.

Coppock and Anderson (1987) feel that the move towards local and/or regional GIS displays a lack of political commitment on the part of national legislators to earmark necessary resources towards an integrated national GIS. Indeed, they go on to state :

> " ... that the first and (in an operational sense) still the only integrated national GIS is that established in Canada in the late 1960s as the Canadian Geographic Information System (CGIS), since this was the result of a perceived need among policy makers for a capability to relate different categories of information, and a recognition that manual methods would be too slow" (Coppock and Anderson, 1987).

As with so many developments, necessity proved to be the mother of invention; in the case of the CGIS this demand led to the development of software for the storing and handling of spatial and attribute data, and to the development of the drum scanner which could digitize maps automatically.

The CGIS was the result of a perceived need among policy makers at the federal level to relate different categories of spatial information to one another. The CGIS has progressed through a number of clearly identifiable phases, namely inventory, analysis and decision support. Today the system is fully interactive and plays an active role in modelling, simulation, and decision-making (Crain and MacDonald, 1983). This type of phased development, inventory - analysis - decision support, is typical of the development that many GIS go through. Where the CGIS is unique is that unlike many other large scale systems, it has not fallen prey to *ad hoc* development along the way (Marble, 1987).

Development in the GIS world continues at a very fast pace in North America, Europe and the developing world. Since Coppock and Anderson (1987) wrote the above opinion, several national and international GIS initiatives have come into operation. The US Bureau of the Census has been working for the last ten years to link census data to the framework of digital maps prepared by the US Geological Survey. This GIS, called TIGER (Topographically Integrated Geographic Encoding and Referencing System), is now in operation. In Europe a program begun in 1985 is just now coming into operation: the Coordinated Information on the European Environment (CORINE) is a spatially comprehensive, compatible and integrated database of environmental descriptors which have relevance to European Community policy (Chorley, 1987; Warnecke, 1988).

These new national/international GIS initiatives as well as all the regional/local GIS developments owe a research debt to the CGIS. Putting aside for a moment the development of software and hardware designed to work with spatial data, the development of the CGIS has fostered an attitude of thinking spatially.

As mentioned earlier, the majority of systems developed to date have been implemented at a subnational level, particularly for planning and management of the natural resource base, and in urban areas. These local or regional developments are a result of perceived need on the part of management and have far more feasible data requirements than their national counterparts.

Today GIS, no matter what its scope, is a multi-million dollar industry. The worldwide revenues for the GIS market in 1988 were estimated to be $192 million (Lang, 1988). By 1991 these revenues may reach $464 million.

## 2.2 DEFINING A GIS

Cowen (1988) notes that while the origins of GIS have usually been traced to early work in computer mapping (e.g., the CGIS), there is a clear notion that the field is now somewhat broader in scope than automating map production. This depth has brought with it problems in definition. It is not that the concept of a GIS is new. Indeed, it has been researched and discussed since the 1960s (Smith, T.R. *et al.,* 1987). Since that time geographers involved with GIS research have repeatedly been asked questions such as: "What is a GIS?"; "How does it operate?"; "Who would be likely to use a GIS?". In response, numerous working definitions for a GIS have been proposed (Calkins, 1984; de Man, 1984; Goodchild, 1985; Burrough, 1986; Cowen, 1988). Extremes range from defining a GIS in terms of what it is intended to do - perhaps best summarized by Goodchild's (1985) definition that "a GIS is a spatial data base that will provide answers to queries of a geographical nature", to a definition which focuses on the operational capabilities of a GIS - "a system that allows for input, processing, manipulation, analysis and output of geographically referenced data" (Calkins, 1984).

In 1985, Goodchild noted that geographers still lacked a clear-cut definition of what a GIS was, what it ought to do and how it might be integrated into fields of geographical expertise. These questions have since been extensively debated at conferences and in the literature, and there is evidence that a consensus to these questions is emerging amongst geographers and others working in the field. Clearly, GIS is a young field of inquiry. A commonly recognized paradigm, precise definitions, and agreed upon terminology are only beginning to emerge.

A conceptual definition of a GIS is required to put this research into a logical framework. For the purpose of this study a GIS can best be perceived as an automated system which stores a digital version of the traditional analogue (paper) map, adding a topologically indexed attribute data base, spatial analysis and modelling capabilities.

A GIS represents a powerful way of going beyond the limits imposed on researchers and planners by the analogue map. This allows them to utilize the digital cartographic database for further analysis at little additional cost of data gathering. A GIS, therefore, represents a "powerful 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, p.7).

## 2.3 COMPONENTS OF A GIS

Before examining some of the applications that GIS can be put to, an exploration of the components of a generic GIS needs to be conducted. At the most general level it is possible to distinguish between the hardware components of a GIS, the software components, and the organizational components. Each of these can be subdivided further as follows:

**HARDWARE**

- input devices
- processing devices
- display devices
- output devices
- storage devices

**SOFTWARE**

- data input and verification
- database management
- output drivers
- data transformation routines
- user interface software
- analytical modules

**ORGANIZATION**

- GIS training/education
- GIS selection
- GIS benchmarking
- GIS integration into the workplace
- GIS monitoring and ongoing evaluation

The above subdivision is based on a discussion of GIS by Burrough (1986). A brief discussion of each of these divisions follows.

### 2.3.1 Hardware

The heart of the GIS computer is the Central Processing Unit (CPU). It is linked to the data storage units. These units, which store data and/or programs, may be disk or tape drives. Data input devices common to a GIS are the digitizer, scanner and keyboard. Output from a GIS is typically in map format, therefore, plotters capable of drafting maps are often employed. Some of these plotters are capable of drafting at an accuracy of .001 inches. A less accurate output can be generated on line and laser printers.

Terminals may also display output from a GIS. However, in order to display graphic output, the terminal must have the capability to address individual points on the screen. These points, which are often called pixels, can then be made to represent the spatial entities of point, line, and/or area. Such a terminal is termed a graphics terminal.

### 2.3.2 Software

The basic software for a GIS includes the six modules noted above. The Data Input module is responsible for taking data that are captured in the form of existing maps, field observations, and remotely sensed data and turning them into a digital form that is compatible with the CPU.

The Database and Database Manager module determine the way in which the data in the GIS are structured, stored and managed. The structure of data within a GIS is complicated by the fact that it must include information about position, possible topological connections with other data entities, and attributes of the objects within the database. Data structures for GIS must have some way of integrating the three basic topological concepts of point, line and area with attributes accorded to these topologies.

The Display and Reporting module controls the way that data are displayed and reported to the users in response to queries. Data output may take the form of maps, tables, or figures.

Data Transformation and Analytical modules perform two separate, yet interrelated functions. The Transformation module removes errors from the data or brings the data set up to date and matches it to other data sets. The Analytical module performs the various types of analysis on the data that may be needed to respond to the user queries. For example, these responses may involve performing statistical operations, modelling the data, or running simulations on the data contained in the GIS.

The User Interface module allows the user to interact with the geographical database via queries about the data. A menu of commands may be listed for the user to choose from or the user might employ a command language.

### 2.3.3 Organizational Components

No system, no matter how advanced, can operate effectively if it is not placed in a proper organizational context. This is especially true in GIS development.

A GIS can be an expensive proposition. In order to perform its functions optimally it needs to be integrated into the work place. This integration should take place long before the GIS is in place. Attention to selecting the GIS that will best meet organizational objectives is the first step.

Initial selection of a GIS is, however, not where the selection process stops. The monitoring and evaluation of a GIS takes place throughout the entire system life-cycle. This ensures that future enhancements to the system are well thought out and necessary. Training of staff is also subject to monitoring and evaluation. Training must continue throughout the GIS life-cycle. Not only will this initiate new users and update experienced ones, but it will aid in GIS integration in the organization.

## 2.4 APPLICATIONS OF GIS

The applications to which a GIS can be put are many and varied. These applications can run from developing strategies for quick response to oil spills (Ramsey *et al.*, 1990) to conducting traffic analysis in a municipal setting (Dangermond and Freedman, 1987). With such a broad set of applications to cover, an extensive review of the GIS applications would be the work of a textbook. Yet a general discussion of GIS would not be complete without some indication of the scope of GIS applications. Therefore, some type of categorization is necessary.

Various authors have suggested different categories for GIS applications. For example, Ripple (1987) suggested that GIS applications be viewed as falling under Land Suitability Studies, Urban Studies, Water Resource Management, Soil Resource Management, Vegetation Resource Management, and Global Studies. However, even a discussion of these categorized applications can be large. A further narrowing of focus for the purpose of application discussion within this thesis is called for. Therefore, this discussion will look at GIS application areas that are in the fore-front of GIS use and development.

Tomlinson (1987) notes that the future of GIS will depend to a large extent on the degree to which the needs of various application areas can be integrated and met by one type of product. He cites several application fields as leading the way in the enormous growth that GIS has enjoyed over the last few years. He suggests that these areas are Forestry, Property and Land Parcel Information, Civil Engineering, Agriculture, and Environment. The case studies presented under these categories are representative of the many uses to which a GIS can be put. Certainly more examples exist and are being discussed in journals, papers, and other GIS publications on a regular basis.

### 2.4.1 Forestry

Forestry is one area where GIS applications have been found useful. Detailing forest inventory, planning long term forest operations, preparing harvest schedules, planning reforestations schedules, preparing detailed cutblock plans, and delivering statistical yield projections are but a few examples of GIS forestry applications. For a more complete overview of GIS applications in forestry the reader is directed to *Forestry GIS: The Next Step* (Ferguson, 1988).

Tomlinson (1987) estimated that, in 1986, there were 100 installed systems in federal, state, and provincial regulatory and management agencies and in the private sector in North America. Certainly this number has increased in the past few years. The examples presented below give some idea as to the scope of GIS forestry applications. They are not by any means representative of all that can be done in forestry with GIS.

The Nez Perce National Forest in Idaho has implemented a GIS as part of a project to estimate the effects of an insect infestation in the forest (Forrester and Vanderwall, 1987). In Ketchikan, Alaska the Tongass National Forest is using a GIS to assist in the development of timber harvesting alternatives (Bobbe, 1987). Information required to model these alternatives in the GIS includes: forest type inventory, stream classification based on hydrology and fisheries habitat, soils classification based on slope, type, and hazard ranking information, wildlife habitat information, and transportation networks within the forest. In British Columbia the Inventory Branch for the Ministry of Forests uses elevation, slope and aspect models in their GIS to determine whether or not an area is harvestable (Hegyi, 1988).

Private forest companies are also involved in using GIS to manage large volumes of timber inventory and stand-related data. The Great Northern Paper Company in Maine is currently involved in testing a harvest planning decision support system which is designed to help the manager answer three questions:

1). Which stands should be harvested?

2). What is the "best" method of accessing the stands?

3). What harvesting equipment is best suited for harvesting these stands?

(Reisinger and Davis, 1987)

### 2.4.2 Property and Land Parcel Information

GIS applications are also used to assist in the management of property and land parcel data. The UK has several local area land and property systems in place in various counties (Grimshaw, 1988). Although not considered to have all the functionality of a full-fledged GIS (Tomlinson, 1987), land information GIS do relate many aspects of land and property together. This is, however, only one opinion. There are those who feel that such Land Information Systems (LIS) should be looked at as part of resource management continuum, with the LIS dealing with the micro scale and the GIS dealing with the macro scale (Dale and McLaughlin, 1988).

LISes can include environmental information, infrastructure information, cadastral information, and socio-economic information. Typically the result of a query to an LIS is a computer generated product, like a map or title certificate, or a service, like the provision of professional advice. For an extensive overview of LIS the reader is directed to <u>Land Information Management: an introduction with special reference to cadastral problems in Third World Countries</u> (Dale and McLaughlin, 1988).

LISes are typically employed to speed up municipal cartographic services and aid in the extraction of spatially encoded information from large data sets. Some of these systems can function as an umbrella GIS to support the facility management needs of different municipal service systems.

Such a system is in the pilot stage of development in Mill Valley, California (Klein, 1987). Although not a topological GIS model, this LIS emulates a topological database. The Mill Valley system consists of database overlays of the land base, the street centerlines (for street maintenance management), street lighting, sewer system, storm drain system, sidewalk repairs, and landslide repairs. The output from this system is usually in the form of maps, which may contain information about any group of overlays.

### 2.4.3 Civil Engineering

A major use of digital topographic data is in large scale civil engineering design such as cut and fill operations for highways construction (Tomlinson, 1987). Another civil engineering use for GIS and topological data is in site selection for facility development.

An example of site selection via GIS occurred when the Illinois Department of Energy and Natural Resources was faced with selecting a site for solid waste disposal in an Illinois county (Lindquist, 1987). Landfill siting is mainly an exercise in avoiding specified features (e.g., parks, subdivisions, wells). However, geological specifications, such as material type, slope and aspect, and underlying bedrock structure, also need to be considered.

In order to narrow down the number of possible sites, a GIS was used to analyze the large amounts of spatial and feature data involved in making the decision. These point and area data were processed by the GIS to determine areas of potential landfill sites.

### 2.4.4 Agriculture

GIS and agriculture have had a long relationship. Indeed, as was already mentioned CGIS and the Canadian Soil Information System are some of the original application areas of GIS.

Smith S.M. *et al.* (1987) has found that GIS can be used as a tool to facilitate agricultural field management. These researchers show that if soil and forage biomass is sampled, and the data incorporated into a GIS, then farmers can obtain information about soil and productions variability in the field. This information can be modelled to produce a plot of soil variability. When combined with elevation data, a Digital Elevation Model (DEM) can be used to model topographic variability as well.

### 2.4.5 The Environment

GIS technology is of considerable interest in environmentally-based land management, particularly the national parks of Canada and the US. Welch (1987) notes that the large ecological inventories of ten of Canada's National Parks are entered into CGIS in Ottawa. In the US, a more regional attitude is taken; spatial park data tends to be collated and processed at regional centres (Van Wagendonk and Graber, 1988). In the UK, this type of land-based environmental management is primarily the concern of the Agricultural Department, the Department of Environment, and the Welsh and Scottish Offices (Chorley, 1987). So far there has been little use made of GIS to manage rural land resources in the UK.

Another area of GIS usage in environmental planning is in evaluating and managing wildlife ranges. Stenback and Travlos (1987) use a GIS to integrate data on land ownership, winter range boundaries, elevation, slope and aspect, and soils and vegetation cover derived from digital Landsat Thematic Mapper data. The result is a habitat suitability rating for the Tehama Deer herd over a 210,600 hectare winter range.

A similar method was used to access a 3600 sq. km. site in southern California for potential California Condor (*Gymnogyps californianus*) habitats (Scepan and Davis, 1987). In this case maps of land use and condor field observation data were digitized and stored as GIS files. Land cover information was taken from Landsat data. All data were combined and registered to a USGS topological map of the area. The object of this research was to characterize the habitats formerly used by condors, quantify amounts of habitat types, and identify and evaluate possible release sites.

On a global, and/or national scale several agencies appear to be interested in environmental monitoring. At a national level, the US Environmental Protection Agency is employing a GIS to analyze and model various hypotheses concerning the long-term response of surface waters to continued acidic deposition (Campbell *et al.,* 1987).

On a global scale the United Nations participates in environmental monitoring using a GIS called GEMS (Global Environmental Monitoring System) to monitor worldwide data about soils, vegetation, precipitation, temperature, and ozone distribution (Mooneyhan, 1987).

## 2.5 GIS EXPECTATIONS AND GIS DESIGN

The successful applications described in the previous section are based on many years of research and development in the GIS field. Not all applications have been so successful. Coppock and Anderson (1987) suggest that failure to determine basic GIS needs before selecting a GIS design may well be responsible for the limited success of some systems.

In some cases the expectations of GIS users may not be met (Tomlinson, 1987). One of the problems inherent in getting involved with GIS is a lack of experience on the part of the new user. Of course not all new GIS users are inexperienced in this field, but due to the youth of the discipline, GIS training programs are only now producing graduates with GIS experience (Douglas, 1988). GIS vendors can capitalize on this inexperience and oversell their product, promising features that their GIS can not deliver, or recommending inappropriate and expensive GIS functions.

The presence of what has come to be known as a "GIS missionary" within the potential GIS-acquiring company can also pose a problem. These "missionaries" can sometimes push through a GIS acquisition which does not meet the company's needs. Although these people can be knowledgeable about GIS capability, they may not know anything about how to select, install, operate, and maintain a GIS. Again, the result can be an inappropriate GIS which does not meet organizational needs.

What the prospective GIS user needs is a guide to structure their approach to GIS task specification (Joffe, 1987). One possible approach to building such a guide is through systems analysis. It is to this possibility that the rest of the thesis is addressed; namely designing a guide for application specialists to use in the selection and specification of a GIS.

# CHAPTER THREE
# AN OVERVIEW OF STRUCTURED SYSTEMS ANALYSIS

## 3.0 STRUCTURED SYSTEMS ANALYSIS

This chapter provides an overview of systems theory, and of a methodology contained in that theory; namely structured systems analysis. Topics that are discussed include the overall concepts of structured systems analysis, the tools of analysis, and the methods of writing system specifications.

## 3.1 INTRODUCTION

The concept of systems is not a recent one; for centuries scientists and philosophers have written about celestial systems, circulatory systems, political, economic, and social systems. In recent years a more formal definition of 'system' has been devised. It is the result of recognition of a system as a construct which may be used to represent the complex set of interrelationships that exist in the real world (Bertalanffy, 1972).

Scientifically, the term 'system' refers to a set of objects together with relationships among the objects and among their attributes (Hall and Fagan, 1968). Systems conceptualization stresses the dynamic relatedness of objects in a holistic manner (Laszlo, 1973); emphasis is upon the relationships of the elements that compose the system, rather than on the specific substance or characteristics of its elements.

One of the more substantive facets of this concept has been the formalization of systems analysis as a methodology for understanding the behaviour of a system. The definition of what systems analysis is and how it operates has filled many textbooks. However, all definitions appear to have a common thread: reduction of a system to its component parts, analysis of these parts and their relationships, and reconstruction of the system (Awad, 1985; DeMarco, 1979; Kaplan, 1968).

Systems analysis is generally regarded as an operational rather than a theoretically oriented practice. The goals of systems analysis involve control or optimization of the behaviour of a system and identification of the most feasible method for accomplishing a purpose (Wilbanks and Synabski, 1968). These are aimed at understanding a system rather than at explaining it (Coffey, 1981). One practical aspect of this approach is that it assists in logical and clear decision-making.

The explicit development of the tools of systems analysis has roots within the Industrial Revolution. The search for more cost-effective production methods led to the consideration of the factory as a system, complete with internal and external relationships. Change in one of these relationships would express itself as a change in various other components of the system. Thus, techniques were developed to search for optimal changes in one or a number of elements of a system in order to reach the goal of increased profits.

Today the systems approach has become one way of thinking about the analysis and design of computer-based applications. These analysis methods tend to be divided into two groups, namely traditional analysis and structured analysis (DeMarco, 1979).

The traditional methods involve collection of relatively unstructured data about the system. These data are then worked into an organizational chart of the physical system. This serves to increase understanding of the system by conceptually simplifying its physical workings. However, the organizational chart represents a physical rather than a logical view of the system, making it difficult to distinguish **what** happens in a system from **how** it happens.

Because of this drawback, systems analysis researchers developed structured systems analysis (DeMarco, 1979; Whitten *et al.*, 1986). Rather than focusing on unstructured data gathering and physical system charting, structured analysis builds a new document about the system prior to design and implementation. This document is the system specification which forms the basis for later system development and implementation. The specification document has three goals:

1). To use graphical representation of the system to facilitate system understanding.

2). To differentiate between the logical and physical components of a system.

3). To build a logical system model to aid in understanding the interrelationships within a system.

(from Awad, 1985: p.167)

These goals aim to model a system in such a way that the model can predict possible outcomes of system changes or modifications.

## 3.2 CONCEPTS OF STRUCTURED SYSTEMS ANALYSIS

The modelling of systems of any type requires some sort of conceptual framework. Since systems, including computer-based systems, are dynamic, structured systems analysis uses a life cycle framework to house the model of the system under study. Table 3.1 displays four possible life cycle frameworks.

| Hussain (1981) | Awad (1985) | DeMarco (1979) | Powers (1984) |
|---|---|---|---|
| - Feasibility Study<br>- Overall System Plan<br>- System Requirements<br>- Design System<br>- Implement Design<br>-Test Conversion Operations and Maintenance<br>- Evaluation | - Recognition of need for analysis<br>- Feasibility Study<br>- Analysis<br>- Design<br>- Implement<br>- Review and Maintenance | - Survey<br>- Analysis<br>- Preliminary Design<br>- Hardware Study<br>- Detailed Design<br>- Testing<br>- Review and Maintenance | - Investigation<br>- Analysis and Design<br>- Design and Implementation<br>- Installation<br>- Review |

**Table 3.1 System Life Cycle Frameworks**

These generalized frameworks differ in form but, they are similar in context. The context stresses five points:

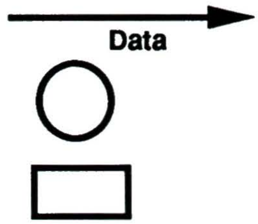
1). Recognition that a need for systems analysis exists.
2). Determination of the resources that can be applied to serving the need.
3). Analysis of the need(s).
4). Design of a system.
5). Implementation and evaluation of the system.

To illustrate further this context the Awad (1985) life cycle is presented in Figure 3.1. Not only does Figure 3.1 demonstrate the idea of a system life cycle, but it utilizes the DeMarco (1979) conventions for system diagrams. Such diagrams are made up of three basic elements:

1). Data Flows, Represented by named vectors

2). Processes, represented by circles

3). Data sources and sinks, represented by boxes




Structured systems analysis, which is represented as Process 3 in Figure 3.1, relies heavily on graphic communication methods. Graphics are used because they make an effective interface between the system users and designers (DeMarco, 1979). Such diagrams can be partitioned which means that the system may be looked at in a top-down or modular manner. The final analysis is a network of connected 'mini-specifications'. Graphic system models are also easier to maintain. Change in one process only entails updating those processes that look to the initially changed process.

DeMarco (1979) sums up the benefits of structured analysis as follows:

1). It attacks the problem of system complexity by partitioning.

2). It attacks the many problems of user / designer communication by iterative communication and inversion of viewpoint.

3). It attacks the problem of specification maintenance by limited redundancy.

Partitioning, or functional decomposition, is the first step in creating a structured design. It involves decomposing an existing system, or the idea for a new system, into its component parts. Figure 3.1 is an example of this type of functional decomposition. Diagrams of this type are called Data Flow Diagrams (DFDs).

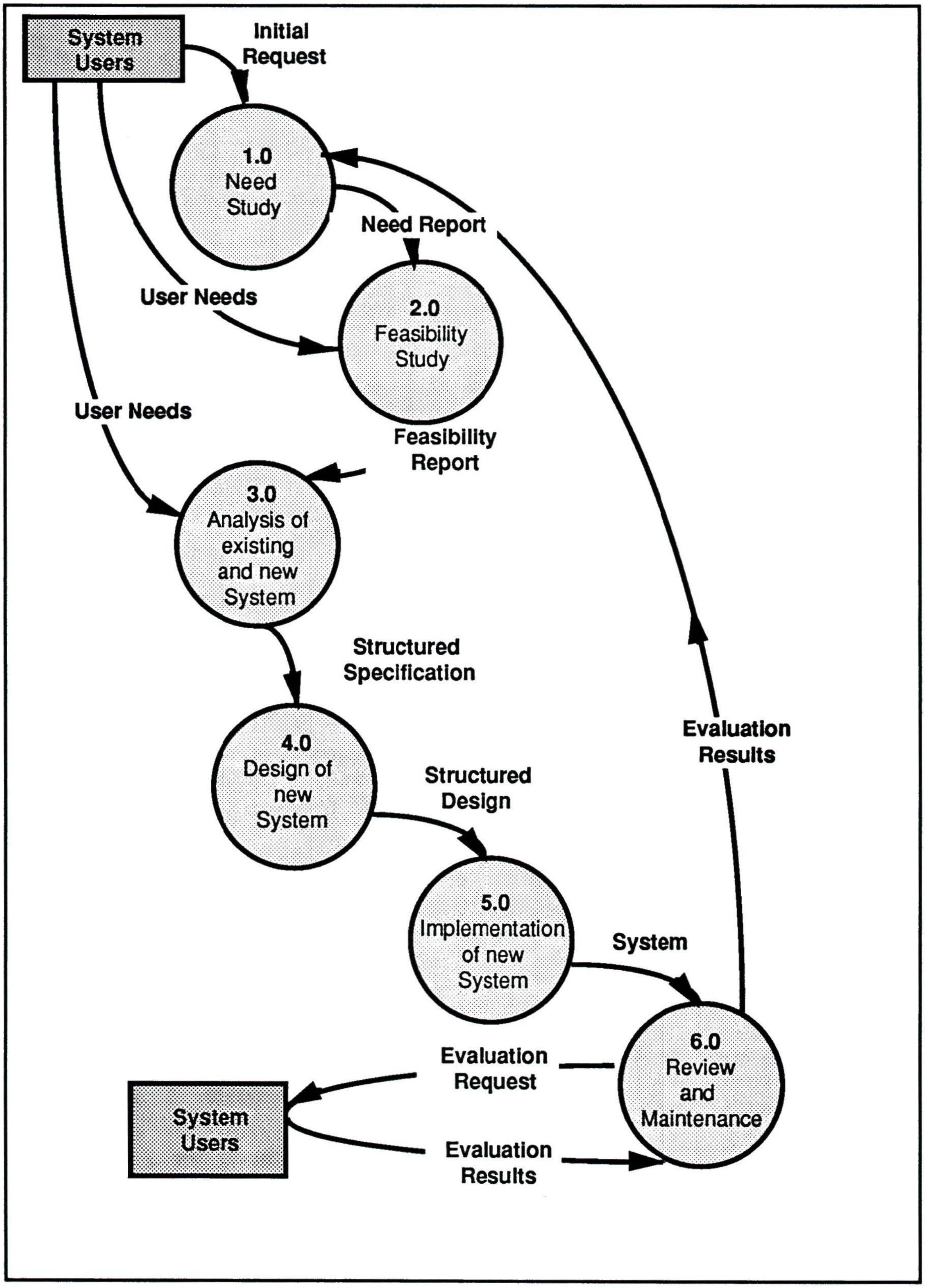



**Figure 3.1** System Development Life Cycle (adapted from Awad, 1985)

The act of partitioning with a DFD calls attention to the interfaces that result from the partitioning. A partitioning with many interfaces indicates that more partitions may be needed to present a better system overview.

Iterative communication allows the user and the designer to communicate through the medium of the DFD. The product that is iterated is the emerging system model and is an integral part of the structured system specification.

Traditional analysis usually produces a document that takes a computer viewpoint. It describes what the computer does, in the order that it does it, using terms that are relevant to computers. The discussion is often limited to processing inside the machine and data transferred in and out. This machine-oriented viewpoint can be foreign to users who seek to use the machine as a tool. Structured analysis adopts an inverted viewpoint: that of the data. This yields a DFD that describes data flow throughout the complete system. As well, the viewpoint of the data is common to those concerned with the machine and those concerned with the use of the system.

Limited redundancy creates a highly maintainable product. A practice common in good programming is the definition of parameters in one place. Thus, if a parameter needs to be changed the programmer goes to the definition and changes it. Thus it should be with the structured specifications for a system.

## 3.3 TOOLS OF STRUCTURED ANALYSIS

The outcome of a structured analysis is the structured specification. It is made up of Data Flow Diagrams (DFDs), a data dictionary (DD), and minispecs (Awad, 1985; DeMarco, 1979).

The DFD partitions the system. The purpose of the DFD is not to specify the system, but to declare it. It declares component processes that make up the whole, as well as interfaces among the components. If the target system is large, several successive partitionings may be required. This is accomplished by lower level DFDs of finer and finer detail. All the levels are combined into a levelled DFD set. Figure 3.1 is an example of a first level DFD.

The data dictionary defines the interfaces that were declared on the DFD. It does this by defining three classes of items:

1). **Data Element**: The smallest unit of data that provides for no further decomposition.

2). **Data Structure**: A group of data elements handled as a unit.

3). **Data Flows and Data Stores**: Data flows are data structures in motion, whereas data stores are data at rest.

The minispecification defines the elemental processes declared on the DFD. A process is considered elemental when it cannot be further decomposed to a lower level DFD. Each of these processes must be described. Commonly accepted methods for doing this include the use of structured English, decision trees, and decision tables. In the minispecification, these three types of relationships serve to describe processes in the DFD.

Structured English is equivalent to a high-level programming language where relational operators like IF, OR, AND, EQUAL, and NOT EQUAL form the basis of the language. A decision table is a tool to distinguish among and specify a set of *n* subsets, only one of which applies in any given situation. The value of *n* establishes the width of the table. Figure 3.2 is an example of a decision table .

| CONDITIONS | Rules | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| - Vegetation Data is more than 10 years old. | Y | N | Y | N | Y | N | Y | N |
| - This area was logged less than 10 years ago | Y | Y | N | N | Y | Y | N | N |
| - A fire occured in the area less than 10 years ago. | Y | Y | Y | Y | N | N | N | N |
| **ACTIONS** | | | | | | | | |
| - Ground Truth the Area. | Y | Y | Y | N | Y | N | Y | N |
| - Use Existing Data for Area. | N | N | N | Y | N | Y | N | Y |

A map sheet is divided into vegetative areas. Ground truthing of vegetative mapping data is required if the most recent vegetation data is older than 10 years. Ground truthing is also required if a fire has occured in the area less than 10 years ago, and if a logging occurred less than 10 years ago.

**Figure 3.2 An Example of a Decision Table**

A decision tree is a graphic representation of a decision table. Figure 3.3 is a decision tree version of the example depicted in Figure 3.2 .

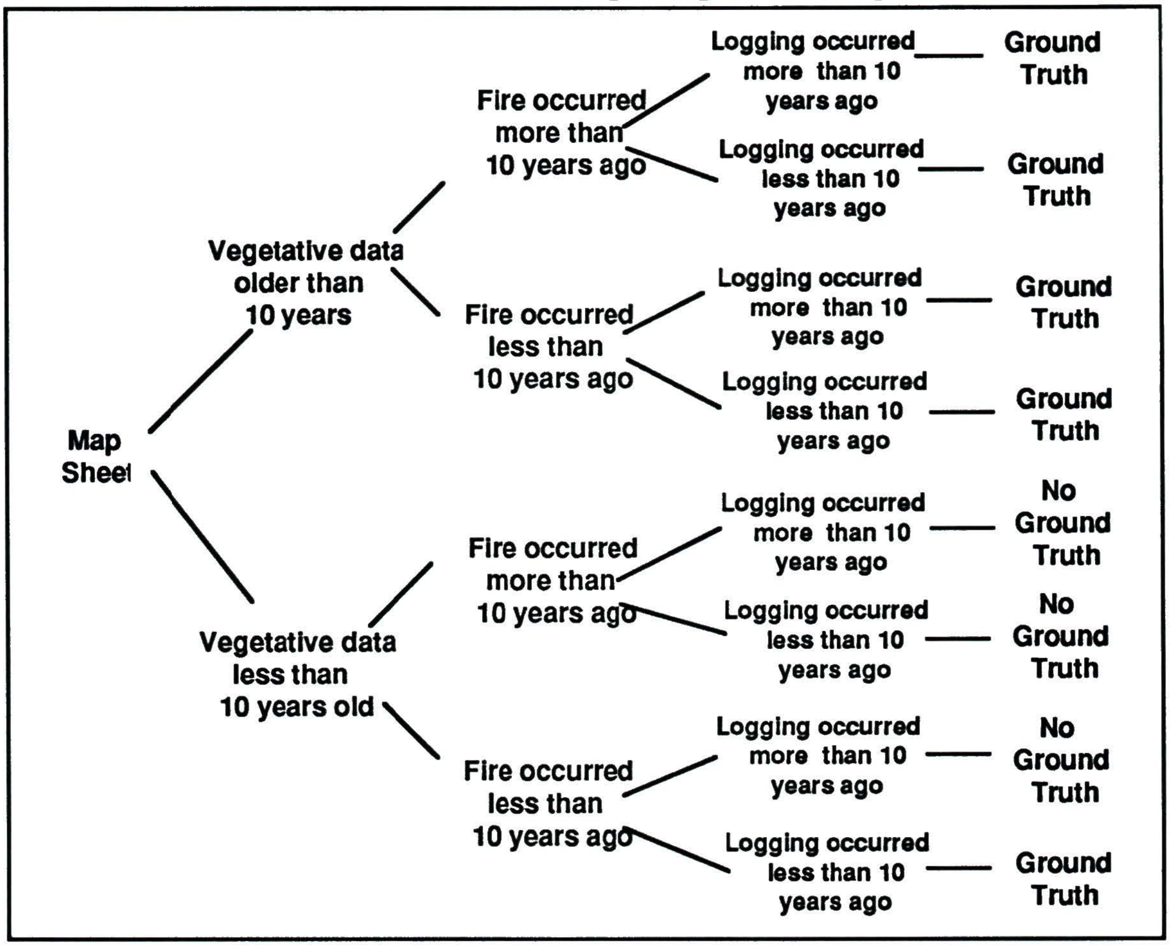
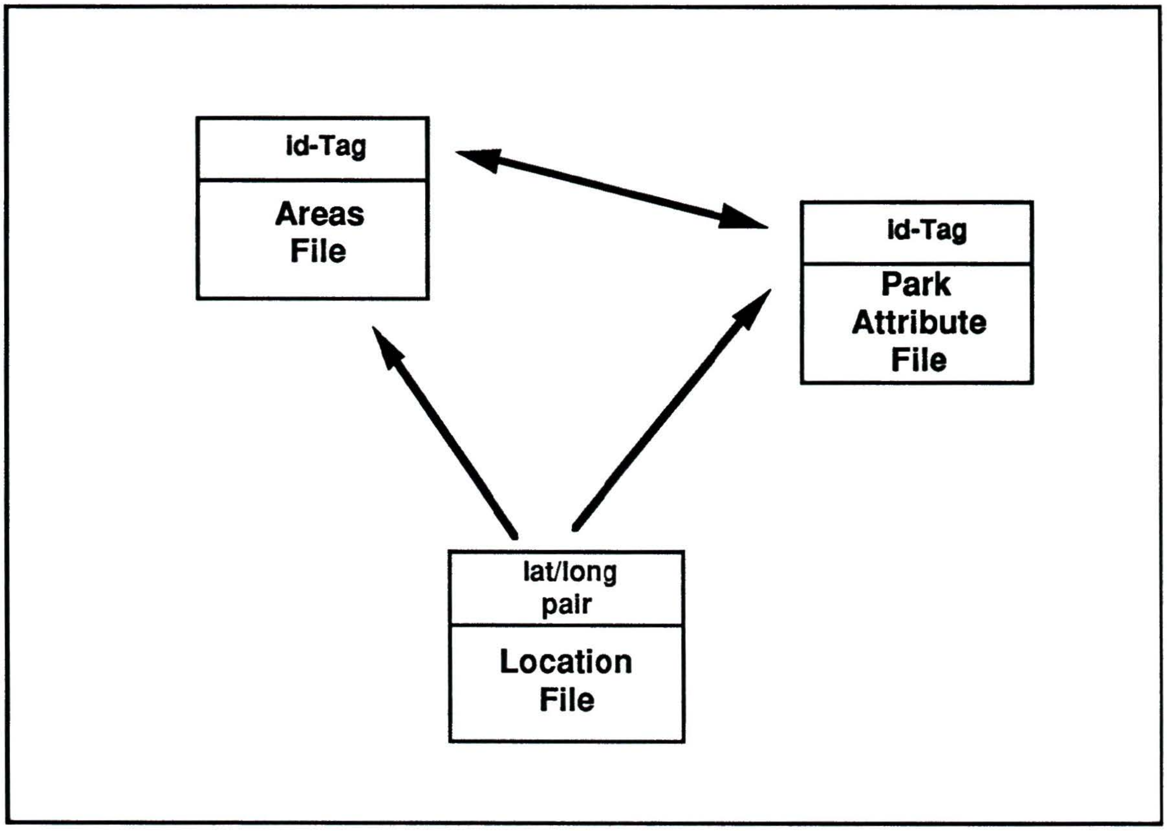



**Figure 3.3 An Example of a Decision Tree**

Another tool that structured analysis can bring to bear on the problem of analyzing a system is deriving a Data Structure Diagram (DSD). This diagram may be considered part of the data dictionary or the minispecs. The DSD does not deal with the physical database, it describes the logical database requirements.

A database, as this thesis uses the term, is defined as a special case of a file in which the components are related to each other by something other that simple concatenation. This allows the access of information in different ways by different keys. Thus, a database is any file that can be accessed by a key other than its ordering key (DeMarco, 1979).

The DSD does not include a description of the physical properties of the data (e.g., digitized *x,y* coordinates), or the database processor (e.g., dBase III ) interface, or methods of calculating new information. What it does display, in a graphic manner, is the logical data requirements of the system database(s). Thus, the DSD allows both the system designers and users to describe and define the data environment in such a way as to be mutually understandable. Figure 3.4 gives an example of a simple DSD.




AREAS FILE = 1 opening x,y coordinate pair, 1 sequential id-Tag, as many x,y coordinate pairs as required to describe the area, 1 closing x,y, coordinate pair.

PARK ATTRIBUTE FILE= id-Tag, use_attribute (heavy, moderate, minimal),
fire_attribute (heavy, moderate, minimal),
trail_type (difficult, moderate, easy).

LOCATION FILE= id-tag, lat/long pair for all x,y, pairs in the area.

The underlined data elements are the access keys to the file structure.

**Figure 3.4 A Simple Data Structure Diagram**

The conventions involved in the use and development of DSDs are encompassed in the following six points:

1). There is one block for each component file.

2). The access key for each file is written into the top portion of the block.

3). The arrows indicate that there are pointers linking the files. Direction of the pointer shows direction of the link.

4). Where the name of the pointing element is different from the name of the pointed-at access key, the pointing element name is written alongside the arrow. Otherwise it is the same.

5). Access to the whole involves entering at any block for which there is a key. Access is then available for that block plus anything it points to.

6). There are as many modes of access as there are blocks.

(From DeMarco, 1979; p.154)

An interpretation of the DSD given in Figure 3.4 shows that users can access the database through two keys: id-Tag and lat/long pair. Users can determine how many designated areas there are in the park. They may determine all the attributes for a given area. Moreover, users can enter a lat/long pair and determine the attributes of the area(s) surrounding the pair. In this example, the users cannot access the areas by the type of attributes that are found in them. If it is desirable to access the areas by attribute (as most planners would need to do), the DSD would be changed to suit the new requirements.

## 3.4 USE OF THE TOOLS

The preceding section has detailed the tools of structured analysis, however, it has not explained how they are used. This section gives a brief overview of their use in structured analysis and their place in the completed structured specification.

Refering back to the System Development Life Cycle portrayed in Figure 3.1 it can be seen that the structured specification is the result of the first three processes. These processes move in a logical fashion from a reported need of a new system, through a determination of how feasible the project is, to an analysis of how the new system should operate. This methodology is after DeMarco (1979) and Awad (1985).

After understanding the needs that the system must meet and ascertaining if the system is feasible, a study of the current system environment should be performed. This involves drawing a set of DFDs to document the current method in place. The completed set of diagrams will move from the general to the specific, with each successive DFD defining the current system to a finer and finer level.

Once the physical description of the existing system is completed the rest of the structured analysis is a series of data transformations. The current physical description is transformed into its logically equivalent DFD. The current logical DFD is transformed into the proposed logical DFD.

The new logical DFD together with the data dictionary and minispecs are the most logical expression of the new system. They state what has to be done, not how it is done. In order to be used in the structured specification, some physical properties must be added. The new logical DFD is converted to the new physical DFD. Hence, the establishment of the human-machine interface, the selection of operational characteristics, and the setting of performance targets.

## 3.5 IMPLICATIONS FOR THE THESIS

The above chapter has gone into some detail about the workings of structured systems analysis in order to provide background material for the model that is developed in Chapters 5 and 6. This model builds upon the idea of a system life cycle to help describe a process that geographers can use to specify the requirements of a GIS. The model utilizes graphics in the same manner as described above. It also utilizes data dictionaries and minispecifications.

There are some departures from the general structured systems analysis methodologies. These departures primarily express themselves as differences in viewpoint. The thesis model is designed to be utilized by geographers and other GIS application specialists, not analysts (although an analyst should have no trouble following the model). It helps application specialists describe how they perform various types of spatial studies. This type of formalized description is necessary when computer-based systems are being considered because of the machine's inability to intuitively perform any function.

The model, much like this chapter, briefly discusses actual system design, implementation, and evaluation procedures. It focuses most strongly on the development of a framework for structured analysis that application specialists can apply to their own GIS needs. The resultant model should serve as an interface between GIS applications specialists and systems designers.

In order to provide further background to this framework, the thesis now turns to an exploration of systems analysis as it has been applied in geography and, more specifically, in GIS.

# CHAPTER FOUR
# SYSTEMS ANALYSIS AND GEOGRAPHICAL INQUIRY

## 4.0 INTRODUCTION

This chapter overviews the use of systems approaches to geographical inquiry. It examines some of the initial geographical systems statements, and looks at recent systems approaches in geography. It then addresses the question of whether or not there is a role for systems analysis in GIS research and development. Finally, it presents some actual examples of how systems analysis is used in GIS research and development.

## 4.1 INITIAL SYSTEMS APPROACHES IN GEOGRAPHY

Geography, as a discipline, has not operated in isolation from the real world. From Ptolemy's *Guide to Geography* (from James, 1972) to the current applications of computers in the discipline, geography seems closely related to the intellectual climate of the time. For example, the initial attempt at a systems approach to geography seemed to coincide with an interest by post World War II science in conceptualizing objects and processes as systems.

As with many of the so-called 'new ideas' in geography, systems theory and methodology in the discipline has its roots in linear programming, input/output analysis, and operations research. From the 1950s onwards, model building was being developed in geography as well as in many other disciplines.

Although the formal application of systems concepts is a relatively recent development in geography, the notion of a system is not. Systems thinking in geography is related to the functional approach, the concept of regions as complex, interrelated wholes, and to the ecological approach (Harvey, 1969).

The first explicit use of a systems approach in geography appeared in 1962 when both Blaut (1961) and Chorley (1962) urged geographers to look for sets of interlocking propositions about sets of objects. Ackerman (1963) presented the criticism that geography was becoming too isolated, an end in itself rather than a contributor to general understanding. Declaring that areal differentiation, long regarded as the "sacred turf" of the geographer, was not a suitable candidate for establishing a common base with other disciplines, he urged geographers to adopt a systems approach to their work. He recommended that geographers be concerned with "the vast interacting systems comprising all humanity and its natural environment on the surface of the earth." Blaut (1961) took a similar view. He prompted geographers to abandon the notion of natural entities as objects of study in and of themselves, urging instead that natural objects be put into a systems context so that interrelations amongst them could be studied.

Neither of these papers identified or speculated about the techniques that might be employed to analyze these phenomena. This was left to Chorley (1962). His paper on geomorphology and systems analysis represented the first attempt in the discipline to provide an explicit framework for geographic inquiry through the application of systems analysis. Most of the paper was a criticism of the Davisian erosion cycle. Chorley argued that Davis treated erosion, essentially an open and changing geomorphological process, as a closed and isolated process.

Haggett (1966), building on Chorley's work, regarded regions as open systems. He claimed that this view causes attention to be directed towards the links between process and form. Stoddart (1965) presented a paper on the ecosystem concept that builds upon this point. The work of both Haggett and Stoddart was the beginning of a somewhat more substantive approach to systems concepts in geography. This approach tended towards a method that is more systems analytic than theoretical in nature.

An example of this operationalization of theory is the approach taken by Ajo (1962) in his attempt to model demographic behaviour. The paper pays particular attention to a situation/response mechanism in human movement. This corresponds to the systems analysis concepts of describing an input, defining a process, and predicting an output.

Perhaps the most comprehensive overview of these early research statements is found in Harvey's *Explanation in Geography* (1969). It comprehensively presents the definitions, typologies, criticisms, models and methodologies concerned with systems studies, relating them directly to geographic inquiry.

## 4.2 RECENT SYSTEMS APPROACHES IN GEOGRAPHY

As with the review of GIS applications in Chapter 2, a comprehensive review of all the recent systems approaches in geography would be the work of a textbook. For examples of these type of reviews the reader is directed to Harvey (1969), and Coffee (1981). As well there are authors who deal with systems methodologies, but place them into one or another different frameworks. The work of Thomas and Huggett (1980) is one such example. They look at various types of systems through the medium of the model. Thus, their categories of review are partitioned into deterministic and probabilistic models. Certainly this can be an effective way to examine geographic systems. However, it may be difficult to put examples from these categories into context with the techniques of systems analysis discussed in this thesis. Another categorisation scheme is needed, one which is more explicitly systems analytic in nature. The work of Coffee (1981) lends itself to this type of categorisation as it presents geographical research in systems analytic terms. The four categories offered by Coffee are :

1). Nodal System Dynamics
2). System Optimization Methods
3). Entropy Models
4). General Spatial Systems Theory

For the most part, this work is operational, with the conceptual ideals left to philosophers like Laszlo (1972). Many of the modelling techniques described by authors like Thomas and Huggett (1980) can find a place within these categories, however, it should be noted that some modelling techniques do "fall through the cracks" within this categorisation scheme. For example, while Coffee does indicate that, in general, deterministic models can be seen as part of General Spatial Systems Theory, the techniques of modelling a cascading system, where flows within the system (for example people, matter, or energy) are resolved into inputs and outputs, are not explicitly noted in his categorisation. Keeping these omissions in mind, this study can still make use of his four systems analytic categories. A brief discussion of each category follows.

### 4.2.1 Nodal System Dynamics

Of late, settlements, settlement patterns, and the interconnecting transportation systems have been classified as sets of nodes and edges that can be placed in a graph theoretic framework. Graph theory has dealt with the development of structural models involving connectivity measures and path analysis, matrix theory, and the theory of radial structures. If these concepts extend to include dynamic conditional states, then the model must consider the growth and decay of centres in response to changing spatial interaction.

Several authors, for example King *et al.*, (1969); Bannister, (1976), have determined that a network of interconnected places is characterized by interdependencies, natural causation, and lead/lag response to stimuli. These studies have investigated the way systems respond to changes in the form of economic impulses which may originate inside or outside the network. Methods have been developed to determine the patterns of interaction and the identification of which node affects other nodes first.

Central place theory was returned to geographical prominence by the work of White (1974). Noting that central place theory is too rigid, White introduces dynamic terms to the theory. The original theory (Cristaller, 1968) is a static model of the distribution of a functionally dispersed set of settlements and their corresponding market areas. Settlements in the model hierarchy are influenced by relative location, services present, and population. The higher-order settlements have larger market areas than lower-order ones. White rejects the idea of location as the driving force behind the theory and replaces the rigid assumptions of the classical model with microeconomic theory of the firm and theories about consumer spatial interaction. Thus, the problem will not be to describe where the centres are, but to describe the growth of each place in the system. The new variables are independent of the old assumptions and thus predict responses to many different changes.

Goodchild *et al.* (1979) further dynamizes the theory by constructing a model in which nodes grow or decline in response to migration. Ideas such as these are system analytic because their goal is to examine the relations between different processes within a model.

### 4.2.2 Systems Optimization Methods

This type of systems research is often known as operations research. The areas of study most often favoured by those involved with operations research are business and economics (Coffey, 1981). Often there is a spatial component to these studies and hence operations research attracts some geographers. These spatial problems often involve influencing the structure or the behaviour of a system by adjusting spatial relations within the system. The goal of the research typically involves the search for some sort of spatial efficiency. For a review of some of the concepts of operational research with spatial components, the reader is directed to Larson and Odoni (1981).

In geography, an example of such problems have become known as location-allocation studies. A set of demand points (consumers) is spatially distributed over an area and a set of supply points (facilities) is distributed to serve them. The question that the geographer seeks to answer is "How can the supply points be optimally located about demand points and demand optimally allocated to the supply points?" (Hodgson, 1986). Location-allocation analysis may also attempt to regionalize or district areas by determining a certain pattern of allocation over an area.

This type of work represents an analysis of a system that is either supply/demand nodes, regions, or transportation networks. Optimization of a system is one of the major goals of systems analysis, hence this type of geographical inquiry is systems analytic.

### 4.2.3 Entropy Models

In contrast to the controlling and regulating approach of the systems optimization methods, entropy modelling focuses on the most probable configuration that a system will take. The basis for this model is the assumption that the final state in any situation is its most probable configuration.

One of the earliest introductions of these models to geography came in geomorphology when Leopold and Langbein (1962) introduced the idea that empirical regularities in the branching of rivers represented maximum entropy: a maximum likelihood distribution of energy. Wilson (1970) began to work with entropy models to estimate distribution probabilities given some prior knowledge about a system. He postulated that the entropy maximization method assigns equal probability to any state in the system which is not excluded by prior knowledge of the system. The most probable state achieved in the largest number of ways is the maximum entropy state (Wilson, 1970, p. 6).

Like system optimization methods, entropy methods concentrate on analyzing the function and components of various systems. In this way entropy modelling qualifies as an area of geographical inquiry that uses techniques of systems analysis.

### 4.2.4 General Spatial Systems Theory

As demonstrated above, recent systems work in geography has tended to be in applied areas. It would appear that operationalization and application have overtaken conceptual work. Some theoretical work, however, has taken place. Warntz (1974) has attempted to develop a conceptual framework for theoretical geography that utilizes systems analysis and General Spatial Systems Theory.

The primary methodology of general spatial systems theory involves model building based on reconciling spatial process (movement) with spatial structure (form). The philosophy underlying this method is identified by Warntz (1974, p.1) in the following manner:

> It is considered to be a valid and important intellectual endeavour to attempt to determine whether or not there exists a certain (small) number of systematic spatial patterns of structure and process among phenomena that may be judged to differ greatly in terms of their non-spatial aspects.

The search for spatial isomorphisms is related to General Systems Theory methodology. This search has led critics to note that isomorphic similarities (in form and relation) may be nothing more than broad mathematical generalizations (Coffey, 1981). Yet the search for isomorphisms has led to the techniques of structured systems analysis discussed in Chapter 3. The basis for these techniques is the determination of isomorphic tendencies in the form and relation of data and processes within a goal-oriented environment.

Perhaps the difference between the highly theoretical work of Warntz (1974) and the highly applied work of DeMarco (1979) is one of scope.

Warntz appears to be looking for a structured systems analytic method to apply to the human-environment interface, while DeMarco has restricted his scope to the human-machine interface. DeMarco's method may be used and empirically tested in a matter of months or years. Warntz's method, when applied to the environment, may not be validated for centuries. There is also the problem of scale: the DeMarco method of structured analysis is very large in scale; almost every variable within the system is accounted for. Conversely, the methods Warntz advocates are very small scale; few variables in the system are accounted for, and most of these are estimated.

Indeed, it is fortunate that geographers have all these methods to choose from when investigating spatial phenomena. Because many of these phenomena are still not described or understood, geographers need the deductive methods of Warntz as well as inductive ones like DeMarco's.

## 4.3 SUMMATION OF SYSTEMS ANALYSIS IN GEOGRAPHIC INQUIRY

Much has occurred in geography in the years since Harvey (1969) noted that systems theory had not progressed much beyond the exhortation to think in systems terms. The previous sections of this chapter point out that a growing number of geographers are either explicitly or implicitly utilizing a systems analytic framework in their research. Regardless of the form it takes, the systems analytic approach appears in much of today's geographical enquiry. It is a rare piece of analytical work that does not have some recognizable elements of systems thinking.

Given this familiarity with systems analysis as a research method, geographers should have little trouble applying these techniques to the problem of defining and describing what they would like a GIS to do for them. To facilitate this understanding, a model of the task, with constraints, inputs, processes, and outputs, is required. The next section looks at how structured analysis might be applied to the definition of a GIS. It also overviews how other researchers have applied these techniques to GIS development.

## 4.4 SYSTEMS ANALYSIS AND GIS

As was noted in Chapter 1, GIS are considerably more than warehouses for the storage of data about the earth's surface. No matter which form they take, the data in a GIS should be thought of as representing a model of the real world (Bouille, 1984). The previous sections have demonstrated that systems analysis has been applied to real world phenomena, some of which are of interest to geographers. Now it must be demonstrated that structured systems analysis can be used in defining a GIS.

#### 4.4.1 Systems Analysis and GIS in the Literature

The use of systems analysis in GIS research within the literature may be examined on a basis of scale. Like systems analysis itself, this research may be seen as moving from the specific to the general, or vice versa. This exploration will take the former route.

Examples of large scale, or specific, applications of systems analysis in GIS may deal with fitting spatial data into an abstract data type (ADT) or model (Frank, 1984). The ADT has found considerable use in software engineering as a method of specifying aggregate information requirements from the standard data types of integer, real, and character (Parnas, 1972). Some typical GIS examples include points described by coordinate values, lines described by a pair of points, or curves described by a sequence of points.

Other examples draw on hierarchical structure to define an ADT. Both Dangermond (1986) and Walker *et al.* (1986), offer definitions of a spatial object, called a 'feature'. Features can contain a set of coordinates for a spatial entity, some attributes about the entity, and a unique tag to identify both. This allows the spatial data to be stored and retrieved in a manner distinct from the attribute data.

Steiner and Gilgen (1984) take a somewhat more ecumenical view when they write database specifications that generalize the database into an external level (user view), conceptual level (logical data model), and internal level (view of the data actually stored). This type of model, and the feature model above, represents a generalized hierarchy.

Keeping with the movement from the specific to the general is the work of Marble *et al.* (1984). These researchers used structured analysis to understand manual digitizing operations as practiced on a large project. They attempted to estimate the level of time and effort required to complete a given digitizing project. Initially they found it difficult to break down a process which contained so many different, yet interconnected, steps. A top-down hierarchical model, the digitizing process was decomposed into levels, each of which accounted for increasingly detailed activities.

Webster (1988) uses a type of data flow diagram to model and assist in the evaluation of network database architectures. His models, which also examined data structure, but in the more general framework of networked databases, led to conclusions that differed from Dangermond (1986) and Walker *et al.* (1986). He determined that a truly disaggregated GIS (large, multi-site applications of GIS) that was heterogeneous with respect to the type of DBMS used and federated with respect to separate database schema at each node would operate more efficiently if there were a single data model for both attribute and spatial data.

Moving closer to the top of the generalization hierarchy is a presentation by Aronson (1985) of the analysis techniques used to design a popular GIS. Environmental Systems Research Institute (ESRI) has used many of the systems analysis techniques discussed in Chapter 3 to design, construct, and maintain their ARC/INFO GIS. The use of techniques such as the ARC/INFO life cycle and 'toolbox' approach are addressed.

Another application of structured systems analysis techniques to ARC/INFO is performed by Brown (1986). He takes a slightly different approach from other researchers in that he highlights human engineering as one of the major components of a successful GIS. He uses the concept of a system life cycle to frame the broader issue of successfully choosing, implementing, and maintaining a GIS.

Perhaps one of the most generalized applications of systems analysis to GIS is taken by De Man (1984). He edited a conceptual framework and guide for establishing geographic information systems. The guide stresses understanding systems purpose, goals, and interrelatedness through the use of DFDs.

The above examples of techniques of systems analysis in the literature are but a few of many. They were selected because they explicitly display structured methodologies. Indeed, the field of GIS research is much like the more traditional domain of geographical research because it is the rare piece of work that does not possess some recognizable elements of systems thinking. In traditional geography this may mean that the systems ideas of holistic understanding, feedback, interdependencies between phenomena, and the interrelatedness of objects have achieved a common acceptance. Because GIS research has a tendency to be oriented towards computer systems, these ideas, which are inherent in systems analysis, form the methodology for development.

This similarity in the acceptance and use of the techniques of systems analysis to model structures, be they spatial or computer-based, may enable the techniques to serve as an interface between the two fields of study.

## 4.5 COMPARISONS BETWEEN TRADITIONAL GEOGRAPHIC INQUIRY AND GIS RESEARCH

Comparing the similarities between the four concepts named in Section 4.2 (Nodal System Dynamics, System Optimization, Entropy Models, and General Spatial System Theory) and systems methods as applied to GIS research yields the following points:

Under the topic of nodal dynamics the work of White (1974) can be compared with that of Marble *et al.*(1984). As noted in Section 4.2, White models an urban system comprised of central places of economic development and sectors surrounding them. The model attempts to predict how the system will react to changes in inputs (e.g. how will the system change if a major industrial employment centre is introduced).

Marble *et al.* models one system found in a GIS: manual digitizing. The system is comprised of operators, manual digitizers, and a changing rate of data. The model attempts to predict how much time and effort will be needed to digitize the data.

White uses simultaneous linear equations to drive his model. The variables he uses are all internal to the model and reflect gains in interaction within system flows and the resulting transmissions from node to node. Marble *et al.* use cost/benefit analysis, which is a linear function of time and cost. Both systems have changing inputs, and both seek to predict output by modelling throughput.

It is possible to demonstrate similarities between system optimization models and GIS research. System optimization models are normative. They describe what should happen, not what will happen. Similarly, researchers like Walker *et al.* (1986) have sought to optimize a system for a certain goal. In their case the goal was a networked GIS.

Unfortunately this study was unable to find any explicit similarities between entropy models and GIS models. Certainly entropy modelling, with its emphasis on maximum likelihood distribution, is the converse of systems analysis as it relates to GIS.

If the study of systems approaches in traditional geographic enquiry can be looked upon as a generalized hierarchy, then systems theory can be looked on as its root node. The similarities between this idea and the work of De Man (1984) involve the search for a methodology in which to frame questions. Warntz (1974) was looking for spatial structure and process that spanned non-spatial aspects; De Man is looking for a way to structure GIS design such that it spans physical limitations. De Man was looking for a logical structure to apply to the design of GIS; Warntz for a logical structure to apply to spatial processes.

## 4.6 CHAPTER SUMMARY

This chapter has made the following points:

1). Techniques of systems analysis exist and are currently used in geographical enquiry.

2). Techniques of systems analysis, and especially structured analysis, can be used to define and describe geographic information systems. These techniques serve to define a GIS into a generalized hierarchy.

3). Systems analysis and structured analysis have been used in the literature to define GIS. The use of these techniques can also be categorized within a generalized hierarchy.

4). There are demonstrable similarities between the techniques of systems analysis that exist in a more traditional geographic enquiry and those that exist in GIS research.

This chapter supports the argument that systems analysis is a valid approach to bring to geographic enquiry. It is also an approach that has been used with success in the field of GIS research. Moreover, because of its use in geography, it is a familiar tool. Therefore, it is logical for this thesis to bring the techniques of structured systems analysis to bear on a problem that involves GIS, geographers, application specialists, and geographical enquiry: namely the development of structured system specifications for GIS from within a geographical framework. This framework, which is called a GIS Analysis Framework, facilitates communication between GIS users and developers through the development of functional systems specifications derived from an optimal GIS design model. Essentially, it serves as an effective medium of communication between GIS applications specialists and GIS designers. Chapter 5 describes this model.

# CHAPTER FIVE
# THE GIS ANALYSIS FRAMEWORK

## 5.0 INTRODUCTION

The preceding chapters have discussed some of the roles that systems thinking has played in both geography and computer science. This chapter discusses how one aspect of systems thinking can be brought to bear on analyzing geographic information systems. The emphasis is upon analyzing geographical input to the system, but the method is derived from structured systems analysis.

Why is an analysis framework of this type important? In a broad sense the reasons are both theoretical and applied in nature. Theoretically, much of what a GIS is supposed to do has its roots in geographical enquiry. The types of analysis performed on data in a GIS are common in geography. Such analysis can run from the calculation of summary statistics to the creation of digital elevation models.

From a more applied viewpoint it would appear that users of a GIS are often geographers, or geographers in conjunction with application specialists. For example, the output from a GIS is often a map. But, how can geographers and application specialists determine what they wish the GIS tool to do for them? Too often geographers and application specialists, in the position of end-user, have unspecified requirements that cause them to purchase and install a GIS that is not suited to their real requirements. This can lead to many problems such as cost over-runs and unexpected user limitations.

Clearly, geographers and application specialists need some way to communicate both their theoretical expertise and their application requirements to those persons who are involved in the design and implementation of GIS. This chapter and the next address just such a communication problem.

## 5.1 A STATEMENT OF THE PROBLEM

GIS research represents a young and rapidly developing field of inquiry, requiring theoretical and applied expertise from many disciplines, most especially geography. The prime directive of the GIS community is interest in the handling and analysis of spatially referenced data. The uses that this data may be put to vary from large scale application, such as landscape planning (Keen, 1989), or municipal GIS, as are in place, for example, at the cities of Calgary and Burnaby, to a very small scale GIS with a global basis like the Global Environment Monitoring System (GEMS), developed by the United Nations Environmental Program (UNEP) (deMan, 1984).

Lines of GIS inquiry prove to be many and varied. This is attested to by Coppock and Anderson (1987) in their editorial review, written for the first academic journal dedicated to GIS. Yet, Coppock and Anderson (1987) note:

> ... important as such developments in hardware and software for handling and manipulating spatially-referenced data are to development of GIS, they represent only one aspect. Equally important, if not more so, are the questions that need to be asked of these data. All too often, at least in published studies, such questions have been taken for granted, yet they affect not only the type of analysis but also the kind and quantity of data that are collected, and hence methods of collection and storage. Of course, for many potential users, especially those with little experience of GIS, defining needs for data and identifying questions are iterative processes, in which what can be done technically influences what is required and, less frequently, what is required stimulates and enlarges what is possible, so that the development of GIS progressively expands users' ideas of what they can do.

In a broad sense it is to this idea - expanding what can be done through the use of GIS - that this thesis addresses itself. As mentioned in the introduction to this chapter, geographical information systems appear to be 'geographic' in several areas. Firstly, the data stored and utilized by the systems is spatial in nature. Secondly, many of the questions asked of these data are spatial in nature. Thirdly, analytical components tend to derive from cartography and spatial analysis. Fourthly, GIS users tend to be, if not geographers themselves, interested in the spatial perspective of a given problem. However, a GIS is often designed by a team of computer specialists with skills in algorithm construction, database management, programming, and computer architecture. While these specialists may be experts within their areas, not many have sufficient experience with geographic data processing to produce useful tools to manipulate them (Aronson, 1985).

Herein lies the problem statement: Since both computer and geographical expertise are necessary for a successful GIS, what type of medium may be designed to allow the experts to communicate effectively the specification of a GIS? This thesis asserts that one such medium may be a structured specification document. This document can be designed using techniques of structured systems analysis that have been modified to place the document in a geographical frame of reference. More explicitly, the specifications are based on three 'geographical' points, namely (a) geographical data requirements, (b) geographers' participation in design and/or use of a GIS, and (c) spatial analysis capabilities.

## 5.2 METHODOLOGY

Geographical information systems are a complex mixture of many different components. This can make selection of a GIS complex. Indeed, with so many hardware, software, and organizational considerations it is little wonder that some GIS users end up with a system that does not meet their needs. The complexities of GIS hardware and software considerations can also make it difficult for geographers involved with the design of GIS to communicate their ideas to other design team members.

These problems are not insurmountable. As described in Chapter 3, techniques of systems analysis have often been brought to bear on complex computer design problems (Dorfman, 1990). If these techniques are modified to reflect a geographic frame of reference, then they can be used to ameliorate communication problems.

Recalling from Chapter 3, the three goals of structured analysis are:

1) To use graphical representation of the system to facilitate system understanding.

2) To differentiate between the logical and physical components of a system.

3) To build a logical system model to aid in understanding the interrelationships within a system.

(from Awad, 1986; p.167)

It is possible to apply these techniques to specifying what a GIS should do for the geographical user.

The tools of structured analysis are, as described in Chapter 3, Data Flow Diagrams (DFDs) that partition the system in question into components, data dictionaries (DDs) that define the interfaces declared on the DFDs, and minispecifications, which define the elemental processes declared on the DFDs. Using these tools in a geographical frame of reference requires some modifications. The modifications include:

1) The use of a logical Data Flow Diagram in which there are few physical and/or machine dependant processes declared. Data flows that are representative of general information, rather than data that is restricted to one type of system, and processes that declare geographical requirements, geographical processes, and organizational structures.

2) The use of a data dictionary in which the data elements are either geographical or organizational in nature, and data structures that treat groups of these elements as units.

3) The use of minispecifications that specify what occurs in each of the geographical and organizational processes. The minispecifications are broader in scope than those of traditional structured systems analysis.

Applying these tools to the problem of specifying what a GIS should do yields a structured specification document. The results of this document are four-fold.

1) They allow geographers and application specialists to undertake a structured overview of their GIS requirements.

2) They allow geographers and application specialists to communicate these requirements to other GIS researchers.

3) They allow the GIS to change as time goes on.

4) They allow geographers and application specialists to build a detailed model about their GIS needs and/or their GIS design contributions.

The first of these results is accomplished by using the techniques of structured analysis to construct levelled DFDs that declare GIS requirements. These are broken down into modules made up of general information data flows, geographical requirements, and organizational processes. Each of these modules can be further broken down, or levelled, until understanding of what occurs at that module is not enhanced by further levelling. This produces a 'top-down' hierarchy in which each level may be looked at individually, or as part of a larger module.

The second result is accomplished by using graphic techniques. These techniques have already been demonstrated in this thesis, and include the use of the DeMarco (1979) conventions for system diagrams. To repeat, these conventions are:

1). Data Flows, Represented by named vectors


2). Processes, represented by circles

3). Data sources and sinks, represented by boxes

The use of graphics allows the GIS analysis framework to move away from discipline-dependent language. Also, it tends to document the system from the point of view of the information within the system, rather than the physical constraints.

The third result is a built-in feature of structured analysis. Because each of the processes declared on the DFDs are subject to 'top-down' modularization, areas where change is contemplated can be easily located. Because of the way in which all of the processes are partitioned, the results of a change in one process can be located in others. This property makes the structured specification document easy to change and maintain.

The fourth result is accomplished when the geographer completes the structured GIS framework analysis. The completed analysis yields a structured specification document, which contains a detailed system model. The document has identified who the GIS users are, what their data needs are, how the data is structured, what type of processes are worked upon the data, what type of output is required, what type of maintenance of the data is performed, and how the data is administered.

As mentioned in Chapter 3, structured systems analysis is one process in the larger process of developing a system life cycle. The same is true of the GIS analysis framework presented here. To clarify when, where, and how the structured specification document is produced within this framework, a GIS life cycle model is presented in Figure 5.0. This model, which is discussed in the following section, is itself an example of an upper level DFD.

## 5.3 THE GIS ANALYSIS FRAMEWORK MODEL

Figure 5.0 presents the GIS Analysis Framework Model. It is an example of a DFD. As such it follows the DeMarco (1979) conventions for DFDs.

The model is composed of 6 upper level processes, 14 upper level data/information flows, and 2 upper level information/data sinks. The model is divided into logical and physical sections, with a time line that corresponds to the relative amount of time that each section should take to complete.

There are some differences between this model and a typical systems development life cycle. The process names and the data/information flow identifiers suggest a more generalized analysis than is usual. This reflects the modifications in the tools of analysis. Also, it is not common to explicitly define a logical/physical interface within the life cycle, or to add a time line.

Typically, systems analysts do all of the system specification. Basically they are called upon because some type of change is required within an organization. Through close contact with the system users in the organization, they design the logical specifications for a given system. In the physical design and implementation phase of development, they act as a guide to the design team and as the interface between the users and the system designers (Awad, 1985). But, as DeMarco (1979, p. 34) remarks: "Nowadays (sic), the user areas we are automating are much more complex and the users correspondingly more high powered". Certainly this is true of geographers and their relationship to GIS. Moreover, it has been demonstrated in Chapter 4 that geographers and application specialists are not strangers to the theory behind systems analysis. Therefore, it seems reasonable to assume that geographers and application specialists could employ modified structured analysis techniques to analyze their own geographical data needs and processes. This would allow geographers and application specialists to determine their own GIS requirements prior to undertaking any outside GIS design.

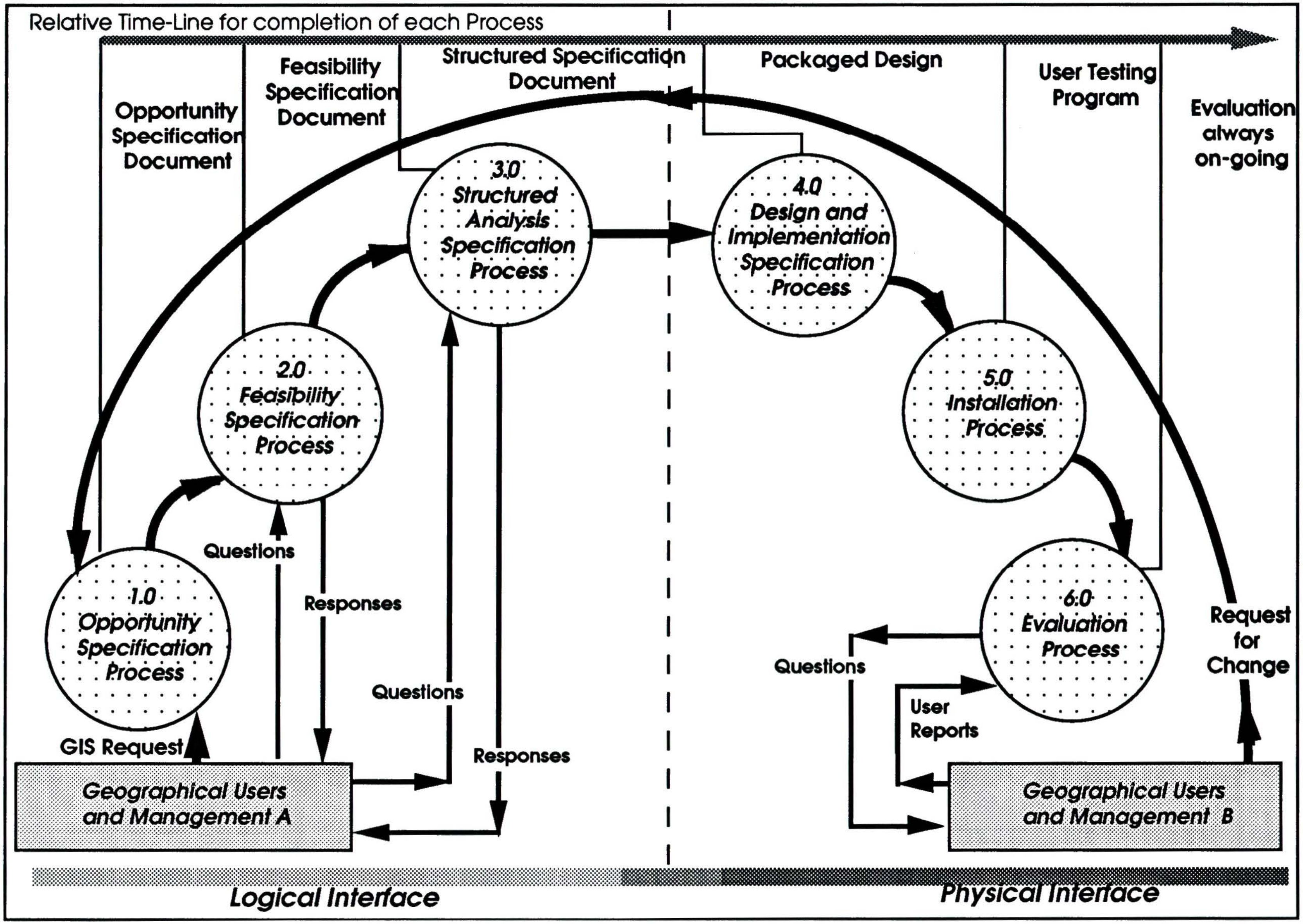



Figure 5.0 The GIS Analysis Framework Model

The objectives of this model are primarily twofold; firstly they are designed to create a descriptive tool for geographers to use in specifying their own GIS requirements, and secondly they provides an effective communications medium to be used between geographers and other experts involved in GIS design. Both of these objectives are met in the structured specification document, which is the result of processes located on the logical side of Figure 5.0. The next chapter looks in depth at the processes, information flows, and data sinks associated with the logical side of the GIS Analysis Framework Model. The remainder of this chapter presents an overview of each of the components in the model.

### 5.3.1 Overview of the Model

Geographical Users and Management A

This data/information sink is more realistically thought of as a data/information source. Typically, it is through these people that the request for either a new GIS, or the updating of an already existing one will come. This element in the model gives guidelines to identify uses that an organization would put a GIS to. Information gathered from this element would include:

- Establishing, in general, what the needs of the users are.
- Establishing what type of work they want a GIS to do.

Output from this element of the model is a formal request for a GIS. This element of the model also receives other input in the form of questions, and gives other output in the form of responses as a result of other processes at work in the model. This element represents the users within the logical stage of development. To differentiate between Geographical Users and Management within the logical and physical stages of development, an A and a B have been added to the element title.

1.0 The Opportunity Specification

The Opportunity Specification establishes the questions that need to be asked of the users regarding their needs. It is based on the initial request. Opportunity questions that need to be asked might include the following:

- Determining if there is already geographic information processing ongoing within the organization.
- Determining how well-defined the tasks are that a GIS will be required to undertake.
- Determining the scope of the application(s).
- Determining if there are any special considerations to be made.
- Determining when the users need the GIS.
- Determining a broad benefit/cost estimate for the GIS.

The output from this process is an Opportunity Specification. The Specification recommends a course of action.

2.0 Feasibility Specification Process

The acceptance of a broad based course of action in Process 1.0 is defined further in this process. The needs/objectives of the user are determined more exactly. This in done through Questions to the User such as:

- What type of input/output is required, and in what volume?
- What will the system be used for? Priorize these uses.
- What degree of accuracy, precision, and resolution is required for the GIS?
- What GIS and/or information systems exist and are in use by the organization?
- What are the database requirements?
- What type of data analysis and/or data use is required?

A more in-depth benefit/cost analysis is undertaken in this process. Possible changes to the organization due to the new or updated GIS are described. The resources available to the project are detailed.

The result of this process is a Feasibility Specification. It recommends a detailed course of action to the next process.

3.0 Structured Analysis Specification Process

By this point the geographical needs of the user have been defined. Now they are joined together into a logical picture of the system. To structure this process the following information is declared.

- The current (if it exists) physical system is studied and presented in a DFD.
- The logical equivalent (or new logical) DFD is declared.
- A data matrix for the data structure of the proposed system is written.
- An analysis matrix for all proposed GIS analysis functions is defined.
- Several human/machine interfaces are declared. These include modified DFDs of the proposed system, minispecifications describing what occurs within the proposed GIS, and data dictionaries describing how data moves through the GIS.
- Administrative structures are outlined in this process.
- Benchmark data structures and analysis functions are determined in this process.

Within this process several human/machine interfaces are suggested. These interfaces are not hardware/software specific, rather they give an indication of where a GIS might fit into a given organization. One of the purposes of this process is to provide some viable GIS alternatives to those whose task it will be to make a GIS selection.

The output from the Structured Analysis Specification Process is a Structured Specification Document. It contains the DFDs that logically declare the new GIS, the DDs that define the interfaces, and the minispecifications that document what occurs inside each process. The document includes some idea of the physical properties that the system might need. This document differs slightly from a more traditional Structured Specification Document in that it does not specify all of the physical requirements of the system, other than to indicate which processes might be performed by the GIS and which might not. Also, the document includes information on the logical data structure and analysis requirements that should be incorporated into the proposed GIS.

The Structured Specification Document produced here forms the interface between the logical and physical considerations in GIS design. What has been produced to date is a structured account of what the GIS should do for the geographical users. What remains to be decided is how the GIS should accomplish these tasks.

## 4.0 Design and Implementation Specification Process

In this process a system or alteration to an existing system will be decided upon. With the Structured Specification Document in hand, GIS designers can begin to determine how a GIS should accomplish its designated tasks.

Typically this phase of system design is undertaken by persons with a background in computer science and computer systems design. This does not mean that there is no role for the geographical user to play here. The GIS user, in conjunction with the GIS designer, must decide on system performance criteria. Often these criteria, along with a copy of the Specification Document, form a request for proposals to vendors. The GIS user also must keep the GIS designers posted on changes in the organizational environment that will effect the GIS. Certainly, any testing that is done must involve the GIS user. Indeed, DeMarco (1979, p. 285) implies that the active and concerned user will want to be involved with the detailed work of system design and implementation to ensure that all the requirements worked out in the analysis stage have been clearly understood.

The following is an example of information that is declared in this process:

- Technological choices
    - input/output devices are selected
    - the host computer(s) is (are) selected

- Software choices
    - database software
    - data transformation
    - data representation
    - data presentation

- user interface
- operating system

• System configuration
  - system centralization, decentralization, or combination
  - response to query time
  - access frequency to data sets

This process concentrates on the chosen GIS. If techniques of structured design are used in this process then it is a relatively clean move between the DFDs of the Structured Specification Document and the structured design of the GIS. As this topic is beyond the scope of this thesis the reader is referred to Dahl, *et. al.* (1972), Orr, K.T. (1977), and Yourdon, and Constantine (1978) for specific information on structured design.

The output from this process is a Packaged Design. It will incorporate structure charts, which detail how data moves throughout a system, efficiency concerns, coding and language concerns, and hardware dependencies.

5.0 Installation Process

It is during this process that the GIS is implemented following the structured design derived in the preceding process. Because that design was top-down in form, the implementation is also top-down. This allows the system designer to test the critical interfaces first.

After the system has been implemented and installed, acceptance testing is determined. Typically there are four types of tests to be performed. The following is a brief overview of these tests:

1). Normal Path Tests
  - they are derived from the Data Dictionary
  - they test a value set comprised of the boundary values and an intermediate value
  - using combinatorics a test data base is derived for each item in the DD
  - the test database is then input to the

system
- the system should be able to handle every item in the database

2). Exception Path Tests
- they are derived from invalid data for each data element
- they are format dependant
- an exception path database is constructed
- the exception database is input to the system

3). Transient State Tests
- the system is forced into each of its possible states and tested
- each input data flow has one or more memory states associated with it
- there is one sequence of normal path tests for each state
- return the system to normal after passing the normal test path database through the state

4). Performance Tests
- determining if the standards set for performance in the structured design phase are reached
- there is one set of tests for each performance restriction (digitizing accuracy, geographical searching and sorting, map overlay)

The output of this process is, along with the already mentioned tests, a User Testing Program. This allows the user to learn something about the system, while trying the system out with actual data. The user also has an opportunity to become familiar with the documentation available for the system and to make appropriate changes.

6.0 Evaluation Process

The testing specifications derived in the preceding process are applied. The users of the new GIS are canvased for their opinion of the system. These User Reports, along with the response to the system tests, are reported on. Areas for future development are noted. Processes for implementing changes to the GIS are determined. Documentation for everything undertaken to date is prepared.

Geographical Users and Management B

The users in this element of the model are the same as those in A. However, the B users are on the other side of the logical/physical interface. They have participated in the design and implementation of a GIS and are now ready to report on how well it does or does not meet their requirements. Users and management in this portion of the model are also able to institute Requests for Further Change. These requests, which go directly back to Process 1.0, are what keep the GIS Analysis Framework functioning as a system life cycle. As both system analysis and design are structured into hierarchical modules, change is relatively easy to accommodate. This, in turn, can make the GIS a flexible tool which can be used by geographers and application specialists to expand what they can do.

## 5.4 CHAPTER SUMMARY

This chapter has made the following points:

1). Geographers and applications specialists need some way to communicate both their theoretical expertise and their application requirements to those persons involved in the design and implementation of GIS.

2). One medium which may aid communication between different GIS players is the structured specification document.

3). This document may be designed using techniques of structured systems analysis that have been modified to place the document into a geographical frame of reference. The document will then allow the creation of specifications that are bases on geographical data requirements, geographers' and application specialists' participation in GIS design and/or use, and the required spatial analysis capabilities.

The chapter then described the tools that could be used to create this document, as well as the modifications necessary to put the document into a geographical frame of reference. A model for undertaking an analysis of GIS requirements was presented. This model, which follows the concept of a system life cycle, outlines the tasks that need to be undertaken to specify, implement, and operate a GIS. The processes are divided up into two major categories: logical operations and physical operations. Each of the components of these two categories is briefly discussed.

An in-depth analysis of each component of this model would be beyond the scope of this thesis. Indeed, such an analysis has not, as yet, been carried out according to the literature. The work that does exist tends to focus strongly on one or two aspects of the GIS life cycle, and then overviews other concerns. This comment is not intended as a criticism of the work of authors like Burrough (1986) or Aronoff (1989), but is included to give an indication of the different types of expertise necessary to specify, implement, and operate a GIS. Chapter 6 of this study examines in-depth all the components of the logical interface portion of the GIS Analysis Framework Model presented in Figure 5.0.

# CHAPTER SIX
# THE LOGICAL COMPONENTS

## 6.0 INTRODUCTION

The preceding chapter introduced the GIS Analysis Model. This chapter deals in depth with the components on the logical side of the model (Figure 6.0) The model is presented as if it were a system to be analyzed. The DeMarco (1979) conventions are used to produce levelled DFDs that describe each process. The model also introduces data dictionaries for each data/information flow, and produces minispecifications where applicable.

It is hoped that this model can be used by those who want to investigate acquiring a GIS, or who wish to have input to the design of one. Currently, there does not appear to be a general-purpose model that will take an organization from an initial GIS request through to analysing their own GIS needs. deMan (1984) attempts to accomplish this task, but the work is geared toward development planning on a global basis. The result is a good conceptual overview towards establishing a GIS, but includes little of the 'nuts and bolts' involved in the process.

In Chapter 9 of *Principles of Geographic Information Systems for Land Resources Assessment* (1987), Burrough introduces some salient points regarding how to choose a GIS, but the result is too hardware specific. Some of the general concepts in establishing a GIS are passed over. Indeed, Burrough says on p. 167 that his information presents "... another approach which should complement and augment some parts of the UNESCO (de Man 1984) study". Structured systems analysis is used here as the medium to join the two sources of information together. Each of the elements in Figure 6.0 is examined in-depth in this chapter. All the upcoming figures in this chapter relate to the logical partition of the GIS Analysis Framework displayed in Figure 6.0.

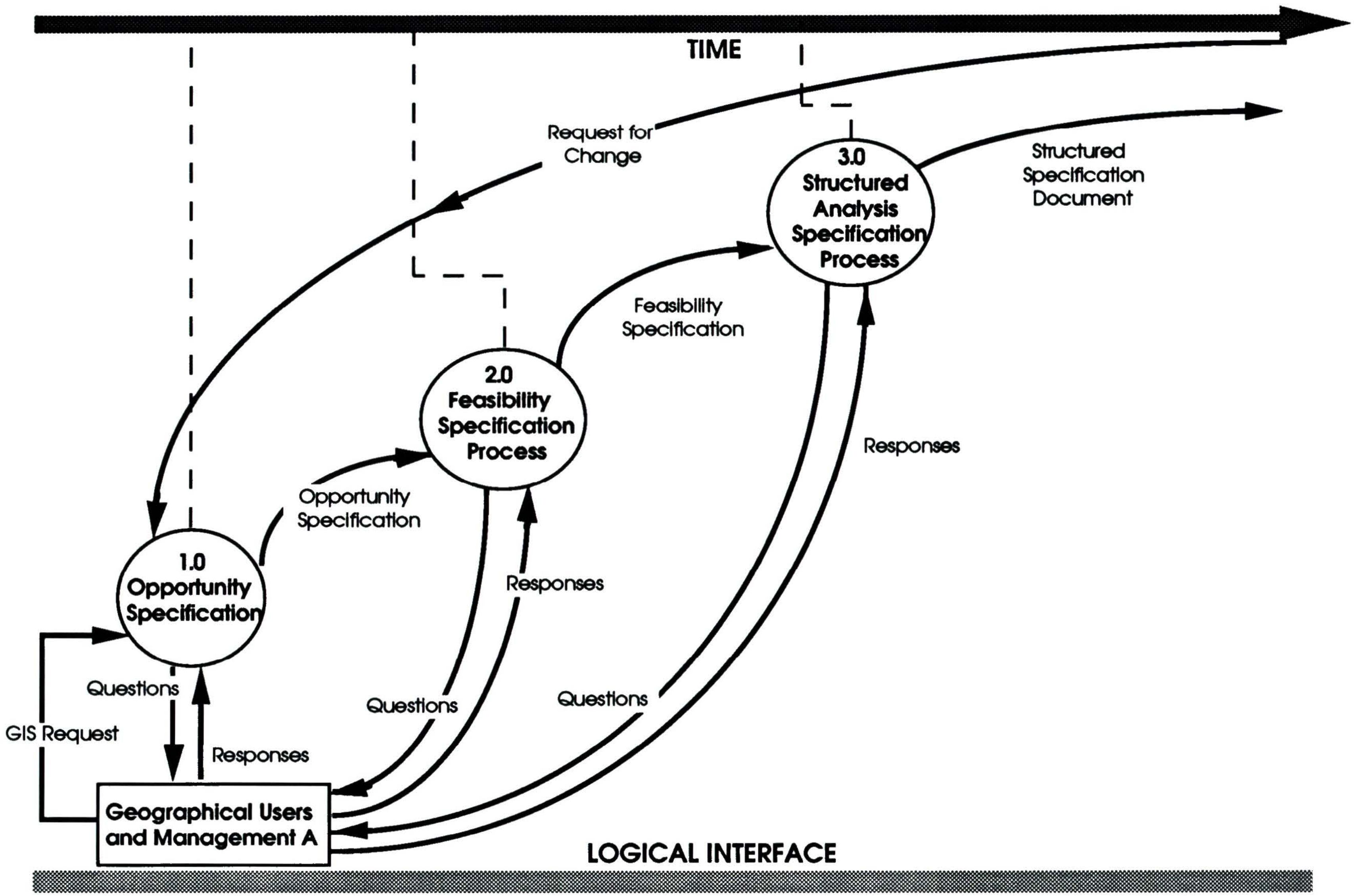



**Figure 6.0 The GIS Analysis Framework: Logical Interface**

## 6.1 THE GEOGRAPHICAL USERS AND MANAGEMENT A

Figure 6.1 shows the data/information sink that is represented by the Geographical Users and Management within an organization. The Geographical Users in this portion of the model represent those that see a need for a GIS, or those who would like to see a major change to an already existing system. Thus, the first output from this element is usually a request for a GIS.

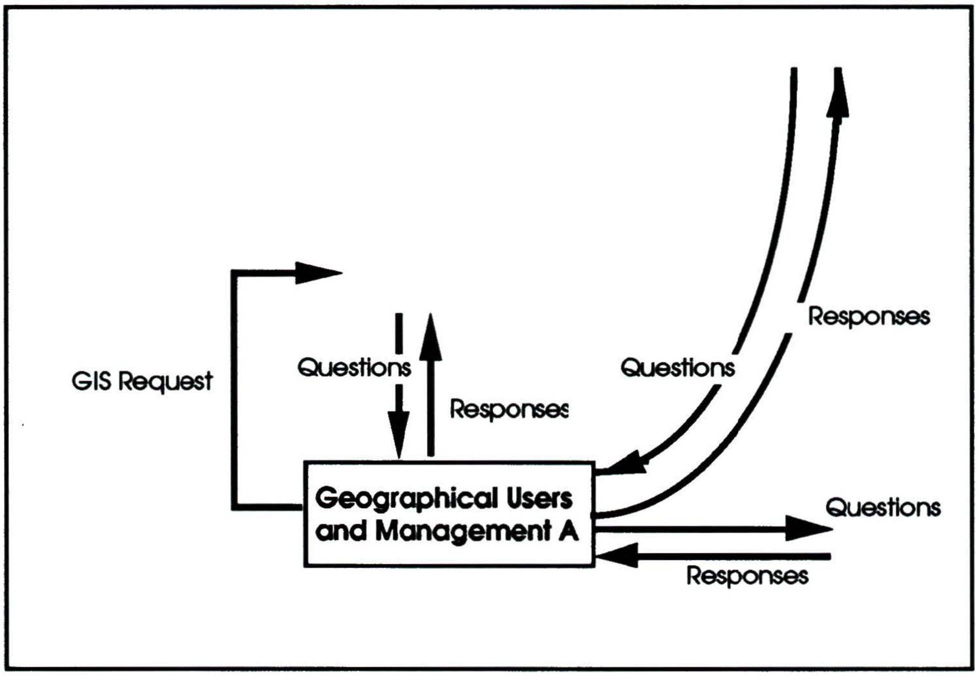



**Figure 6.1 Geographical Users and Management A**

Although not a process itself, it is here that the GIS users are identified. deMan (1984) suggests that there are two main considerations in this identification process, both of which relate to data flow. He suggests that an inventory of the existing flows of data and information be made. This will produce a list of present users. He then suggests that an inventory of relevant decision processes and the potential users be made. This will identify both the current users of geographical information, and the potential users of this information.

Burrough (1987) suggests that the geographical users be separated into categories. These are (a) users with an exact, defined GIS task, (b) users with part of the GIS task defined, but whose undefined work may make variable demands on a GIS, and (c) users with no part of their GIS task defined exactly. Users in (a) generally want to automate existing tasks, with the goal of increased efficiency in mind. Users in (b) typically want to house a variety of GIS capabilities under one system. Users in (c) may be using a GIS in different types of research and/or teaching. This last group may have unknown or variable information requirements.

In a more general manner DeMarco (1979) has identified three types of users. These are (1) the hands-on user, or operator of the system, (2) the responsible user, or the one that has direct business responsibility for the procedures being automated, and (3) the system owner, usually upper management. In a GIS setting the hands-on users may be thought of as the system users. These people would use the GIS under direction from a responsible user or from the system owner. The responsible users in a GIS setting would be involved with the development of GIS projects, goals, and objectives within the organization. The GIS owner would be responsible for setting overall goals and objectives for the GIS.

To amalgamate the work of these people the following four steps are suggested.

1. Derive an organization chart of the group under study.

2. Determine how many hands-on users, and how many responsible users there are at each level. The system owner(s) should also be identified here. Table 6.1 gives an example of a user profile chart.

3. Determine the category of user at each level in the organization. This means determining which users view the GIS as having a defined set of tasks to undertake, which view it as having some, as yet, undefined tasks, and which view it as having no defined tasks. Table 6.1 also describes these categories.

4. Determine the existing flows of data and information at each level. This involves noting how data/information is utilized. The final result of this step is to show which levels produce information, and which levels utilize it. There may be levels that do both. These should be noted. Table 6.1 displays an example of this information/data flow.

**Table 6.1 GIS User Profile**

| Organizational Levels | USER TYPES | | | DEFINITION OF TASKS | | | PRODUCTION AND/OR USE OF INFORMATION | | |
|---|---|---|---|---|---|---|---|---|---|
| | # of hands - on users | # of responsible users | # of system owners | Defined tasks % | Undefined tasks % | Mixed % | Info produced % | Info used % | Mixed % |
| This is the structure of the organization. | For each level, the # of GIS users in the three categories should be determined. | | | For each level, the % of defined, undefined, and mixed definition GIS tasks should be determined. | | | For each level, determine the % of GIS information that is produced at that level, used at that level, or is both used and produced at that level. | | |
| For example: A university teaching and research facility. Organizational levels here might include faculty, faculty doing research, instructional staff, graduate students, and undergraduate students | User types or profiles would be different at each level. For example, the research faculty would all probably be responsible users or system owners. The faculty in general could fall under any or all of the three categories. Instructional staff would probably tend to be responsible users, or hands-on users under the direction of a responsible user. Graduate students would tend to be responsible users while most undergraduate students would be hands-on users. | | | The definition of task would be different at each level. These differences would also tend to change over time. For example, if a GIS is only just being installed, then many teaching tasks might be undefined. Research tasks would also become more and more defined as the scientists became used to using the GIS tool. Tasks at the undergraduate level are defined in that someone guides the student through various GIS procedures. | | | Often organizations have groups that produce GIS data and groups that use the data for management. This is especially true of government departments. In the academic setting production of information and use of information often go together. | | |

Although the "Geographical Users and Management A" element of the model does not have any processes associated with it, knowledge of the GIS user population will assist in the first explicit process defined in the model: Process 1.0, the Opportunity Specification. Indeed, it is this process, along with Processes 2.0 and 3.0 that form or instigate the input and output data/information flows in this element. The only data/information flow that is generated directly from this element is the 'Request for a GIS'.

When this part of the user investigation is finished the organization will have a profile of its geographic information users. Table 6.1 is an example of how the user profile can be structured. All of this information will play an important part in the upcoming analysis.

## 6.2 PROCESS 1.0 : THE OPPORTUNITY SPECIFICATION

This process, along with the next two, form the crux of the GIS Analysis Framework model as it relates to this thesis. Each of the upcoming sections that deal with the three processes outlined in Figure 6.0 will be structured as follows:

1) A set of leveled DFDs of the process is presented.
2) A Data Dictionary describing all the data flows in the process is produced.
3) Minispecifications describing the actions that take place in the process are presented.
4) Comments from DeMarco (1979), de Man (1984), and Burrough (1987), and others regarding this type of process are presented.

### 6.2.1 The Levelled DFDs for the Opportunity Specifications, Process 1.0

Figure 6.2 presents a hierarchical view of all the sub-processes that are involved in Process 1.0. Figure 6.2 does not show links between the siblings in the tree structure. It serves to indicate which DFD a group of siblings belongs to. Figures 6.2.0, and 6.2.1 show all of the sub-process, and data flows that make up Process 1.0.

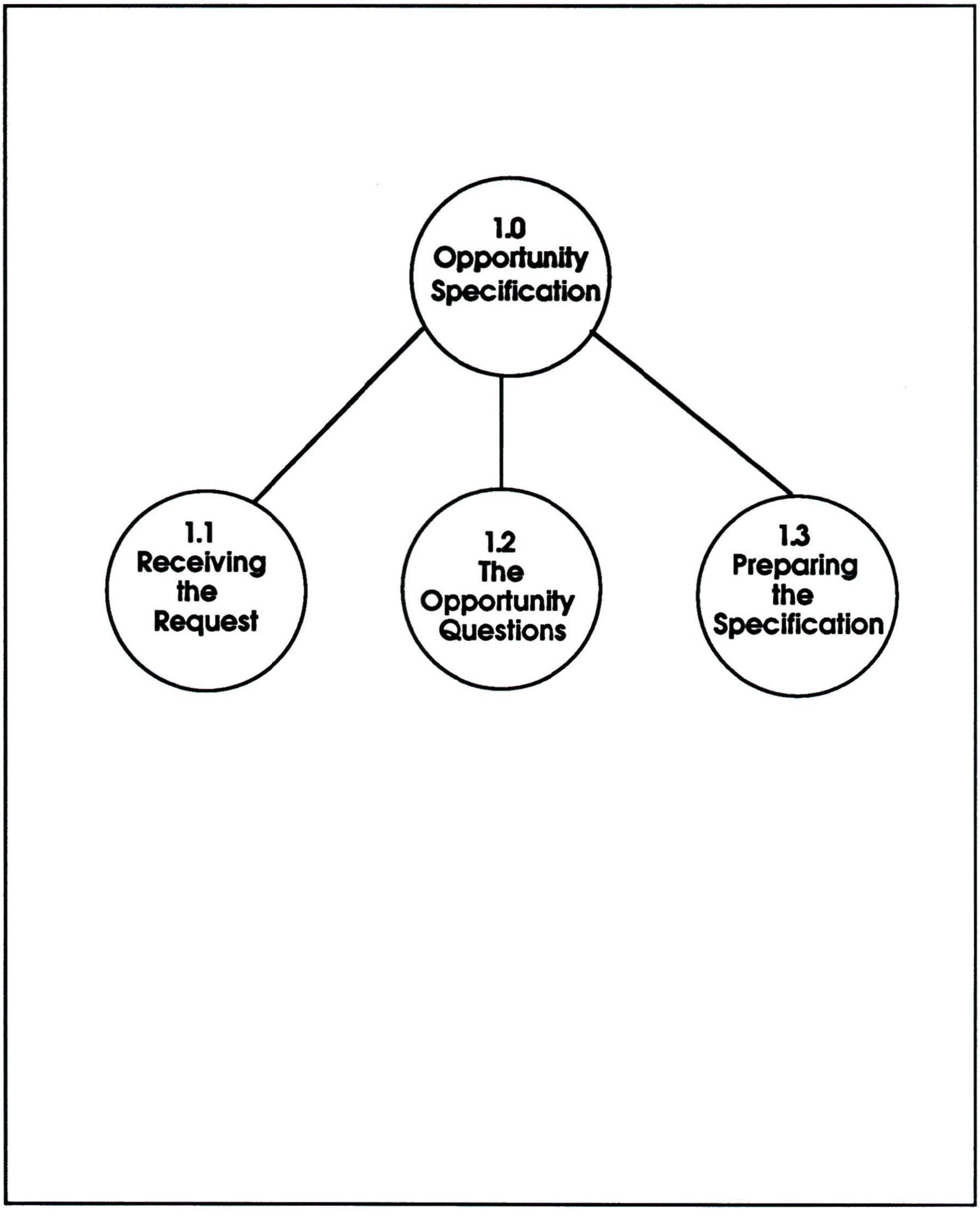



**Figure 6.2 The Hierachical Structure of Process 1.0**

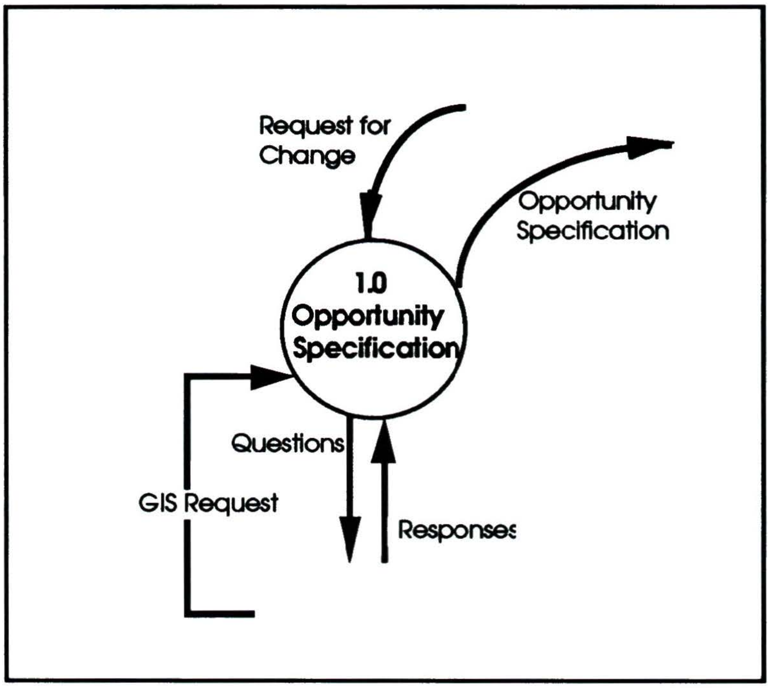



**Figure 6.2.0 Process 1.0: The Opportunity Specification Overview**

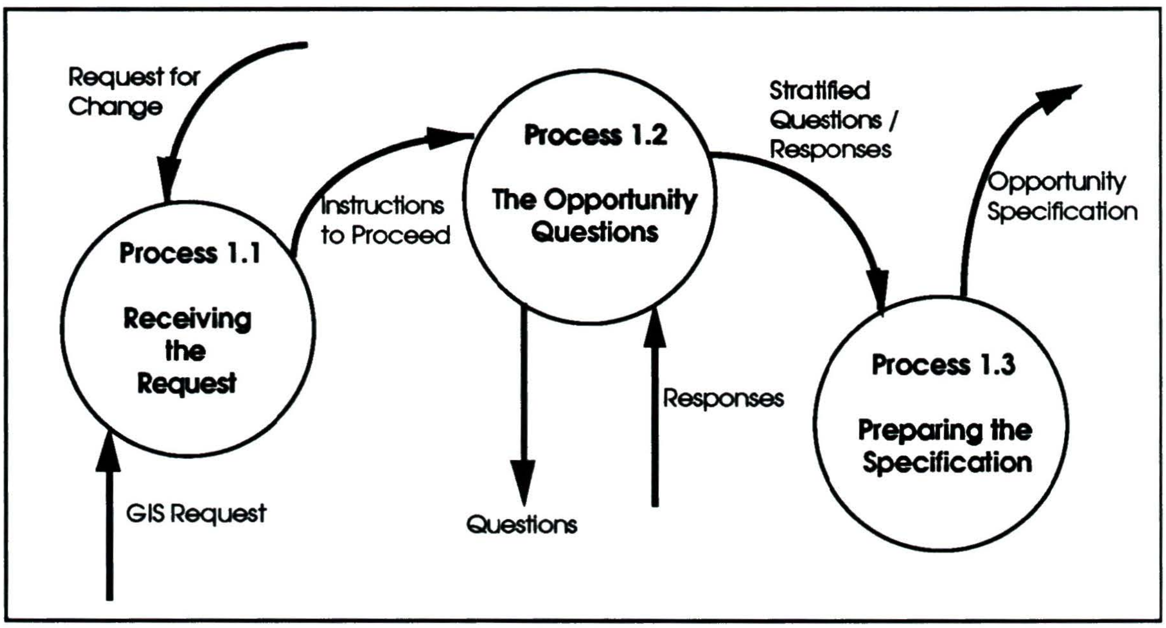



**Figure 6.2.1 Process 1.0: The Opportunity Specification**

### 6.2.2 The Data Dictionary for Process 1.0

The Data Dictionary presented here relates to each of the data flows found in Figure 6.2.1. Each flow has its own table. The tables are as follows:



The tables are designed so as to denote the flow name, provide a brief description of it, note its source, and in which processes it plays a rôle. Each table also indicates the elements that the flow is made up of and includes comments on how to interpret the data.

**Table 6.2.1 The GIS Request Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | GIS Request |
| **Description:** | A request from a person or persons using geographical information for a GIS. The request is usually typified by stating why a GIS is needed, and who would use and benefit from it. |
| **Source:** | Geographical Users and Management A |
| **Involved Processes:** | 1.0 The Opportunity Specification; 1.1 Receiving the Request. |

| Elements Included | GIS Data Interpretation |
|---|---|
| • Name and organizational positions of persons request GIS. | • This information assists in the development of the user profile (Table 6.1). |
| • General description(s) of the problem(s) that exist which GIS can help to solve. | • This information gives clues as to how well defined the GIS task is. |
| • Listing of department(s) or group(s) in the organization will directly benefit from the use of a GIS. | • This information helps to set the general scope of the problem which a GIS can help to solve. |

**Table 6.2.2 The Request for Change Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Request for Change |
| **Description:** | A request from a person or persons using geographical information for some change in an already existing GIS. The request is often a call for maintenance, or for upgrading the current system. Requests for change are typified by stating why an existing system needs to be changed. Change requests are a main component of a system life cycle. |
| **Source:** | Geographical Users and Management B |
| **Involved Processes:** | 1.0 The Opportunity Specification; 1.1 Receiving the Request |

| **Elements Included** | **GIS Data Interpretation** |
|---|---|
| • Name and organizational positions of persons requesting a change in an existing GIS. | • This information places the request for change within the user profile chart. |
| • General description(s) of the problem(s) that exist within a GIS which give rise to the change request. | • This information can be used to determine how critical the change request is. |
| • Listing of department(s) or group(s) in the organization that will directly benefit from the proposed change. | • This information can be used in a cost/benefit estimation. |

The Request for Change data flow is an important one because a GIS is not likely to remain a static entity. Change in long and short term goals, research interests, and software and hardware make it imperative to allow for future GIS modification. Thus, some mechanism to request change should be present.

**Table 6.2.3 Instructions to Proceed Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** Instructions to Proceed | |
| **Description:** Instructions from management on a course of action. If the action is not to proceed then the analysis stops here until the situation changes. | |
| **Source:** 1.1 Receiving the Request | |
| **Involved Processes:** 1.1 Receiving the Request; 1.2 The Opportunity Questions. | |
| **Elements Included** | **GIS Data Interpretation** |
| • Yes, continue the analysis | • Proceed to the next process. |
| • No, discontinue the analysis. | • Document reasons why the request is refused. |
| • Continue, but with restrictions. | • Proceed, in the context of the restrictions. |

The Data Dictionaries presented here are not derived from any one text on structured systems analysis. They are the amalgamation of work presented by DeMarco (1979), Awad (1985), Whitten *et al.* (1986), and Ehle (1987), but targeted toward GIS needs.

**Table 6.2.4 The Questions Data Flow**

**Data/Information Flow Name:** Questions

**Description:** General questions put to all the users that might be involved with the development, implementation, and/or use of a GIS. The questions are broad in scope. They attempt to target the overall GIS needs of the organization.

**Source:** The Opportunity Questions

**Involved Processes:** 1.0 The Opportunity Specification; 1.2 The Opportunity Questions; Geographical Users and Management A

**Elements Included**

- What is the scope of the GIS?
  - What types of tasks need to be performed?
    - mapping/inventory;
    - special projects in a given resource;
    - special projects in many areas;
    - research into new GIS areas (dynamic modelling, three dimensional modelling, object oriented programming (this list from Waters, 1989));
    - other.
  - What is (are) the GIS work area(s)?
    - resource inventory;
    - resource decision making;
    - utility inventory and management;
    - planning (regional, national, global, local);
    - teaching;
    - research;
    - other.
  - What type of GIS funding is available within the organization?
    - unlimited with respect to funding many different projects concurrently;
    - fixed with regard to each GIS project;
    - limited, possibly under-funded;
    - a combination of fixed project budgets with an overall operating budget.
  - What personnel are available to staff a GIS?
    - Low GIS skills:
      - typists;
      - computer operators;
      - drafts-people;
      - digitizing/scanning staff.
    - High GIS skills:
      - managers/decision makers;
      - cartographers;
      - programmers;
      - consultants (user liaison staff);
      - scientists.

**Table 6.2.5 The Responses Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Responses |
| **Description:** | Responses to general GIS questions asked of many of the people that might be involved in a GIS. The responses are broad in nature and present a general picture of GIS needs and wants. |
| **Source:** | 1.2 The Opportunity Questions |
| **Involved Processes:** | 1.0 The Opportunity Specification; 1.2 The Opportunity Questions; Geographical Users and Management A. |

| Elements Included | GIS Data Interpretation |
|---|---|
| • The tasks that need to be performed. | • There may be a number of general tasks. Attempt to priorize them. |
| • The GIS work areas. | • There may be more than one work area. Try to determine approximately how much time will be spent in each area. |
| • The time frame for GIS projects. | • Time frames help in budgeting projects and in establishing project milestones and/or interim goals and objectives. |
| • The types of funding available. | • The knowledge that funding is available gives an indication of organizational commitment to GIS. |
| • The personnel available. | • Establishment of skill levels within an organization gives an indication of the amount of staff retraining or new hiring that will need to be done. |

**Table 6.2.6 The Stratified Questions/Responses Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Stratified Questions/Responses |
| **Description:** | The collation of general GIS questions and responses given out to people within the organization who might be involved with a GIS. The information is stratified as per Table 6.1. |
| **Source:** | 1.2 The Opportunity Questions |
| **Involved Processes:** | 1.0 The Opportunity Specification; 1.2 The Opportunity Questions; 1.3 Preparing the Specification. |

| **Elements Included** | **GIS Data Interpretation** |
|---|---|
| • The information in this part of Table 6.2.6 is the same as in Table 6.2.5 and Table 6.2.4. At this time in Process 1.0 the data should be stratified as per Table 6.1. This means that for each level in the organization a series of questions and responses should be put together. This will allow those persons undertaking the GIS analysis to see differences and similarities in GIS needs, wants, and expectations throughout the entire organization. | |

**Table 6.2.7 The Opportunity Specification Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Opportunity Specification |
| **Description:** | The Opportunity Specification is a broad characterization of the problem(s) that a GIS might solve within the organization under study. It is a brief analysis of the responses from those who might use a GIS. It outlines, in general, the resources that a GIS will require. |
| **Source:** | 1.3 Preparing the Specification |
| **Involved Processes:** | 1.0 The Opportunity Specification; 1.3 Preparing the Specification; 2.0 Feasibility Specification Process. |

| Elements Included | GIS Data Interpretation |
|---|---|
| • Characterize the request.<br>- What problem(s) will the GIS solve?<br>- What is the general purpose of the GIS as it relates to the organization under study? | • Present the GIS characterization as a working paper on the general goals that would be met with a GIS. |
| • Outline the resources that can be applied to the GIS.<br>- How big is the problem?<br>- How many levels of the organization will be affected by the placement of the GIS?<br>- What staff will be affected?<br>- Roughly, what amount of funding may the GIS have?<br>- Roughly, what is the timeline to completion? | • Outline how big the GIS will be by characterizing it in terms of organizational resources devoted to it. |

### 6.2.3 The Minispecifications for the Opportunity Specification

Typically, the minispecifications detail what occurs within the processes declared at the lowest level DFD for a given process. Here the minispecifications relate to Figure 6.2.1, which is the expanded view of the Opportunity Specification. There is one minispecifications for each of the processes represented in Figure 6.2.1. The list of minispecifications covered in this section is as follows:

| | |
|---|---|
| Table 6.2.8 | Minispecification: 1.1 Receiving the Request. |
| Table 6.2.9 | Minispecification: 1.2 The Opportunity Questions |
| Table 6.2.10 | Minispecification: 1.3 Preparing the Specification |

Each minispecification provides a short description of one process, and describes what happens in the process using structured English and/or decision tables (See Chapter 3 for details about these description methods).

**Table 6.2.8 Minispecification: 1.1 Receiving the Request**

**Name of Process:** Receiving the Request

**Description:** The collation of general GIS questions and responses given out to people within the organization who might be involved with a GIS. The information is stratified as per Table 6.1.

**Declare Process:**

Receive Request for GIS.
- Identify users:
  - build user profile,
  - document type and characteristics of users.
- Identify the GIS problem(s) that exist and the rationale behind the request:
  - interview the users that request the GIS,
  - document the types of tasks that the GIS should perform.
- Identify possible organizational changes:
  - document which departments might be affected,
  - roughly estimate possible GIS costs by requesting general vendor information.

Prepare a report and submit it to management.

Follow management directive.

**Table 6.2.9 Minispecification: 1.2 The Opportunity Questions**

**Name of Process:** Opportunity Questions

**Description:** A number of questions need to be asked of all the potential GIS users. These questions help to determine the scope of the GIS, and to describe it in general terms. As well, this process helps to ascertain the depth of GIS knowledge found at all levels of the organization.

**Declare Process:**

IF management issues a proceed OR proceed with conditions
THEN:

Prepare questions for the system owners and/or those who utilize geographic data for decision making. Interview this group on an individual basis. Questions should determine the following:

- Ascertain level of GIS knowledge.
- Identify main GIS work area(s).
- Determine funding availability.
- Determine availability of personnel.

Prepare questions for the responsible GIS users and/or those who utilize and/or those who produce geographic data in the departments which will be affected by a GIS. Attempt to interview the people in each department on an individual basis. If this is not possible, administer a survey. Questions should determine the following:

- Ascertain the level of GIS knowledge in a given department.
- Identify the main GIS work area(s) in a given department.
- Identify, in general, the tasks that a GIS must be able to perform.
- Identify the time frame that a GIS would be expected to complete projects in.
- Identify the type of staff found in a given department with respect to GIS working levels.

Prepare questions for existing or potential hands-on GIS users users in each department. Questions include:

IF the hands-on users are familiar with the concepts of a GIS THEN:
- Identify the tasks that a GIS must be able to perform in the hands-on user area.
- Identify the time frame that a GIS should be able to perform these tasks in.

ELSE:
Determine how amenable the hands-on users would be to GIS training.

Prepare a series of stratified questions and responses.

ELSE :
Discontinue the GIS analysis.

**Table 6.2.10 Minispecification: 1.3 Preparing the Specification**

**Name of Process:** Preparing the Specification

**Description:** Use the stratified questions and responses from Process 1.2. Characterize the request for the GIS. Present a statement of the opportunity that presents itself to the organization as regards GIS.

**Declare Process:**

Receive the stratified questions and responses.
Analyse each group of responses:

FOR each group characterize the following:
- what problems will be solved by a GIS.
- What the general goals of a GIS should be.

Combine the characterizations from each group into a statement of general GIS goals as regards the organization.

Identify, in general, how these goals will be reached.

Identify organizational resources:
- personnel involved
- departments involved
- funding assurances.

Conduct a preliminary request to vendors and review current GIS literature to estimate the cost to the organization.

Estimate a time line for the development of GIS capabilities within the organization.

Produce a statement that outlines the opportunity for the organization to acquire and/or use a GIS.

### 6.2.4 Comments on the Opportunity Specification

This process specifies the opportunities that are available to the organization regarding the use of a GIS. It serves several purposes: (1) it gives management (the system owners) an opportunity to decide at an early juncture whether or not to go ahead with studying the uses of a GIS in the organization, (2) if management has decided to continue, it gives the potential GIS users an opportunity to contribute to the GIS design, and (3) it gradually introduces the idea of change into an organization.

These last two points are ones that systems analysts have addressed for some time, but that proponents of GIS have only begun to realize in the past few years. As Tomlinson (1987) says:

> "The success or failure of a GIS effort has rarely depended on technical factors, and almost always on institutional or managerial ones...We have found that the only effective way out of this sociological impasse is to undertake a complete and comprehensive functional requirements study with full cooperation of the agency directors. The ways in which GIS's products will be used by the agency must be documented well before the GIS is installed, so that they become obligations on the part of the agency staff to use and understand the function of a system."

Involving the potential GIS users in all aspects of the design stage may help the system succeed. This, at least, has been the experience of others who have been involved in automating information tasks (DeMarco, 1979; Awad, 1985).

This part of the GIS analysis should not consume too much time. The goal of this process is the production of a working paper, the essence of which should be: 'This is our problem, we feel that GIS can assist in solving it. This is what we want a GIS to do for us. Here are the resources that we have available to help us reach that goal.'

Neither de Man (1984) or Burrough (1987) explicitly say anything about developing an Opportunity Specification. They do, however, recommend that some requirements be determined before any GIS design is decided on. de Man (1984) says that "... the types of utilization situations (e.g. research, inventories, monitoring/evaluation, 'underpinnings of informal information') and the required degree of accuracy, precision and resolution in data must be identified." Burrough (1987) also discusses many of the GIS requirements that must be decided upon before designing a system.

Both of these authors apply no systematic method of selection to these GIS requirements. For example, if an organization followed only the advice of de Man (1984), then the organization would have defined the accuracy of data that is required before they have addressed the general scope of the problem that the GIS is supposed to ameliorate. In the Burrough (1987) case, he moves into determining technical choices right after establishing the scope of the project. In itself, this may not be incorrect, but structured analysis is far more concerned with what the data does, rather than how it does it. Also, when discussing a relatively new technology, like GIS, with potential users, it may be best to put aside technical matters until the new users are better acquainted with the general concepts of the new system.

Thus, the Opportunity Specification Process is not something that GIS researchers have ever proposed before. It is, however, a common methodology in structured systems analysis (DeMarco, 1979; Awad, 1985). It is included in this thesis as a bridge between the more explicitly technical aspects of determining GIS requirements (that will be demonstrated in the next two sections) and determining what the overall goals of a GIS should be within a given organization.

## 6.3 PROCESS 2.0 : THE FEASIBILITY SPECIFICATION PROCESS

The Feasibility Specification Process accepts information about the opportunity for the organization to pursue a GIS. After reviewing the opportunity, management and/or those responsible for the GIS decide on whether or not to continue the analysis. If the analysis continues it is here that determination of GIS data and analysis requirements will take place. The output of this process is the Feasibility Specification, which outlines the feasibility of implementing a GIS designed to reach the stated data and analysis requirements.

### 6.3.1 The Levelled DFDs for the Feasibility Specification, Process 2.0

Figure 6.3 presents a hierarchical view of all the sub-processes that are involved in Process 2.0. Figures 6.3.0, 6.3.1, 6.3.2, and 6.3.4 show all of the sub-process, and data flows that underlay Process 2.0.

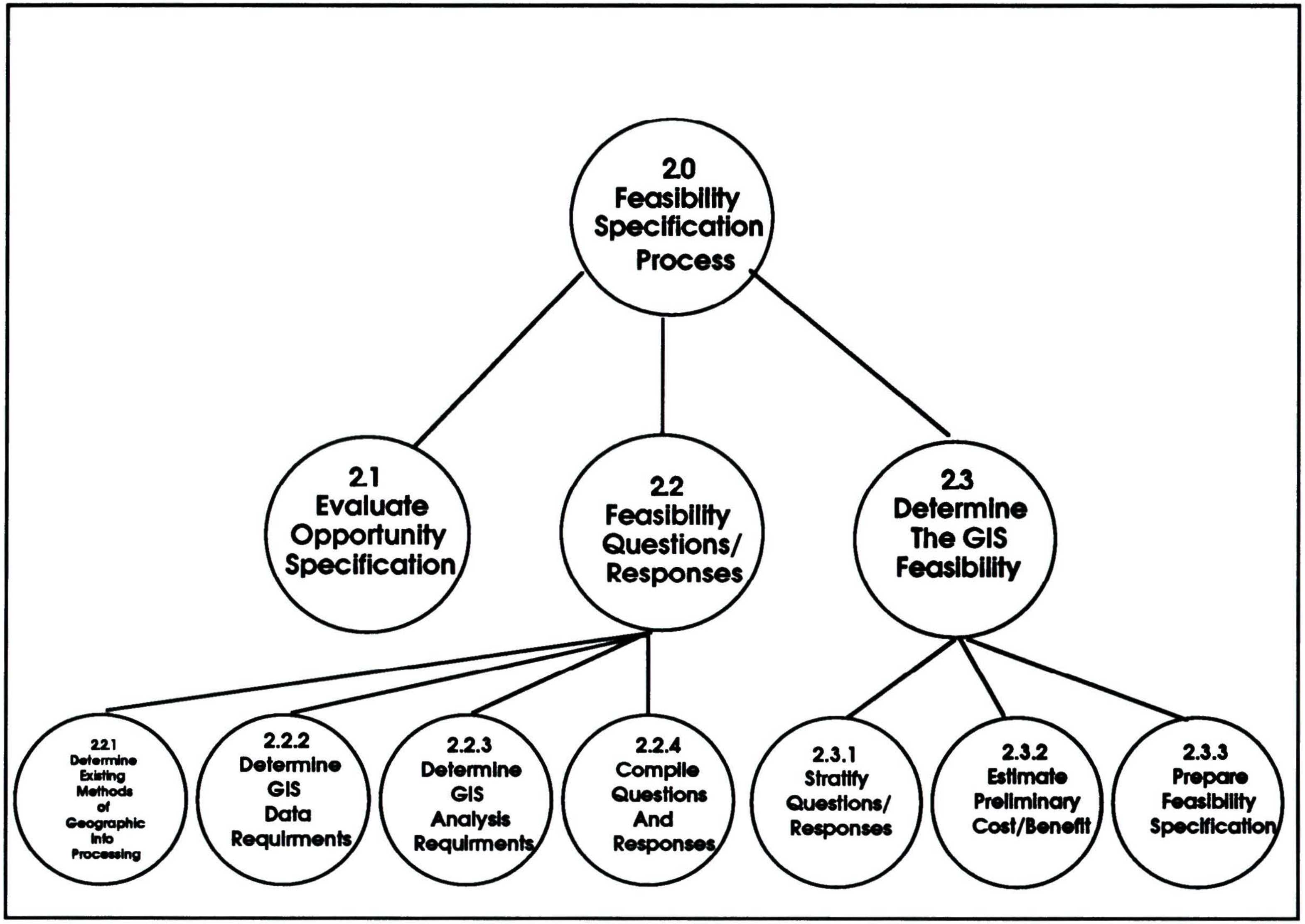



Figure 6.3 The Hierachical Structure of Process 2.0

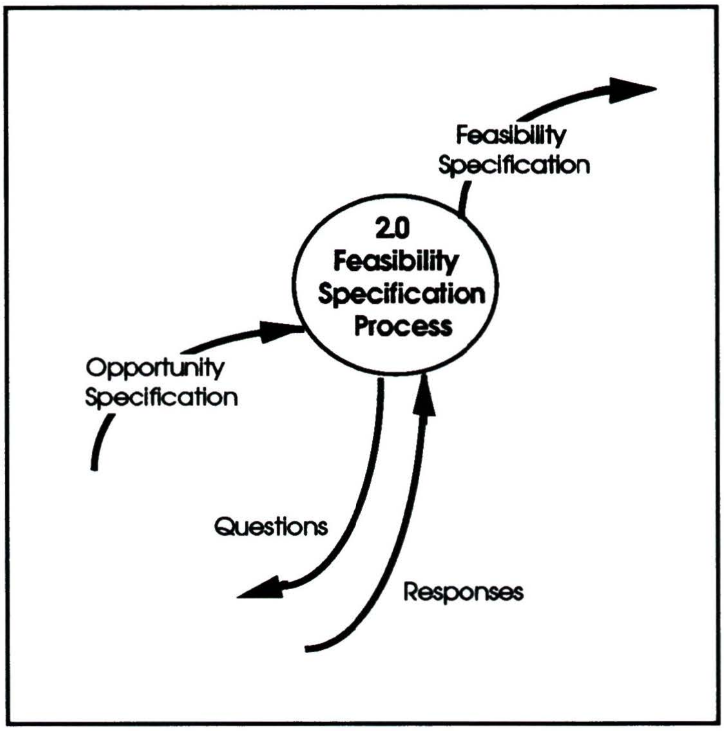



**Figure 6.3.0 Process 2.0: The Feasibility Specification Overview**

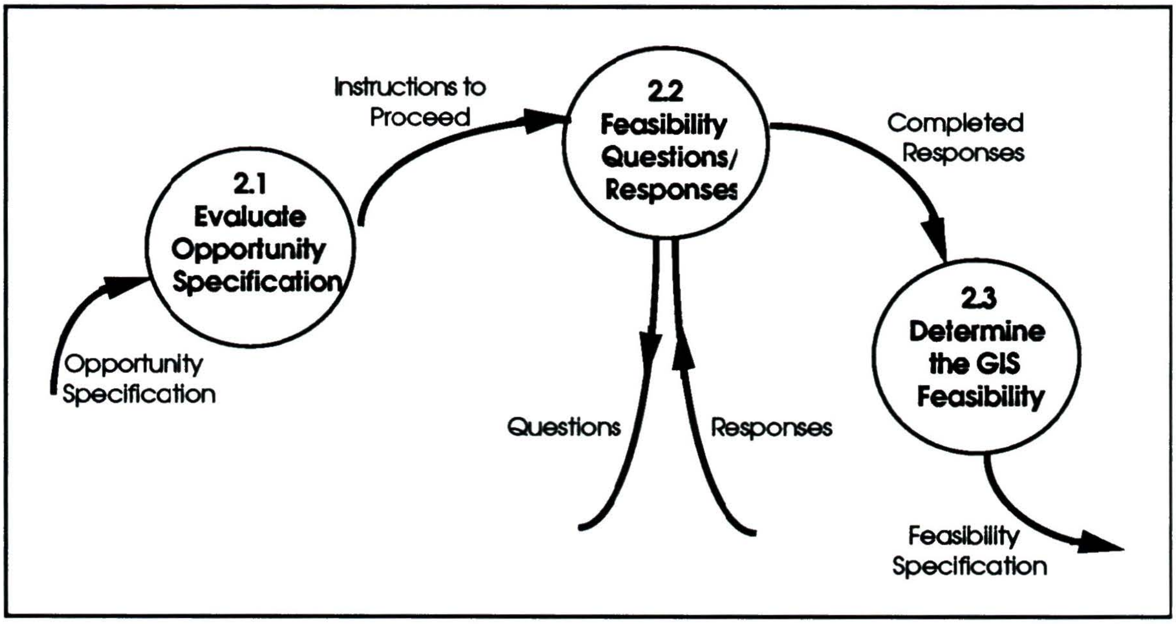



**Figure 6.3.1 Process 2.0: The Feasibility Specification**

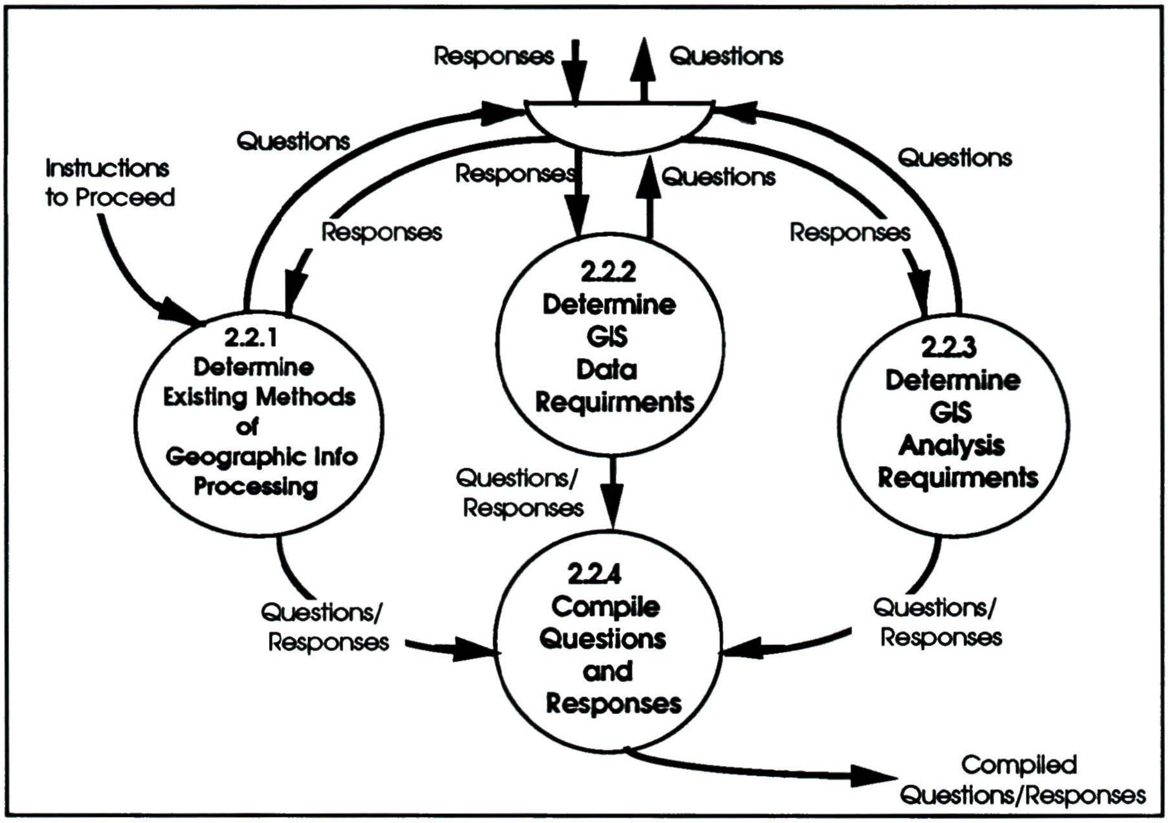



**Figure 6.3.2 Process 2.2: The Feasibility Questions and Responses**

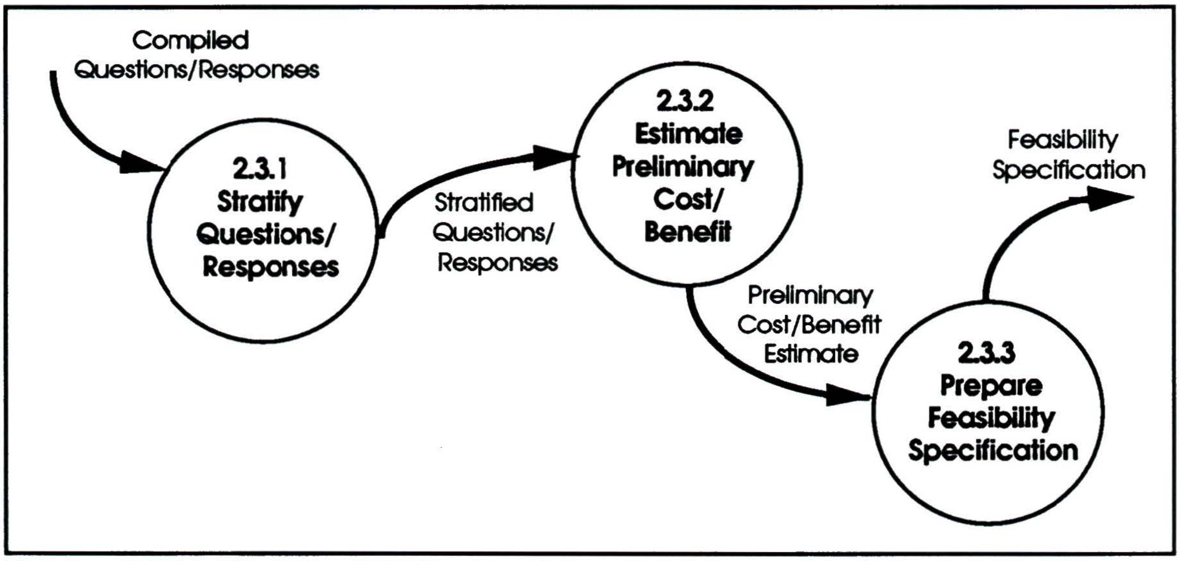



**Figure 6.3.3 Process 2.3: Determining the GIS Feasibility**

### 6.3.2 The Data Dictionary for Process 2.0

The Data Dictionary presented here relates to each of the data flows found in Figure 6.3.1, 6.3.2, and 6.3.3. Each flow has its own table. The tables are as follows:

**Table 6.3.1 Instructions to Proceed Data Flow**

**Data/Information Flow Name:** Instructions to Proceed

**Description:** After management has had an opportunity to evaluate the Opportunity Specification, a course of action can be decided upon. If the action is not to proceed, then the analysis stops here until the situation changes.

**Source:** 2.1 Evaluate Opportunity Specification

**Involved Processes:** 2.1 Evaluate Opportunity Specifications; 2.2 Feasibility Questions and Responses; 2.2.1 Determine Existing Methods of Geographic Info Processing

| Elements Included | GIS Data Interpretation |
|---|---|
| • Yes, continue the analysis. | • Proceed to next process. |
| • No, discontinue analysis. | • Document reasons why the Opportunity Specification request was refused. |
| • Continue, but with restrictions. | • Proceed in the context of the restrictions. |

**Table 6.3.2 The Questions Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Questions |
| **Description:** | Specific questions to members of the organization about current methods of geographic information processing, data requirements of a GIS, and analysis requirements of a GIS. |
| **Source:** | 2.2 Feasibility Questions/Responses |
| **Involved Processes:** | 2.2 Feasibility Questions/Responses; 2.2.1 Determine Existing Methods of Geographic Info Processing; 2.2.2 Determine GIS Data Requirements; 2.2.3 Determine GIS Analysis Requirements. |
| **Elements Included** | |
| **• Existing Geographic Information Processing Questions** | |
| Existing Data<br>- What kinds of data are in use?<br>  - topographic, cadastral, geologic, population, services/urban, natural resources<br>- How is the data stored?<br>  - hardcopy, reports, paper maps, electronic medium<br>- What is the format of the data?<br>  - various map projections, scale of map, area boundaries, remotely sensed data, statistical data<br>- Ownership of data<br>  - What are existing informational management practices?<br>  - How readily is data obtained?<br>  - How compatible is the data from different sources? | Information Gathering and Analysis Capabilities<br>- At what level is info gathered?<br>  - international, national, regional, local<br>- Which agencies are involved in data gathering?<br>  - governmental, international organizations, academic institutions, internal groups in the organization under study<br>- What type of analysis is performed on the data?<br>  - attribute at location studies, aggregation of attributes over areas, surface calculation /surface modelling, distribution analysis/modelling, logical operations, location/allocation analysis, statistical analysis (spatial autocorrelation)<br>- What is the geographic information used for? |

Table 6.3.2 continued...

Table 6.3.2 continued ...

| • GIS Data Requirements Questions | |
|---|---|
| Scope of GIS Data<br>- International, National, Regional, Local<br><br>Standardization of GIS Data<br>- What sources do the data come from?<br>- Would in-house primary data gathering take place?<br>- Would there be much digitizing of existing analogue data sources taking place?<br>- Which scale will most GIS data tend to be?<br>  - small<br>  - large<br>  - various scales<br>- What type of quality assurance will be required for GIS data?<br>  - How old can acceptable data be?<br>  - Which methods of data collection will be accepted?<br>  - What resolution of data will be required?<br>  - What resolution and/or sampling methods for attribute data will be acceptable? | Required attributes of GIS Data<br>- Topographic<br>  - elevation data<br>  - geodetic data<br>- Networks and surrounding area<br>  - streets/roads<br>  - census tracts<br>- Property/parcel information<br>  - urban property data<br>  - land title data<br>- Thematic/statistical<br>  - environmental data<br>  - inventory data<br>  - tabular data<br>- Image processing<br>  - remotely sensed data<br><br>Administration of GIS Data<br>- Who will "own" GIS data within the organization?<br>  - project groups, committee(s), central control<br>- How will data be accessed?<br>  - subsets taken from overall data<br>  - all data available constantly<br>  - project dependent<br>- How will data be stored and/or archived? |
| **• GIS Analysis Questions** | |
| What type of GIS analysis will take place?<br>- Attribute location<br>- Attribute aggregation<br>- Surface calculation/surface modelling/surface display<br>- Logical operations<br>- Statistical methods<br>  - Univariate<br>  - Multivariate<br>  - Geometrical<br>  - Spatial autocorrelation<br>- Overlaying one mapped area (theme) on another<br>- Converting one type of data (raster) into another (vector)<br>- Converting from one coordinate system to another<br>- Editing and updating GIS data | GIS output requirements?<br>- Maps<br>- Reports<br>- Electronic images<br>- Electronic data files<br><br>What will GIS Data be used for?<br>- Planning<br>- Decision making<br>- Education<br>- Consulting<br>- Combination of uses |

**Table 6.3.3 The Responses Data Flow**

**Data/Information Flow Name:** Responses

**Description:** Responses to the Feasibility Questions. The responses should be as specific as possible and should come from all of the possible user groups within the organization.

**Source:** 2.2 Feasibility Questions/Responses

**Involved Processes:** 2.2 Feasibility Questions/Responses; 2.2.1 Determine Existing Methods of Geographic Info Processing; 2.2.2 Determine GIS Data Requirements; 2.2.3 Determine GIS Analysis Requirements

| Elements Included | GIS Data Interpretation |
|---|---|
| • Answers to questions about existing geographical information processing. | • Answers to questions of existing geographical information processing can show how geographical data moved through the organization before the installation of a GIS. If the purpose of the GIS is to automate all or some of these functions this information can point out where bottlenecks in data flow may occur. |
| • Answers to questions about GIS data requirements. | • The cost for implementing a GIS data base can often be three to five times as expensive as the hardware and software (Sety and Chang, 1987). Determination of the data requirements at the outset will allow the organization to plan for these costs. Also, prior determination of data requirements can lead to the development of meaningful GIS benchmarks from which to evaluate various GIS. |
| • Answers to GIS analysis questions. | • Knowing the types of analysis required of the GIS can lead to meaningful benchmark setting and to clear requests to vendors regarding the type of analysis that a proposed GIS must be able to perform. |

**Table 6.3.4 Questions/Responses Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** Questions/Responses | |
| **Description:** Gathered questions and responses. | |
| **Source:** 2.2 Feasibility Questions and Responses | |
| **Involved Processes:** 2.2 Feasibility Questions and Responses; 2.2.1 Determine Existing Methods of Geographic Info Processing ; 2.2.2 Determine GIS Data Requirements; 2.2.3 Determine GIS Analysis Requirements. | |
| **Elements Included** | **GIS Data Interpretation** |
| • Questions and matched responses. | • Examine the questions/responses for inconsistencies and possible problem areas. |

**Table 6.3.5 Compiled Questions/Responses Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Compiled Questions/Responses |
| **Description:** | Compiled questions and respective responses from the various user groups in the organization. |
| **Source:** | 2.2 Feasibility Questions and Responses |
| **Involved Processes:** | 2.2 Feasibility Questions and Responses; 2.2.4 Compile Questions/Responses; 2.3.1 Stratify Questions/Responses |

| **Elements Included** | **GIS Data Interpretation** |
|---|---|
| • Questions and matched responses compiled by user types within the organization (see Table 6.1). Written report pointing out inconsistencies, possible data bottlenecks.<br>- e.g. Possible inconsistency between scope and data sources. Data might need to be gathered from field work. | • Examine the questions / responses for inconsistencies and possible problem areas. Look for characteristic changes between how geographic data is treated currently and how it will be treated within the GIS. |

**Table 6.3.6 Stratified Questions/Responses Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Stratified Questions/Responses |
| **Description:** | Combination of information generated in the Opportunity Specification and from the Compiled Questions/Responses stratified into categories based on GIS data. |
| **Source:** | 2.3 Determine the GIS Feasibility |
| **Involved Processes:** | 2.3 Determine the GIS Feasibility; 2.3.1 Stratify Questions/Responses; 2.3.2 Determine Preliminary Benefit/Cost |

| **Elements Included** | **GIS Data Interpretation** |
|---|---|
| • Combination of information gathered in the the Opportunity Specification and from the Compiled Responses and stratified into five categories based on attributes of GIS data.<br><br>- Tasks that can be accomplished with current geographical data held by the organization.<br><br>- Tasks that can be accomplished by modifying current geographical data held by the organization. | • Geographical databases can be three to five times as expensive to create or obtain as the hardware and software that can manipulate them. Thus geographic data might be considered to be the entity upon which the GIS is economically based. If this is true, then stratifying tasks according to data availability can present a framework in which to view the benefit/cost of the GIS. |

Table 6.3.6 continued ...

Table 6.3.6 continued ...

| | |
|---|---|
| - Tasks that can be accomplished by finding existing geographical data somewhere outside of the organization.<br><br>- Possibly modifying incoming geographical data.<br><br>- Tasks that can be accomplished by gathering primary geographical data sponsored completely by the organization.<br><br>- Tasks that can be accomplished by a combination of the above methods. | • The next phase of this process is to determine an estimate of the benefits and costs associated with developing or acquiring a GIS. Therefore, a structuring of tasks according to geographic data availability will assist in preparing this estimate. |

**Table 6.3.7 Preliminary Cost/Benefit Estimate Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Preliminary Cost/Benefit Estimate |
| **Description:** | An approximate estimate of the costs and benefits attached to the acquiring of a GIS to fulfil the data and analysis needs as outlined in the Stratified Questions and Responses. As there may be more than one set of data/analysis needs outlined, estimates of cost and benefits should be given for each identified data/analysis scenario. |
| **Source:** | 2.3 Determine the GIS Feasibility |
| **Involved Processes:** | 2.3 Determine the GIS Feasibility; 2.3.2 Estimate Preliminary Cost/Benefit; 2.3.3 Prepare Feasibility Specification. |

| **Elements Included** | **GIS Data Interpretation** |
|---|---|
| • An overview of cost estimates.<br>- Development:<br>- Hardware, software, GIS analysis, GIS design, implementation, and data preparation.<br>- Operation:<br>- Cost of changing current geographical processing into GIS, training, staffing, data gathering, maintenance, hardware and software upgrades, and administrative costs. | • The costs given here should be considered as a broad estimate. No rigourous cost/benefit analysis can be done at this point because no hardware, software, or implementation strategies have been decided upon. These costs represent an estimate that will help management decide on how feasible it would be to implement a GIS at the present time. |

Table 6.3.7 continued ...

Table 6.3.7 continued ...

| | |
|---|---|
| • An overview of possible benefits.<br>- Tangible benefits:<br>- Increased productivity, elimination of job steps, faster throughput, increased analytical capability.<br>- Intangible benefits:<br>- Staff gains understanding of what a GIS will be able to do for them by being part of the GIS specification process,<br>better service to clients,<br>improved decision making capability,<br>ability to do analysis that was not possible before the | • At this stage of the GIS analysis it will be difficult to assess accurately any financial advantage that a GIS might give an organization, because no GIS has as yet been specified. However, information of this type will weigh in the balance when a determination of GIS feasibility is made. |

**Table 6.3.8 Feasibility Specification Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** Feasibility Specification | |
| **Description:** A report putting together all of the information gathered in Process 2.0. | |
| **Source:** 2.3 Determine the GIS Feasibility | |
| **Involved Processes:** 2.3 Determine the GIS Feasibility; 2.3.3 Prepare Feasibility Specification; 3.0 Structured Analysis Specification. | |
| **Elements Included** | **GIS Data Interpretation** |
| • An overview of information on the following topics:<br>- The possible scope of the GIS.<br>- The primary GIS tasks required by the organization.<br>- The probable degree of accuracy, precision, and resolution required by the GIS.<br>- The database requirements.<br>- The data analysis and final output requirements.<br>- An estimate of the possible costs and benefits that a GIS might bring to the organization. | • The Feasibility Specification is a measure of how beneficial the development or acquisition of a GIS would be to an organization. Management wants to know if a GIS would be operationally, technically, and economically feasible. At this stage of the analysis, a rigourous feasibility analysis is not possible, because specific user requirements and technical solutions have not been specified. However, the Feasibility Specification at this stage of the analysis lays the groundwork for determining user specifications in Process 3.0. |

### 6.3.3 The Minispecifications for Process 2.0

The minispecifications detail what occurs within the processes declared on the lowest level DFDs for a given process. Here the minispecifications relate to Figures 6.3.1, 6.3.2, and 6.3.3, which provide expanded views of the processes underlying the Feasibility Specification. The list of minispecifications covered in this section is as follows:



Each minispecification provides a short description of one process, and describes what happens in the process using structured English and/or decision tables (See Chapter 3 for details about these description methods).

Table 6.3.9 Minispecification: 2.1 Evaluate Opportunity Specification

| | |
|---|---|
| **Name of Process:** | 2.1 Evaluate Opportunity Specification |
| **Description:** | This process represents an opportunity for management to overview the GIS development/selection process that has taken place to date. Management can see some of the general GIS directions that the organization may be heading towards. This process allows management to evaluate the opportunity for the organization to acquire and/or develop a GIS. |

**Declare Process:**

Management reviews the Opportunity Specification generated in Process 1.0. The GIS is characterized by identifying general problems that the GIS will solve. The Specification also outlines the resources that the organization will need to apply to the GIS.

IF management issues a proceed OR proceed with restrictions

THEN
Issue a request to proceed with the GIS analysis. Note restrictions where applicable.

ELSE

IF management issues a discontinue analysis request

THEN
Document reasons for discontinuation.
Determine if GIS analysis might be possible in the future.

Generate an Instructions to Proceed directive.

**Table 6.3.10 Minispecification: 2.2.1 Determine Existing Methods of Geographic Information Processing**

| | |
|---|---|
| **Name of Process:** | 2.2.1 Determine Existing Methods of Geographic Information Processing |
| **Description:** | Following the guide-lines outlined in the Instructions to Proceed dataflow, determine if there is already some geographic information processing going on within the organization. |
| **Declare Process:**<br><br>IF there is some geographical information processing within the organization<br><br>THEN<br>Interview representative members from each of the user categories (Table 6.1) to ascertain information about the following topics:<br>- Existing geographic data in use within the organization.<br>- The information gathering and analysis capabilities within the organization.<br>- The use to which geographical information is currently put.<br>- The administrative structures supporting the current geographic information processing.<br>These questions should be as specific as possible (see Table 6.3.2).<br><br>Gather responses to the various questions.<br>Match questions and responses together.<br><br>ELSE<br>Go directly to Process 2.2.2 and determine GIS data requirements. | |

The next two minispecifications deal with determining what the GIS data and analysis requirements are for a given organization. It is important to remember that not all personnel in the organization will have a good knowledge of what a GIS is or what it can do. Questions must therefore be posed in a form that is completely machine independent. For example, when asking questions about GIS analysis requirements, the questions should be directed to type of analysis to be performed, and not the machine requirements.

The responses by persons new to GIS are just as important as responses coming from the skilled GIS user. Indeed, the responses from the unfamiliar user may be more important, because these responses can illustrate not only what the expectations of potential GIS users are, but the generic types of analysis and data capabilities required by potential GIS users.

**Table 6.3.11 Minispecification: 2.2.2 Determine GIS Data Requirements**

| | |
|---|---|
| **Name of Process:** | 2.2.2 Determine GIS Data Requirements |
| **Description:** | Through interviews with potential or existing GIS users in the organization, determine, in general, what the GIS data requirements of the organization will be. |
| **Declare Process:** | |

Select representatives from all levels of the potential GIS user community. Cover all user categories within the organization. Ask questions and gather responses about the following GIS data requirement points:

- Scope of the GIS data for use within the organization.
- Standards for GIS data within the organization:
  - e.g. sources, scales.
- Quality assurance questions:
  - e.g. age of data, resolution of data, sampling methods.
- Required attributes of the GIS data:
  - e.g. topographic, network, statistical.
- Administrative procedures for GIS data storage, acquisition, and control.

Cover these points with all representative members of the potential GIS user community in as much detail as possible (see Table 6.3.2 for details on the GIS data requirements).

Gather responses to the various questions.
Match questions and responses together.

**Table 6.3.12 Minispecification: 2.2.3 Determine GIS Analysis Requirements**

| | |
|---|---|
| **Name of Process:** | 2.2.3 Determine GIS Analysis Requirements |
| **Description:** | Through interviews with potential or existing GIS users in the organization, determine, in general, what the GIS analysis requirements of the organization will be. |
| **Declare Process:** | |

Select representatives from all levels of the potential GIS user community. Cover all user categories within the organization. Ask questions and gather responses about the following analysis requirements for the proposed GIS:

- Types of analysis that will take place.
- Types of output that will be required.
- Uses to which the geographical information will be put.

Cover these points with all representative members of the potential GIS user community in as much detail as possible (see Table 6.3.2 for details on the GIS analysis requirements).

Gather responses to the various questions.
Match questions and responses together.

**Table 6.3.13 Minispecification: 2.2.4 Compile Questions and Responses**

| | |
|---|---|
| **Name of Process:** | 2.2.4 Compile Questions and Responses |
| **Description:** | Take existing questions and corresponding responses and group them into user levels. Draft a question/response report. |
| **Declare Process:** Examine the questions and responses looking for discrepancies between user levels within the organization. Also look for inconsistencies between scope and data sources, and for characteristic changes between how geographic data is currently treated within the organization and how it will be treated with the GIS. Draft a report noting questions, responses , and possible problem areas. | |

**Table 6.3.14 Minispecification: 2.3.1 Stratify Questions and Responses**

| | |
|---|---|
| **Name of Process:** | 2.3.1 Stratify Questions and Responses |
| **Description:** | Determine the tasks that the GIS will most likely be called upon to perform. Stratify these tasks based on GIS data requirements. |
| **Declare Process:** | |

Review the Opportunity Specification produced in Process 1.0. This sets out the basic problem(s) that the GIS will be expected to address.

IF the basic problems identified in Process 1.0 are to be solved by a GIS

THEN:

Stratify the questions and responses based on attributes of the required GIS data:

- Tasks that can be accomplished with data currently held by the organization
- Tasks that can be accomplished by modifying current geographical data held by the organization.
- Tasks accomplished by finding existing geographical data somewhere outside of the organization.
- Tasks accomplished by gathering primary geographical data by the organization.
- Tasks accomplished by a combination of any of the above methods.

Before embarking on cost/benefit analyses for GIS, it should be remembered that these quantitative evaluations are only one part of the decision making process (Aronoff, 1989, p. 261). Indeed, it is often very difficult to attach a dollar value to many of the benefits that a GIS can bring, and in some cases the move to a GIS is not necessarily dollar based. Dickinson and Calkins (1988) suggest that there are GIS situations that are too complex for basic cost/benefit analysis. In general these cases involve situations where the objective of the GIS can not be expressed in terms of products, as could happen when a GIS is used to improve decision making, or when the economic value of one or more GIS products can not be measured, as could occur if the output of one GIS product was the input to another, larger, GIS process; Thus, a cost/benefit analysis at this point in the GIS Analysis Framework should be considered as a broad estimate only, and not a final document.

**Table 6.3.15 Minispecification: 2.3.2 Estimate Preliminary Cost/Benefit**

**Name of Process:** 2.3.2 Estimate Preliminary Cost Benefit

**Description:** Using the Stratified Questions and Responses and the Opportunity Specification, develop an approximate estimate of the costs and benefits attached to acquiring/developing and operating a GIS.

**Declare Process:**
FOR all the GIS data requirements noted in Process 2.3.1:
Estimate the costs for the new GIS:

Make beginning overtures to GIS vendors/developers and review the GIS literature to determine some approximate values for the following:
- Hardware, software, maintenance and upgrades to software, training costs.

Approximate the costs involved with creation of the required GIS database(s).
- Consider the following costs as noted by Sety and Chang (1987):
  $.035 - $.40 US per acre for building a resource GIS database;
  $50,000 - $100,000 US per year over a period of 5 to 7 years for a municipal data base.

Approximate staff costs:
- Will new staff be required? Entrance level wages for trained GIS staff range from $20.000 to $30,000.00 US per year ;
- Will existing staff need retraining? Will salary raises be required for all GIS staff?

Approximate administrative costs:
- Will new administrative procedures and positions need to be developed to handle the GIS? Will existing administrative procedures and positions be used?

Approximate special GIS analysis programming costs:
- Do user requirements necessitate that special GIS analysis procedures be custom written for the organization?

IF geographic information processing is currently being done within the organization THEN compare and contrast existing costs with estimated GIS costs.

Estimate the benefits that the new GIS show to the organization:

Tangible Benefits:
The benefits of new marketable services;
- Products and expertise

Elimination of job steps;
Faster throughput, increased analytical capability;
The benefits of better decisions.

Intangible benefits:
Better communication within the organization;
Improved job satisfaction, better service;
Improved public image.

**Table 6.3.16 Minispecification: 2.3.3 Prepare Feasibility Specification**

| | |
|---|---|
| **Name of Process:** | 2.3.3 Prepare Feasibility Specification |
| **Description:** | The GIS needs and objectives of the organization are presented based on questions to and responses from potential GIS users. Several rough GIS plans are presented. A cost/benefit estimate accompanies each plan. |

**Declare Process:**

Go over documents produced to date. Prepare overview(s) of possible GIS configurations that might fit the stated needs and objectives .

FOR each possible GIS scenario prepare a report that uses the questions and responses from users and/or potential users of the GIS consider the following points:

- Geographical data requirements ;
- Use of geographical information within the organization;
  - Identify overall uses of GIS
  - Priorize overall uses
- Identify general database requirements from user questions and responses;
  - Identify the types of attributes that will most likely be found in the GIS database.
- Identify the general analysis requirements of the GIS;
- Identify the general output requirements of the GIS;
- Identify the general organizational changes or modifications that will need to take place.

Estimate costs and benefits involved in implementing a GIS that will meet the outlined needs.

Address points of feasibility. Give an overview of what would be involved in making a GIS operationally, technically, and economically feasible within the organization

### 6.3.4 Comments on the Feasibility Specification Process

The Feasibility Specification Process has several purposes within the GIS Analysis Framework model. Most importantly, it seeks to determine how feasible it will be for the group or organization to develop or acquire a GIS for the purposes stated by the members of the organization. As well, this process tries to build a framework which will allow all of the issues surrounding GIS acquisition/development, administration, and use to be examined. This process tries to involve many individuals at different levels within the organization so that GIS requirements can be determined from as wide a user base as possible.

The end result of this process is the production of several GIS configurations that might meet organizational needs. It should be stressed that these configurations are only generalizations. No specific organizational GIS need has been identified yet, so no specific GIS can be suggested. However, some general themes should be present. For example, the overall scope of the GIS should be known, as should the overall type and quality of output that will be expected. Some information about availability and type of geographic data required will also be known. Information like this can be used to determine basic GIS configurations. Some cost/benefit estimates should also be included for each configuration presented.

The GIS configurations that are produced form the Feasibility Specification Document. This document is intended to be part of a decision making process. The document will be one of the tools that management uses to determine if it is feasible for the organization to undertake the next step in the development and/or acquisition of a GIS at the present time.

Whitten *et al.* (1986, p. 187) says that a feasibility specification can help measure or establish the level of management's commitment to the project. Moreover, it establishes a preliminary statement of problems and objectives. In the GIS literature no author has specifically addressed the need for a feasibility specification. However, several writers do mention that functional definitions and user needs analysis should be performed (Aronoff, 1989, p. 254; Burrough 1987, p. 167; deMan, 1984). Yet the literature in systems analysis indicates that a feasibility study is considered part of establishing user needs and functional definitions (Davies, 1990). Therefore, looking at what some of the GIS authors have to say about functional definitions and user needs analysis can help to put Process 2.0 into context with other GIS assessment techniques.

Aronoff (1989), in writing about GIS from a management perspective, touches on the subject of how one would go about implementing a GIS within an organization. He sees GIS implementation as a six phase process:

1. Awareness: People become aware of GIS technology and what some of the GIS possibilities might be.

2. Development of System Requirements: A systematic and formal process instigated within the organization to identify potential GIS users and their needs.

3 System Evaluation: Alternative systems are proposed and evaluated.

4. Development of an Implementation Plan: After deciding to acquire a system, a plan is developed to buy equipment, hire staff, make organizational changes, and fund the GIS.

5. System Acquisition and Start-Up: The system is purchased, installed, and staff are trained.

6. Operational Phase: Operational issues are addressed, such as database maintenance, GIS user service issues, and performance evaluation.

adapted from Aronoff, 1989, p.253

Unfortunately, Aronoff does not expand at length on any of these issues, and certainly does not give any method for implementing these six phases. However, most of the first four phases would be able to find themselves at home in Processes One to Three of the GIS Analysis Framework model proposed here. Phase 2 and part of Phase 3 would fit easily into the Feasibility Specification Process. As well, work done in the Feasibility Specification Process would play a part in the development of an implementation plan (Phase 4 above), as the organization would certainly want to develop an implementation that was feasible.

## 6.4 PROCESS 3.0: THE STRUCTURED ANALYSIS SPECIFICATION

At this point, the question might be raised: "Why is it important to consider both information and process in the GIS Analysis Framework when no one else working in the field seems to explicitly do so?" This question is especially puzzling in light of Process 2.0, where so much effort was devoted to detailing information flows in comparison to the effort spent in outlining the processes involved in getting this information. The above question is answered by considering the rationale underlying the Feasibility Specification Process and the Structured Analysis Specification Process.

The Feasibility Process tries to outline what the needs of the potential GIS user might be, and to suggest practical methods of realizing these needs. It is an initial attempt to identify not only user needs, but organizational and interactive changes that might be necessary within the organization if a GIS were to be implemented. The stress here is on the word initial. Nothing is specified, rather recommendations are made as to how the organization might continue with the GIS analysis. This process is an information gathering exercise, hence the importance placed on the information components of the Feasibility Specification Process.

The recommendations from Process 2.0 are evaluated and acted upon in Process 3.0. As will be seen, the Structured Analysis Specification Process takes the information gathered in Process 2.0 and places it within a structured framework. Thus, the emphasis in 3.0 is on process - the "what" rather than the "how". The output of this process is a Structured Specification Document. It will be used to guide the organization in issues regarding hardware and software acquisition, benchmarking, implementation, and GIS evaluation. This document will be the interface between the logical and physical issues surrounding GIS acquisition within an organization.

The following three sub-sections break down and declare Process 3.0 in much the same manner as was done in Process 1.0 and 2.0, but will include examples of information and process where appropriate.

### 6.4.1 The Levelled DFDs for Process 3.0

Figure 6.4 presents a hierarchical view of all the sub-processes that are involved in Process 3.0. Figures 6.4.0, 6.4.1, 6.4.2,and 6.4.3 show all of the sub-process, and data flows that make up Process 1.0.

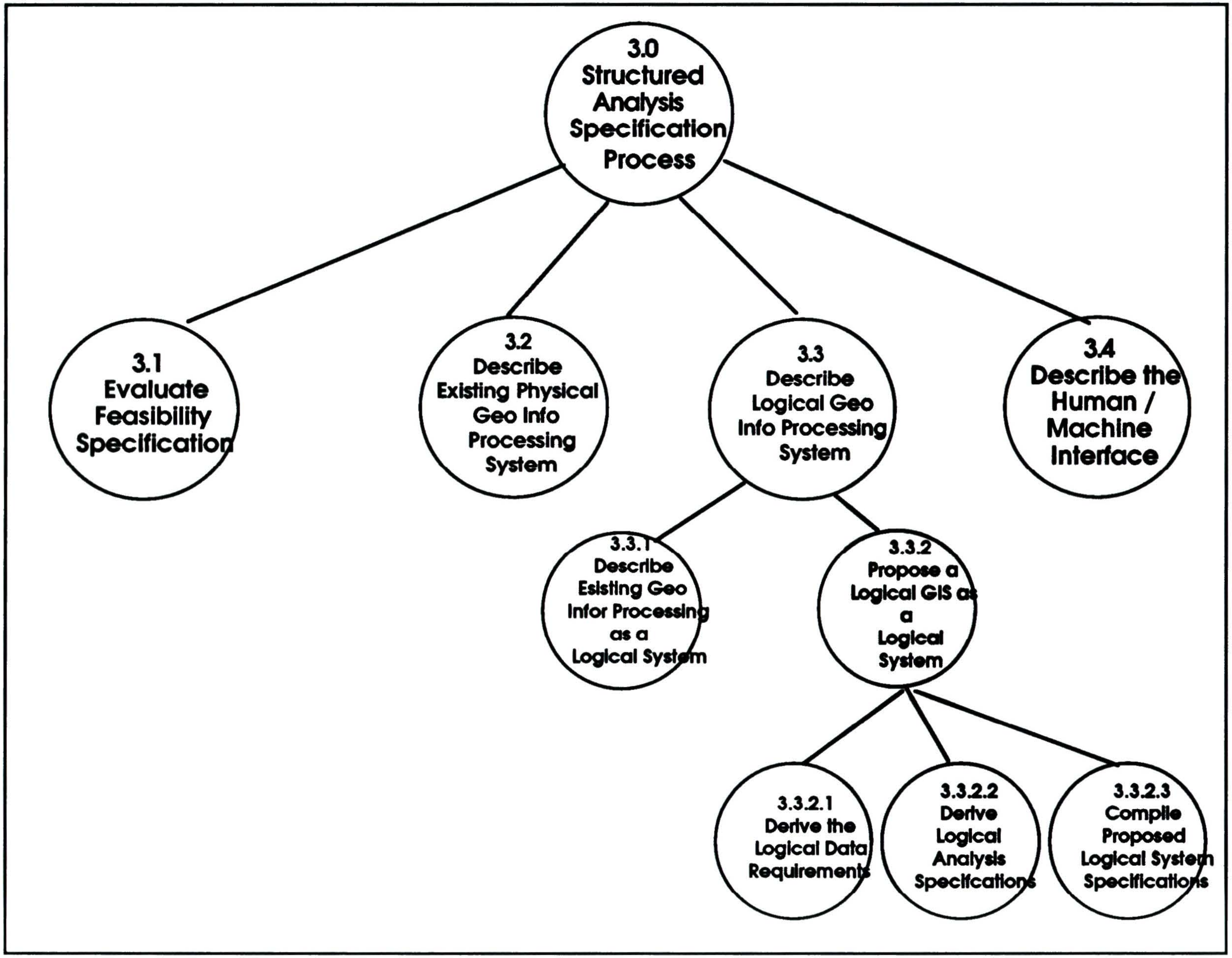



Figure 6.4 The Hierarchical Structure of Process 3.0

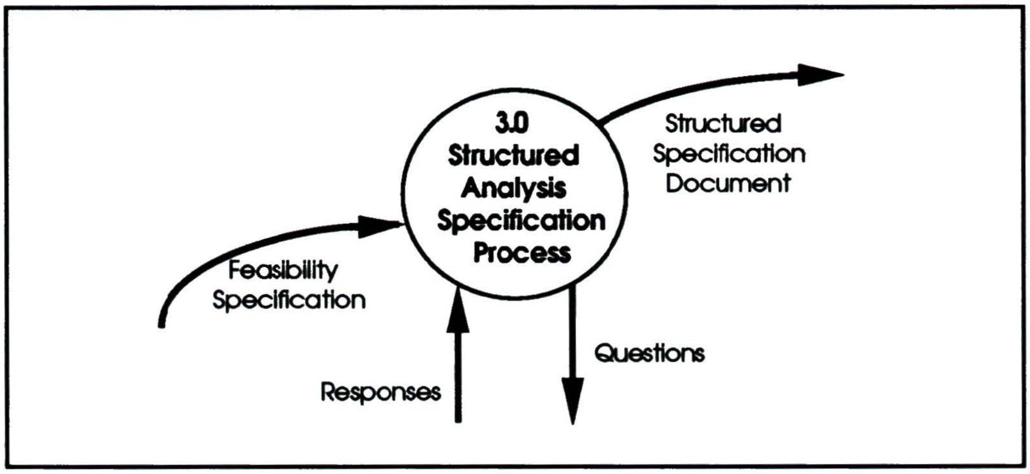



**Figure 6.4.0 Process 3.0 The Structured Analysis Specification Process: First Level**

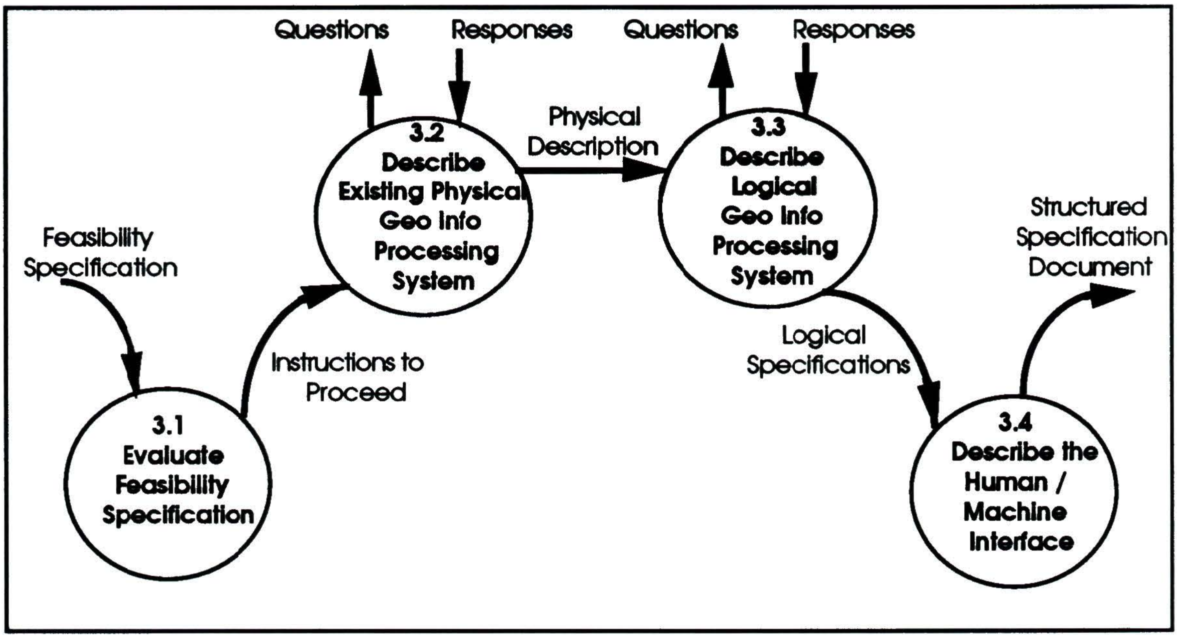



**Figure 6.4.1 Process 3.0 The Structured Analysis Specification Process Second Level**

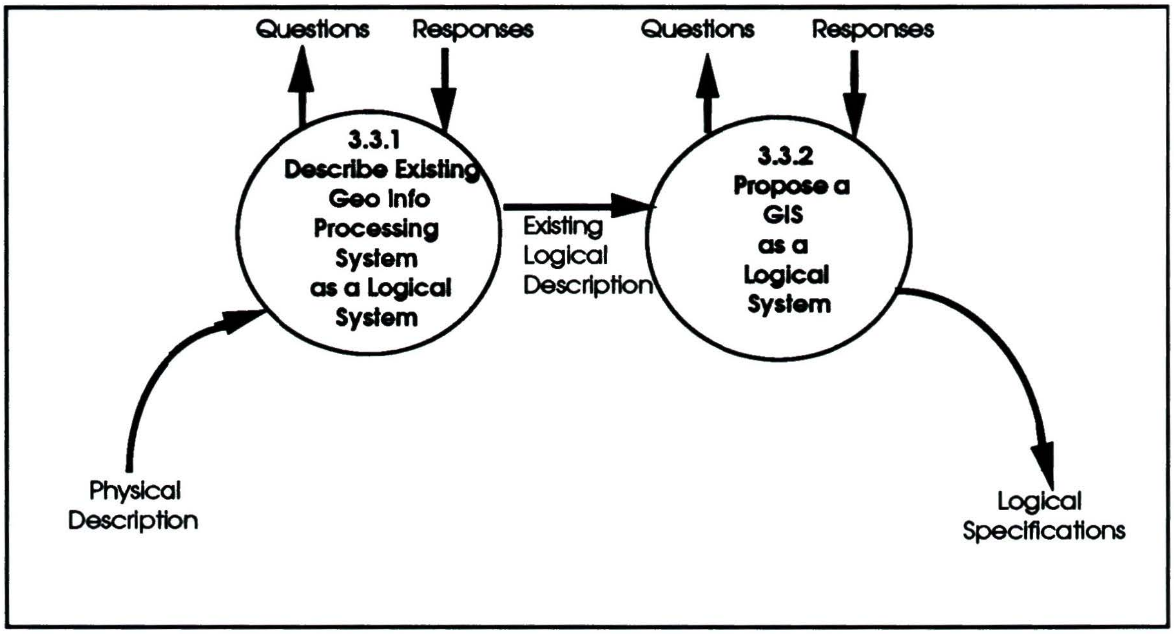



**Figure 6.4.2 Process 3.3 Describe Logical Geo Info Processing System**

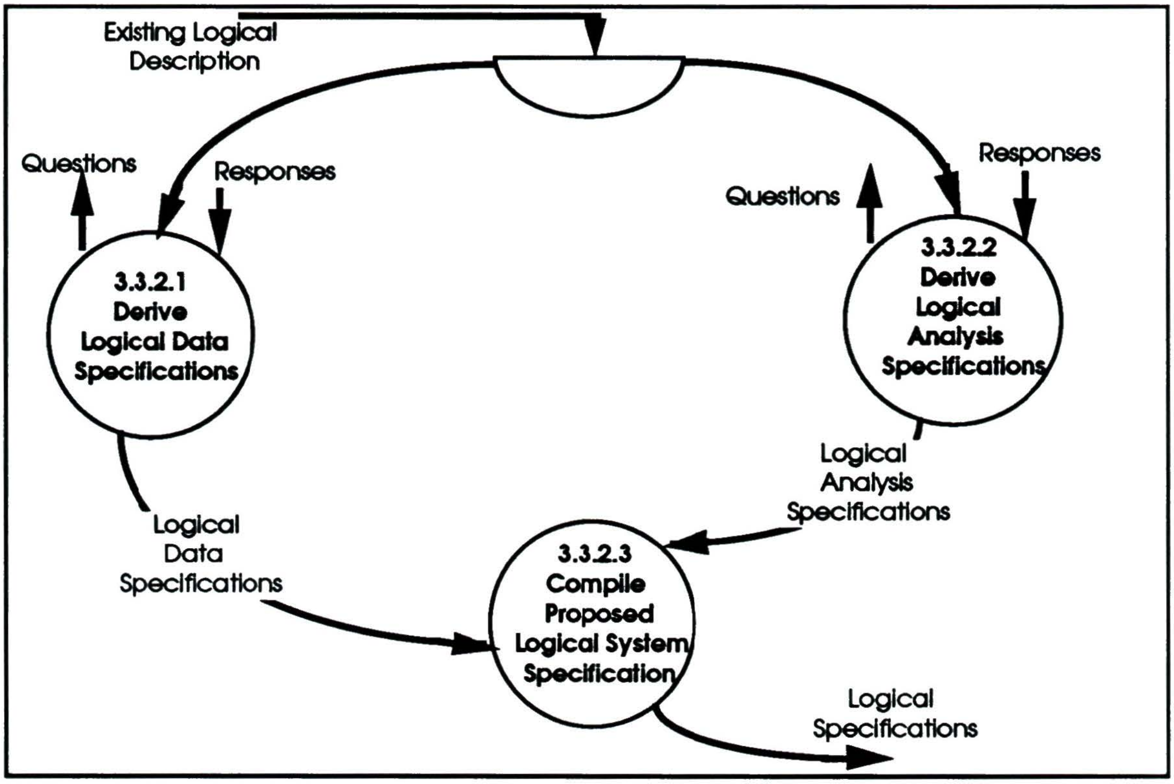



**Figure 6.4.3 Process 3.3.2 Propose a GIS as a Logical System**

### 6.4.2 The Data Dictionary for Process 3.0

The Data Dictionary presented here relates to each of the data flows found in Figures 6.4.1, 6.4.2, and 6.4.3. Each flow has its own table. The tables are as follows:

Table 6.4.1 Instructions to Proceed Data Flow
Table 6.4.2 Questions Data Flow
Table 6.4.3 Responses Data Flow
Table 6.4.4 Physical Description Data Flow
Table 6.4.5 Existing Logical Description Data Flow
Table 6.4.6 Logical Data Specifications Data Flow
Table 6.4.7 Logical Analysis Specifications Data Flow
Table 6.4.8 Logical Specifications Data Flow
Table 6.4.9 The Structured Specification Data Flow

**Table 6.4.1 Instructions to Proceed Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Instructions to Proceed |
| **Description:** | After management has had an opportunity to evaluate the Feasibility Specification, a course of action can be decided on. If the action is not to proceed, then the analysis stops here until the situation changes. |
| **Source:** | 3.1 Evaluate Feasibility Specification |
| **Involved Processes:** | 3.1 Evaluate Feasibility Specification; 3.2 Describe Existing Physical Geo Info Processing System. |

| **Elements Included** | **GIS Data Interpretation** |
|---|---|
| • Yes, continue the analysis. | • Proceed to next process. |
| • No, discontinue analysis. | • Document reasons why the recommendations in the Feasibility Specification were refused. |
| • Continue, but with restrictions. | • Proceed in the context of the restrictions. |

**Table 6.4.2 Questions Data Flow**

**Data/Information Flow Name:** Questions

**Description:** Working with selected members of the user community, a series of in-depth questions are asked about any existing geographic information processing (if there is any), and about the proposed GIS. These questions, and their corresponding responses, may need to be posed and answered several times before those persons undertaking the analysis, and those answering the questions, understand one another fully.

**Source:** 3.0 Structured Analysis Specification Process

**Involved Processes:** 3.0 Structured Analysis Specification Process; 3.2 Describe Existing Physical Geo Info Processing System; 3.3 Describe Logical Geog Info Processing System; 3.3.1 Describe Existing Geo Info Processing System as a Logical System; 3.3.2 Propose a GIS as a Logical System; 3.3.2.1 Derive Logical Data Specifications; 3.3.2.2 Derive Logical Analysis Specifications.

**Elements Included**

**Existing Geographic Information Processing: Physical and Logical**

| | |
|---|---|
| • If geographic information processing is on-going, then question select members as to the correctness of the physical diagrams, data flows, data dictionaries, and minispecification used to describe the existing system.<br><br>- Questions will be structural, tracing the route of geographic data through the organization from initial request to end product.<br><br>- The questions (and responses) are an iterative process. The end result is a clearly understood document describing the existing system. | • The existing geographic information processing operations must be described in a manner that does not concern itself with the physical components of the processing. Only the logical components are described.<br>- How is the existing geographic data structured? For example:<br>- hierarchical structure: each geographic unit can be broken down into smaller units (ie. The NTS map series considered at different scales).<br>- attribute-based structure: one or more attributes with some indication as to spatial location.<br>- How is analysis performed on existing geographic data? For example:<br>- by topological methods<br>- by predicate logic methods<br>- by terrain modelling methods<br>- by regional analysis methods |

Table 6.4.2 continued ...

Table 6.4.2 continued ...

| Logical Data Questions | |
|---|---|
| • Questions about the logical structure of the data, whether for describing the geographic information processing currently in use or for describing the data in the proposed GIS, seek to find out what the data structure looks like. Questions might include the following:<br><br>- Does the geographic data have a hierarchical structure? For example a map coverage which can be divided into areas of larger scale, which in turn can be divided. The data may be considered to represent a taxonomic hierarchy.<br><br>- Is the data better thought of as a network? Data of this type could be represented by a planar graph. Each node can hold information, and each edge can have information related to it as well.<br><br>- Will the areal units tend to be regular in shape, or will more complex shapes be the norm? | - Would boundary measurements need to be exact geographic coordinates, or would approximations be more appropriate? For example, vegetation mapping from air photos may not require the same geographical accuracy as legal land parcel mapping.<br><br>- Will information tend to be point type? For example, elevation data matrices.<br><br>- Will information tend to be areal in nature? For example, vegetation studies.<br><br>- Will information tend to be related to line work? For example, drainage basin studies?<br><br>- Will the geographic information in either the existing system, or in the proposed GIS tend to be an equal mixture of many different types of data? |
| **Logical Analysis Questions** | |
| • Logical discriptions of the types of analysis that will be required from the geographic data need to be determined. Questions such as the following should be asked:<br><br>- What kind of transformations will be performed on the geographic data?<br>  - topology transforms like rotation, scale transformation, and 3-D display;<br>  - transformations based on predicate logic;<br>  - transformations based on univariate and multivariate statistical procedures. | - What type of regional analysis questions would be asked?<br>  - length, perimeter, area, shape;<br>  - univariate and multivariate statistical exploration of regional attributes.<br><br>- What type of modelling will be performed on the geographic data?<br>  - neighbourhood modelling, clustering;<br>  - terrain modelling, slope and aspect;<br>  - continuous slope modelling;<br>  - network analysis, shortest path. |

**Table 6.4.3 Responses Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Responses |
| **Description:** | Responses to questions asked of selected users. Responses can deal with descriptions of an existing physical system, and with logical descriptions of the data and analysis capabilities of a proposed GIS. |
| **Source:** | 3.0 Structured Analysis Specification Process. |
| **Involved Processes:** | 3.0 Structured Analysis Specification Process; 3.2 Describe Existing Physical Geo Info Processing System; 3.3 Describe Logical Geo Info Processing System; 3.3.1 Describe Existing Geo Info Processing System as a Logical System; 3.3.2 Propose a GIS as a Logical System; 3.3.2.1 Derive Logical Data Specifications; 3.3.2.2 Derive Logical Analysis Specifications. |

| **Elements Included** | **GIS Data Interpretation** |
|---|---|
| • Responses to questions about the existing physical system, the proposed GIS, the structure of the data, and the types of analysis to be performed by the GIS. | • The responses, and their initiating questions are designed to probe into the logical assumptions that underlay the data and analysis requirements of the GIS. These responses represent the way that potential GIS users understand the geographic data that will be used in the system, and the types of analyses that will be expected from it. |

**Table 6.4.4 Physical Description Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Physical Description |
| **Description:** | If geographic information processing is currently on-going, the information in this data flow is a description of the system. The description should contain data flow diagrams, data dictionaries, and minispecifications, all of which declare how geographic data comes into the system, what happens to it, and where it goes. |
| **Source:** | 3.2 Describe Existing Physical Geo Info Processing System |
| **Involved Processes:** | 3.2 Describe Existing Physical Geo Info Processing System; 3.3 Describe Logical Geo Info Processing System. |

| Elements Included | GIS Data Interpretation |
|---|---|
| • The physical description of an existing geographic information processing system within the organization should contain the following elements:<br><br>- A set of levelled data flow diagrams (DFDs) that go from a generalized picture of the system to depictions of specific processes within the system.<br><br>- Explanations of all the lowest level data flows and processes. These are in the form of data dictionaries and specifications for each low level process. | • The physical description of existing geographic information processing can show up areas where a GIS would easily fit in. It can show bottlenecks in data flow, and it can point out the administrative structure that underlies the existing system. Even it the existing system is not automated at all, this description can show how those persons involved in geographic information processing expect to treat geographic data. This kind of knowledge can be used to develop training programs that will come up to user expectations.<br><br>• The data dictionary for the existing system can give good insight into the structure of the geographic data used within the organization. Knowledge of data structure can be used to specify the database used in the proposed GIS. |

**Table 6.4.5 Existing Logical Description Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Existing Logical Description |
| **Description:** | The logical description of the existing system uses DFDs, data dictionaries, and minispecifications to examine the movement of only the geographical data contained in the system. |
| **Source:** | 3.3.1 Describe Existing Geo Info Processing System as a Logical System. |
| **Involved Processes:** | 3.3.1 Describe Existing Geo Info Processing System as a Logical System; 3.3.2 Propose a GIS as a Logical System. |
| **Elements Included** | **GIS Data Interpretation** |
| • The same tools as are used in describing the physical system are used to describe the logical representation of that system. However, all references to the physical portion of the system are removed. Only the movement of the geographical data is of importance. | • Abstracting the physical setting from what the geographic data is actually doing makes it easier to see the transformations that occur within the geographic data. This information can be used as guide-lines in the next step, which involves proposing the new GIS as a logical system. |

**Table 6.4.6 Logical Data Specifications Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** Logical Data Specifications | |
| **Description:** A logical description of the structure that the proposed GIS data might take. | |
| **Source:** 3.3.2.1 Derive the Logical Data Specifications | |
| **Involved Processes:** 3.3.2.1 Derive the Logical Data Specifications; 3.3.2.3 Compile Proposed Logical System Specification. | |
| **Elements Included** | **GIS Data Interpretation** |
| • A description of the data structures that might be used in the proposed GIS. The logical data structure is machine independent. Only the information and generalized structure of the data are noted. | • This information can be used in specifying a GIS database. |

**Table 6.4.7 Logical Analysis Specifications Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** Logical Analysis Specifications | |
| **Description:** A logical description of the type of analysis that the proposed GIS might be expected to perform. | |
| **Source:** 3.3.2.2 Derive the Logical Analysis Specifications | |
| **Involved Processes:** 3.3.2.2 Derive the Logical Analysis Specifications; 3.3.2.3 Compile Proposed Logical System Specification. | |
| **Elements Included** | **GIS Data Interpretation** |
| • A description of the analysis techniques that the proposed GIS might be required to perform. The description uses DFDs, data dictionaries, and mini-specifications to describe the analysis specifications. | • This information can be used in specifying the analytical capabilities of the proposed GIS. It can be used to develop benchmark tests. In its structured analysis format, it is not discipline specific, thus it can be understood by the many different people who will be involved in the design, implementation, and operation of a GIS. |

**Table 6.4.8 Logical Specifications Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** Logical Data Specifications | |
| **Description:** A logical description of the proposed GIS, including data structure and analysis requirements. | |
| **Source:** 3.3.2.3 Compile Proposed Logical System Specification. | |
| **Involved Processes:** 3.3.2.3 Compile Proposed Logical System Specification; 3.4 Describe the Human / Machine Interface. | |
| **Elements Included** | **GIS Data Interpretation** |
| • The integration of the logical data and analysis specifications with the existing logical system description (if a system was in place) to form a new logical system specification. DFDs, data dictionaries, and mini-specifications are used to describe the proposed logical system. | • The logical specifications describe what happens to geographical data within the proposed GIS. The next process takes as input this information and makes recommendations as to how the GIS should handle the geographical data. |

**Table 6.4.9 The Structured Specification Document Data Flow**

| | |
|---|---|
| **Data/Information Flow Name:** | Structured Specification Document |
| **Description:** | The document contains a description of the existing system (if it exists), a description of the data and analysis needs of the proposed GIS, a description of the administrative needs of the GIS, information on the training and personal required to run the GIS, some proposals on GIS hardware/software combinations and costs, and some recommended benchmarks for system testing. |
| **Source:** | 3.4 Describe the Human / Machine Interface |
| **Involved Processes:** | 3.4 Describe the Human / Machine Interface; 4.0 Design and Implementation Specification Process. |

| **Elements Included** | **GIS Data Interpretation** |
|---|---|
| • The Structured Specification document takes the GIS information given in Process 2.0 (Feasibility Specification Process) and places it in a structured format. The structured information deals with the following points:<br><br>- A set of DFDs, data dictionaries, and minispecifications that describe an existing system. | • The information in this document contains data from all of the previous processes. It represents the requirements that geographical data users within an organization will expect a GIS to meet. As well, the requirements are presented in a way that can be understood by the many parties who are involved in GIS development. |

Table 6.4.9 continued ...

Table 6.4.9 continued ...

| | |
|---|---|
| - Logical descriptions of an existing system, and data and analysis descriptions of a proposed GIS. These descriptions make use of the tools of structured analysis (DFDs, data dictionaries, minispecifications).<br><br>- Recommendations on potential GIS administrative structures for the organization.<br><br>- Recommendations on training that take advantage of the GIS data structure recommended and the GIS analysis requirements.<br><br>- Benchmarking recommendations based on GIS data structure, and analysis requirements.<br><br>- Suggestions for the human / machine interface, including the following:<br>  - determination of information to be included in any request for proposals to vendors;<br>  - determination of the type of data and problem sets to be used in benchmarking;<br>  - preparation of several GIS hardware/software combinations that will fit the identified administration, data, analysis, and output requirements. | • This document will be the interface between the physical and logical portion of the GIS Analysis Framework. In the upcoming processes, more attention will be paid to hardware and software dependent GIS questions. However, this document will still be an important reference, because it describes what the GIS is to do. In essence, it sets the GIS policy for the organization. The physical portion of this framework will determine the most effective way to implement this policy. |

### 6.4.3 The Minispecifications for Process 3.0

The minispecifications detailed in this section may appear to be very similar to Process 2.0, and one might ask "why duplicate Process 2.0?". Process 3.0 is not a duplication of effort it is a refinement of information. In this process the information gathered in 2.0 is structured in such a way as to be understandable by non-geographic specialists. This structuring of information is especially noticeable in the treatment of geographic data and geographic analysis found in sub-process 3.3.

The focus throughout this process is on what happens to the geographic data in the organization, rather than on how the data is manipulated. This abstraction does not come about easily. Those people within the organization who work with geographic data and analysis are the key. They must be interviewed extensively about their understanding of the data. Then, through collaboration with those persons doing the GIS analysis, this specialized knowledge is turned into a more readily understood form - the logical specification.

This section details how to undertake this type of collaboration. It describes through minispecifications the elemental processes shown in the DFDs for Process 3.0. There is one minispecifications for each of the elemental processes represented in Figures 6.4.1, 6.4.2, and 6.4.3. The list of minispecifications covered in this section is as follows:

**Table 6.4.10 Minispecification: 3.1 Evaluate Feasibility Specification**

| | |
|---|---|
| **Name of Process:** | 3.1 Evaluate Feasibility Specification |
| **Description:** | This process represents an opportunity for management to overview the GIS development/selection process that has taken place to date. Management can see the resources that it would take to implement a GIS. This is an opportunity for management to decide on continuation of the GIS analysis. |

**Declare Process:**

Management reviews the Feasibility Specification generated in Process 2.0. Overviews of possible GIS configurations are presented. Overall GIS use within the organization is identified. Database requirements and analysis requirements are overviewed.

IF management issues a proceed OR proceed with restrictions

THEN
Issue a request to proceed with the GIS analysis. Note restrictions where applicable.

ELSE

IF management issues a discontinue analysis request

THEN
Document reasons for discontinuation.
Determine if GIS analysis might be possible in the future.

Generate an Instructions to Proceed directive.

**Table 6.4.11 Minispecification: 3.2 Describe the Existing Geo Info Processing System**

| | |
|---|---|
| **Name of Process:** | 3.2 Describe Existing Geo Info Processing System |
| **Description:** | If geographic information processing of any sort is on-going within the organization, Process 3.2 describes how this processing is conducted. Using data flow diagrams, data dictionaries, and minispecifications, the existing system is described from the point of view of the geographic data flowing through it. |

**Declare Process:**
Select a group of representative members from each of the user categories (Table 6.1) involved in processing geographic information.

IF geographic information processing of any type is on-going

THEN
ask questions and receive information from the selected group regarding the description of the existing system.

Questions and responses are designed to do the following:

- Build a levelled set of DFDs that describe the current geographic information processing system. The current system does not have to be computerized in any way in order to build the DFDs.
    - Begin with an overview of the system, much as the GIS Analysis Framework model has done. Explore all of the sub-processes that are involved in the overall process. Use the techniques outlined in Chapter 3 to further develop the DFDs.
- Match a data dictionary to each of the low level data flows found on the low level DFDs.
    - Only describe those data flows that are at the lowest level in the DFDs. Then any upper flows which encompass the flows described in the data dictionary are described by default.
- Describe what happens at each low level process element through minispecifications.

It may take several iterations of similar questions and responses before a clear understanding of the existing system can be described through this process.

Prepare a Physical Description report which encompasses all of the above information.

ELSE
Proceed to Process 3.3.

**Table 6.4.12 Minispecification: 3.3.1 Describe the Existing Geo Info Processing System as a Logical System**

**Name of Process:** 3.3.1 Describe Existing Geo Info Processing System as a Logical System

**Description:** If geographic information processing of any sort is on-going within the organization, Process 3.3.1 takes the Physical Description from Process 3.1 puts it into a logical context. All references to the physical components of the existing system are removed from the description.

**Declare Process:**

IF geographic information processing of any type is on-going

THEN

change the Physical Description of the existing system into a logical one using the following technique:

Using the members of the GIS user community selected in 3.2, go over the Physical Description and determine which of the physical processes in the system can be replaced with logical ones.

Changing from a physical to a logical point of view is easiest if each of the processes from the top of the DFD hierarchy down to the lower levels are examined. Most of the major changes to the DFDs will occur in the mid to lower level processes. The upper processes tend to be quite generalized and the data flows and data dictionaries tend to be more logical in scope than physical. Except for the occasions when a data flow is actually a physical object.

The output from this process will be an Existing Logical Description, which will be made up of the same components as the Physical Description, but will deal only with how the geographic data moves within the system.

ELSE

Proceed to Process 3.3.2.

Perhaps the best way to clarify what occurs at this sub-process is to give an example. Consider a small forestry management company. Its major income is from sub-contracting to larger firms for the creation of harvest planning maps. Typically harvest planning maps are created by overlaying map sheets, each of which contain information about different facets of the planning area. Such things as slope, aspect, forest cover type, forest cover age, drainage patterns, soil type, etc. are all used in deciding where and when areas in a given region will be cut.

It is not the responsibility of this small company to gather the primary data, or even to develop the requirements that will determine if an area is harvested or not. They simply implement a given policy for a given region. The end product from the company is a map which lays out which areas are to be harvested, and when this will occur within the harvest rotation cycle.

A DFD of the company would show up several different sub-processes. This example concentrates on the sub-process wherein geographic data is received by the company and stored. Figure 6.4.4 shows how the geographic data is handled upon receipt by the company.

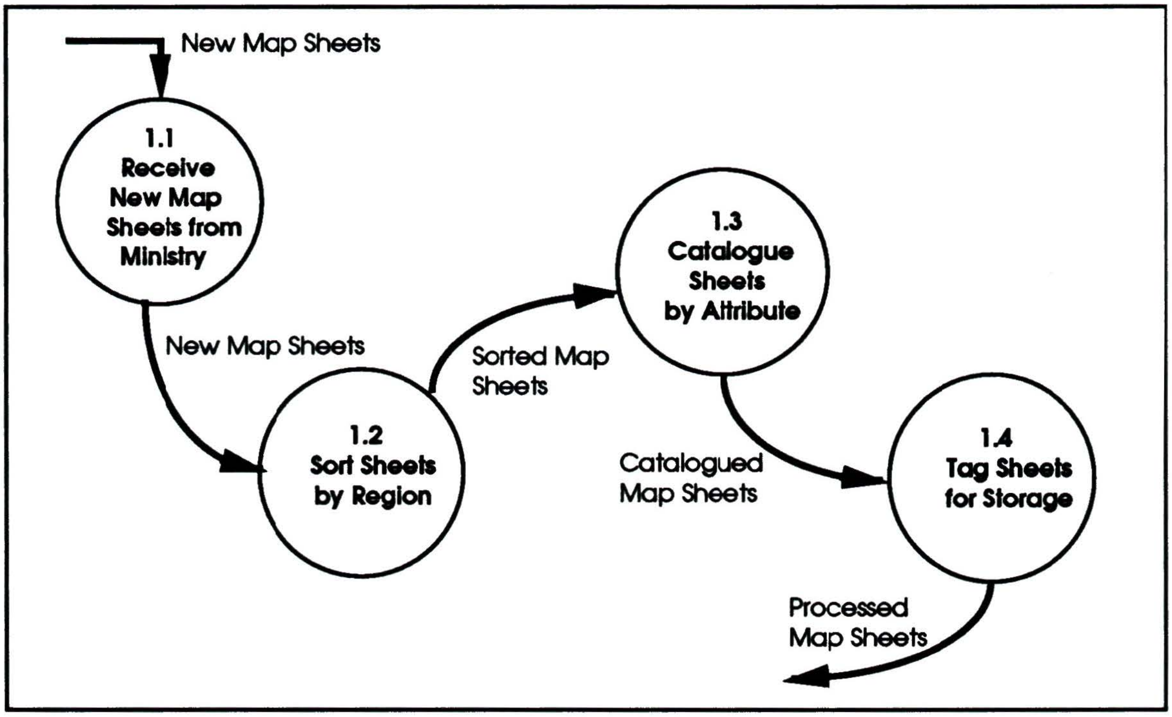



**Figure 6.4.4 Physical Diagram Showing Data Reception**

In order to turn the viewpoint of Figure 6.4.4 from the physical to the logical, certain items in the sub-processes must be presented in another manner, and some sub-processes are dropped entirely. This alteration of viewpoint is displayed in Figure 6.4.5.

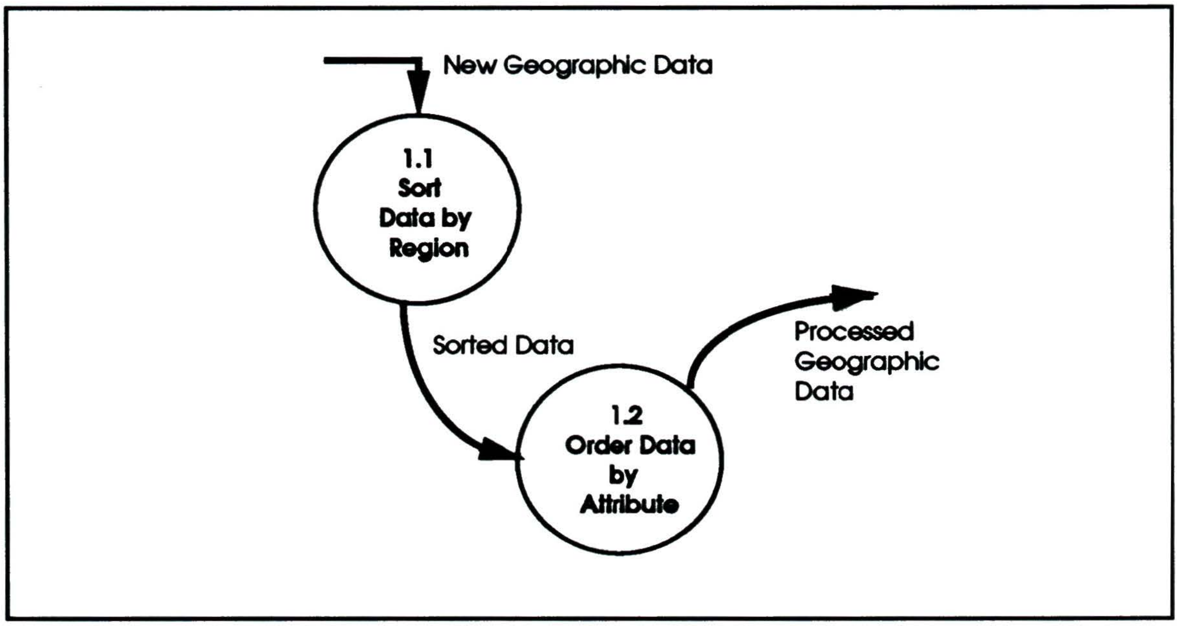



**Figure 6.4.5 Logical Diagram Showing Data Reception**

The physical constraints are now removed and it is easier to see what needs to be done with geographic data when it arrives at the organization. This method also makes it easier to specify what a potential GIS should be able to do for the organization. In this case, if a GIS were to be brought into the organization one of the tasks that it might be asked to undertake would be the initial processing of new geographic data. However, a diagram like this also allows the organization to think about what aspects of the system they might change in order to become more efficient, do more processing, take on more clients, etc.

For example, in this scenario the organization might wish to add data verification to its initial data processing. If it is considered as a logical diagram then the physical questions of how to implement this process could be left until later.

**Table 6.4.13 Minispecification: 3.3.2.1 Derive Logical Data Specifications**

**Name of Process:** 3.3.2.1 Derive Logical Data Specifications

**Description:** Derive logical data specifications by characterizing the geographic data that will be used in the proposed GIS.

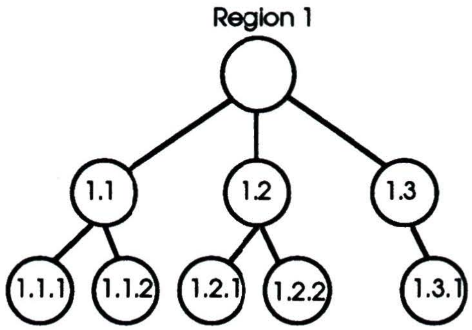
**Declare Process:**

Working with the specified group of people from the user community within the organization ask questions and evaluate responses to
Characterize the GIS data.

IF there is existing geographic information processing THEN
IF the proposed GIS will use the same type of data THEN
Characterize existing geographic data.
Include any additional data characteristics .

Geographic data is characterized in the following manner:

- STRUCTURE
  - What is the general structure of the data?
  - Is it a hierarchy, as in some forest resource applications?
  - Is it a network, as in some facility management applications?
  - Is it an attribute based set of data about a given region, as in some monitoring applications?
  - Is it a combination of several of these structures?




Diagrams should be used to describe the structure of the data. These do not have to be DFDs, but it is convenient if the naming conventions are followed. Directly opposite is a diagram of a hierarchical structure. Each of the sub-regions make up their parent region. The data at each parent node is made up of the joined data from each of the child nodes.

Table 6.4.13 continued ...

Table 6.4.13 continued ...

- TYPES OF DATA IN THE STRUCTURE
  - In general, what type of data will underlay the structure?
  - Point data with different attributes attached to the points.
  - Area data with many small regions containing attribute data defined in a larger region.
  - Line data with the ability to associate other attributes (like elevation) to lines.

- DESCRIPTIONS OF DATA IN THE STRUCTURE
  - After identifying the structure and, in general, the types of data to be found in the proposed GIS, some logical example of the data should be derived. Just as in the data dictionaries and minispecifications, describe data only when it is at its lowest level in the diagram. This prevents duplication of effort and keeps the analysis as brief as possible.

| Data Entity | Geographical Data Types | Components | Scale | Attribute Type |
|---|---|---|---|---|
| Roads | | | | |
| Age | | | | |
| Species | | | | |
| Elevation | | | | |

If the hierarchical structure of Region 1 were to have a data description done, only the lowest level processes would be described. To describe the geographical data, a data matrix, like the one pictured to the left, could be used. The simple one shown here outlines some of the common data entities found on a forest cover map sheet. The column items should be tailored to the individual organization, however, some basic information about the data needs to be noted. The column items displayed here illustrate what this basic information should encompass.

- Data Entity: The name of the data element required in the GIS.
- Geographical Data Types: Area, point, and/or line associated with this entity.
- Components: The items that make up this entity (eg. $x$ $y$ coordinates, attributes at a point, attributes in a region, $z$ coordinate ).
- Scale: The scale at which the data is required.
- Attribute Type: The type of data that comprises all of the attributes in that element (eg. interval, ordinal, ratio, nominal).

The output from this process is the Logical Data Specification.

**Table 6.4.14 Minispecification: 3.3.2.2 Derive Logical Analysis Specifications**

**Name of Process:** 3.3.2.2 Derive Logical Analysis Specifications

**Description:** Derive logical analysis specifications by characterizing the types of analysis that will be required in the proposed GIS.

**Declare Process:**

Working with the specified group of people from the user community within the organization ask questions and evaluate responses to
Characterize the GIS analysis requirements.

IF there is existing geographic information processing THEN
IF the proposed GIS will use the same type of analysis THEN
Characterize existing analysis.
Include any additional analysis characteristics .

Analysis in a GIS is characterized in the following manner:

- GENERAL ANALYSIS FUNCTIONS
  - What is the general type of analysis that the proposed GIS will undertake? The following are examples of some categories:
    - Regional Analysis (eg. monitoring some environmental factor);
    - Resource management (eg. forestry, mining);
    - City/municipal planning, facility management (eg. legal land parcel information);
    - Forecasting and modelling (eg. the spread of an environmental contaminate, or a disease).

- ANALYSIS SPECIFICS
  - What are the specific types of analysis that will be required from the GIS? Use of an analysis matrix, like the one pictured below, will help to structure these specifications.

Table 6.4.14 continued ...

Table 6.4.14 continued ...

| Analysis Categories | Procedures | Required | Scale | Accuracy | Attribute Data Type |
|---|---|---|---|---|---|
| Transformations | Rotation | | | | |
| | Scaling | | | | |
| | 3-D. | | | | |
| | Logical | | | | |
| | Statistical | | | | |
| Regional Analysis | Length | | | | |
| | perimeter | | | | |
| | area | | | | |
| | shape | | | | |
| | statistical attributes | | | | |
| Modelling | Terrain modelling. | | | | |
| | Network Analysis | | | | |
| | Cluster Analysis | | | | |

- The analysis categories rep- resent ed here are only a sample of the many different types of geo- graphic analysis that are possible. Each organization will have their own categories.

The columns in this matrix can be interpreted as follows:

- Required: Is this an analysis function that will be required for all data, not at all required, or required for some data?
- Scale: At what scale(s) will this type of analysis be required?
- Accuracy: What type of accuracy will be required for this analysis? There are many aspects surrounding the term "accuracy" (see for example Burrough 1987, chapter 6), especially as it relates to GIS. In this matrix the term "accuracy" is used to refer to positional accuracy. For example, a high degree of positional accuracy is required for placing objects such as houses, roads, and land parcels in a geographical data base. Such accuracy may not be necessary for environmental boundaries, like soil classes or forest cover areas.
- Attribute Data Type: What type of data will this analysis deal with? This could be any of the four categories of nominal, ordinal, interval, or ratio, or it could be a combination.

The output from this process is the Logical Analysis Specification.

**Table 6.4.15 Minispecification: 3.3.2.3 Compile Proposed Logical System Specifications**

**Name of Process:** 3.3.2.3 Compile Proposed Logical System Specifications

**Description:** Examine the logical data and analysis specifications looking for possible matches and discrepancies between the data structure and the required analysis types.

**Declare Process:**

- Examine the logical analysis and data specifications looking for the following:

  - Similar data type requirements between analysis and structure. This will give an indication of the types of analysis that can be undertaken at different levels within the structure. For example, if rotation of regions is a required analysis function, and must use ratio data, then it should be able to be performed at every level that has ratio data in regional (areal) format.
  - Possible mis-matched logical requirements between structure and analysis. For example, an analysis procedure may have been specified at a large scale, but if the structure does not support the required data at that scale then a mis-match exists.
  - The outlines of benchmark test suites for data structure and analysis functions.

IF a system exists

THEN

- go back into the Logical DFD and point out where the proposed GIS data structure and analysis request might fit in. For example, if the current system has data verification as one of its tasks, and if the proposed logical analysis has identified data verification as one of its tasks, then the current logical DFD can be combined with the proposed analysis specification. If the proposed analysis function does not look like it will fit well in the current position, then the logical DFD may be altered to accommodate a more efficient placement of the proposed analysis component. A new document, which is comprised of the modified logical DFDs, modified data dictionaries, and modified minispecifications is created.

To illustrate how a new logical process can be mixed with the logical Data Flow Diagrams from the existing system consider again the example of the small forestry consulting firm. In Figure 6.4.5 a logical representation of how the firm received geographic data was presented. If it was determined that the firm would like to institute some error checking of the data before cataloguing the data, it might be logical to insert it into this process. Figure 6.4.6 shows how this might be done.

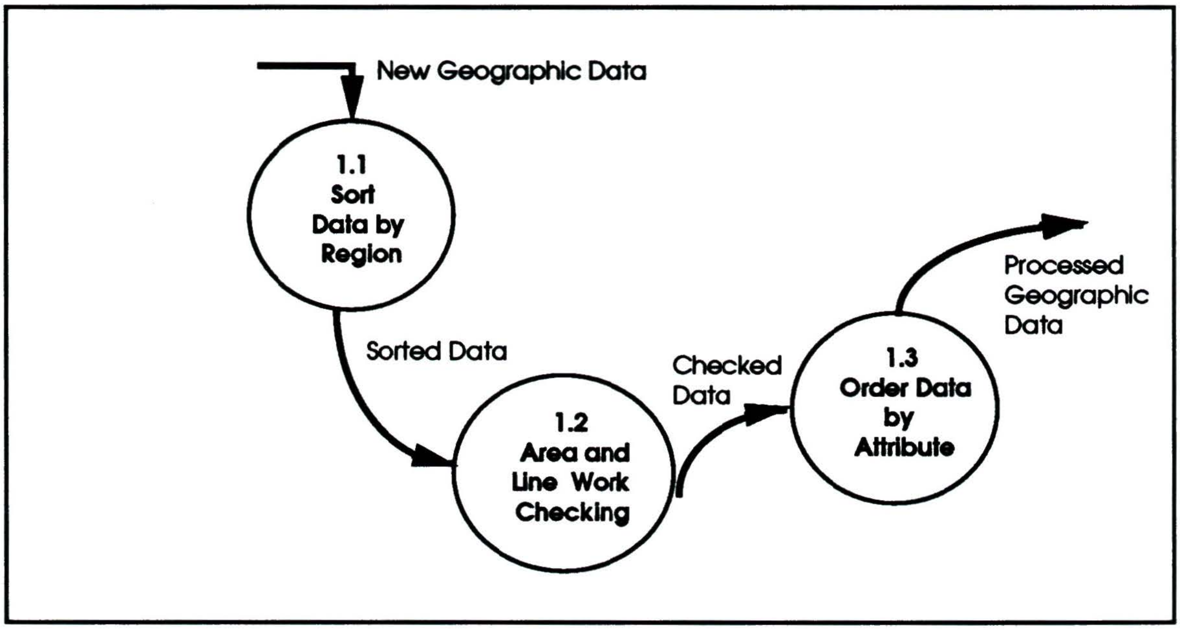



**Figure 6.4.6 Proposed Logical Diagram Showing Data Reception and Checking**

The minispecification and the data dictionary will define what the area and line work validation requirements are. For example, the clients of the firm could be noticing that the forest harvesting sheets generated from the company have line work on them that does not agree exactly with their maps. In a logical analysis specification this problem could be identified and solutions suggested. Certainly one step in ameliorating this problem would be to check the data as it came in. This would give any future products with this information something to be checked against.

The analysis group would define what it means to check data. This type of validation usually requires a comparison of the current data with something that is known to be correct. If this method is sufficient, then Process 1.2 is logically defined and ready for the next step.

**Table 6.4.16 Minispecification: 3.4 Describe the Human / Machine Interface**

| | |
|---|---|
| **Name of Process:** | 3.4 Describe the Human / Machine Interface |
| **Description:** | Examine the logical specifications together with the physical definitions of the existing system (if one exists), and put them in context with the issues of GIS acquisition/development, administration, and operation as laid out in the Feasibility Specification. |

**Declare Process:**

- This process addresses some of the implementation issues surrounding the development or acquisition of a GIS. It takes the logical data and analysis specifications and puts them in a structured context with administration and operation issues as laid out in the Feasibility and Opportunity specifications.

  IF geographic information processing is on-going
  THEN
  - Compare the existing physical DFDs and the proposed logical DFDs compiled in process 3.3.2.3. Instead of moving from the physical to the logical (as was done in Process 3.3.1) perform the reverse operation. Although most of the hardware aspects of the proposed GIS will still not be defined in this process, at least the areas where the proposed GIS will fit into the existing organization will be evident.
  - A new physical description of the proposed system is developed. It contains, where necessary, new DFDs representing the proposed changes, new data dictionaries to define the new data interfaces, and new minispecifications, where necessary, to define proposed GIS tasks.
  - Administrative changes can be noted on the new physical description. For example, a new physical description can note a central storage area for data files in use. The data dictionary can note a new cataloguing convention (e.g. file names identifying area and year of last update). The minispecifications can note how this data should be accessed and replaced.
  - If acquisition of a new GIS is the goal, then requests to vendors can go out that contain structured information regarding data structure, analysis, output, and administrative concerns.
  - If GIS development is the goal, then the structured information regarding data structure and analysis can be submitted and discussed with the GIS research team.
    - Benchmarks can be specified with data that the organization will actually use, on required analysis functions, and with output specifications.

Table 6.4.16 continued ...

Table 6.4.16 continued ...

| |
|---|
| ELSE<br>- Benchmarks can be specified with the data structure and analysis requirements that would most likely be used within the GIS.<br>- Feasibility and Opportunity statements can be examined with the Logical Specifications to find matches and mis-matches between the proposed GIS data and analysis structure and the proposed administrative structure, staffing, and output requirements.<br>- If the goal is acquisition of a GIS, then requests to vendors can be made with data structure and analysis functions that are logically specified.<br>- If GIS development is the goal then information regarding structure and analysis can be submitted and discussed with the GIS research team.<br><br>The output from this process is the Structured Specification Document. |

### 6.4.4 Comments on the Structured Analysis Specification Process

The process of determining a structured specification for computer based applications has been in use as an analytical technique for almost 20 years (Davies,1990). In this time, the questions and complaints on the part of management over why so much time should be spent on requirements analysis do not seem to have abated (Nelson, 1990). Indeed Yourdon (1989) suggests that too much time spent on this component of analysis can induce "paralysis through analysis". So why is this process undertaken in this thesis? The reasons are four-fold:

1). This process produces an unambiguous requirement document that has been logically structured by the persons who will use the system. Yet, this document can still be understood by non-geographic specialists. Thus the document is a communication medium.

2). The document will be used in subsequent processes, not least of which will be the system evaluation. As the document has been prepared by those persons who will use the GIS, it represents their initial expectations as to what the system will be able to do for them.

3). Administrative changes, staffing, and training issues can all be identified in this document. Training can be targeted to expand

# CHAPTER SEVEN
# SUMMARY AND CONCLUSION

## 7.0 INTRODUCTION

This study has demonstrated that Geographic Information Systems are powerful tools which can be put to a variety of different uses in completely different areas of expertise. However, the GIS tool is not a simple one to understand, nor is it an inexpensive tool to experiment with. Indeed, the development of GIS has come about through the integration of expertise from many different academic disciplines, not the least of which is geography. Yet how can this tool continue to be developed such that it will function well for spatial application specialists in any field?

There are several reasons why this research was undertaken, but mainly this study has tried to outline a communications method that answers the above question. The method, which is based on techniques of structured systems analysis, provides a framework for applications specialists to specify what they want a GIS to do for them. This type of effective communications among GIS participants can only aid in increasing the understanding of what a GIS should be able to do.

The literature surrounding GIS development and use has consistently called for an increased understanding of GIS specifications by all GIS participants. deMan, (1984) presents one of the first attempts to specify GIS requirements. Burrough, (1986) devotes a chapter in his GIS text to some of the issues around GIS specification. Aronoff (1989) also devotes a chapter to these issues. However, his work did not suggest a method for achieving the necessary integration of expertise. This thesis has tried to provide such a methodology.

This study was also undertaken to allow the author to gain an understanding of the capabilities of Geographic Information Systems, and of the GIS requirement issues from different application areas. Moreover, this research provided the author with an opportunity to explore and apply systems analysis techniques to a new area: the specification of GIS requirements.

The application of systems analysis techniques to GIS specification required that the GIS Analysis Framework presented here be a synthesis of on and make use of the existing expertise within the organization. This will help to put use of the GIS into a frame of reference that is familiar to the existing staff.

4). This document is the result of collaborative work between many people at different levels within the organization. Thus, people from throughout the organization will have a vested interest in seeing something that they have worked on (ie. the proposed GIS) become a success.

In the GIS literature there have been many calls for Geographic Information Systems designed to meet the needs and perform the functions that geographic information managers require (see for example Crain 1987; Trenholm 1987; deMan, 1984). Yet actual methodologies for accomplishing these tasks are not forthcoming. The GIS Analysis Framework Model advanced in this chapter has tried to provide a portion of this methodology - the portion that allows geographers to state what their needs and required functions are. Certainly this must be the starting point for any successful computer-based system that must rely on the expertise of scientists from many disciplines.

analysis techniques from geography and from computer science. It is the opinion of this study that such a synthesis is required if GIS specification by application specialists is to be successful.

Geographic Information Systems are complex tools. To be successful they cannot be the product of one discipline. In order to bring together the required expertise from different disciplines some form of communication tool is required. This thesis has explored the development of one such tool: The GIS Analysis Framework.

## 7.1 THE STUDY

This study has covered several objectives. In Chapter 1 it noted the importance of effective and efficient communications between the different disciplines involved in GIS research and use. This chapter also pointed out that, although there had been many calls for research into issues surrounding GIS specification, not much methodology in this area has been produced. Chapter 1 finished by stating that this study would present a method of communication to be used between scientists involved in the design, implementation, and use of GIS.

Before delving into the communication method, the study established some of the background surrounding GIS use, systems analysis techniques, and the use of systems analysis in geography.

Chapter 2 began with a brief history of GIS and reviewed the components of a typical GIS. It outlined some of the GIS applications available today, and pointed out some of the problems surrounding unfulfilled GIS expectations.

Chapter 3 reviewed some of the methods of systems analysis used in specifying complex computer-based systems. It focused on the use of one successful specification method, that of structured systems analysis. Several tools are associated with this method, and they were discussed in this chapter.

Chapter 4 examined some of the different methods of systems analysis that are used in geographical research. Commonalities between some geographic research in GIS and techniques of structured systems analysis are explored.

The first four chapters were used to set the scene for Chapters 5 and 6. The first four chapters made the following points:

- GIS can be complex tools requiring expertise from different disciplines.
- There are tools available that can help deal with these complexities.
- Geographers have used tools like these in many different areas.
- There is room for tools to be developed so that geographers and application specialists can specify their GIS requirements.

Chapter 5 put together several of the components of the first four chapters to form a GIS analysis model that placed geographic requirement specification into a framework with other parts of a GIS model. The model has two interfaces: the Logical Interface, which is between the GIS life cycle and those persons who specify "what" the GIS ought to do; and the Physical Interface, which is between the GIS life cycle and those persons who specify "how" the system will accomplish its task.

Although geographers and application specialists are shown to have a role in all areas of a GIS life cycle, it is in the requirements specification (the Logical Interface) where they can specify the tasks that are to be performed by the GIS.

Chapter 6 outlined a method that allows geographers and application specialists to set out GIS requirements in an unambiguous medium. This chapter developed the Logical Interface portion of the GIS Analysis Framework. In addition, this chapter used the method advocated in the thesis to describe the workings of the Logical Interface.

## 7.2 THE OUTCOME

This study is largely a theoretical construct focusing on a method for assessing and choosing a GIS. It did no statistical hypothesis testing, and analysed no data. The model it presents can, however, be looked at in a rigourous fashion for positive and negative aspects.

There are several negative aspects to the model put forward here. First of all, it can be very slow to put into place and follow through on. For example, an organization considering the acquisition of a GIS will have to decide if they want to undertake a formal requirement specification analysis (the Logical Interface). If they decide to do such an analysis, do they commit in-house staff to the project, or do they hire an outside consultant? Perhaps, they hire a consultant, but provide in-house support staff to work with the consultant. In any event, the organization will have to commit time and resources to such an analysis. In the Logical Interface portion of the GIS Analysis Framework several opportunities are give for management to review the progress of the GIS specification, but more opportunities may be required if the specification is going slower than expected.

Secondly, such an analysis depends on the cooperation of many different people within the organization. Sometimes the implementation of a "new, automated system" can frighten staff. They worry that their jobs may be threatened, or that they will not be able to understand the new technology. Even the offer of retraining can be intimidating to staff. If staff are worried about their jobs, they may not work well with those persons undertaking the specification analysis. Yet, it is the expertise of these staff members that will need to be tapped if the specification analysis is to be a success.

Thirdly, it is possible for those persons undertaking the requirement specification analysis to become too detailed. They may try to design the entire system. This is not the purpose of a requirement specification. It should be machine independent. Trying to keep the consultant(s), and/or in-house people on target can be a difficult task.

Fourthly, this model has not been tested in a GIS setting. The model is the result of research, on the part of the author, through papers, journals, and conferences, through working experience in the field of GIS, and through four years of experience as a computer systems analyst. This expertise does not, however, make up for the actual testing of the model in an organization which is considering acquiring a GIS.

There are several positive aspects to this research. Firstly, it does provide a communications medium among geographers, application specialists, and other scientists interested in GIS design, implementation, and use. To date such a medium has not been presented in the literature.

Secondly, the model presented here is based on the concept of a system life cycle. Thus, such a model is dynamic and open to change. In this case, if further research showed that one of the sub-processes within the Feasibility Specification (Process 2.0) can or should be improved, then a change can be made to the appropriate sub-process(es), while leaving the rest of the model intact.

Thirdly, this model considers, and places into context, the non-technical aspects of GIS implementation that can be crucial to the success of a GIS. Although the non-technical aspects of GIS implementation have been well noted (see for example Crain, 1987), they have not been put into context with the more technical matters surrounding GIS implementation.

Fourthly, this model can be tailored for use at different levels of GIS requirements specification. It is not designed to be used only with large organizations, or only with specific application concerns. In many cases the model could be used as a guideline for undertaking a requirement specification.

Overall, this study undertook to provide a greater understanding of GIS requirements on the part of those who would like to use a GIS tool. The study tried to show an understanding of the complex interconnections of data, analysis, and organization components that underlay a successful GIS. It attempted to synthesize some analysis techniques from computer science and geography to be able to provide a communications medium between scientists involved in the design, implementation, and use of GIS.

Was the study successful? Certainly it enhances the understanding of GIS requirements, but without several attempts to apply it in the field, it is difficult to say. However, it does provide a well developed and necessary starting point for further study.

## 7.3 IMPLICATIONS FOR FURTHER RESEARCH

As noted above, the model needs to be tested. Such a test would require the assistance of at least one, but preferably several, organizations who are interested in acquiring a GIS. The study would follow each of the processes laid out within the model. It would require a method of monitoring how satisfactory (or unsatisfactory) the GIS was after some established time periods. Indeed, a longitudinal study could provide the GIS community with interesting information on how the use of a GIS evolves over time within an organization.

This model could be modified so as to be appropriate within a developing world setting. Testing these modifications would require the assistance of organizations within the developing world, and within the sponsoring agency. Again, some long-term satisfaction studies would need to be carried out.

The model could be used as to compare different GIS installations with an eye to discovering why some installations are successful and others are not. With the model as a frame of reference comparisons could be made across installations.

In closing, it should be noted that other types of analysis methods could be considered for the model. For example, Object Oriented Analysis (OOA), in which objects and classes of objects are defined, could be used as the underlying model framework.

# CHAPTER EIGHT
# REFERENCES

## 8.0 REFERENCES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