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1 Module 1: Background

This module serves as an introduction to the terminology and methods which will be used throughout the course. It begins with a discussion of where GIS technology and staff with GIS skills fit within organisations. It then explains a generalized planning process which may be applied to all development efforts, from a small GIS project to a large-scale GIS project involving many people and varying technologies. This generalized process is called the Systems Development Lifecycle (SDLC). The third topic addresses how this generalized SDLC may be applied to projects of varying scale. It refines the process for each application, and discusses which modules of this course will focus on particular components of the SDLC. This module concludes with a discussion of the Proposal document, addressing its nature, purpose and composition. A discussion of proposal evaluation is also included.

Module Outline

1. Overview of GIS Roles and Professions
2. Project Lifecycles
3. Methodology Overview
4. Proposal Purpose and Content

1.1 Overview of GIS Roles and Professions

1.1.1 The Role of GIS

There has been significant debate in recent years regarding the nature of GIS. Some support the idea that GIS is a tool which allows specialists in many different disciplines to perform spatial analyses, much as a microscope allows examination not otherwise possible for scientists. Others suggest that GIS is a profession, where those trained in the field may apply themselves to problems stemming from many areas of study but essentially spatial in nature. Others have suggested that GIS is a specialisation in the broader discipline of information technology; GIS merely adds the spatial component to something that is fundamentally a database technology. The truth likely lies somewhere in between. Likely, depending upon your point of view, GIS could be any one of these things.

Clearly, GIS has become an integral part of the way many specialists perform their work. Resource managers, planners, engineers, and environmental scientists, among others, rely on spatial data and analytical processes to perform their work. Increasingly, such professionals include spatial data processing as part of their skill-set.

Figure-1 shows the relationship between skills relating to various disciplines and their relationship to GIS skills. Each specialist has some skills in the GIS realm, and some share skills with specialists in other disciplines. The inclusion of GIS simply as a set of skills in addition to their primary training (as a field biologist, for example) is likely more prevalent at the technician level. A manager in a planning department, for example, would have less need for technical GIS skills but would still need to have an understanding of any requirements specific to GIS projects.

But is there really a “GIS professional”? The question is whether the blue area in Figure-1 not shared by these other specialties represents purely GIS skills, or whether this is really just the information technology (IT) part of GIS. It has been stated that since there are individuals trained and employed specifically in GIS theory and techniques, and that many such individuals serve as a GIS specialist in many application areas over their careers, GIS must be a profession (GITA, 2005).

Regardless of which perspective you subscribe to, the important point is that GIS skills can form part of an organisation in many ways. They can be present as a part of the technical skills of discipline specialists, or in larger organisations with significant a GIS investment, as staff devoted specifically to supporting and performing geographic analyses.

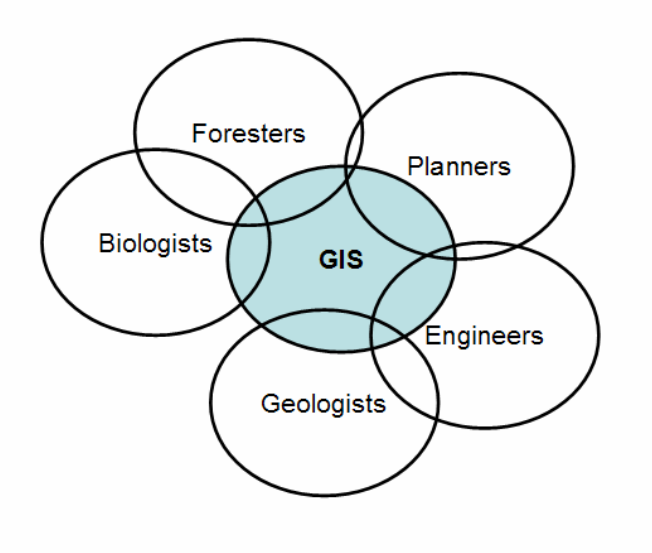

Figure-1 Relationship between discipline skills and GIS skills

GIS technology can likewise be integrated into the workings of an organisation in several ways. Its involvement in an enterprise may vary in scale and in structure.

The scale of integration refers to how deeply rooted GIS is, in how an organisation accomplishes its tasks. The smallest scale might be referred to as the Project-Level GIS. In this situation, a single employee, or a small number of employees utilise GIS to accomplish a single task, or project. The technology and data are not used throughout the organisation, and very few people require the skills to use the software.

The largest-scale involvement of GIS in an organisation is often referred to as Enterprise GIS. In this situation, GIS functionality and data are widely used within the organisation, and many people are capable of using the technology. In large organisations, staff may be dedicated solely to creating, maintaining and distributing geographic data. The complexity of the Enterprise GIS is high; data flow, maintenance and quality must be well defined and strictly monitored.

This concept of the scale of GIS involvement with the workings of a business or organisation is central to this course. We will look at defining, managing and implementing GIS at both the project and enterprise level.

The structure of GIS integration refers to how the technology fits within the organisational structure of a group, usually in Enterprise GIS-scale ventures. It was originally thought that GIS might serve as a central branch of an organisation, and serve to bind technologies, data and users. In such a model, a “GIS Department” would serve the GIS needs of the entire organisation. Most employees of such a department would be GIS experts, with little training in the specialised disciplines which would require GIS services.

Likely GIS has resolved itself into a more pervasive technology and exists as an integrated part of all departments, rather than the hub which connects them. As a result, there may be fewer “pure GIS” positions in the professional world (Kratzschmar, 2004). A person working with data for a specific discipline needs to be as much an expert in the data as the tools which operate on them. According to Kratzschmar, “GIS is a tool, not a section”.

1.1.2 GIS Professionals

Professionals who work with GIS as part of their daily schedule will perform a wide variety of tasks, including some or all of the following:

- Database Design
- Project Management
- Cartography
- Application Design
- Application Development
- Training
- Planning
- Management
- Database Administration
- Data Processing
- Web Site Design
- Web Site Administration
- System Integration
- Reporting
- Forecasting
- Field data collection
- Spatial Analysis

While many of these tasks may seem generic, and not specific to GIS, such tasks will always be a component of a GIS project and responsibility must fall to GIS staff. As a result, these skills must be present within a GIS department.

These activities may be loosely grouped into three major areas of similar activity:

Technical, “pure GIS”:

- Cartography
- Data Processing
- Spatial Analysis
- Reporting
- Field data collection
- Training

Technical, IT emphasis but utilising spatial data:

- Database design
- Database administration
- Application design
- Application development
- Web site design
- Web site administration

- System integration

Management, again, focusing on spatial data and GIS projects:

- Project management
- Planning
- Managing resources

It might be argued, based on this grouping, that the "higher" an employee moves within an organisation, the less GIS has a direct bearing on daily activities (Figure **2**). As an employee gains experience and seniority within a large, enterprise-GIS organisation, they will rely increasingly on complementary skills.

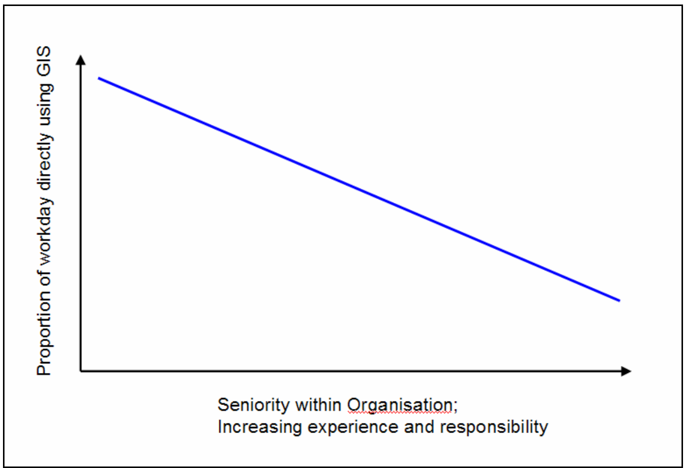

Figure 2 GIS Emphasis in Employee Roles

In the technical realm, for example, senior GIS analysts will increasingly solve complex problems by customising off-the-shelf GIS applications, writing their own automation scripts or applications. They will spend significant effort designing these applications and the data structures that will support them. They may begin to create internet applications to provide data or analysis to a wider audience. They will need to create and maintain large and complex relational database systems. So although they are functionally still a GIS analyst, and work with spatial data and analyses constantly, the tools and techniques they utilise (programming, data modeling, web development) become more universal and less specific to geographic data processing. Such an employee will still need to have a firm grasp of GIS skills and methodologies, but the background of such a person may be increasingly a technical computer science one.

Management positions, as well, will make use of more universal skills such as project management, to guide and monitor a GIS project. Again, a person serving in this capacity will need to have a firm grasp of GIS concepts and techniques, but they will likely not be spending their day actually using the applications and data.

This course will focus on this latter role, that of managing GIS operations. Such a person will need to be able to plan, execute and monitor GIS operations from the project scale to the enterprise scale. As a result, many of the skills will be relevant to managing projects with no GIS component, but all exercises and examples will focus on geographic data and problems.

1.1.3 GIS Job Descriptions

Thomlinson (2003) decomposes the three basic divisions defined above even further. He defines six major roles within an organisation making significant use of GIS technology. The following position descriptions are loosely based on these six roles:

Cartographer / GIS Technician

This person will have responsibility for most purely technical aspects of a GIS operation. Duties will specifically involve collecting and integrating data from a variety of sources and presenting results effectively. This role will typically involve the following responsibilities:

- Cartographic design and production
- Compilation / editing of spatial data
- Creating Map surround elements
- Cartographic editing of geographic data
- Text placement
- Symbol creation

GIS Analyst

This role is probably the most variable from one organisation to another, and may encompass a significant proportion of GIS activities. The responsibilities of a GIS analyst focus more on the analytical functions necessary within the organisation. This person will be responsible for the development and delivery of GIS data, products and services in an organization. In organisations large enough to have a GIS technician, the analyst will not perform tasks such as cartography and data compilation or editing, but it is common for a single person to perform both these roles. An analyst will often be capable of customising GIS software and programming smaller applications, and have a good grasp of relational database structures and applications. A GIS Analyst will often be responsible for the following tasks:

- Database construction and maintenance for smaller projects
- Data collection, reformatting, pre-processing
- Designing procedures and monitoring data quality
- Minor programming / customization tasks
- Spatial analysis
- Usually has 2 – 5 years of experience at the technician level
- Experience which distinguishes an analyst include RDBMS skills, programming.

GIS Database Analyst

This role will be necessary in a larger organization where data needs require a dedicated person to support the database. Functionally this person is a database administrator (DBA) with Spatial Data experience, and so must have a strong theoretical database *and* GIS background. Responsibilities will include:

- Development and implementation of data models
- Setup, maintenance and tuning of RDBMS
- Migration of large data volumes between structures

GIS Programmer

Again, where the organisation or project requires significant software development component, there may be a need for a dedicated programmer role. This situation may arise as part of an enterprise GIS implementation, a onetime development of tools for the organisation, or a pure software development project. Responsibilities would be beyond the capabilities/experience of a typical GIS Analyst. Responsibilities of the GIS Programmer may include:

- Design, code and maintain software applications for GIS users
- Determine user needs and translate them into useful applications
- Usually has 2+ years of programming experience, VB, C++ or vendor-specific programming language

GIS Systems Administrator

This is far more an IT position, supporting a very large GIS implementation with a large number of users, and large volumes of GIS data. Responsibilities will include:

- User support
- Systems admin functions for network servers and client machines
- Technical degree – CSC or diploma with 2-5 years experience
- High skills in UNIX and or Windows operating systems

GIS Manager

Again, for an agency with a large GIS department or many GIS technicians in different departments, it may be necessary to define the role of GIS Manager. This employee provides on-site management and direction of services to develop, install and integrate GIS within the organisation. Responsibilities will include:

- Ensuring agency-wide standards over GIS platform, data standards, coordinate systems, etc.
- Project design and workplan development
- Database system and application design
- In some cases, maintenance and administration of a large database
- Project management skills
- Hiring and setting priorities/duties for staff

- Preparation and maintenance of project documentation, including contracts, proposals and technical specifications

Additional Resources:

- Letham, G. *What's in a GIS job title? A Look at common geospatial Career Opportunities*. GISUser.com, 2006. http://www.gisuser.com/content/view/9496/28/
- Marble, D.F., *Defining the Components of the Geospatial Workforce—Who Are We?* Castlereagh Enterprises, Inc., 2005http://www.esri.com/news/arcnews/winter0506articles/defining1of2.html

Assignment:

Assignment 1: The GIS Role in Your Organisation

1.2 Project Lifecycles

1.2.1 Introduction

When we develop software or database applications or implement a GIS, we typically follow a process flow called the Systems Development Lifecycle (SDLC). For the purpose of the discussion following, we will use the term "system" to mean a newly created software application, a database application or a GIS initiative or project. All require the same basic phases of development.

The accepted process involves some very general steps. Although terminology will vary and the stages themselves may be aggregated in a slightly different manner, most authors follow a very similar process. These general steps can be defined as in Figure Klaida! **Dokumente nėra nurodyto stiliaus teksto.**3, and the steps are described in detail in the text that follows.

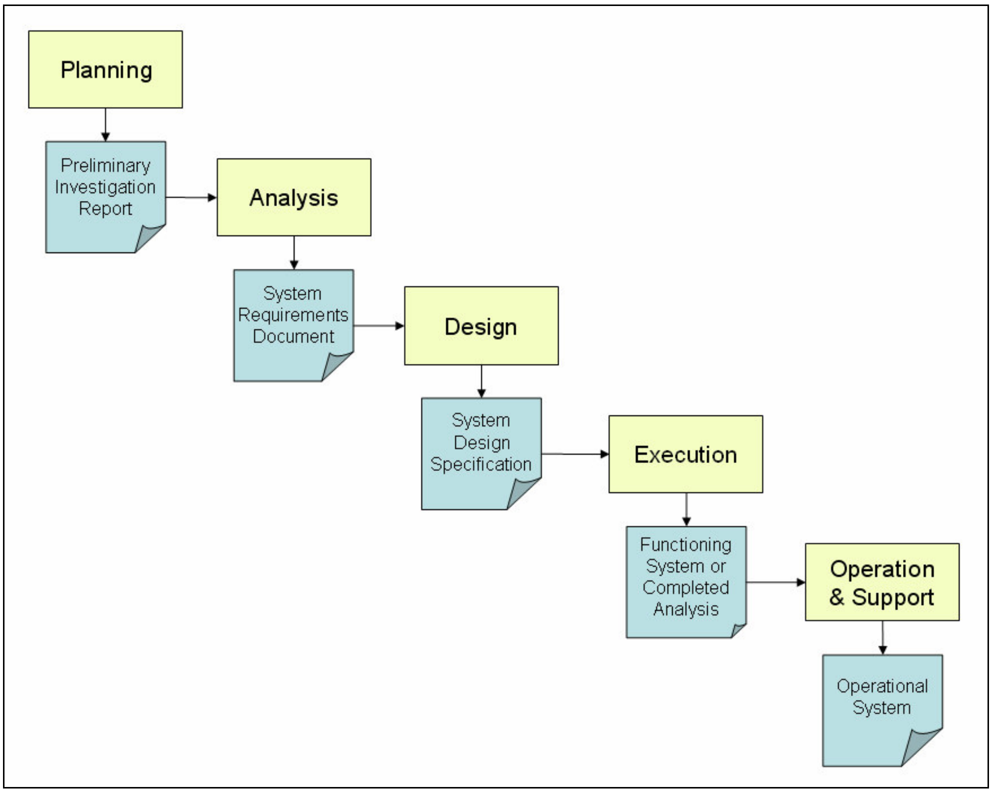

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**3 Typical Project Lifecycle**

This topic of the course describes a generalized lifecycle, applicable for most development efforts. An understanding of the generalized process and the accompanying terminology is necessary before applying it specifically to GIS initiatives. The topic following, Methodology Overview, will discuss how this lifecycle applies specifically to GIS implementations, and how it will be adapted for the purposes of this course.

1.2.2 Project Planning

Suppose you are a GIS analyst with an organisation and you receive a request for a small application to automate some GIS processing which might currently be performed manually. Your first step is to determine whether it makes sense to begin developing software at all. Often you will have to learn more about what the user wishes to do before you can reach a conclusion. After the investigation, you might find that this task is seldom performed and the effort involved in creating an application is not warranted by the time-savings for the user. In other cases, you might recommend a change in the way the user currently does their manual processing. In other cases, you might agree with the request and proceed with application development. This initial investigation is the planning phase of the development lifecycle.

In the planning phase of a project the overall goals and extents of a project are defined. During this stage, we wish to:

- Define the problem
- Confirm project feasibility
- Produce a preliminary project schedule
- Staff the project, or prepare to subcontract

If the project being planned is the establishment of an enterprise-wide GIS, there are several additional considerations for this stage in a project. It will be necessary to convince decision-makers that it is necessary to spend large sums of money to improve the efficiency of what the organization already does. This can sometimes be a difficult proposition.

Prior to proceeding with the development effort, it is important that two things be present. The first is that management or decision-makers are committed to evaluating GIS in more detail. There does not have to be a firm commitment to proceed with full-scale implementation, but there must be an expectation that some time and money will be invested in exploring the process. The second requirement is that there be a “GIS Champion” within the organization, who is entirely committed to the idea of implementing the system within the organisation. They pursue the goal of GIS implementation by selling the idea to senior managers and co-workers at every opportunity. It is widely accepted that without a champion, an organisation cannot successfully implement a GIS.

If development is not to be done internally, that is, that external consultants will be heavily involved in the process, this is one of two points at which experts may be become involved. The two entry points for external resources are typically either just prior to the analysis phase, or just prior to system construction. Consultants are often brought into the process to assist with the Analysis and Design phases, as well as the actual system construction. In other cases, the organisation has the internal capacity to do the Analysis and Design, but perhaps not the staff or expertise to do the programming, data migration, documentation and training that may be necessary to actually create the finished product.

One of the documents which may be prepared at this point is a detailed Request for Proposals (RFP) which will define the problem as it is understood after this preliminary planning phase. The RFP will seek qualified parties to enter into the Analysis and Design phases.

There may or may not be deliverables at this stage, and this typically depends upon the size of the project and the degree to which external parties will be involved. For a small project-based GIS situation, the planning stage may simply result in a decision to proceed or cease development. For software application development, or enterprise GIS implementations, this stage may result in a Preliminary Investigation Report summarising the findings of the planning stage, and/or an RFP document seeking assistance in future stages.

1.2.3 Systems Analysis

In our example of the GIS Analyst writing an application to automate a manual process, the analysis phase is where you must sit down with the GIS operator to determine precisely what data is being used, what processing needs to happen, and what the result looks like. To illustrate how you hope to solve the problem, you might make a small prototype for the user to look at and discuss with you. All of this must occur prior to writing any code. These sorts of activities would fall within the Analysis phase of a project.

The Analysis phase seeks to understand and document the business needs and processing requirements of the new system. This phase typically encompasses the following activities:

- Gather information about current processes, staff and data
- Define resulting system requirements
- Evaluate alternatives and prioritize requirements
- Document resulting requirements and review with management

Typically an analyst will meet with users to learn as much as possible about how the user performs their job and how that job fits into the larger context of the organization. Particularly if this process is performed by an external consultant, the objective here is to gain as thorough an understanding as possible about the workings of the organization. Gaining this understanding can be accomplished in a number of ways:

- Observing staff performing their duties
- Written or online surveys seeking documentation of staff function
- Oral interviews with staff
- Reading existing documentation on data and procedures
- Reviewing existing automated systems

The process of reviewing, analyzing, and structuring the information gathered to obtain an overall understanding is called defining the system requirements. In many cases, a series of diagrams is used to convey the processing requirements.

It is common to develop a prototype of pieces of the new system for users to review. In many cases users can articulate requirements far more effectively when there is an example to discuss. The phrase “users don’t know what they want until they see what they don’t want” can be true in many cases, and the prototype gives an arena for users to better define the requirements without developers expending significant effort on the full implementation.

One of the key activities of the analysis phase is to prioritize system requirements. There will never be enough time or budget to implement all possible automation applications, so prioritizing them here will allow alternative solutions to be developed and documented prior to construction.

The output of this phase is called a System Requirements Document. This document will define the results of the analysis phase, and will allow the system to be designed effectively.

1.2.4 System Design

Let's look quickly back at our GIS Analyst writing an automation application. You now know what the application has to do, and should be thinking about how to solve this particular problem. In a small development effort, the next stages may not be formalized, but often you will write down a data structure which will hold incoming data, preliminary results and final output. You will also perhaps sketch a diagram or write pseudo-code (programmer's shorthand which defines what sort of actions a program needs to take) to define how the application will perform the required tasks. These notes might even be in a form which could be passed to another programmer to complete. This kind of documentation is part of the system design phase.

A System Design is the blueprint which specifies how the system will be built. In many cases, depending upon the nature of the project, all activities may not be applicable but these topics will have to be considered at least in a summary way. During the Design Phase, activities may include:

- Design the application architecture
- Design the user interface
- Design how the system interfaces with existing systems
- Design the database
- Prototype for design details

The application is the part of the system which provides the processing functionality. Designing the application architecture means taking the models and diagrams produced in the analysis phase and designing appropriate computer programs. The user interface refers to the forms, screens, reports and workflows that are used by the operator to interact with the system. An effective user interface is a significant component in the success of a new system.

The terms **High-Level** and **Low-Level** design refer to the level of detail in a specification document. A high-level design is the more general document, consisting of a structure for programs, databases, the user interface and the operating environment. A low-level design entails developing detailed algorithms and data structures that are required for program development.

The completion of System Design also marks the point in the project at which the Project Manager should be able to plan, in detail, all future project phases. A major goal, from a management perspective, of the Design phase is to know:

- What you are about to do

- How much it will cost
- How long it will take
- What your staffing requirements are

The deliverable for this stage of the process is a System Design Specification document.

1.2.5 System Execution

As our GIS Analyst, once you have determined what you are doing, and how you will do it, all that remains is to actually do the work. Here, you will actually write, test and deliver the application you have written. Once your user has tried out the application, and is satisfied that it meets their needs, you are free to continue with other duties. This is the Execution phase; where the work gets done.

During Execution, software is written, databases are constructed and loaded with data, staff members are trained, and documentation such as User Guides and help systems are written. This is typically the most time-consuming and expensive phase of any project. In major projects, the **acceptance testing** process, to confirm that the system meets functional expectations, may be significant and it is sometimes described as a phase unto itself.

The final part of the Execution phase is sometimes called **closeout**. This is really a project management consideration, but in some circles this is described as a project phase in its own right. The purpose of Project Closeout is to assess the project and derive any lessons learned and best practices to be applied to future projects.

From a management perspective, we will have to manage a number of things during execution. These tasks are primarily the domain of the Project Manager, and will be discussed in detailed during Module 3 of this course. Managers of the execution phase will need to consider:

- Work Plans and timelines for task completion
- Staff Responsibilities
- Workspace Arrangements
- Procedures for data collection, handling and quality control (some form of internal audit to ensure the data is of acceptable quality)
- Cost and time audits during construction

1.2.6 Operation and Support

In our GIS Analyst example, this represents the state where your user is happily using your application during his or her workday. Occasionally, you may have to make minor modifications to deal with unusual situations with the data, or make small changes to make the application easier to use.

This phase represents the stage where the system has been completed and is in regular use by an organisation. During Operation and Support, GIS and/or IT staff will maintain and enhance the system. Maintenance refers to the act of repairing a fault with the system or procedure, while Enhancement refers to the refinement of the system by modifying existing functionality or adding new functions to better support the users. The objective here is to maximize the return on the development investment by making the applications or products as useful as possible.

1.2.7 Conclusion

The generalized systems development lifecycle gives us a structured process that can be applied to virtually any project. There are a variety of tools and techniques that are used during a development effort, including modeling, prototyping and computer-aided software engineering (CASE) tools. Modeling uses a graphic representation to show a concept, while prototyping uses a preliminary working version of an application to illustrate functionality or interaction. CASE tools allow an analyst to quickly design and build software applications. We will discuss some of these tools and notations later in the course.

To many this development lifecycle seems to burden a project team with significant analysis and documentation before any of the work of construction can even begin. Why do we go through this lengthy process? Really we do it to ensure that we do the project right. The more we understand of the work we are about to perform, the more likely it is that we get it right the first time. Not fully understanding the work we are about to start can lead to:

- incorrect estimates of implementation and operational costs;
- overly optimistic timelines; and most damaging,
- acquisition of a GIS or analysis which does not fulfill the organization’s needs.

This raises the issue of “Expectation Management”. Whether you are an external consultant, or are working within an organization which is trying to acquire GIS, managing expectations is critical. GIS projects are expensive, long-term affairs, and we need funding and commitment from management or elected officials to be present throughout the project. Selling the idea of implementing a GIS, for example, with an incomplete understanding of what we’re about to do can cause problems in the future. If we cannot meet the schedule and budget we’ve defined, decision-makers may choose to cancel the project, or simply be less supportive our initiatives in the future. The idea of a well-documented project is to ensure all parties (users, consultants, management) have a common understanding of what is about to transpire.

Obviously for smaller projects, the analysis and design phases may be significantly simpler, and the documentation requirements less demanding. In Section 3 we will discuss how we will apply this generalized process to our two operating scales: project-level GIS and enterprise GIS.

Additional Resources:

- Additional context on the SDLC, including discussion of how it relates to the Project Management lifecycle.
- New York State Office for Technology. Management's Guide to Project Success. Chapter III: Project Lifecycles. New York State Office for Technology, 2002.http://www.oft.state.ny.us/pmmp/guidebook2/Phase.pdf

1.3 Methodology Overview

1.3.1 Introduction

The same SDLC stages apply whether we are building a home, writing a software application, performing a complex GIS analysis project or implementing GIS throughout an organisation. The systems development process has typically been the realm of the Systems Analyst, usually trained in Computer Science. For specifically GIS-focused projects, however, a systems analyst must have significant experience or training with geographic data, their storage, analysis and presentation. In addition, some stages of analysis or design may be unique to GIS implementations.

In GIS-based projects, we need to consider the spatial context as well as all the standard things such as data flows and user interfaces. We need to consider how database entities will be represented in a spatial sense; what things in our database will reside as point, line or polygon feature classes, what scale will be appropriate for the capture of our data, and what sorts of spatial relationships might exist between features.

Figure **4** shows generally how the standard SDLC process will be addressed in this course. Modules 2 and 4 will discuss planning stages, but at two scales: project-level and enterprise-level. Module 3 will focus on project management, which primarily deals with managing the execution of a project.

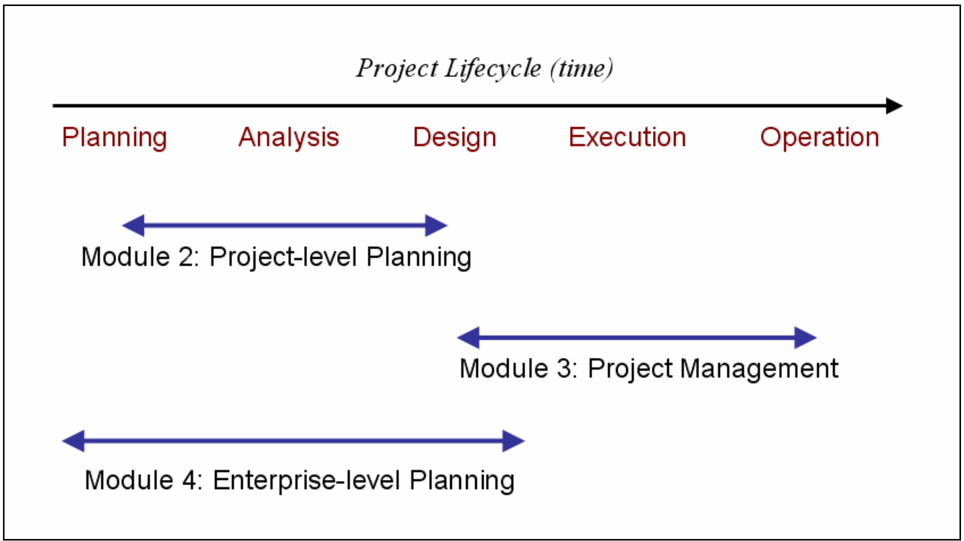

Figure 4 Course Modules and the SDLC

This course topic will describe how the generalized SDLC framework will be addressed in this course

1.3.2 Project GIS

Module 2 of this course will discuss in detail issues relating to a single, GIS-related project. Such projects would typically entail a data collection or creation exercise, a specific GIS analysis, or a visual presentation of geographic data. It might also involve some or all of these types of activities. Examples of a GIS project include:

Write a software application for a City government. The application must be able to take a point in the city water delivery network (usually underground pipes), do a network trace "downstream" on the water pipe network, and generate a mailing list of all residents who would be impacted if the water network were to be interrupted at the specified location.

Perform an environmental impact analysis for an industrial development. GIS operators must define the disturbances associated with the development, such as a mine footprint and all associated modifications to the landscape, such as roads, structures or increased vehicle traffic. Given these disturbances, quantify the impact upon the environment due to the disturbance. Impacts will include degradation of air or water quality, loss of species habitat, loss of rare or endangered plant species, and socio-economic impacts such as loss of recreation areas or impacts to a viewshed.

The project might be simple, and short in duration, such as the water network application (A above). Such a project might require a single programmer and only a few weeks to complete. Other projects, such as the environmental impact assessment (B above), are larger and more time-consuming. Such a project may take several months to complete and involve a project team of GIS analysts, field biologists and others.

The situation we're describing here is where an organisation has a specific data need, problem to resolve, or question to answer, which warrants the use of GIS technology. GIS is not necessarily prevalent throughout the organisation, so we're not dealing here with issues of data sharing, data maintenance or optimising information use in the organisation. We are putting GIS to use to solve a specific, clearly-defined problem.

The distinction we'll use between small-scale, project-level GIS (module 2) and large-scale, enterprise-level GIS (module 4), lies primarily in the Analysis phase of the SDLC. With project-level GIS, a technical problem is generally well-understood by the people who will do the work, so the Analysis stage may be fairly short in duration. The stages of the SDLC will revolve around the Design phase, defining how the work will be done.

With large-scale GIS projects, or when implementing an enterprise-level GIS, the Analysis stage becomes as complex and important as the Design stage. The discovery process of determining what each department or employee in an organisation does is difficult and time-consuming and makes the process quite different than simpler GIS projects.

Figure **5** shows the relationship between the Project GIS topics and the generalised SDLC.

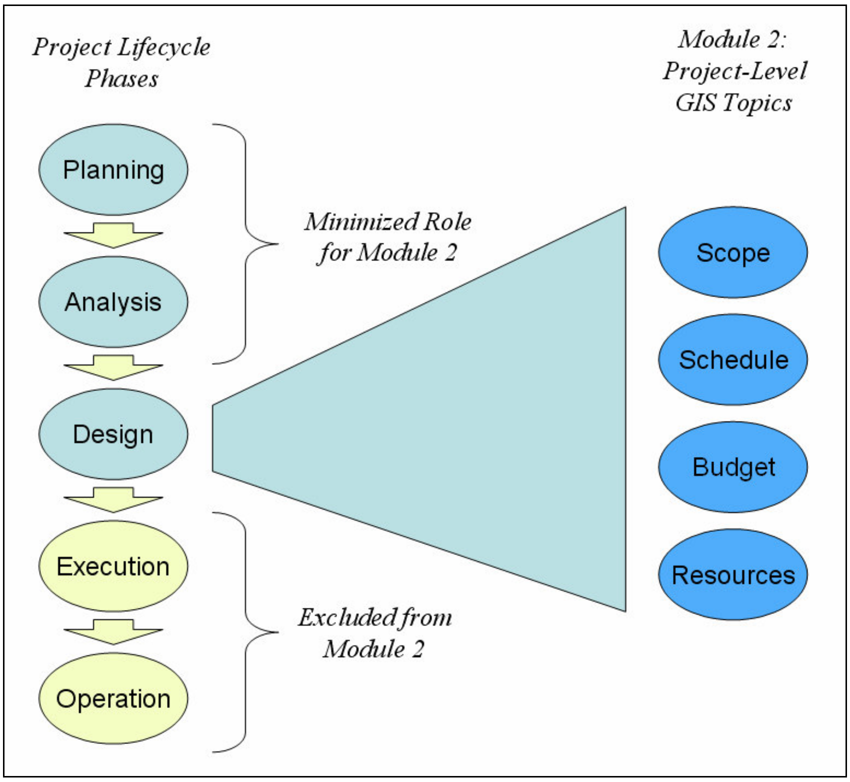

Figure 5 Module 2 (Project GIS) Focus

Module 2, then, will include the first three steps of the SDLC: Project Planning, Project Analysis and Project Design, but will necessarily focus on the Design phase. We're working on the assumption here that the problem is well-understood, so what really needs to happen before the Execution may begin is to document what will be done, how long it will take, how much it will cost and who will do the work. The four main topics for Module 2 will be:

- Scope (define the work to be done);
- Schedule (how long it will take);
- Budget (how much it will cost); and
- Resources (who will do the work, and what equipment is necessary).

As well, in project-level GIS initiatives there may not really be an Operation phase per se. At the close of a GIS project, typically the result is a final report or summary of analysis which would be delivered to the party requesting the project. The project may simply terminate there, with no further interaction with the delivered product. For this reason, the Project GIS module will exclude discussion of the Operation phase of the SDLC.

1.3.3 Project Management

Module 3 of this course will deal with the process of managing a GIS project. Obviously, a Project Manager is involved in all aspects of the project, from initial planning stages until project completion. However, Project Managers are participants in the planning stages, but do not typically have responsibilities beyond the usual planning and analysis tasks. Conversely, during execution Project Managers will perform a number of tasks not specifically related to writing the software, creating the data or training the users. These tasks are necessary to ensure that the execution is performed correctly and within a reasonable time period.

During the Execution phase of a project, Project Managers must be involved with such things as:

- Allocating staff or equipment to tasks;
- Serving as a point of contact for Communication between development staff and the recipient of the system or analysis; and
- Monitoring the project, so that if there are delays or cost overruns corrective action may be taken in a timely manner.

So while Project Managers have involvement in the entire SDLC, Module 3 will focus on these new functions that are necessary during the execution stage of a project. This module will continue to work with the components of scope, schedule, budget and resources found in module 2, and explore how these project elements are related and how they may be monitored and controlled over the course of a project. While the methods apply to all scales of projects (small and large-scale GIS implementations), the terminology more readily relates to Module 2. For this reason, Project Management is discussed immediately following the Project GIS module.

Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**6 shows the relationship between the Project Management topics and the generalised SDLC.

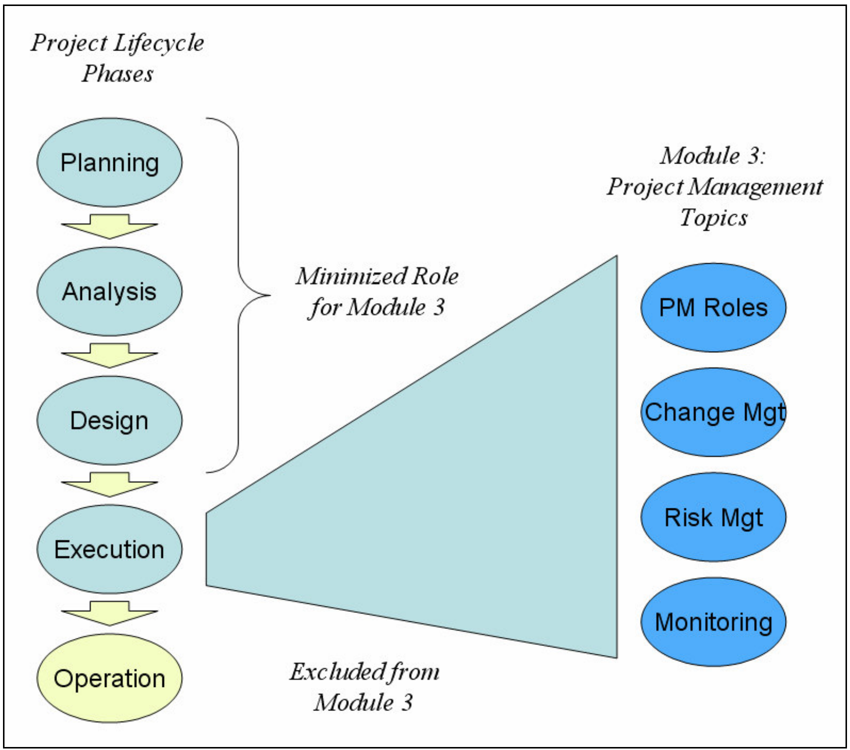

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**6 Module 3 (Project Management) Focus**

The Project Management module will focus on the following four topic areas:

- Project Manager Roles: discussion of what types of tasks Project Managers are required to do, and the relationships among scope, budget, schedule, resources and quality.
- Change Management: why changes to scope occur, and what can be done to manage change.
- Risk Management: quantifying risk, types of risk, risk mitigations, and techniques to manage risk effectively.
- Monitoring Project Progress: tracking and documenting project status. Introduces the concept of project earned value and the relationship between time and budget expended and earned value.

1.3.4 Enterprise GIS

Module 3 of this course will explore large-scale uses of GIS. The primary focus will be on the establishment of GIS throughout an organisation (Enterprise GIS), but the terms, methods and processes are equally applicable to very large analytical or data creation GIS projects.

The role of a GIS in a local government may be far more than simply a tool for analysis or an automation of commonly performed functions. It may be an opportunity to make significant changes to the way the government performs its work. Adopting GIS throughout the organisation may afford an opportunity to reorganise the data that are used and the procedures used to maintain and utilise them.

When GIS is adopted across the various departments of an agency, and data are shared and managed in an organised manner, the result is called an **Enterprise GIS**, or **Corporate GIS**. With a corporate database, users have fast access to up-to-date information and the construction and maintenance of the database is done in the most efficient manner possible.
Figure **7** shows the relationship between the Enterprise GIS topics and the generalised SDLC.

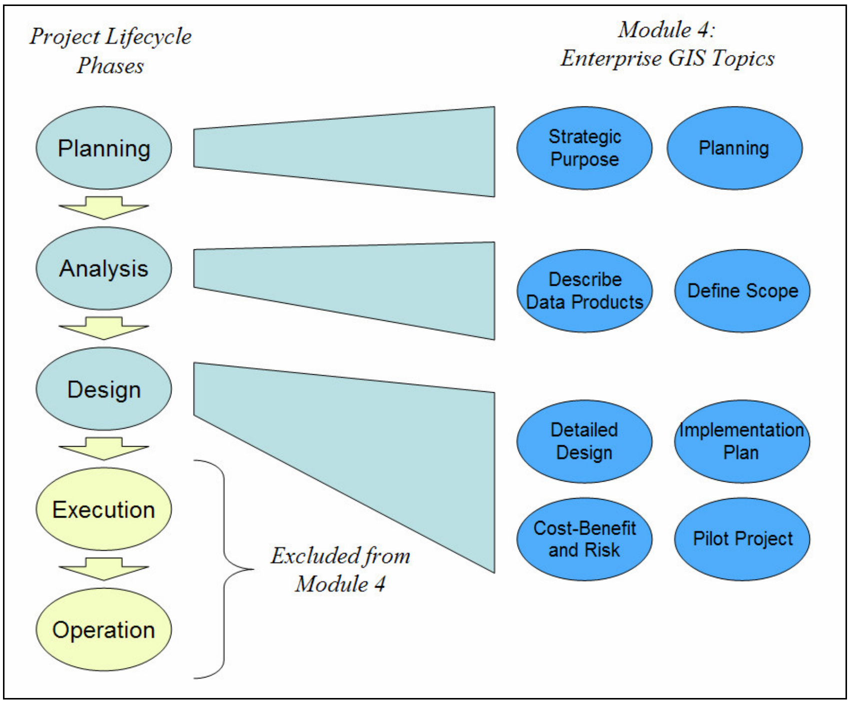

Figure 7 Module 4 (Enterprise GIS) Focus

The complexity of large-scale GIS implementations requires that significant planning be undertaken to ensure the success of the venture. Typically an overall understanding of all datasets, movements of data, processing steps and output products is not as well-understood as with a simpler GIS project. The discovery portion of the SDLC must be extensive, and specific methods or documents will be useful during these stages. In addition, we must examine aspects of the project, such as hardware and software acquisition, training and security, which generally are not considerations in smaller scale GIS projects.

Required Readings:

Introduction to the idea of an Enterprise GIS, and the methods employed to ensure a successful implementation.

- Thomlinson, 2003. *Thinking About GIS*, Chapters 1 and 2 (pp 3-17).

Additional Resources:

- New York State Records Management Services. *Geographic Information System Development Guides: Manager's Overview*. New York State Records Management Services, June, 1996. Viewed January, 2007. http://www.archives.nysed.gov/a/nysaservices/ns_mgr_active_gisguides_overview.shtml

1.4 Proposals

1.4.1 Introduction

There are many circumstances in which you may wish to embark on a body of work, but need agreement to proceed either from a superior within your organisation, or from another agency. In such cases, a document is prepared which defines what work you plan to do, how long it will take and what resources you need (in terms of staff, equipment or funding. With such a document, the decision-maker can make an informed decision. Proposal documents are written in many different situations, including the following:

- You wish to undertake a project at work, but need approval from a superior within your organisation so that you can gain the release time or the equipment you need to do the job.
- You wish to work on a project as a consultant, and the agency requesting your services needs to decide whether the methods you will employ are acceptable, and that the work you will do justifies the fees you will charge.
- Your organisation wishes to undertake an industrial development, and you need approval from a government regulatory body, who needs to decide whether you have met all necessary obligations.
- You wish to embark on a research project and must compete for research grant money with other researchers.

In these and other situations, the proposal document defines the work in a clear manner such that decisions may be effectively made.

Proposals generally answer a variety of questions about a project which is about to begin. The proposal should answer many of the following (Bawa, 2004):

Who

- Who will do the work?
- Who will manage the work?
- Who does the customer call if there is a problem?
- Who is responsible for what tasks?

What

- What needs to be done or delivered?
- What will be required to do it?
- What can the customer expect?

Where

- Where will the work be done?
- Where will it be delivered?

When

- When will you start?
- When will key milestones be scheduled?
- When will the project be complete?
- When is payment due?

Why

- Why have you chosen the approaches and alternatives you have selected?
- Why should the customer select the proponent?

How

- How qualified is the proponent to do the work?
- How will the work be done?
- How will it be deployed or delivered?
- How will it be managed?
- How will you achieve quality assurance and customer satisfaction?
- How will risks be mitigated?
- How will the work benefit the customer?
- How much will it cost?

There are several types of proposals:

A **Solicited Proposal** is one in which a proponent writes a proposal when asked to do so by another party. The most common example of a solicited proposal is when an agency needs the assistance of a contractor or consultant, and issues a **Request for Proposals** (RFP) defining what they need done. Proponents write a solicited proposal addressing how they would do the work and how much it would cost, among other things. The agency issuing the RFP then evaluates which proposal best meets their needs, and awards the work to that firm or individual.

Solicited proposals are not always part of a competitive process. In some cases an agency will approach a single consultant or contractor to have them write a proposal. The agency may then make a decision based on project cost, methodology or timeline as to whether to proceed.

An **Unsolicited Proposal** is one that an agency receives without having issued an RFP. There are some circumstances where a consultant or contractor feels they have a service that would be needed by the agency. The consultant prepares the unsolicited proposal defining why the agency should consider doing the work. Unsolicited proposals must be especially convincing since the customer has not anticipated, planned, or budgeted for the proposal. With an unsolicited proposal a consultant runs the risk that the customer will not bother to read it, since they didn't ask for it, but in some circumstances the lack of competitive pressure may compensate for the risk.

The use of proposals is a good way of ensuring that a contractor is ready to undertake a particular body of work. It forces a proponent to define clearly what they will do, and it serves as a strong basis for project management activities. With a clearly defined scope, budget and timeline, project managers can gauge progress and adjust the project if necessary.

Proposals are a significant portion of any SDLC and can be a part of several phases in the process, depending upon circumstances. As an example, consider an organization wishing to implement an Enterprise-wide GIS. Proposals may form part of the project in several ways.

At the completion of the initial Planning phase in the SDLC, the feasibility of the project has been confirmed, and the objectives defined. At this stage, however, we need to obtain a commitment from senior management to proceed with the Analysis and Design phases. To obtain this commitment, a proposal is often prepared as an internal document to inform decision-makers of what work lies ahead and what funding will be necessary.

If the organization does not have the internal capacity to do all of the work themselves, they will likely hire consultants to assist them. In such a case, they may issue an RFP prior to the Analysis phase. At that point the initial strategic planning is complete, and they have commitment from senior management. They may then request proposals to be prepared by qualified consultants to perform the Analysis and Design stages. After the Design phase, with a detailed design document prepared, an RFP may be prepared seeking consultants to execute the system. Where some internal capacity exists, organizations may perform the Analysis and Design internally and then have consultants do the implementation or execution once the design is complete.

A typical proposal document will contain the following elements:

Abstract
Background/Objectives
Workplan
Project Management
Project Team and Facilities
Schedule
Budget
Deliverables
Client Support
Appendices

These elements are described in detail in the sections which follow.

1.4.2 Abstract

The Abstract contains a brief summary of all the key points of the proposal. This needs to be a short section, which could be read by someone who wants to gain a quick understanding of what is being proposed. It might address:

- What the proponent is planning to do for the client
- How this proposal is different or better than others
- Strengths that the proponent may have that others do not

- Bid Price or Funding Requested

1.4.3 Background/Objectives

The Background and Objectives section of the proposal should simply outline a brief background of the project and how it fits into the overall function of the client organisation. It should state the purpose of the project and what the proponent is trying to achieve. It may also contain a brief history or description of the proponent's firm.

1.4.4 Workplan

The workplan is the most important part of the proposal, and will often be the largest single section. It describes the tasks which must be performed and any outcomes which will result. Defining the scope in this manner does three things:

- Demonstrates the proponent understands the nature of the project
- Serves as documentation of what the proponent will do, and may form the basis of the contract and project management activities.
- Prevents disagreements during the project about what is to be done

1.4.5 Project Management

The project management section addresses any additional tasks which have to be done to make sure the real work gets done. It may include the following:

- Is a project initiation meeting necessary?
- How frequently will the proponent meet with or report to the client?
- Quality assurance requirements
- Technical specifications that will be followed
- What are the Risks/Assumptions?

1.4.6 Project Team and Facilities

This section will describe the capabilities of the proponent. It will address both the facilities and equipment available to the proponent, and also a description of the personnel the proponent intends to have performing the work.

The facilities component simply describes where the work will be performed (at the client site, or at the proponent's offices), and if the proponent has any specialized equipment that is necessary to complete the work.

Detailed resumes of team members are typically placed in an appendix, so that the proposal is not too cumbersome to read. Capsule (short, summary) resumes may be present within the body of the proposal. In addition, the personnel component must address several factors:

- Who will be assigned to the project, and in what capacity they will serve (e.g., project manager, technical lead, etc.).

- In some cases the amount of effort allocated to each team member is defined, and a person is identified who will serve as backup to each role should someone leave the project unexpectedly.
- There may also be a description of the structure of the team, including lines of communication

This information may be presented in a variety of formats. Table **1** shows an example of a table defining team member responsibilities for a simple GIS project involving interpretation of satellite imagery to quantify deforestation over a period of time. Numbers within the table indicate the level of effort (days) for each role.

Table 1 Team Responsibility Matrix

Role / Person	Project Management	Ecological Classification	Quality Control	Digitizing and Data Entry
John	5.5		1.0	
Susan		13.0		
Harry		1.0	4.0	
Technician				15.0

For projects with large teams and complex lines of communication, it may be necessary to define an **Organisation Chart** for the project. This will illustrate who is responsible for each area of the project, and how communication is expected to proceed. Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**8 shows an example of a simple organisation chart for a large environmental mapping project.

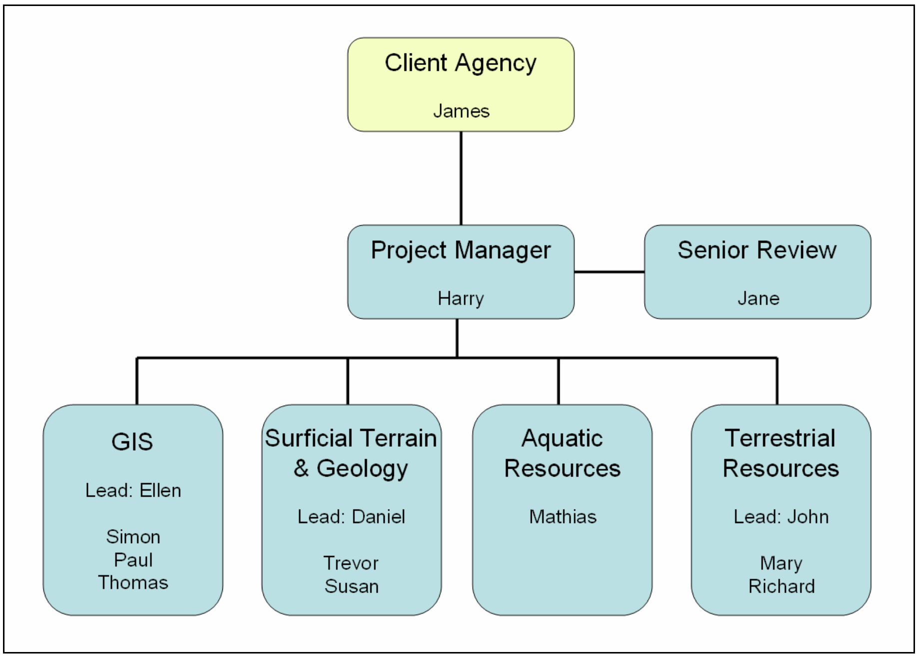

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**8 Example Organisation Chart**

It is worth noting in this organisation chart example, that the project manager from the proponent team is the single line of communication to the client representative. This ensures that the project manager is informed of project status and key decisions, and he or she can communicate information to the appropriate team members as necessary.

All of these structures demonstrate that the proponent has considered the team composition, team member responsibilities and operational structure and is prepared to undertake the work from a personnel and facilities perspective.

1.4.7 Schedule

This section of the proposal will provide a detailed description of the project timing. It should indicate:

- How long each task will take
- Which tasks can be done concurrently, or which depend on completion of other tasks
- When the project will be complete

It may address the notion of **Milestones**. Milestones are specific, measurable points in the progress of the project. They usually correspond to delivery of some part of the work, and are often tied to payments.

The simplest means of presenting a project schedule in which there are very few tasks is to list the milestones and the dates they should be achieved. An example of a simple milestone schedule is shown below in Table **Klaida! Dokumente nėra nurodyto stiliaus teksto.** 2.

Table Klaida! Dokumente nėra nurodyto stiliaus teksto. **2 Milestone Schedule Example**

Date	Milestone
February 17, 2005	Project Initiation Meeting
February 21, 2005	Interpretation, sample plot summary data and co-georeferenced images delivered for first interpretation.
February 24, 2005 (set 1) March 2, 2005 (set 2)	Interpretations, sample plot summary data and co-georeferenced images delivered.
March 7, 2005	Full revised interpretation and sample plot summary data for all study areas delivered.
March 11, 2005	Preliminary summary report delivered.
March 31, 2005	Revisions complete and final data product delivered to CFS.
March 31, 2005	Final summary report delivered.

There are a variety of notations and software applications which can assist in the presentation of project schedules. The most prominent of these is MS Project, which uses a notation called a bar chart, or a Gantt chart. The premise with a bar chart is that each task is represented as a horizontal bar, the length of which indicates the length of time required to complete the task. Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**9 shows an example of a Bar Chart generated with MS Project.

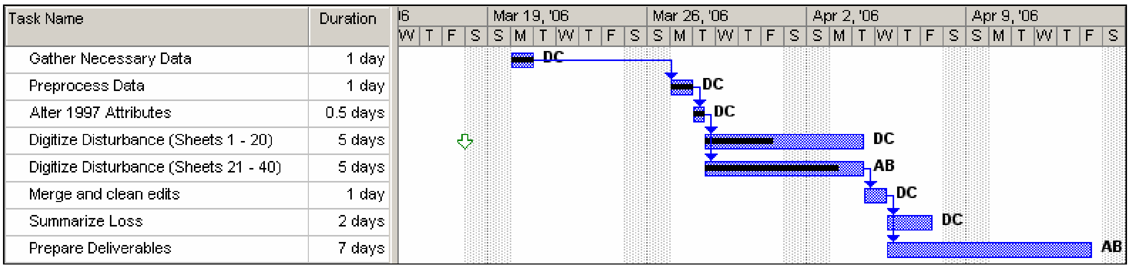

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**9 Example Bar Chart**

Bar charts can be used to indicate which tasks can be completed in parallel and which tasks have **Dependencies**. A task has a dependency if it requires some previously-occurring task to be completed before it can begin. For example, one cannot begin digitizing polygons from an airphoto until the airphoto has been satisfactorily georeferenced. Thus the digitizing task *depends* on the completion of the georeferencing task. This ability to illustrate graphically both dependencies and task duration makes bar charts a far more effective presentation tool than a simple Milestone Schedule, especially for complex tasks with many interdependencies.

Bar charts may also be used to indicate resourcing and project status. In some cases a task bar may have the name of the person assigned that task, and it may have a shading or hatching pattern to indicate the proportion of that task which is complete.

The bar chart in Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**9 clearly shows the length of each task, and the blue arrows connect those tasks where dependencies exist. The initials "DC" and "AB" indicate the staff member that is assigned a given task. The black bar inside the blue bar indicates the status of each task, or the percent complete. You can see, for example, that the first task ("Gather Necessary Data") is complete, and the fourth task ("Digitize Disturbance (Sheets 1 – 20)") is slightly less than halfway to completion.

1.4.8 Budget

The proposal budget will provide a detailed description of the costs of doing the work. It should include:

- Fees (for time spent on the project by staff) for each task in the workplan
- Expenses, such as equipment, travel, photocopying, courier or communications
- Relevant taxes, depending upon the jurisdiction where the work is done

It is important that the tasks in the budget match the tasks in the workplan. By being consistent between these two sections, a decision-maker can easily grasp what work is involved in each task (by reading that section of the workplan), and the costs associated with that task (by reading that section of the budget).

Table **3** shows an example of a budget which accomplishes these goals. Each task is presented as a column in the table, and each potential cost (team member or expense) is listed as a row in the table. The values within that table indicate where each cost is incurred for each task in the project. The reader can quickly tell that the major task in this project is

Task 4, where about 70% of the expenses are incurred. One could refer back to the workplan section of the proposal to read a detailed description of what must be done as part of Task 4.

Table 3 Example Budget

	Daily Rate	TASK 1 Project Management	TASK2 Database Update	TASK3 Identify Disturbed Polygons	TASK 4 Modify Polygons	TASK 5 Analysis & Summary Report	Total Days	Total $
Professional Fees								
Harry *Project Management/QC*	$565	1.5	1		2	2	6.5	$3,672.50
James *Disturbance Identification*	$500			2	9	2	13.0	$6,500.00
Susan *GIS Analyst*	$500				4	1	5.0	$2,500.00
Robert *GIS Technician*	$340				15		15.0	$5,100.00
Total Days		1.5	1.0	2.0	30.0	5.0	39.5	
Sub-total		$847.50	$565.00	$1,000.00	$12,730.00	$2,630.00		$17,772.50
Disbursements								
Travel		$100						$100.00
Communications		$50						$50.00
Subtotal		$150	$0	$0	$0	$0		$150.00
Total		**$997.50**	**$565.00**	**$1,000.00**	**$12,730.00**	**$2,630.00**		**$17,922.50**
GRAND TOTAL								**$17,922.50**

Budgets may be presented in a variety of forms, but as long as the cost of each task is clearly indicated, and how each cost is incurred, a decision-maker can effectively evaluate the proposal.

1.4.9 Deliverables

This section of the proposal will specify a detailed list of what the proponent will provide the client at the end of the project. This may include written reports, and any processed data or programs which were created as part of the project. Wherever possible, define the file format of written deliverables (e.g., “Final Report Document, in PDF format”), and any relevant information about spatial data being submitted (e.g., “Completed vegetation polygons, in Arc Export (E00) format, UTM Zone 34N coordinate system, WGS_84 Datum”). It is important to specify file formats, for example, to identify problems with software versions between proponent and client before the project begins, not after the work is complete.

1.4.10 Client Support

This section defines all of the things the client must either do or supply over the course of the project. It is important to specify these items to ensure that the client is aware of both the effort that is expected of them, and the date these things must be supplied or done by. In some cases client delays are the source of overall project delays, so support dates must be documented at the outset to avoid misunderstanding.

- Client support might include such things as:
- data necessary to perform the work

- background documentation or hard-copy maps which will assist in the work
- review of preliminary findings or draft documents over the course of the project
- decisions regarding methodology which are taken in response to preliminary analysis during the project

Again, where possible, identify details such as file formats and spatial data coordinate systems to ensure the client support can be used effectively by the proponent.

1.4.11 Appendices

All material that supports the proposal but that is too lengthy or detailed to place in the body of the document should appear in an appendix. Appendix materials may vary widely, but often will include topics such as:

- Detailed Resumes of team members
- List of relevant projects proponent has worked on
- Previous clients who have agreed to act as a reference
- Highly technical material such as data dictionaries, specifications or data quality requirements relevant to the project

1.4.12 Evaluating Proposals

Any organisation that issues a Request for Proposals as part of a competitive process must then evaluate the proposals submitted for consideration. To do this effectively, the client organisation must prepare a rigorous set of procedures by which the proposals will be consistently evaluated. In most cases, these procedures are published as part of the Request for Proposals, so that proponents understand how their submission will be measured against its competitors. Evaluation procedures can be exceedingly complex, but a generalized process is outlined below.

a) Elligibility

In many cases, there are conditions that a proponent must fulfil, or be disqualified. These might include that the proponent firm is incorporated and legally permitted to practice business in the applicable jurisdiction, or that the proponent has sufficient insurance in place to satisfy the terms of the work. Conditions such as these must be fulfilled to the satisfaction of the evaluators prior to proceeding with the formal evaluation. Proposals from proponents not meeting these conditions are disqualified and need not be evaluated further.

b) Criteria

Each project has quite distinct requirements. In cases where the work to be performed is straightforward and already well-documented, client agencies may look primarily at the proposed price in order to choose a consultant. In cases where the methods are unclear but an overall budget is already in place, the primary differentiation between proposals will be the clarity and completeness of the suggested methodology. For each project, then, the agency issuing the RFP will have to decide what is important to them. Evaluation criteria may include factors such as:

Approach or methodology

- Proponent has outlined a methodology for efficiently completing the work
- Methods are consistent with the overall goals of the client organisation
- Proponent has suggested an innovative approach which will provide a better deliverable or more efficient process

Experience

- Proponent team has demonstrated experience with project of similar scope, nature or time constraint
- Proponent team has demonstrated experience with software or techniques necessary to complete the work

Price

- Proponent has suggested a reasonable and competitive budget to complete the work

References

- References have indicated that the proponent has completed work satisfactorily for similar projects in the past

Schedule

- A realistic schedule has been proposed, which also conforms to the requirements of the client organisation for both milestones and completion

Project Management

- The designated project manager has demonstrated experience successfully managing projects of similar scope
- Proposed meeting schedules and communication strategy will meet the project needs
- Proponent has suggested quality control measures which satisfy the client that the deliverables will meet expectations
- Proposed mitigations to anticipated risks are satisfactory.

Past Associations

- Proponent has successfully performed work with the client organisation in the past.
-
- The factors which are included in the evaluation will depend on the nature of the work and constraints in budget and schedule which must be met.

c) Quantifying Criteria

Once the specific criteria that are important for a given project have been identified, a method of quantifying the degree to which each proponent meets these criteria must be developed. Each criterion may have its own method for quantifying conformance.

Many criteria can simply be subjectively assigned a numeric score based on evidence in the proposal. For example, one might quantify the degree to which a proponent demonstrates past experience with similar projects using a scale of zero to five, as follows:

0	*The proposal fails to address the issue or can not be judged against the criterion due to missing or incomplete information*
1	*Poor*
2	*Fair*
3	*Good*
4	*Very good*
5	*Excellent*

Some criteria, such as Price, can be quantified more objectively. A simple way would be to award the lowest-price bid 5 points, the second-lowest bid 4 points, and so on. Another method is to assign 5 points to the lowest bid, zero points to the highest bid, and a proportionate score between 0 and 5 depending upon closeness to the highest or lowest bid. For example, if the highest bid were $20,000 (receiving zero points) and the lowest bid were $10,000 (receiving 5 points), a proposal bidding $18,000 would receive:

$$\frac{(\$20{,}000 - \$18{,}000)}{(\$20{,}000 - \$10{,}000)} \times 5 = 1 \text{ point}$$

d) Thresholds

Some RFPs suggest that a proponent must achieve a specified score for each criterion, rather than simply a winning overall point total. This ensures that a proponent can address all concerns, rather than having a proposal that is exceptional in a few categories and poor in others.

e) Weighting

With a defined set of criteria and a means of quantifying each, the evaluators must then develop a ranking system to reflect the most important criteria. Often this is expressed as a percentage of the overall proposal score, like this:

Project Approach (40%)
Qualifications and experience (20%)
Overall cost (20%)
References (10%)
Schedule (10%)

When the criteria weighting is defined like this, proponents know where to invest the effort in writing a successful proposal. In the example above, a proponent would make sure that the methodology and workplan were thoroughly documented before investing significant time working out a competitive budget.

1.4.13 Conclusion

Proposals are a common mechanism to define a project and to make decisions regarding a project. As a tool, they may be used at several points in the SDLC, as well as for other purposes. As part of this course, proposals will form a significant portion of Module 2, Project GIS. We will learn to define a project and document it in proposal format.

Additional Resources:

Good illustration of how complex evaluating proposals can be, and how rigorous the standards must be to be universally applied.

1. European Commission. *Guidelines on Proposal Evaluation and Selection Procedures*. European Commission, 2003. Viewed January, 2007. http://www.6pr.pl/images/prezentacje/ip1/ges_200301_en.doc

Example Proposals

2. Coolbaugh, Mark, et al. *Revival of Grass-Roots Geothermal Exploration in the Great Basin – A New Approach to Assessing Geothermal Potential Using a Geographic Information System*. Proposal PDF, 2005. Viewed January 2007. http://www.unr.edu/geothermal/pdffiles/CoolbaughProposal05.pdf

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2 Module 2: Project GIS

This module serves as an introduction to methods used in planning for small GIS projects. It begins with a review of methods for defining the nature of the work, or the project scope. In this topic, there are some methods which are specifically applicable to GIS projects and an example project scope is developed using these methods. The second and third topics examine the process of creating a schedule and budget for a project, respectively. The methods discussed are universal and not specific to GIS projects, however all examples examine purely GIS projects. The final topic discusses the assignment of resources (people, equipment) to the project.

Regardless whether you are involved in planning a project, or the one receiving the results of a project plan (in the form of a proposal, for example), it is important to understand how the planning process works.

Module Outline

1: Scope

2: Schedule

3: Budget

4: Resources

2.1 Scope

2.1.1 Introduction

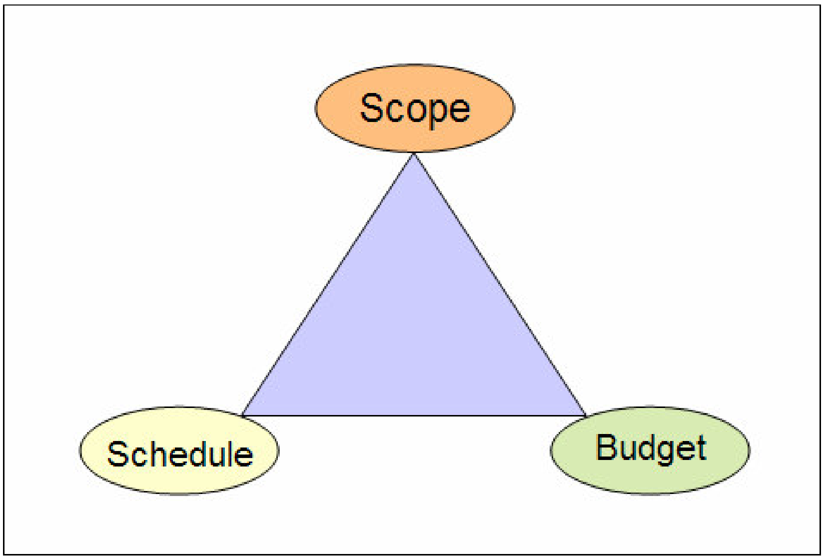

Figure 10 Basic Project Elements

Projects are composed primarily of the **scope**, meaning what tasks have to be done, the **schedule**, meaning how long the tasks will take, and the **budget**, meaning how much will it cost. If you make a change to any one of these, the other two must necessarily be changed too. For example, if you add one more task to what needs to be done, the whole project will need to take longer and/or cost more.

There are many other variables to a given project, like how many people are working on it, but the main components are these. We'll talk about the detailed components when we address managing projects.

Scope can be considered the **common understanding** as to what work is included in, or excluded from a given project. We are not talking about deciding how long it will take, or how much it will cost at this point. That comes after the scope is defined. Having defined the scope, you can calculate cost and time. If you get the scope wrong, the time and cost will be wrong. Thus the scope definition is the most important part of the planning process. Scope may also be called a **Workplan**, or a **Task List**.

This term *common understanding* cannot be overstressed. If the scope is poorly expressed, and subject to interpretation, the party doing the work and the party having the work done may have different understandings of what will transpire. One of the parties will be disappointed at the end of the project. If all parties understand what's going to happen, it's far easier to do the work and adapt to changes in the job as it progresses.

For example, let's say you were having a large GIS dataset interpreted from orthophotography by a consultant (e.g., vegetation or landuse polygons). The contractor thought you were going to make the final cartographic plots yourself, but you thought the consultant was going to supply a full set of plots. If the contractor's estimated price didn't include the map creation, one of two things has to happen here: either you pay extra to have the plots made, or you convince the contractor to do it for free, and functionally he's paying for your maps. Obviously something as major as an entire set of plots would be clearly articulated in a workplan, but you can see how different understandings of a project can affect how money changes hands and how happy each party is at the end.

For discussion purposes, we will call the party having the work done the Client, and the party doing the work the Consultant, or the Contractor. We will try to examine the planning process from both viewpoints. In some cases, you may be required to develop a project scope for internal documentation. In other situations, you may be evaluating a scope that was developed by competing consultants in order to determine which one is most qualified to do the work. In either case, it's important to understand project planning and management.

2.1.2 Why is scope important?

- To be able to derive an accurate estimate of schedule and budget.
- To recognize and deal with things that are beyond the original scope.
- So all parties are in agreement about what is in and out of the original scope.

The scope of a project is almost sure to change over the lifetime of the project. We always hope that it won't, but the reality is that we cannot predict at the outset how a project will develop. We call changes to a project while it is underway **Scope Change**. Scope is bound to change for two reasons:

- A task wasn't considered when the scope was defined. This is expected - as the detail becomes clearer, more complications creep in.
- The client, due to changing priorities, actually requires something different, or in addition to, the original scope

For both of these reasons, it's important to have a clearly documented scope before starting. By clearly documenting as much detail as possible at the outset, the consultant has leverage to renegotiate fees or schedule when a change is encountered. Conversely, the client has leverage to force a consultant to live up to what was originally agreed upon. If circumstances change part way through a project, both parties will clearly understand a new task is **Out of Scope**.

Consultants love that phrase: "Out of Scope". It means if the client wants it done, it will cost more money. In our map production example on the previous page, it means that the client will have to pay more than the previously agreed-upon price because nothing in the scope stated that maps were to be produced by the contractor.

The scope changes that usually cause problems are those where the *perception* of what was in and out of scope was different between various parties. This situation is not necessarily a change at all, but merely different understandings of the original scope.

For example, the Project Manager assumed there would only be four or five different map products as part of a GIS project, and the client assumed ten to twenty. Nobody felt it was worth talking about because they assumed the other person thought the same way they did.

The result, however, is that disagreements will develop over the course of the project. A clearly written scope will reduce these disagreements.

2.1.3 Task-Focused Decomposition

Defining scope is the process of documenting clearly what work needs to be done. The generally accepted process for doing this is to develop a hierarchical structure of tasks. At the top of the hierarchy, there are a small number of very general tasks or task groups presented in the general order they will occur. We'll call this top level Level 1. A project will typically be broken into 2 to 20 major tasks at this level. We need at least 2 tasks, or we're not decomposing the project at all, and 20 is the largest number of interrelated tasks which can be presented, sorted or scheduled.

Each task identifed at level 1 is then decomposed further into 2 to 20 subtasks. This is level 2. Each level 2 task is similarly broken down into the level 3 tasks, and so on. This process is continued until the detailed tasks at a level are so well understood that there is no need to continue the breakdown. Figure **11** shows an example of such a decomposition.

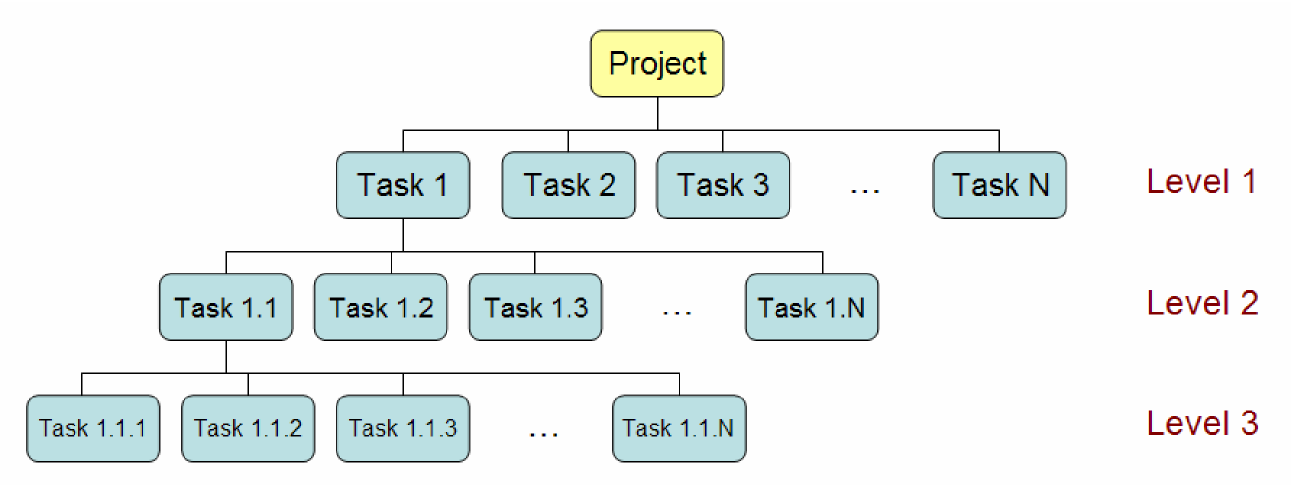

Figure 11 Hierarchical Project Planning

This structuring of tasks in a project may be called many things. The most common term for this technique is **Work Breakdown Structure** (WBS), but it may also be referred to as **Functional Decomposition** or **Hierarchical Planning**.

This style of breakdown focuses purely on a **top-down** breakdown of the tasks. It is called top-down because it starts with the general and builds in detail from there, and the result is a tree structure of tasks which begins with the "root" at the top. Data requirements and deliverables will be considered, but they will be a minor point of discussion within the more detailed task discussion. This technique would be applicable for almost any project, from building a house to writing a software application.

An alternative process for accomplishing the same task breakdown is to start with the detail and slowly aggregate tasks until the task hierarchy is constructed from the **bottom-up**. This is best accomplished in a group setting, with a small number of team members participating. The team structure will typically be in the order of 5 – 7 participants. More people than that will make for a cumbersome process, and with fewer people content may suffer for lack of viewpoints.

The concept of bottom-up planning is that team members identify tasks at any level of detail, and a facilitator will begin ordering and grouping tasks as team members discuss the project. The process might resemble the following:

- Team members identify all tasks required to complete the deliverables of the project.
- Remove any duplicate or similar tasks and agree on task descriptions for these
- Group tasks into logical categories and order tasks
- Add any new tasks that are identified as naming and grouping proceeds
- Document the results

The final result of both Top-Down and Bottom-Up work breakdowns should be identical. Which technique should be applied may depend on the project team (top-down is often easier for smaller teams or an individual performing the breakdown), the complexity (if, perhaps no single person understands the entire process) and simply the preference of a manager (many people find it easier to break down a problem one way or the other).

2.1.4 Data-Focused Decomposition

While the task-focused technique can be effective for a variety of project planning efforts, there are many projects, particularly GIS projects, which benefit from examining the data requirements of the project more closely. When determining scope for many IT and GIS projects, it may help to consider the following:

5. Tasks / Processing / Functionality
6. Data Required / Inputs
7. Deliverables / Outputs

As with all hierarchical planning, the work to be done must be central to the planning effort. During the Tasks/Processing/Functionality identification, we must consider all the things that must be done over the course of the project, and may use the identical top-down or bottom-up techniques described above. With data-focused decomposition, however, we will do the task decomposition in conjunction with a data definition and consider what data are required for each step.

For all GIS projects, we will need to carefully consider what data we may require to complete the tasks that were identified. As we identify each task, we will need to think about what data are required to complete the task. It will be necessary to consider, for each dataset, where these data will come from and in what form (file format, separate mapsheets vs contiguous area) they will arrive. Since many GIS datasets are not immediately useful in their existing form, we may need to consider whether there will be preprocessing (reprojection, translation, merging, etc.) required to prepare them for use.

As a result of the work, in a GIS project, there will usually be a definable deliverable or output. Most GIS projects will result in new GIS data, cartographic outputs or analytical results. As part of the scoping exercise, these final deliverables should be clearly articulated. Consider:

What are the final products going to be?

- Data? Maps? Tables? Documents?
- File Format? Coordinate System?
- Number of revisions (if any) to be allowed?

As with the data inputs, it is important to identify details such as file formats or coordinate systems to ensure compatibility between client and contractor prior to beginning the work.

2.1.5 Example Scope Definition Process

As an example of the scoping process, we will look closely at the Sensitive Ecosystems Inventory project we used as part of our Module 1 assignments. This example was selected because students will be familiar with the requirements of the project and can follow the task description without significant elaboration. In this example, we will use the data-focused method described above.

Sensitive Ecosystem Inventory
Project Objective: Update 1997 SEI polygons using 2002 Orthophotos. Digitize and attribute new disturbance to existing ecosystem polygons, and summarize the loss.

Step #1: Develop Initial Scope
The first thing we need to do is to develop an initial, generalized scope which will begin our top-down decomposition:

Alter 1997 attribute table to include loss fields

Digitize disturbance, update attributes

Summarize loss

Task 1 simply describes the fact that we need to add fields to the 1997 SEI polygon attribute table in which to note the nature of any disturbance found in the 2002 orthophotos. For example, we would add fields in which to note that a given polygon was deleted due to urban development within the polygon, thus destroying the ecosystem as it was defined in 1997.

Task 2 describes the process of examining each SEI polygon together with the new orthophotos to determine if new disturbance exists. If this is the case, disturbed parts of the polygon must be digitized and attributes entered to indicate the nature of the disturbance. This will encompass the vast majority of the project effort.

Task 3 describes the process of summarizing the results of the project. The client has requested a series of tabular summaries quantifying how much of the original ecosystems have been lost due to development in this region.

Step #2: Consider Input Data

Next, we'll flesh out this basic task list by documenting what we know about the data necessary for this job. In any GIS job, getting the data together and in a useable form is always a significant part of getting the "real" work done and should not be underestimated. We will add two steps to the beginning of our task list to accommodate the data gathering and preparation.

Throughout this example for the sake of clarity, any tasks which remain as above are not elaborated on will remain in their summary form. The complete scope, with all expanded tasks, may be found in Appendix A of this module.

After adding tasks for data gathering and preparation, our scope looks like this:

1. **Gather necessary data:**

Dataset	Source	Format/Coord Sys
1997 SEI Polygons	Client	ESRI Coverage BC Albers standard projection
2002 Orthophotos	Client	JPG format 4 per 1:20,000 mapsheet, 272 images in all Georeferenced to BC Albers standard projection

2. **Preprocess incoming data**

Dataset	Preprocessing
1997 SEI Polys	Coverage to SHP or Geodb (coverages can't be edited in ArcMap)
2002 Orthos	Import into SDE Raster Dataset or Write Script to manage 272 images

3. Alter 1997 attribute table to include loss fields
4. Digitize disturbance, update attributes
5. Summarize loss

The *Gather Necessary Data* task now includes not only a list of all the data we require to complete the work, but where the data currently reside and in what form. The *Preprocess Incoming Data* step ensures that the data we need are ready to use.

The SEI Polygons themselves, which will be provided in ESRI Coverage format, cannot be edited in ArcMap directly (this is a limitation of the software). To be able to modify the polygons, we will have to convert the coverage into either Shapefile or Geodatabase format. The noted coordinate system "BC Albers Standard Projection" is an Albers equal-area projection with two standard parallels appropriate for mapping the province of British Columbia. This projection is the standard for most digital data products in British Columbia, Canada.

The orthophotos will be supplied as a large number (272) of small image files. It is not practical to work with 272 image files in the ArcMap table of contents, since we would either suffer performance problems if they were all made visible, or we would have to add time for an operator to determine which image is relevant to his/her current editing and find and make visible the appropriate image(s). An alternative would be to either convert these JPG files into a seamless Spatial Database Engine (SDE) raster dataset, or write a small software application which will determine automatically which image is relevant and make only that JPG file visible. Either solution will require some time to prepare.

Step #3: Add Detail to Tasks
Our next step is to add detail to our generalized tasks. For example:

1. Gather necessary data
2. Preprocess incoming data
3. **Alter 1997 attribute table to include loss fields**

Add Modification_Type String(30)

Add Disturbance_Type String(20)

4. **Digitize disturbance, update attributes**

Scale of digitizing is 1:10,000

Identify all disturbances over 0.2 ha

5. **Summarize loss**

Quantify loss by Disturbance Type and Ecosystem, one for each region (5)

For Task 3, we have defined precisely what fields need to be added to the polygon attribute table, and their data type. *Modification_Type* stores the type of change to the polygon, such as Deleted (where a large, contiguous disturbance exists), Fragmented (where many small disturbances exist within the polygon) or Reduced (where part of the polygon has been removed, but the remaining portion remains intact). These possible values, or the **Domain** of the attribute, would also be defined in this section of the scope.

Disturbance_Type indicates the source of the disturbance, and would include such values as Urban Development, Cleared/Logged, Roads/Trails or Agriculture. Again, the range of possible values would be fully defined here.

For Task 4, we should define any part of the digitizing process which will impact the amount of time spent performing the task. Here, we define that the working scale is 1:10,000, and we will not be digitizing individual disturbances under 0.2 ha in size. These are important details, since if our working scale were larger, or if our minimum polygon size were less than 0.2 ha, it would necessarily take longer to complete the digitizing process because more small disturbances would need to be digitized. We may even choose to define a detailed discussion of how to go about digitizing disturbance (see Appendix A).

Note that in the Task 5 description, it explicitly lists the number of summaries to be created. Reports and map figures can take a long time, so make sure contractor and client agree before beginning.

Step #4: Consider Deliverables
To complete the scope, we will also need to consider the required outputs or deliverables of the project. We may add a new task: Prepare Deliverables, which will define precisely what will be the result:

1. Gather necessary data
2. Preprocess incoming data
3. Alter 1997 attribute table to include loss fields
4. Digitize disturbance, update attributes
5. Summarize loss
6. **Prepare Deliverables**
    6.1. **Data**: Completed SEI Polygons, in E00 (Arc Export format), in BC Albers
    6.2. **Documents** (one draft, one final)

Methodology and Results Document, in Word2003 & PDF format (includes loss tables)

Data Dictionary, in Word2003 & PDF format (defines fields, domains)

6.3. **Maps**: 68 1:20,000 maps, in PDF format (one final – no drafts)

Detailed spec of map layout?

More data necessary? Roads, Hydrology, hillshade?

The first deliverable is the polygon coverage, with the completed edits. Again, we provide as much detail as possible regarding file formats and coordinate systems. We define two reports: one outlining the methods and results, and the other providing a technical reference document regarding the finished data. It is often worth noting explicitly the number of revisions which will be permitted. Revising a final report using input from several people can sometimes be a time-consuming task, so it is important to clearly define the expected number of revisions to any documents. The same is true of cartographic outputs.

The final deliverable is a full set of 68 1:20,000 maps. This will likely be a significant level of effort to complete, so we should define anything about these plots which will influence the time it takes to make them. For example, if we need to be manually placing polygon labels, we will be faced with significantly more effort than if automatically-placed labels are sufficient.

When considering what the final maps will look like, it may become apparent that we will actually need more digital data in order to complete this task. Most maps will have reference data on them, such as hydrological features, coastline, roads and relief. If this is to be true of our SEI maps, we will need to revisit the *Gather Necessary Data* and *Preprocessing* steps to identify any data we will need. To a limited degree, the scope definition process may be iterative. At several points in the process we may need to go back to previously-defined tasks and add detail or other datasets to the scope.

The final scope for the SEI project can be found in Appendix A of this module. It includes the entire expanded scope, including all discussion of field domains and map layout requirements. This short scope definition would serve as a basis for either project management, or a detailed proposal.

2.1.6 How Much Detail?

People new to scope definition will inevitably ask: "How do I know when I have decomposed the tasks to a sufficient degree?" The determining factor is that there should be no outstanding detail that might affect how long the project will take, or change how much it will cost.

For example, a task might be articulated as "Scan and georeference airphotos". This might seem to be a clear statement, but if you were asked to complete this task, you might find yourself asking:

- Where do the airphotos come from? Do I have to buy the air photos? From whom? How much are they going to cost? How long will it take to get the airphotos?
- How am I going to scan the photos? Does my employer have a suitable scanner? Will I have to get them scanned commercially? How much will it cost to scan them?
- What am I going to use to georeference the images? Are there existing registration points? What accuracy do I need?

So in fact there are a number of details which might change how long this task might take, and how much it might cost. This task might more appropriately be expressed as:

- Obtain Airphotos BCC92041 through BCC92132 from vendor ABC ($12.00 each, 3 week delivery time, direct invoice to employer).
- Scan airphotos using employer-supplied HP ScanJet scanner to TIFF files and make a backup copy on CD.
- Georeference data to Control Points 144, 152, 183, 201-244, 246, 247, 259-263 located in digital file control.shp (Mapsheets 92G054, 064). Required RMS Error < 3.0m.

Some of these details might not be known at the time we write the proposal, but we must at least address them. So how do we *address* something we don't know?

2.1.7 Documenting What You Don't Know

It is likely that the client will not be absolutely clear on all the deliverables before beginning the work. In this situation you may be forced to make generic assumptions. Many things won't be known at the time you write your proposal / scope, and we cannot always wait until we know everything before beginning the work.

US Secretary of Defence Donald Rumsfeld famously remarked in 2002 that there are *Known Unknowns* and *Unknown Unknowns*. We can obviously do nothing about the latter, but we can try our best to define the former: things that we know we need to understand better, but we cannot wait until we have all the answers before beginning the project. We need to document these known unknowns, and they will become either **Assumptions** or **Risk**.

For example, you know a client will want maps, but you don't know at what scale or how many. In this situation we can make an assumption, or our best guess as to how many maps they might want. Let's say we think they'll want 10 1:50,000 maps at the end of the project. This assumption allows us to proceed with the project planning stages, and it allows us to make a time and budget estimate. If there is significant deviation from this assumption once the project is underway, it gives both parties room to renegotiate based on a common understanding of the initial assumptions.

On another project, for example, you are asked to write a Visual Basic program to do something, but you've never written a program like that before. This becomes a risk; you're being asked to do something you've never done before and so cannot make a reasonable estimate of how difficult this will be. We will discuss Risk in detail during Module 2: Project Management.

2.1.8 Other Scope Considerations

Task Breakdown

We will later produce time estimates and budgets for each task in the scope. As a result, it is worth using Task Groups, rather than many, many small tasks. This way, we don't have to have a separate budget and schedule for acquiring the SEI Polygon data, for example. It is common to use the top level or second level of decomposition for many budgeting or project management tasks.

In our example, then, each of the following tasks would have a time and budget estimate associated with it:

8. Gather necessary data
9. Preprocess incoming data
10. Alter 1997 attribute table to include loss fields
11. Digitize disturbance, update attributes
12. Summarize loss
13. Produce Deliverables

If we use this same breakdown of tasks for budget, schedule and scope, a reader can easily look between these sections of a proposal or report and determine what work is necessary for a given task, how much it will cost and how long it will take.

Task Wording

Tasks defined in a scope document should clearly state the nature of the task. Tasks should be:

Specific: a task description should unambiguously describe the work to be done.
Measurable: it should be clear when the task is complete. There are a number of GIS-related tasks which may be done with varying levels of detail. Unless that level of detail

is defined, the work may never appear to be complete to the satisfaction of all. A good example of this is the digitizing of disturbances in our example SEI project. Without the 0.2 ha minimum polygon size and 1:10,000 working scale defined it might be difficult to decide when the task is over. The farther you zoom in, the more small disturbances you will likely find, especially with high-resolution orthophotos. Obviously viewing the data at a large scale and digitizing very small (< 0.2 ha) polygons will take much longer.

Attainable: it needs to be realistic to expect that the task can be completed in the time allotted. Setting a goal that cannot be achieved ensures the failure of the project.

Additional Scope Tasks

There are a number of tasks which appear in projects, but which may not be immediately obvious. The following is a list of things that commonly add to the cost or time involved in a GIS project:

- Project management and Communications
- Hardware / Software upgrade or purchase
- Recruitment of permanent or contract staff
- Automation/Scripts necessary
- Internal Quality Assurance/Senior Review
- Data preparation for delivery (translation, burning CDs)
- Revisions / Drafts of deliverables
- Support after delivery
- System / Data documentation (metadata)
- Preparation of training material / Delivery of training

2.2 Schedule

2.2.1 Introduction

In this module we will continue to look at the planning process, and this time concentrate on project scheduling. A schedule is the conversion of a project workplan, or scope, into an operating timetable. It serves as a basis for project management activities which monitor progress, and may form part of a proposal or contract document. Schedules, with scope and budget, are one of the major tools for planning and managing projects.

The duration of a task or set of tasks is obviously closely tied to its cost. In many GIS projects, time will equal money, because most of the expenditure is in time invested by GIS staff rather than in tangible expenses. There are, however, some reasons to explicitly list schedule and budget separately:

- Direct expenses (e.g., data purchases or travel) will not translate directly to time / fees
- Several staff members with different billing rates or salaries may work on the same project at the same time
- There may be slack time in the project, so although time passes, cost is not being accrued (e.g., waiting for data or client review)

Schedule is time passing, whether you're working a full day or not. Budget is functionally the amount of time you or your staff are working, plus expenses. For example, to get something done on schedule, you work 16 hour days instead of 8 hour days. In this case, the schedule is fine, but you will be over-budget because you need to pay for the extra time expended on the project. Conversely, if you worked 4 hour days but took twice as long as expected, the project is on-budget, but behind schedule.

The project schedule should define the duration, resourcing and sequencing of tasks:

- How long will each task take?
- Who will do the task?
- What are the dependencies within the schedule: which tasks cannot be started until a predecessor is complete?

For example, to illustrate duration and sequencing, consider a simple project: *Getting to Work in the Morning*. The task "Eat Breakfast" may have a longer duration if you prepare and eat a full meal rather than some fruit and a coffee. It doesn't matter which order you complete the tasks "Eat Breakfast" and "Get Dressed". However, it is important to complete the "Get Dressed" task before starting the "Drive to work" task.

A good schedule should:

- Use same task breakdown as Scope, so that the two can be readily compared
- Be easily communicated – a graphic/tabular representation works well
- Be flexible – easy to update, because projects frequently change

- Show task interrelationships, so that the reader can discern any tasks which might delay the entire project

2.2.2 Example Project

For the examples in the coming sections, a small GIS project will be used to illustrate the concepts. This project would involve a small team, perhaps even a single analyst, and several common GIS tasks. It was chosen because the GIS tasks are not complex, and also because it is interesting from a scheduling standpoint; there are several tasks which may be done in parallel, and some which depend on the completion of other tasks.

A City government manages development within the city. In order to reduce environmental impacts, developers are required to adhere to a number of regulations regarding where and how they may build. One of the things the City would like to implement is a series of rules governing how close a development can be to a riparian area. Permitted proximity will change from one area to another, based on such factors as vegetation, slope, and geology. The City wants to produce a map which documents areas near streams where development will not be permitted. They currently have detailed geological mapping and a detailed digital elevation model (DEM). They do not at this time have detailed vegetation data.

To complete this mapping, they have identified a series of tasks:

14. <u>Acquire Airphotos</u> – detailed airphotos will be used to map vegetation cover in the city, so we will need to gather the necessary photos. The photos already exist, we merely have to compile them and get them ready to scan.
15. <u>Scan Airphotos</u> – airphotos are currently in hard-copy format, so we will need to scan them.
16. <u>Acquire Digital Basemapping</u> – we will need to gather the DEM, hydrology and geology layers prior to beginning our analysis, plus any addition layers which will help in georeferencing (e.g., roads). These exist within the organisation, but must be gathered and organised. Some preprocessing, such as creating a slope map from the DEM, may be necessary.
17. <u>Georeference Airphotos</u> – once we have the basemapping and the scanned airphotos, we may begin georeferencing the scanned photos. Planimetric features and the DEM will be used to georeference these images.
18. <u>Define Riparian "Rules"</u> – at this time, the precise rules for defining areas which cannot be developed have not been defined. Part of this project will be to meet with staff engineers, ecologists, etc., to define acceptable limits to things like slope.
19. <u>Digitize Riparian Polygons</u> – once the rules have been determined, the riparian areas may be digitized. Much of this process may be automated, such as extracting high-slope areas, or areas of geological concern.
20. <u>Calculate Summary Statistics</u> – with a final map of restricted areas, basic descriptive statistics may be calculated which articulate the proportion of land where development is no longer permitted.
21. <u>Create Final Plot(s)</u> – self explanatory.

22. Deliver Final Report – a short report which defines the final riparian rules, the methods used and the results.
23.

We will examine a number of tools or notations in the sections which follow which may assist with project scheduling, using this example project:

- Milestone Charts
- Bar Charts
- Network Diagrams
- Full-wall schedule

2.2.3 Milestone Charts

As you'll remember from the previous module, a **Milestone** is a point in time representing a key event in the life of a project. Milestones are often tied to a major deliverable or payment. A Milestone Chart is the simplest form of scheduling a project, and is simply a list of tasks, when they must be completed, and who will do the work. This method of scheduling is good for small projects, but does not document dependencies between tasks. During project execution, a milestone chart may include extra information, such as Percent Complete, as a means of tracking project progress. Table **4** shows an example of a Milestone Chart.

Table 4 Example Milestone Chart

Task	Due Date	Resources
(1) Acquire Airphotos	Jan 11, 2007	John
(2) Scan Airphotos	Jan 18, 2007	John
(3) Acquire Digital Basemapping	Jan 18, 2007	Sara
(4) Georeference Airphotos	Jan 25, 2007	John
(5) Define Riparian Rules	Jan 25, 2007	William
(6) Digitize Riparian Polygons	Feb 9, 2007	John
(7) Calculate Summary Statistics	Feb 16, 2007	William
(8) Create Final Plot(s)	Feb 16, 2007	John
(9) Deliver Final Report	Feb 19, 2007	Sara

2.2.4 Bar Charts

Bar charts, also called **Gantt charts**, are one of the oldest methods of representing project schedules. The Gantt chart was developed around 1917 by Henry Gantt. It shows tasks and task progress using a series of horizontal bars, the length of which indicates the duration of the task. Figure **12** shows an example of a bar chart.

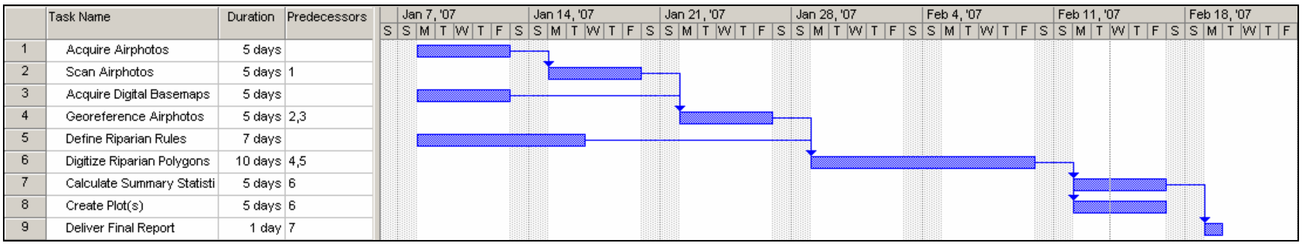

Figure 12 Example Bar Chart

The bar chart shows graphically how long each task takes and how tasks relate to each other. This is probably the most important advantage of a bar chart: that although they can contain considerable amounts of information, they are very easy to understand. In Figure **12**, for example, the arrow connecting task 1 with task 2 indicates that task 1 must complete before task 2 can begin. The longer bar for task 6 indicates that it will take longer to complete that task (10 days), than it will to complete task 7 (5 days). The parallel lines for tasks 1, 3, and 5 indicate that these 3 tasks may be under way at the same time. Bars may also indicate the progress of a task by shading a portion of the bar length in a different colour.

Microsoft Project is a commonly-used tool for graphically depicting and managing project schedules using bar charts. It can maintain information regarding project status (e.g., percent done), project resources (staff allocation to tasks) and budgets.

Float

When all tasks have been listed and sequenced, you may see that some tasks have some flexibility in their required start and finish date. This is called float, or slack. Float is indicated in Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**-13 by the dashed red lines. In that figure, for example, task 3 (acquire digital basemaps) is estimated to be 5 days in duration, but there are 10 work days in which to perform the task. This is because it is not until January 22, when the digital airphotos are ready to georeference, that we will actually need the digital basemap data. In this case, there are 5 work days of float for this task, so the task may start a few days late or take slightly longer than anticipated without having an impact on the overall project schedule.

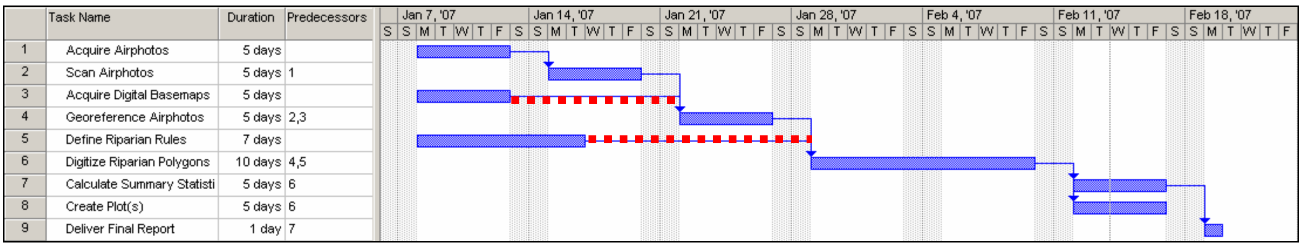

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**-13 Float Example**

Critical Path

Other tasks have no flexibility, or zero float. A line through all the tasks with zero float is called the **Critical Path**. All tasks on this path, and there can be multiple, parallel paths, must be completed on time if the project is to be completed on time. In Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**14 below, the critical path(s) are indicated with a red dashed line.

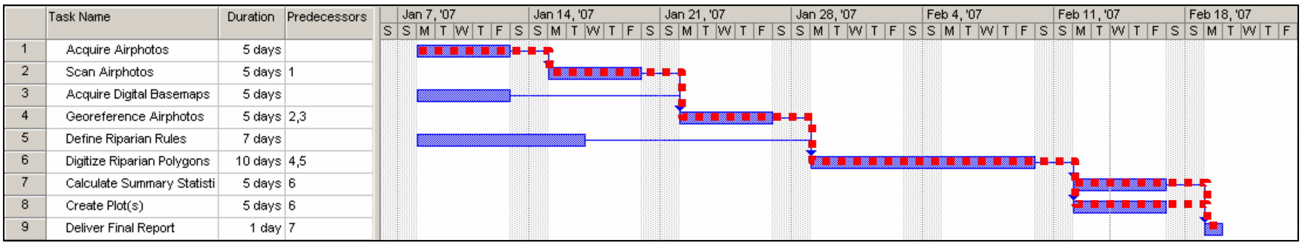

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**14 Critical Path Example**

2.2.5 Task Interface / Network Diagram

Second to Gantt charts, the next most common technique for scheduling relies on a network diagram. The Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM), both standard methodologies, use a similar network notation. The most common application of PERT is Research and Development projects, while CPM was designed specifically for construction projects. Very recently the terms PERT and CPM have been replaced by, or become synonymous with, the Arrow Diagram Method (ADM) and Precedence Diagram Method (PDM), respectively.

The focus of a network diagram is on the relationships between tasks, not the time taken for each task. At times, this notation will be used in conjunction with a milestone chart or bar chart which can depict progress. In its most simple state, a network diagram shows tasks in boxes, and dependencies between tasks as lines with arrows. Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**15 shows an example of a simple network diagram.

It may be easier to spot critical tasks on which everything hinges in a network diagram.

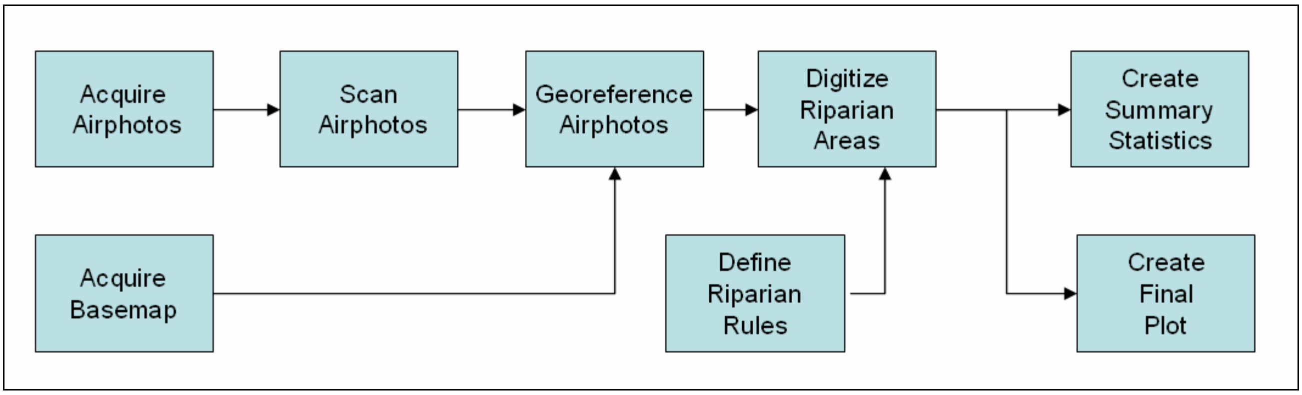

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**15 Example Network Diagram**

2.2.6 Full-Wall Scheduling

The final scheduling technique we will discuss is called Full-Wall Scheduling. This is really a network diagram built in a group setting. The notation is functionally the same, but the execution is slightly different.

With full-wall scheduling, we would set up a large blackboard, or even an empty wall. The horizontal axis is time and the vertical axis represents team members. We then would use many Post-It notes (or other means of temporarily attaching paper to the wall) to represent the tasks. We can then move tasks around, aligning them with who will do the work, and at what point in time the work will be done. The general process would look something like this:

24. Prepare preliminary schedule and circulate to team members prior to the scheduling meeting.
25. Gather the team members and together identify any additional tasks not in the preliminary schedule. We can also use this meeting to identify staff availability problems (e.g., other concurrent projects, holidays or other commitments)
26. Once we have a workable schedule, everyone commits to the result.
27. Usually after the schedule is complete, it is converted to a bar chart or other format for distribution.

The advantage of this consensus approach to scheduling are that it accomplishes three goals concurrently: it develops a workable project schedule, it confirms the project scope (as some new tasks may be identified in this workshop environment), and it ensures there are no staff availability problems for the project.

Estimating Time

While there are many methods for documenting a schedule, and we have discussed several, the problem at the heart of scheduling is always the estimation of how long things will take. To a large degree, this will always be based on experience. Staff members who have performed the same or similar tasks in the past can be confident in estimating time for a task. Staff members who have not been involved in similar projects will not have the confidence in their estimates.

For some simple projects, or estimates we are very confident in, we may simply assign an estimated time for each task. This is the situation we have presented in the previous examples: a single time estimate for each task. There are methods of estimating which take the uncertainty of an estimate into account, however.

One simple method of including uncertainty is to estimate the expected time for task completion using the expression:

$$TE = \frac{(a + 4m + b)}{6}$$

Where:

TE	is the expected time for task completion
a	is the most optimistic time,
b	most pessimistic time
m	most likely time; our best estimate

Here we take best and worst case estimates for our project (a and b above), and the most likely outcome, and perform a weighted average of the three, with most likely outcome being weighted the highest. If *m* is exactly halfway between *a* and *b*, then *TE* is simply *m*, but in many cases, the worst-case estimate is often significantly farther from *m* than our best-case estimate. Figure **16** shows the distribution of all possible completion times for a given task.

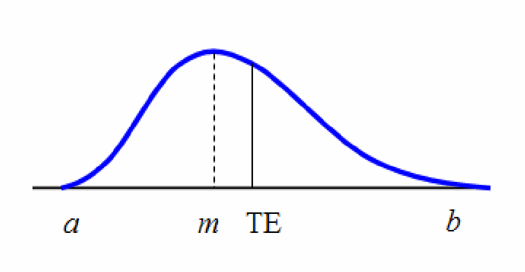

Figure 16 Distribution of Possible Completion Times

For example, if our best estimate for a task (*m*) was 10 days, we might find the best possible situation we could envision is that we complete in 7 days. The worst-case, however, might be something like 20 days. Here, the difference *b* – *m* is far greater than *m* – *a*, so the expected completion time (TE) will be larger than our best guess (*m*). This is the situation shown in Figure **16**.

We can use this mechanism to accommodate uncertainty in our estimation. Where we are very confident in our estimate, *a*, *m*, *b* and thus *TE* will all be very close together. Where we are unsure of our estimates, *a*, *m*, *b* and *TE* may be quite far apart, and usually *TE* is larger than *m.* We can then use *TE* as our estimated duration in our schedule, rather than *m*. This is a simple method for accommodating uncertainty in our estimates.

Several techniques exist which model the probability of completing a task in a given length of time, and offer ways of including this probability in the schedule. However, these techniques are far more complex than are necessary for a small GIS project and we will not address them here.

2.2.7 General Scheduling Process

Regardless which scheduling notation/method you choose to implement, the general process for creating a project schedule is more or less the same. To illustrate the steps, we will use bar charts, but they could also be implemented using network techniques. The general process is as follows:

- List the Tasks

The first step is to simply list the tasks that were defined during the previous planning stages. These should come directly from the Scope task list. Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.** 17 shows the initial task definition for our example riparian zone project.

	Task Name
1	Acquire Airphotos
2	Scan Airphotos
3	Acquire Digital Basemaps
4	Georeference Airphotos
5	Define Riparian Rules
6	Digitize Riparian Polygons
7	Calculate Summary Statisti
8	Create Plot(s)
9	Deliver Final Report

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto. **17 Task Definition**

- Estimate Time

For each listed task, the time necessary to complete the task must be estimated. This time estimate should include all necessary delays, such as internal review or revision. Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**-18 shows the MS Project interface after task time estimates have been entered. At this point, no dependencies have been defined, so all tasks may be done in parallel.

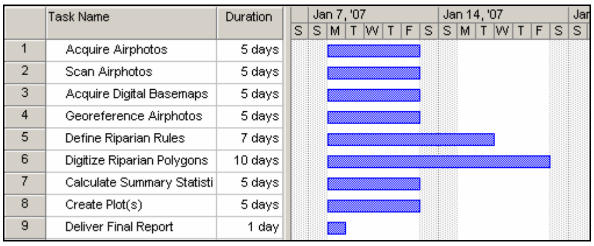

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**-18 Time Estimation**

- Establish Dependencies

For each task, define any dependencies where tasks cannot begin until a previous task is complete. Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**-19 shows the MS Project interface once all dependencies have been entered. It indicates clearly that task two cannot begin until task 1 is complete, and that both tasks 2 and 3 must be complete before beginning task 4. This makes perfect sense, in that you cannot scan an airphoto until you have acquired it, and you cannot georeference an airphoto until you have both a digital image and digital basemapping with which to tie it to real world coordinates.

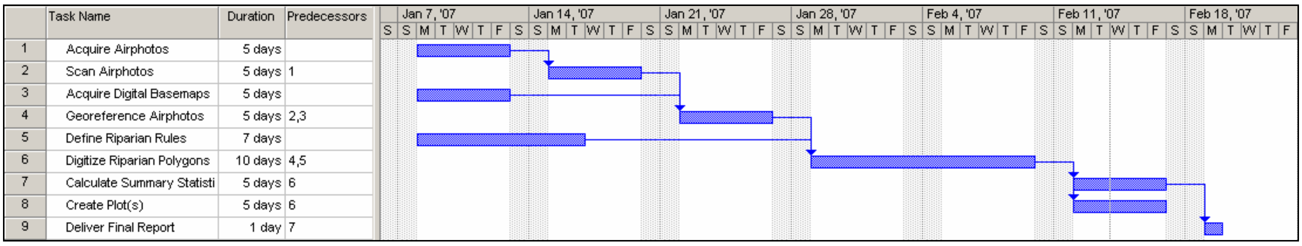

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**-19 Example Dependencies**

- Resourcing

The final stage of developing a schedule is to ensure that the people who are to do the work have the available time, and are not assigned concurrent tasks. This stage is commonly referred to as Resourcing, and will be discussed in Topic 4 of this module.

Reading/Assignments

TBA

2.3 Budget

2.3.1 Introduction

The budget is a documented plan for the allocation of financial resources. It is to some extent similar to the schedule, in that it is an estimate. However, it is not simply a multiplication of the length of the schedule by a static fee. At times several people may be working on a project, or there may be times nobody is working on it, and there will be other costs associated with the project such as equipment and travel, which do not directly relate to time.A budget will typically include fees (for time expended), expenses and any applicable taxes.

The standard way of representing a budget is to have the tasks along one axis of a table, and either individual team members (for small projects) or time aggregations (monthly, quarterly; for large projects) along the other axis.

Following are examples of two quite different formats for a budget document. Table **5** shows a format which can be effective for short, simple projects. The tasks are presented as columns, and team members and other costs are presented as rows. It could also be presented equally well with the tasks in the rows, however. The primary distinction here is that time (fees) are broken out by individual team members. For a small project this can be very helpful, but obviously for a very large project maintaining this level of detail is no longer feasible.

Table 5 Example Budget for a Simple Project

		Task 1 Acquire Airphotos	**Task 2** Scan Airphotos	**Task 3** Acquire Basemap	**Task 4** Georef Airphotos	**Task 5** Define Rules	**Task 6** Digitize Riparaian	**Task 7** Calculate Stats	**Task 8** Final Plots	**Task 9** Final Report	**Total**
Fees	Daily Rate										
William	$600					7		5			12.0
Sara	$550			5						1	6.0
John	$350	5	5		5		10		5		30.0
Subtotal		$1,750	$1,750	$2,750	$1,750	$4,200	$3,500	$3,000	$1,750	$550	$21,000
Expenses:											
Airphoto Purchase		$4,000									
Printing									$500		
TOTAL		$5,750	$1,750	$2,750	$1,750	$4,200	$3,500	$3,000	$2,250	$550	**$25,500**

Table **6** shows a simpler format, which is often used for presentation of very complex or long-term budgets. Here all fees, regardless of the team member that incurs them, are aggregated so that the total cost per task is indicated. For long-term projects, these costs may be decomposed by month, quarter or year as appropriate. Although this format does not provide the detail necessary to determine precisely how fees are calculated, it does provide an overview of the rate at which expenses will be incurred. Obviously, since our simple example spans a very short time period (two months), it does not make for a terribly interesting monthly breakdown, but it illustrates the concept.

Table 6 Example Budget for a Large Project

	Jan	Feb	Mar	Total
Tasks				
(1) Acquire Airphotos	$1,750			$1,750
(2) Scan Airphotos	$1,750			$1,750
(3) Acquire Digital Basemapping	$2,750			$2,750
(4) Georeference Airphotos	$1,750			$1,750
(5) Define Riparian Rules	$4,200			$4,200
(6) Digitize Riparian Polygons	$1,050	$2,450		$3,500
(7) Calculate Summary Statistics		$3,000		$3,000
(8) Create Final Plot(s)		$1,750		$1,750
(9) Deliver Final Report		$550		$550
Expenses				
Airphoto Purchase	$4,000			$4,000
Printing/Reproduction		$500		$500
Total	$17,250	$8,250		**$25,500**

The tasks for all budget formats come directly from the scope definition and the duration numbers come from the schedule. In both of the above examples, we can clearly see the need for a third element of budgeting: the **billing rate** for each resource.

A billing rate allows us to translate time expended on a project into a monetary equivalent. With a consulting firm, the billing rate will include the hourly wage paid to the employee, plus the overhead of maintaining the employee (benefits, office space, hardware and software, etc.), plus a certain level of profit. For projects performed internally within a large organisation or government branch, the billing rate will simply be the salary of the employee plus any overhead costs associated with maintaining the employee. Billing rate may be expressed in hourly, daily or monthly terms as appropriate.

2.3.2 Bottom-Up Budgeting

The term **Bottom-Up** typically means that one moves from the very detailed view to the very general or aggregated view. We discussed the bottom-up and top-down concept with respect to defining the project scope. The same concept can apply to the budgeting process. However, “bottom-up” can refer to both the estimating process (using the hierarchy of tasks), or the political or interpersonal process (using the hierarchy of an organisation’s staff).

In the bottom-up model, basic tasks, their schedules and their individual budgets are prepared separately. It is common to involve staff who will perform each task in this estimating process. Initially, estimates are made in terms of staff hours and direct expenses, and they are later converted into monetary equivalents. The resulting task budgets are then aggregated to create task group budgets and finally an overall project budget. Once this preliminary project budget is in place, a project manager will typically consider such factors as profit margins and contingency funds before determining a final project budget.

Typically the benefits of bottom up pricing relate to the fact that the people who will actually do the work have participated in the budgeting process. They will often have a better sense of the cost of a given activity than their superiors. Once the project is underway, it is also common that the people doing the work are far more accepting of the budgetary constraints if they had input into the estimation process.

The bottom up budgeting process is most effective when the scope is very well understood and we wish to apply a budget to these tasks. Figure **20** shows a simple schematic of the bottom-up budgeting process. It reads from the bottom up (as the name suggests).

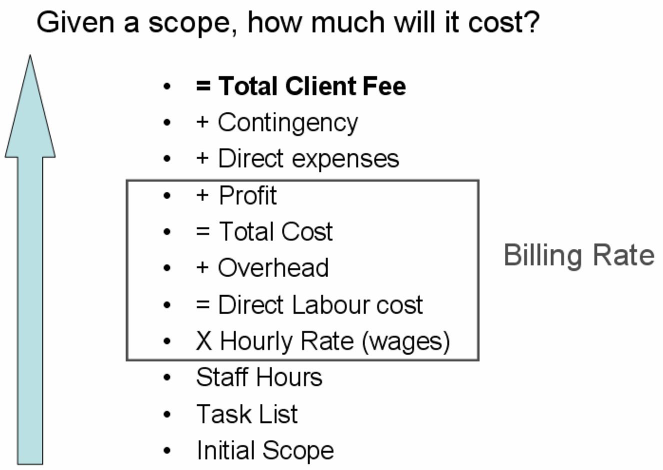

Figure 20 Bottom-Up Budgeting

Stating at the bottom of Figure **10**, we will address each element in order:

Initial scope	is the work that must be done, or what the objectives of the project are.
Task List	is the resulting set of steps and methods that will accomplish the objectives of the project.
Staff Hours	is the estimate of how many hours each person must expend in order to complete the tasks in the task list.
X Hourly Rate (wages)	is how much the organisation must pay the people expending the hours. Multiply the hours for each employee times the hourly wage you pay them.
= Direct Labour Costs	is the product of hours x hourly rate.
+ Overhead	is the cost associated with having employees. Your organisation may have to pay for computers, software, office space, heat,

	phones, secretarial staff, etc. These costs should be added into what is charged for the work done.
= Total Cost	is the sum of the labour costs and the overhead costs.
+ Profit	If all we're doing is covering the costs we incur with a project, really a company is merely taking money from a client, and paying it to employees as salary and paying rent and heating bills. There's really no point in doing the work, since we're not actually taking a profit from the income. We need to add a level of profit into every hour we expend.
Grey Box (billing rate)	All of these things within the box: the hourly rate + the overhead + the profit are together what we have described previously as the billing rate. The billing rate will be different for each staff member, since each staff member is presumably paid slightly different wages. For example, if Susan is paid $25 per hour, after we add in overhead and profit, we might charge the customer $75 for each hour she spends on the project. It is not uncommon for customers to be charged in the order of 3 or more times what the employee is actually paid.
+ Direct Expenses	are costs such as courier, materials, travel, etc., that will be incurred to complete the project. They should be added into the cost of the project.
+ Contingency	The idea here is that if a task takes longer than planned, the project will lose money, so we want to build a "buffer" into the cost of the project that will accommodate some of the tasks taking longer than we've planned. This will be different for each project, and often depends on how sure the consultant is of the time estimates, and so on. There is a trade-off here: if you have little or no room for contingency, you risk losing money. If you have too large a contingency, you risk alienating customers or failing to win competitive bids.
= Total Client Fee	After starting with a number of hours, then adding in all of these things: labour costs, overhead, profit, expenses and contingency, we arrive at the final overall estimated cost.

Many of these points of discussion focus on the situation where the work is being done by a consultant, but all of these elements should be considered even where projects are being undertaken internally within an organisation.

2.3.3 Top-Down Budgeting

Top-down budgeting is the inverse – we start with a price for the overall work, and break it down in successive steps to determine budgets for each individual task. For large projects, senior managers with significant project experience may assign a budget to the entire project, or large aggregations of tasks. These budget values are passed down in the organisation to junior managers and area specialists, who break down the larger numbers to determine budgets for each task.

A similar process may be undertaken if an organisation is approached with an allowable budget and a set of project tasks, and asked to determine how much of the work can be accomplished for the available budget. This is a similar task to what the junior managers and area specialists must do in the earlier circumstance.

Figure **21** shows a schematic of the top-down approach. The terms are the same as bottom-up budgeting, but this time we start at the top. For this reason, we will not discuss each element of the process in detail.

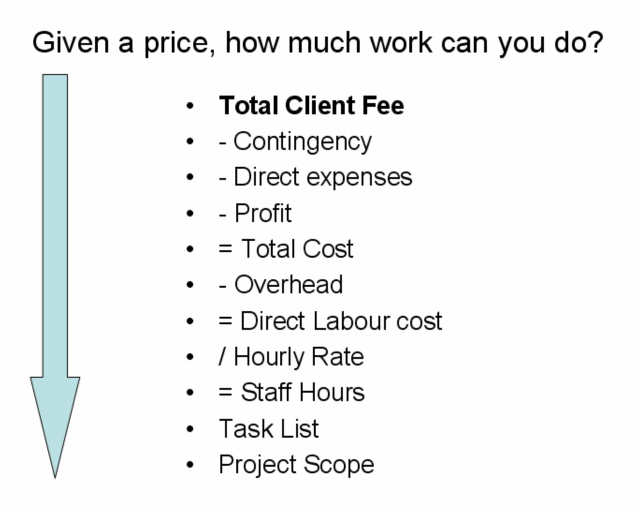

Figure 21 Top-Down Budgeting

Starting at the top, with a fixed budget figure, we deduct from the budget the contingency, profit and overhead. We then divide that by the hourly rate of employees working on the project, and come up with the number of hours we can expend.

The top-down description falls apart a little here, since we have to start at the bottom (scope) and develop the task list and a time estimate for the tasks. Now we can compare the hours required to accomplish the tasks with the number of hours we can fund with this budget. We can then work with the client or senior manager(s) to decide which of the tasks can be completed for the given budget, and which tasks are a priority for completion.

2.3.4 Unit-Price Budgeting

In some very specialised organisations, the work performed from one project to the next is so similar that the costs associated with performing the work are extremely well-understood. In such cases, these organisations may be able to quote a price purely based on the volume of work. This is seen frequently in construction, where tasks like installing flooring might be priced by the square metre. In the GIS realm some contractors specialise in creating and editing spatial data. Requests for proposals might ask them for a price per point, or a price per mapsheet to create new digital data or to modify existing data. This sort of estimating is often called **Unit-Price** estimating.

Unit-price budgets prepare a cost per unit, but the unit of decomposition can be any number of things. In GIS projects we might find the cost broken down by:

Cost per mapsheet, per feature or per hectare. This is a convenient way in which to decompose GIS projects involving data creation (digitizing, for example) or editing.

Proportion of overall project cost. This might be seen in very large projects where GIS would form a minor component. For example, in a large environmental impact assessment involving field biologists, water or air quality experts and other area specialists, it may be shown through experience that GIS typically ends up accounting for a certain proportion of an overall project. If this proportion is quite stable from project to project, estimators may simply budget for the major parts of the project and add in a cost for GIS without breaking down the work further.

In this kind of budgeting, one has to build overhead, profit and contingency into each unit of work to be done. This kind of estimating often fails because it doesn't take into account some of the other tasks involved in completing the job, like meetings with the client or an internal review of the completed work. Typically companies can only be successful budgeting this way if they have done similar work many, many times in the past and have a very clear understanding of what it costs to do such work.

Readings/Assignments

TBA

2.4 Resources

2.4.1 Introduction

The term resource, in its broadest project-related definition, can refer to money, equipment or people. When related to project planning, however, the most common definition relates specifically to people. This section will discuss issues relating to the assignment of people to complete project tasks.

Generally the resource assignment process is part of the scheduling stage of project planning, though we have separated it here for clarity. Resourcing is as much a scheduling issue as anything, since changes to the schedule will change the resource needs, but just as importantly the timing of the resource needs. Timing the use of resources can be very important to the profitability of a project.

In this topic, we will look at how resources may be optimised to reduce the duration of either a single task, or the entire project. We will also discuss ways of influencing project expenses by altering resources working on a project and the concept of resource gap analysis.

2.4.2 Reducing Task Duration

If a project manager wishes to complete a task more quickly, one would think that the simplest solution would be to have more people help with the work. While this is effective in some cases, it can actually be counter-productive in others. Brooks (1975) characterised the relationship between the number of people working on a task and the duration of that task in a variety of situations. Figure Klaida! **Dokumente nėra nurodyto stiliaus teksto.**22 shows the situation we hope to encounter. The application of more people to a task causes a significant reduction in the time necessary to complete the task. At a certain point, there becomes less gain for each person added, but in general adding at least a small number of additional people to this task can be seen to improve the overall task duration.

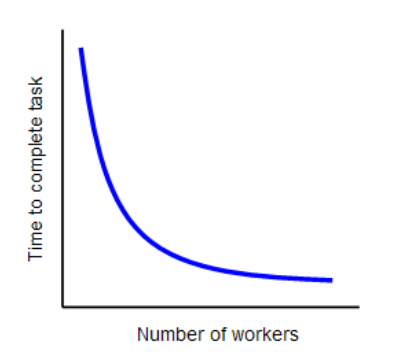

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**22 Perfectly Partionable Task**

This situation arises when we have a **perfectly partitionable task**, that is, one that can be divided easily between many people without adding additional work or communication between the people. Brooks notes the example of picking cotton as a perfectly partitionable task. Cartographic production, where each operator is responsible for creating separate maps, is one of the few examples of perfectly partitionable tasks found in GIS projects.

More likely is the situation where there is a gain by adding more people to a task, but there is also time expended in communication, coordination or additional work as a result of having divided the task among several people. Figure **23** shows a gain in project duration similar to above, but the limit to that gain is reached at a much higher duration.

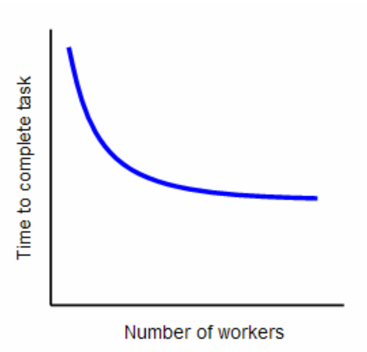

Figure 23 Partitionable with Communication

Situations such as this occur in GIS projects frequently because spatial tasks may fairly easily be divided into discrete spatial units. For example, large land areas are often broken into a series of mapsheets at a given scale, each covering the same amount of space. Tasks such as spatial data creation and maintenance may be fairly easily broken up into separate mapsheets. The overhead lies in having to merge several discrete datasets into a single seamless one, reconciling adjacent areas along mapsheet boundaries once the separate sheets have been completed.

Some complex tasks, however, require so much communication or additional work that it becomes difficult to realize a gain by adding people to the task. There can be a small gain by adding very few people to create a small, efficient team, but the addition of any more people actually makes the task take longer.

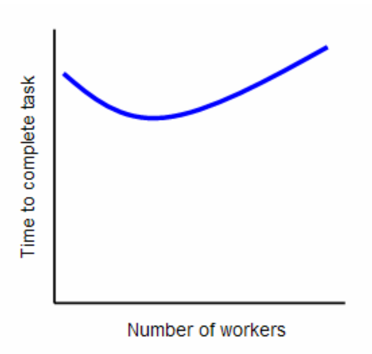

Figure 24 Task with Complex Interrelationships

In GIS projects we might see this situation with a spatial analysis or modeling task. One analyst or a very small group of analysts can implement a series of geoprocessing tasks, but the nature of the work makes it quite difficult to divide among many people. The writing of a final report document is likely another of these. A small number of people might be able to write a single, cohesive document but a large number of people certainly cannot.

There is a fourth type of task, of course, being the sort that simply cannot be partitioned at all. In this case, the graph is simply a horizontal line – adding more people does nothing at all to change the duration. In GIS there may be some very short tasks which fall into this category, but generally there is at least some gain to sharing a task.

All of the above discussion applies to the partitioning of a single task. However, the same concept applies to a project as a whole, in that there are many situations where adding resources to the project can efficiently reduce the overall project length.

2.4.3 Reducing Project Duration

While individual tasks may be divided among several people under some conditions, there are also circumstances under which a project may be divided among several resources without sharing tasks. Where parallel tasks exist, especially if different skills are necessary to perform the tasks, we can often shorten the overall project duration by integrating several resources.

In our Riparian project (introduced in Schedule), for example, there are several tasks which have little to do with each other. In the schedule for this project, we have assigned one person to acquire the airphotos, while another acquires the digital basemap data, and a third interviews staff engineers and ecologists to determine the rules which define areas in which no development may occur. These tasks are completely unrelated, so they may be done by separate people without any additional time or cost to the project. If a single staff member were responsible for these three tasks, the tasks can no longer be done in parallel. Figure **25** shows a bar chart for our Riparian project with a single staff member performing all the tasks.

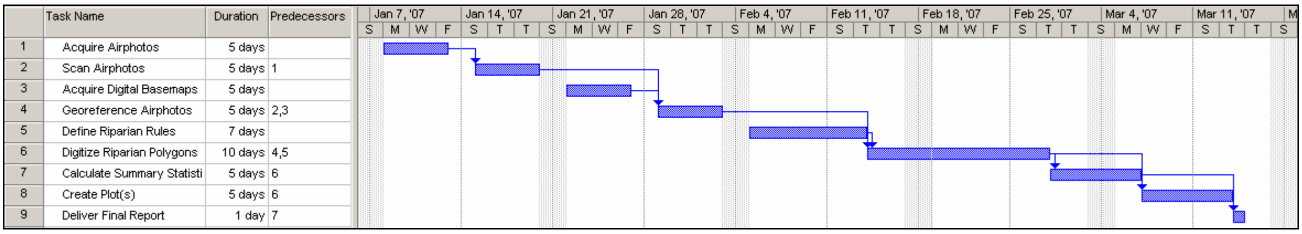

Figure 25 Riparian Project with One Resource

The dependencies are not as clear to read, because now some of the dependency lines cross, but it is clearly evident that our project becomes a very linear process now. For a single person to finish our project, it will take 17 working days, or the majority of a calendar month (from February 19 to March 14^{th}), longer to complete. This is a significant increase in the overall schedule. Projects with tasks scheduled in parallel can always be shortened by adding resources. These gains are made without the overhead of having workers share in any single task.

2.4.4 Billing Rates and Project Cost

Another reason bringing additional resources into a project is sometimes attractive is that some tasks may be done by a more junior person in the contractor's company. In our Riparian example, William has a chargeout rate of $600 / day, while John has a chargeout rate of $350. If John is capable of the same type of work, we could expend $250 per day less by having John do the work than by having William do it.

If William were to do the entire Riparian project himself, the overall project cost would rise from $25,500 to $33,300. In the budget defined in the previous topic of this module, resources have been applied in a considered manner. William, the most senior and costly team member, is utilised for tasks requiring more experience. John, our technician, performs the more straightforward tasks such as digitizing. As with many GIS projects, the bulk of the effort is expended on tasks which may not require significant experience. By matching skills with task requirements, we incur costs far more efficiently.

2.4.5 Resource Gaps

Resourcing a project efficiently means looking closely at what skills are necessary for the project and what skills are available in the staff assigned to the project. The first step is to define the resource requirements in isolation from the people involved. To do this, create a "roles and responsibilities" listing for the project. Start with the ideal way in which the project should be organised. Once the roles and responsibilities have been listed, we look at the people who have been nominated to fill those roles, and see how they fit. In the end it is possible to define a gap analysis which defines which skills or roles are necessary but not currently fulfilled by existing staff.

There are a number of strategies for dealing with this situation:

External Resources: Where necessary skills are missing in the project team, it is common to seek these skills externally. For very large or lengthy projects, it may be worthwhile hiring permanent employees with these skills, but another common approach is to hire contractors or consultants as subcontractors.

Training Resources: Another solution is to train your employees to fill the gap, especially if you have staff with similar skills. For example, if we have staff who are familiar with MapInfo's customisation language (MapBasic), it may be fairly simple to train them in ArcMap's development environment (ArcObjects).

Alternative Funding: If the resource constraint is the result of a funding decision, perhaps there are other sources of funding available.

Constrain the Activity: If a particular task requires skills you do not possess, perhaps the task may be modified. For example, if the project requires an Oracle RDBMS application, but you have SQL*Server expertise, perhaps the project can be modified so the completed application uses SQL*Server instead.

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- **Appendix A**

Complete SEI Project Scope

1. Gather Necessary Data

1.1. SEI Polygons
Supplied by client
ESRI Coverage format
BC Albers coordinate system

1.2. SEI Orthophotos
Supplied by client
4 per 1:20,000 mapsheet, 272 images in all
Georeferenced to BC Albers standard projection

1.3. 1:20,000 Basemap data
Supplied by client
Rivers, lakes, coastline, contour lines, transportation features
ESRI Coverage format
BC Albers coordinate system

2. Preprocess Data

2.1. Translate SEI Polygons from Coverage to SDE Feature Class
2.2. Import SEI Orthophotos into SDE Raster Dataset

3. Alter 1997 attributes to include loss fields

3.1. Add Modification_Type String(30): Type of change to the polygon.
Possible Values:

Deleted due to disturbance; Polygon contains contiguous disturbance over 0.2 ha and is no longer a viable ecosystem.
Deleted due to fragmentation; greater than 25% of the polygon has been fragmented by disturbances too small to be mapped individually. Polygons are not physically deleted from the database. This flag functionally toggles the polygon on/off based on the temporal scenario being mapped.
Reduced; some portion of this polygon has been deleted due to disturbance, thus reducing the size of the intact ecosystem.

3.2. Add Disturbance_Type String(20): the reason for the change to the polygon.
Possible Values:

Clearing / Logging
Industrial Activity
Agriculture
Trails / Recreation
Rural Use
Urban Use
Roads
Other

4. Digitize Disturbance, Update Attributes

4.1. Digitizing Requirements

Where visible at 1:10,000, disturbance within the polygon can be dealt with in three ways:

a) Flag the entire polygon as deleted due to disturbance:

Ecosystem polygons that cease to be viable due to disturbance are marked as 'deleted due to disturbance'. They are not physically deleted from the SEI, but given an attribute which states that the polygon is no longer a valid SEI ecosystem. The original ecosystem value is retained as an attribute to allow change statistics to be calculated. Ecosystems were marked as 'deleted' if:

- disturbance affects the entire polygon to the extent that all remaining intact portions (if any) are less than 0.2 ha.

A polygon is 'deleted' if the disturbance affects the whole polygon or if the disturbance affects the entire polygon to the extent that all remaining individual patches of the original ecosystem type are less than 0.2 hectares in area.

b) Digitize out the disturbance:

Where contiguous areas > 0.2 ha of disturbance can be delineated within a larger intact polygon, the polygon is split such that the disturbed area becomes a new polygon.

- The polygons are heads-up digitized (digitized on screen) in ArcMap using the digital orthophoto as a backdrop to define the revised spatial extents of the polygons to be updated.
- Heads-up digitizing is performed with a display scale of 1:10,000 or better.
  Resulting polygons must be at least 0.2 hectares in size. Areas of disturbance less than 0.2 hectares are ignored, unless many small disturbances constitute > 25% of the polygon. Remnant ecosystem polygons under 0.2 ha are not retained.

c) Flag the polygon as deleted due to fragmentation:

Where no individual disturbance is > 0.2 ha, but over 25% of the polygon is disturbed by small disturbances, we flag the polygon as "deleted due to fragmentation".

4.2. Attribution Requirements

The two fields Modification_Type and Disturbance_Type should be updated as defined in the following table:

Situation	ModificationType Value	DisturbanceType Value
A polygon remains intact	Empty	Empty
A polygon has been split to delineate disturbance > 0.2 ha	Disturbed portion: DD Intact portion: R	The disturbed portion receives a code corresponding to the correct type of disturbance The intact portion is empty.
The polygon, or polygon portion, has internal disturbance, none of which are > 0.2 ha, but > 25% of the polygon is impacted	DF	A code corresponding to the correct type of disturbance

5. Summarize Loss

5.1. Loss by Ecosystem and Region
One table with Ecosystems (e.g., Riparian, Old Growth, etc.) on one axis, and Region (administrative areas) on the other. Define loss in hectares and percent.

5.2. Loss by Disturbance Type and Ecosystem, one for each region (5)
Five separate tables. Each has Ecosystem on one axis and Disturbance Type (e.g., Roads/Trails, Agriculture, etc.) on the other. Define loss in hectares and percent.

6. Prepare Deliverables

6.1. Data: Completed SEI Polygons, as E00, in BC Albers

6.2. Documents (one draft, one final)
- 6.2.1. Methodology and Results Document, in Word2003/PDF format (includes loss tables)
- 6.2.2. Data Dictionary, in Word2003/PDF format (defines fields and domains)

6.3. Maps: 68 1:20,000 maps, in PDF format (one final – no drafts)
Plots are to have all supplied basemap data (Rivers, lakes, coastline, contour lines, transportation features) depicted as per provincial standard symbology, and SEI polygons. SEI polygons will be labelled depicting primary ecosystem and polygon identifier. Automatic label placement will be satisfactory.

3 Module 3: Project Management

In the previous module, we discussed methods of planning for a project. We have also noted that however well planned a project is, in all likelihood the progress of the project will proceed quite differently in reality. This is the essence of project management – to manage performance of the project team, changes to the project scope and project risks once the project is underway.

One might ask, "What is the definition of a *successful* project?" The obvious answer is that the entire project scope was completed on time, and on budget. The answer might be simpler, however. Very few projects actually happen as they were originally planned. Scope will change, which might make the project longer or more expensive. These things don't necessarily make the project a failure, however.

It might be suggested that anytime two things happen, the project has been successful:

- The client is happy (they got a service or product that they are happy with); and
- The contractor is happy (they made a profit).

This situation has to be considered successful; that both parties leave the project with what they sought. Project management, then, is largely about adaptation; making sure that change and progress are managed and communicated to all interested parties such that expectations are being met to the best possible degree.

This module will examine project management by presenting the following four topics:

1: Project Management Roles

2: Change Management

3: Risk Management

4: Monitoring Project Progress

3.1 Project Management Roles

3.1.1 Introduction

Project Management is the discipline of defining and achieving targets while optimizing the use of resources (time, money, people, materials, energy, space, etc) over the course of a project (a set of activities of finite duration). Resources are managed in such a way as to complete the necessary scope within a specified schedule and budget.

Projects making use of project management techniques often find a resulting improvement in customer relations, delivery times, product quality and worker morale. There can be negative effects relating to project management activities as well, relating mostly to the addition of unnecessary complexity and management overhead. It should be noted that the size and complexity of a project should dictate the degree of project management that is necessary. For small GIS projects involving a small number of team members, it is likely not necessary to devote significant effort to monitoring project progress.

Project Management tries to gain control over five variables throughout the course of a project:

1. Time: The amount of time required to complete the project. Typically broken down for analytical purposes into the time required to complete each task contributing to the completion of the project.
2. Cost: Calculated from the time variable. Cost will typically be determined by the consultant or firm's hourly rate multiplied by the time to complete, plus equipment and expenses.
3. Quality: A measure of how well a task is done. Some tasks may require a given amount of time to complete adequately, but given more time could be completed exceptionally. Over the course of a large project, quality can have a significant impact on time and cost (or vice versa).
4. Scope: The overall definition of what the project is supposed to accomplish, and a specific description of what the end result should be or accomplish. Can be expanded or contracted over the course of the project
5. Resources: People or equipment which facilitate task completion.

All of these variables are interrelated, to the extent that a change to one of these will necessarily change at least one of the others. For example, if we increase the resources (either the number of people or the equipment assigned to a task), the cost of the project will likely rise and the time necessary to complete the work will likely decline. If we reduce the quality of the final product we will most likely see a corresponding decline in the time necessary to complete the work, and the cost necessary to achieve completion.

There are typically five or more key types of “players” or people involved in a project. These are defined below:

The **Project Sponsor** is a manager with an interest in the outcome of the project, who is responsible for securing spending authority and resources for the project. The

Project Sponsor provides support for the Project Manager, approves major deliverables, and signs off on approvals to proceed to each succeeding project phase.

The **Client** (or **Customer**) is the business unit or external organisation that identified the need for the product or service the project will develop. Typically a single Client Representative will serve as the contact between the organisation doing the work and that receiving the work.

The **Project Manager** has the overall responsibility for the successful planning and execution of the project.

Project **Team Members** are responsible for executing tasks and producing deliverables as directed by the Project Manager.

A **Stakeholder** is one who is in any way affected by the new product or service.

We will concentrate on the role of the Project Manger for this topic.

3.1.2 The Project Manager

The **Project Manager** has the overall responsibility for the successful planning and execution of the project. A project manager is quite distinct from discipline, or departmental, managers. A discipline manager is usually a specialist, may be analytically oriented and understand the technical details of each operation which falls under their area of responsibility. A project manager is far more of a generalist, and must oversee many areas of a project. The project manager does not necessarily need to understand the technical details of the work being done, but must have the ability to form a coherent whole from the pieces of any task.

In large projects with many team members, the project manager position may be a full-time one. For smaller projects a team member may devote part of their time to project management, or a project manager may simply manage several concurrent projects. Project Management demands will increase proportionally with the size and complexity of the project.

A Project Manager (PM) frequently faces competing needs. They must simultaneously satisfy the needs of the employer, the client and the team members themselves. These needs are not always complimentary and are frequently at odds. The PM's responsibility to the employer includes the need to conserve resources, to provide careful and competent management of the project, to protect the firm from high or unnecessary risk and to provide timely and accurate communication. Responsibilities to the client include the preservation of client and project integrity, and ensuring that timelines and budgets are met. Team members require the PM to demonstrate fairness, consistency, respect and honesty in the management of the project.

Project Managers participate in several different types of activities, such as:

- Participating in proposal writing
- Planning the work
- Estimating resources

- Organizing the work
- Acquiring human and material resources
- Assigning tasks
- Directing activities
- Controlling project execution
- Reporting progress
- Monitoring budget and progress
- Monitoring product quality
- Analysing the results based on the facts achieved
- Scheduling and attendance at meetings
- Reviewing and approving billing

The most important role filled by a project manager, however, is that of a facilitator of communication. The PM must ensure that, especially in large projects, the various team members, subcontractors, stakeholders, customer representatives and senior management are effectively kept informed of each other's activities and needs. Above all, a project manager must not allow senior management or client representatives to be surprised. A good PM cannot be afraid to bring bad news.

Beyond these traditional tasks involving planning, organising, directing and controlling a project, a project manager also has a strong role in the marketing of the agency. This is primarily the case with consulting firms, but to a limited degree this concept applies to the public sector as well. Project managers should always keep the goal of attaining additional work in mind in all dealings with the customer. PM's should be looking to expand the scope of existing work, secure a positive referral and in general get this client back for future work. This entails a certain level of client management. Beyond the duties of the current project, a PM should be actively seeking to understand the customer's business, to "know the client". Customers want consultants to perceive themselves as a partner in an endeavour, not simply one who is financially gaining by completing the work. Toward this end, the PM should seek to foster trust, be prepared, communicate effectively and demonstrate credibility.

Project Managers get their training in several ways. The most common is to gain experience managing projects on-the-job. PM's may begin managing small, short projects to gradually gain experience and begin managing larger and more complex projects. Additional training may be provided by project management seminars and workshops, and by participation in the programs of organisations such as the Project Management Institute. The alternative route for project management training is to gain formal education via degree/certificate programs specifically in project management.

Experience as a PM serves to teach the importance of an organized plan for reaching an objective, negotiation with one's co-workers and sensitivity to the political realities of organizational life.

3.1.3 Project Manager Attributes

In the previous section, it was noted that a project manager is a generalist. However, there are several attributes or qualities which are important in a potential manager. Project managers require credibility, sensitivity, managerial skills and an ability to deal with conflict and stress.

The PM will need credibility with all parties engaged in the project. With the client, the PM must be seen to possess the technical knowledge and administrative experience necessary to direct the project. The PM must also have the confidence and trust of the project team to effectively manage the team members.

Sensitivity is necessary in project management as an ability to sense interpersonal conflict between project team members or between team members and client representatives. A good PM does not avoid conflict, but deals with it effectively before it escalates into a significant project issue. Dealing with conflict effectively requires significant sensitivity and diplomacy.

Another major attribute of a good project manager is leadership. Leadership may be defined as an ability to influence team members toward the attainment of a specified goal. Leadership is based largely on the credibility discussed in the previous section, but also includes attributes such as energy, tenacity, motivation and persuasion.

A PM must also have a strong sense of ethics. Some common ethical missteps include participating in “wired” bids and contracts (where the winner has been predetermined), bidding low with the intention of cutting corners or forcing subsequent contract changes, taking shortcuts to meet deadlines or budget goals, using marginal materials or techniques, violating standards, or showing a lack of objectivity (for example in allowing loyalty to a client to influence the results of a study).

A variety of other attributes may be helpful to a good project manager:

- Political awareness
- Entrepreneurial inclination
- Ability to listen
- Enthusiasm
- Optimism
- Courage
- Personal maturity
- Adaptability
- Handles multiple priorities well
- Technical proficiency
- Delegates well
- Ability to negotiate

3.2 Change Management

3.2.1 Introduction

In module 2 of this course we discussed the importance of a clearly defined scope, indicating that well-defined projects make it easier to recognize and respond to changes in project scope. A well thought-out work plan will minimize changes to scope, but cannot eliminate them entirely; changes to a project scope are inevitable.

A scope change may be considered any change to the deliverables or objectives from what was originally intended. In practice, a scope change is any deviation from the *documented* scope. This distinction between documented and intended scope is important, since documentation is often far less specific, and subject to interpretation. The documented scope constitutes a commitment to complete a body of work for a specified cost within a defined timespan. Any change to the deliverable or objective will necessarily change the amount of work, and thus the cost and time necessary.

When change is encountered it can be managed well, controlling the impacts of the change and documenting the results. It can also be managed poorly, meaning that changes are happening in an uncontrolled way and perhaps not entirely understood by all parties involved.

Coping with change or changing priorities is seen as the single most important problem facing a project manager (Meredith and Mantel, 2006). Uncontrolled change is one of the most likely causes for project failure. It puts additional stress on project managers and team members, it destroys project timelines, it erodes or eliminates profit margins and it may force you to cut scope from the project. This topic examines techniques for managing change in an effective manner.

3.2.2 Design Change vs Scope Change

A project may undergo two kinds of changes: **Design Change** and **Scope Change**. A design change is a change to the arrangement of the work or the specific methods required to complete the work. Typically such a change will be suggested by a team member, and is a response to an error or omission in the original scope. This sort of change may be considered and “internal scope change”, and does not affect the goals or outcomes of the project. A customer should never be required to pay for design changes.

For example, consider a GIS project in which a large amount of new data will be created. Well into the project, it is decided that it will be too time-consuming for a single analyst to develop the completed dataset, and other analysts should be added to the project. In order to accommodate more than one person digitizing, it is decided to break the dataset into a series of mapsheets. The extra work involved in breaking apart and later merging these mapsheets once the work is complete is an example of a design change. More work will be required, but this extra work was necessitated by a change in the internal process, not as a result of a change in the volume or type of data being created.

A true scope change is where work will be required which extends beyond what was originally agreed upon. This type of change is usually initiated by the customer, but there are circumstances where a team member makes a suggestion that s/he feels will improve the deliverable. These types of changes add more work and deliver either something different than, or something in addition to, the originally specified scope. The client should pay for changes of this sort, because they derive additional benefit from the additional work.

For example, consider the same GIS project as above, where a new dataset is being created. Part way through the project, the customer states that they have their quarterly meeting in two weeks, and it would be very helpful to inform other departments of the work that is being done. To facilitate this, the customer would like 2 or 3 large-format maps made which show the progress to date. The time and materials necessary to create these maps are clearly outside the scope of the original agreement, and while it may also be beneficial to the consultant (increased corporate exposure, raised project awareness) these new costs should be born by the customer. In addition, the customer needs to be made aware of any delays to the project schedule which will result from the creation of these plots prior to work commencing on them.

The process for managing change discussed below primarily relates to scope change, but some of the methods may be used internally to manage design changes as well.

3.2.3 Management Methods

A change in scope requires a change in both the schedule and the cost. If either the client or the party doing the work identifies something that is different than was laid out in the work plan, both parties need to agree on how that impacts time and cost. This is the basis of change management.

The change management process for a project will vary depending upon the organisation, but fundamentally it should resemble the steps shown below. Figure **26** outlines this process.

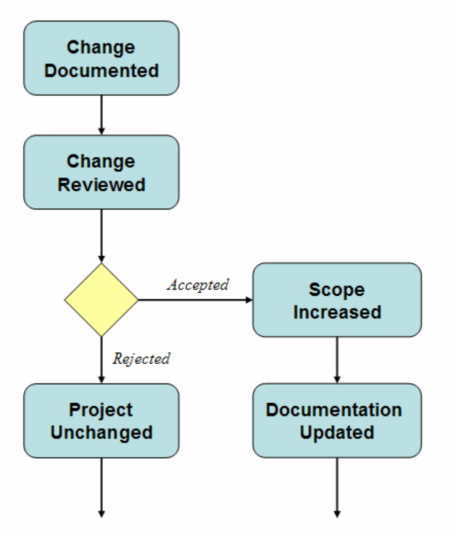

Figure 26 Change Control Process

1 Describe how change will be managed. This should be documented in all agreements and contracts and all team members and client representatives should be familiar with the process prior to project commencement. Many consultants include an example of a Change Request Form and a discussion of the process in the project proposal, so that all

parties are aware of the intended approach before the project even starts. As with virtually everything in project management, ensuring all parties are aware of expectations is important.

2 All changes should be managed through the use of a Change Request, or Change Order. At a minimum, this is a document which outlines the following:

- Define the nature of the change;
- Describe why it is necessary and what benefits will be realised; and
- Describe impacts to the project, including any budget/schedule increases which will result if the change is accepted.
- A simple example scope change form is presented in
- Table **7**.

3 Changes must be approved in writing. In larger projects, there may be a change committee made up of representatives from the project team, the client organisation, and perhaps external stakeholders. For smaller projects, the project manager and client representative may simply review the change and arrive at a decision. This approval process ensures that each change is considered with the overall project deadlines and budgets in mind, and that only those changes deemed necessary by all concerned are approved. In many cases the schedule and budget may be revised to reflect the altered scope.

4 Once approved, changes are incorporated into the project documentation. Scope, schedule and budget should be amended to show the result of the scope change, and a record of the changes should be maintained.

The scope change process involves several facets. The scope management process, as outlined above, is a predefined process for documenting and reviewing change. This process will always include an element of additional planning. When a change is being considered, it must be clearly documented what will happen to the project timeline and budget if the change is accepted. As part of the documentation process, then, significant planning must often be undertaken to fully understand the costs and benefits of adopting a change.

Scope change management must also include a component of performance measurement. As part of the review process, the existing budget and schedule are examined. Without a clear idea of the current project status, a well-informed decision regarding a new change cannot be made. For example, if a small change is requested, and the project is clearly ahead of schedule, it may be more likely that the change is accepted and integrated into the existing project timeline. We will examine project monitoring and measurement of project status later in this module.

Table 7 Example Scope Change form

Project:	Contract#:
Initiated By:	Date:
Nature of Change:	
Justification/Benefits:	
Schedule/Budget Change:	
Other Impacts	

Project Manager:	______________________	Client Representative:	___________________________
Date:	______________________	Date:	___________________________

3.2.4 Evaluating Changes

Each change must be reviewed to decide whether to proceed with the change or not. This is fundamentally a cost-benefit analysis, examining the benefits of adding to or changing the existing scope, versus the additional cost and/or time necessary to perform the extra work. It has been stated that the cost of making a given change increases as the project progresses; the later a change is made, the more likely it is that the change will result in other tasks having to be redone or modified as well. Figure **27** shows such a situation.

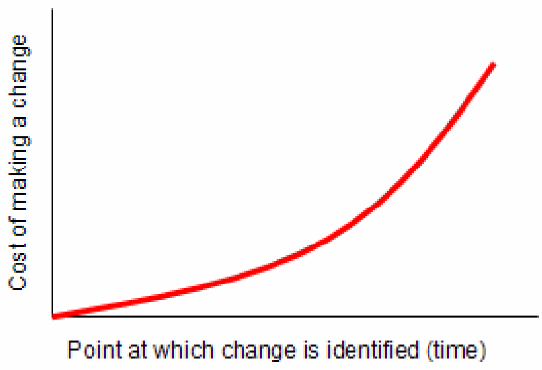

Figure 27 Cost of making a change vs Time

For example, a change suggested very early, perhaps still in the planning stages, will not be costly to make. In the worst case, however, a small change late in a project may require significant portions of the project to be done again. This situation may be disastrous to both budget and schedule.

This is really only half of the consideration: the cost half. The benefit side of the evaluation process suffers a similar relationship to time, especially for design changes. The earlier a change is suggested the more likely it is that a benefit will be derived. For example, the decision to divide a digitizing task by mapsheet has virtually no benefit to the project if the work is almost complete. The relationship between cost, benefit and time may appear as indicated in Figure **28**.

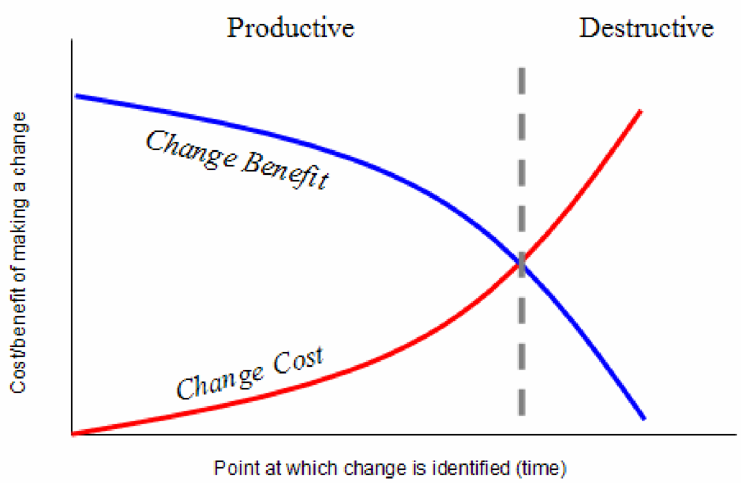

Figure 28 Cost and Benefit through Time

Here, the decline in benefit and the increased cost of a change are indicated together. At some point, the two graphs cross. Prior to this crossover, a change can be viewed as *productive*, meaning that there is more benefit derived from the change than there is cost. After the crossover, the change may be characterised as *destructive*, since the inverse is true. In reality we cannot necessarily graph costs and benefits to determine whether the proposed change is productive. Benefits, in particular, are often difficult to quantify. Benefits tend to be such intangible things as an improved user workflow, or a likelihood of lower maintenance cost in future. In most cases, a subjective decision must be made as to whether the benefits justify the cost.

Some types of changes should be accepted regardless of cost, such as if the change is essential to maintain standards required by a newly-adopted law. For example, if new safety or environmental regulations which relate directly to a project are enacted, the project will most likely be changed immediately to reflect this legislation regardless of cost.

3.2.5 Scope Creep

In many situations, changes may be so small that the PM has a difficult time denying the change or taking them forward as formally documented changes. The process of documenting and reviewing all changes must be offset by the need to run the project efficiently, so taking a two-hour change through the documentation and review process may not seem an effective use of time. Often project managers are given discretion to approve small changes without the formal review process, to deal with extreme examples such as this.

When these sorts of changes begin occurring frequently, however, the result can be disastrous. Obviously, 2-hour changes can add up to significant time if there are enough small changes. This gradual, unplanned expansion of scope is called **Scope Creep**. Scope Creep may arise as a result of unanticipated, unthought-of conditions, deliberate attempts by clients to get slightly more for the same price, or well-intentioned employees trying to improve the project *after* it has been won.

Using an example students will be familiar with, the Sensitive Ecosystems Inventory (from the Module 1 Assignment) project illustrates this latter situation. The reader will recall that the intended working scale for discerning disturbance to an ecosystem polygon was to be 1:10,000. The ecologist assigned to the task, however, was extremely well-meaning and diligent. She felt that if she zoomed the map in to a scale of 1:5,000 she would find far more disturbance, which to her way of thinking was a good thing and provided a better estimation of disturbance.

This is definitely a scope change, and there are two problems with doing so. Firstly, it takes more time to find and delineate the disturbance at this larger scale. Secondly, and perhaps less obviously, the project was an update of an existing dataset which was also created at 1:10,000. Finding disturbance at 1:5,000 introduces the possibility that these smaller disturbances were actually present in the original inventory, but not seen at 1:10,000. Assessing loss at 1:5,000 has the potential to misrepresent loss to ecosystems, by representing existing disturbance as new disturbance. Thus by not adhering to the originally agreed-upon scope, a well-meaning team member not only jeapardized the project schedule, but risked compromising the final analytical results.

Small changes may be difficult to manage. Usually the problem is that the PM does not wish to be overly bureaucratic and avoids the use of the Scope Change document in favour of a more informal, perhaps verbal process for changes less than a few hours. Misunderstanding often results from this level of informality, however. It is suggested that even though the formal Scope Change Documentation and Evaluation process may be avoided with small changes, project managers should ensure these small changes are documented at least in a brief way. In this way, as small changes accumulate and project deadlines become harder to meet, the PM will have documentation of how and why this is occurring, and will have reason to deny small changes in future if a deadline is in jeopardy.

The discretionary approval powers of the PM to approve small changes should be used only if it is felt that the change can be accommodated without compromising the project deadline. It should be kept in mind, however, that although a single change may not cause the project to miss deadlines, a given change will still use up any buffer time in the schedule. Scope creep is cumulative; no single small change will cause the project to experience budget or schedule problems, but when viewed in aggregate, they can.

3.3 Risk Management

3.3.1 Introduction

When embarking on a project, there is a likelihood that something may go wrong, or perhaps will not go as we had planned. It is unrealistic to assume that everything will go as expected, consequently there is a need for project Risk Management. Risk management seeks to deal with problems in an orderly and premeditated manner, and attempts to reduce the impact of unexpected events.

A **Risk** is something that *may* happen and if it does, it will have an *adverse* impact on the project. The phrase "…*that may happen*…" implies a probability of less then 100%. If it has a probability of 100% (in other words it will happen) it is an issue, and will be managed differently to a risk. The phrase "…*will have an adverse impact*…" means that we're speaking here only of "bad" things. If it will not have an adverse impact, it is not a risk. Suppose we said a risk was that we would find the project less complicated than we thought, and could finish early. There is no need to manage for this eventuality, since we'd be perfectly happy should this be the case.

Risk Management is the process through which we attempt to recognize and lessen risk events throughout the project lifecycle. It includes the processes of identifying, quantifying and responding to risk. Identifying risk is the process of determining any risks which are likely to affect the project and documenting their attributes. Quantifying risk is the attempt to estimate the likelihood of a given event occurring and the impacts should the event occur. Risk response is the process both of defining contingency plans prior to project commencement, and dealing with events as they occur.

Risks fall into a number of categories. Relying on new technology or embarking on a task that an organization has never performed before are examples of Technical Risk. Financial Risk might be taken if a contract is structured to have huge milestone billings at the end of the project. In this case, the organization must carry all expenses and payroll until the tasks are completed and payment may be received. An example of Contractual Risk might be if payments in a contract are tied to a milestone which is not clearly defined. In such a circumstance, the customer might rightfully withhold payment feeling the project is not yet complete. Safety Risks are more common to construction projects, but there could be a risk associated with field data collection, for example. These are a sample of the many different types of risk.

3.3.2 Identifying Risks

When identifying project risks, every attempt should be made to determine both internal and external risks. Internal risks are those within the influence of the project team, such as staff availability and time estimates. External risks are those completely beyond the control of the team, such as problems with third-party software or changes in government legislation.

The nature of the project will often dictate the risk level. A project which utilizes well-understood techniques or technology will by nature be less risky than a project which involves some level of innovation.

GIS projects share many similar characteristics to IT or programming projects, and so tend to share the same types of risks. There are rarely risks that relate purely to GIS. However, some of the more common risks might include:

Data Quality: Data supplied by third parties for a GIS project may become a source of risk. Data problems such as incomplete or incorrect attribution, or spatial problems such as sliver polygons can mean that the data cannot be used to solve the problem at hand. Significant effort may be necessary to complete or correct these data. While this work would hopefully be beyond the scope of the original project, any time spent correcting problems will put the project behind schedule. Even datasets produced by reputable agencies with rigorous data quality procedures may have unexpected problems.

Data Delivery Time: Another potential problem with third-party data is that any delay in receiving the data will necessarily cause a delay in the project. While many data suppliers automate the delivery process, some datasets will require time to locate and prepare.

Data Volumes: Many GIS projects work with massive amounts of data. At times, these volumes may cause software performance to be degraded such that it is slow or even unusable. Other times the limits of the software, such as a maximum number of features or file size, may be reached. In these circumstances, either data must be partitioned into discrete pieces, or the data must be migrated to a more powerful database format. There are costs or delays associated with both of these courses of action.

Data Loss: As with any IT project, the risk of data loss due to file system failure or human error is always present. In all projects a comprehensive backup process must be part of the project planning.

Spatial Data Density: Where a project involves creating or updating a spatial dataset, the density of observations or classifications will dramatically affect the time necessary to perform the work. For example, in a project to digitize landuse polygons, large contiguous areas of the same landuse will take far less time to digitize than areas with highly fragmented landuse simply because more polygons will have to be created and attributed in the latter case.

Unfamiliar Processing: Any time an organization embarks on a project where the methods are new, there will be risk involved since the time and cost estimates will necessarily be uncertain.

Risk identification relies to a large degree on past experience. Staff experience and past project files will help identify risks and get a sense of the likelihood of problems occurring again. Related to past project experience is the identification of circumstances that are unusual surrounding a new project. Tasks that have not been done before can be risky in that we will have less confidence in our estimates. Identifying what is new about a project (and thus subject to increased risk) is as much a part of experience as knowing what went wrong on previous projects.

3.3.3 Quantifying Risk

It is usual that a large number of risks are identified for a given project. In order to effectively prioritize these risks so that one may concentrate on the most significant risks, we will need some mechanism of measuring risk severity. This can be done in a **qualitative** or **quantitative** way.

Qualitative Evaluation:
All risks can be considered from two viewpoints, the risk impact (or the loss associated with the event), and risk probability (or the likelihood that the event will occur). The overall magnitude of a risk can be expressed as a function of these two characteristics (probability and consequence)

Table **8** Risk Estimation Matrix shows an example of a qualitative evaluation of risk. Probability and consequence are merely ordinal classifications (High, Medium, Low), and the intersection of these two criteria yields a classification for a given risk.

Table 8 Risk Estimation Matrix

	Low Consequence	**Medium Consequence**	**High Consequence**
High Probability	Medium Risk	High Risk	High Risk
Medium Probability	Low Risk	Medium Risk	High Risk
Low Probability	Low Risk	Low Risk	Medium Risk

For example, a risk which is highly likely to occur, but which has a low impact would become a Medium Risk element. A risk which is both highly likely to occur, and which yields a significant consequence should it occur, would be classified as a High Risk. In this manner, each risk may be categorized and prioritized so that the most significant risks may receive the most attention in the project management process.

Quantitative Evaluation:
Taking this process one step farther, each risk probability and consequence is assigned a numeric score, rather than the simple ordinal classification. Wideman (2006) suggests a numeric score rating system as defined in Tables 3-3 and 3-4 below.

Table Klaida! Dokumente nėra nurodyto stiliaus teksto.**-9 Risk Probability Scores** **Table** Klaida! Dokumente nėra nurodyto stiliaus teksto.**-10 Risk Severity Scores**

Probability	Numeric Score
Highly Unlikely	0.10
Unlikely	0.30
Possible	0.50
Moderately Probable	0.70
Highly Probable	0.90

Severity	Numeric Score
Insignificant	0.05
Moderate	0.10
Medium	0.20
Severe	0.40
Catastrophic	0.80

The estimation of these scores can be considered quite subjective, however, in the absence of any real data regarding the probability that your senior programmer will find a new job part way through your project, for example. One must always make a subjective estimate where concrete probabilities do not exist.

The risk magnitude or exposure is then quantified as the product of probability and consequence (severity) as follows:

Risk exposure = (risk probability) x (risk severity)

The result is a far more refined assessment, as summarized in Table-11 below.

Table-11 Quantitative Risk Estimation Matrix

	Severity				
Probability	**0.05**	**0.1**	**0.2**	**0.4**	**0.8**
0.9	0.05	0.09	0.18	0.36	0.72
0.7	0.04	0.07	0.14	0.28	0.56
0.5	0.03	0.05	0.10	0.20	0.40
0.3	0.02	0.03	0.06	0.12	0.24
0.1	0.01	0.01	0.02	0.04	0.08

The result of either the quantitative assessment, or the more generalized qualitative assessment above, is a means of ranking the project risks, by assigning a relative measure of the significance of each risk.

Risk Assessment Worksheets:
Where an organization performs many projects which are similar, a standard risk-assessment worksheet may be used. This is simply a list of risk factors commonly found in projects, and space to quantify each on a scale of 1 to 4 (four being the greatest risk), for example. Risk factors may include the following:

- Project requires hiring of new resources
- Project has overlapping scope with other projects in progress
- Inexperienced team lacking the appropriate skills
- High staff turnover
- Extensive modification to existing application software necessary
- Significant dependence on existing or developing systems not under the control of staff on this project
- Plans and estimates are not based on reliable data
- Project requires the use of several subcontractors
- Many, or remote, sites are involved

The risk scores are then summed and a total risk score is developed. The total scores are usually classified into ranges such that the highest set of scores correspond to the highest project risk. This tool assists in both the identification of risk, and the estimation of a measure of the overall project risk.

3.3.4 Risk Response

All the techniques defined thus far help us identify and prioritize project risk, but they do nothing toward reducing the effect on the project of these risks. To do that, we will need to consider each risk in turn to evaluate potential courses of action. Potential courses of action include the following:

Accepting Risk: Where a risk has insignificant consequences, it may be reasonable to simply accept the risk, and absorb any related costs if the risk event occurs.

Mitigation: With more consequential risks, we may wish to accept the risk, but actively pursue actions which reduce either the probability or impact of a risk. This may involve simply adding an adequate amount to both the project budget and schedule to accommodate the risk occurrence. It may involve simply creating a well thought-out contingency plan for what will be done should the risk materialize. The mitigation strategy will obviously vary according to the nature of the risk, but it may involve hiring practices, technological changes or changes to the structure of the project.

Avoidance: In cases where there may be few reasonable mitigations, but the risk is too great to accept, one solution is to simply avoid the risk entirely. This may involve changing the scope of the project to omit a task with high risk, or selecting different technical methods or equipment which do not have the same inherent risk.

Transfer: Where a risk is deemed too great to accept, yet it cannot be avoided, there are circumstances where the risk may be transferred to another party. For example, it may be helpful to hire a subcontractor more familiar with a task than to proceed with the task yourself without adequate experience. In such a case, the subcontractor assumes the risk. It may also be possible to purchase insurance for some risks, particularly for liability and safety risks. In these cases, the insurer assumes the risk.

At the end of this process, we will have a prioritized list of major project risks, with a description and consequences. We will also have a discussion of how the risk will be handled, whether by acceptance, mitigation, avoidance or transfer. Any number of notations may be acceptable here, but a table such as indicated in Table 12 below will serve to document the risk management process for a given project.

Table 12 Example Risk Summary Table

Risk	Impact	Mitigation
Delays in receiving necessary project data from 3rd party	Schedule is delayed	1. Order data prior to May 1 start date to give lead-time to data supplier 2. Have concurrent tasks (identify specifics) which can be done if there are delays
Unknown address data quality: significant proportion of data points may not geocode automatically.	Low proportion of data can be used for the project, or significant time will be required to place points manually.	1. Geocode a subset of the data early to get a sense of how good/poor the addresses are. 2. Work with sponsor to identify priority tasks. If manual placement is required, low priority tasks may be dropped from scope.
Subcontractor Coordination	Deliverables from a series of subcontractor projects are required for interrelated tasks. Delays by one subcontractor can delay a series of tasks.	Structure subcontracts such that : 1. completion dates are well ahead of necessary deadlines, and that 2. penalties for non-performance are specified. That way if a subcontractor is late, it will release funds to assist with overall budget/schedule shortfalls.

Each risk is documented here, in order of decreasing risk (i.e., the most significant risk is first in this table). Depending upon the risk quantification technique, a numeric score for each risk may be added to this table.

One final thought regarding risk: communication and monitoring to keep abreast of the status of each risk is as important as the quantification part of the process. Ensure that a risk update is a standing agenda item at all status meetings, and communicate the results of the risk update are circulated widely within the project team.

3.4 Monitoring Project Progress

3.4.1 Introduction

In Topic 1 of this module, we defined Project Management as the discipline of defining and achieving targets while optimizing the use of resources (time, money, people, materials, energy, space, etc) over the course of a project. The goal of everything we have discussed in modules two and three is to ensure that projects proceed as efficiently as possible. Projects are rigorously planned to ensure the tasks and risks are well understood. If we stop there, however, there is no mechanism to ensure that the way the project actually progresses has any resemblance to the way it was planned. Thus we need to **monitor** project progress to ensure performance is as we have planned.

Monitoring is the process of gathering, recording and reporting information about how a project progresses. The purpose of monitoring is to ensure availability of information necessary to effectively control the project, to keep senior managers and client representatives apprised of progress, and to document projects so that we may learn from our mistakes in future.

The primary reason for monitoring projects is to ensure that actual project performance is as close as possible to planned performance. With this information, managers can identify problems early and resolve them without delay.

3.4.2 Earned Value

As a means of discussing project status, consider the following scenario:

Project as defined in the Proposal

$100,000 budget

10 month schedule

Present Project Status

$40,000 spent

6 months spent

How close are we to finishing?

The above information tells us that we've spent 40% of the budget, and 60% of the available time, but how close are we to actually completing the work? The answer is that we do not have enough information to determine that. Nothing in the above statement tells us how much of the scope has been completed. Without an estimate of how much of the work is complete, we cannot judge how well or how poorly we are performing.

Typically we would compare our actual expenditures to the planned costs for a project. The problem with this method is that the funds expended on a project do not indicate actual progress, since the scope accomplished is not examined. The other problem with this method is that often Accounting departments have difficulty providing up-to-date expenditure figures with the result that status reporting lags by several weeks.

Hence the **Earned Value** approach. Functionally earned value states "what you got for what you spent" (Wideman, 2006). With this method, we estimate the work completed to date, and can view the project scope and budget status together. A simple Earned Value analysis uses a percent complete estimate for each task to determine how much of the budget has been earned, or completed. Table **13** shows an example of this using the example project (creating Riparian Areas) from Module 2.

Table 13 Example Earned Value Statement

Task	Deadline	Budget	Percent Complete	Earned Value
Acquire Airphotos	11-Jan-07	$ 5,750.00	100%	$ 5,750.00
Scan Airphotos	18-Jan-07	$ 1,750.00	100%	$ 1,750.00
Acquire Basemap	18-Jan-07	$ 2,750.00	100%	$ 2,750.00
Georeference Airphotos	25-Jan-07	$ 1,750.00	100%	$ 1,750.00
Define Rules	25-Jan-07	$ 4,200.00	100%	$ 4,200.00
Digitize Riparian	09-Feb-07	$ 3,500.00	85%	$ 2,975.00
Calculate Statistics	16-Feb-07	$ 3,000.00	40%	$ 1,200.00
Final Plots	16-Feb-07	$ 2,250.00	60%	$ 1,350.00
Final Report	19-Feb-07	$ 550.00	0%	$ -
		$ 25,500.00		$ 21,725.00
Total Progress = $21,725 / $25,500 =			85%	

In this table, two columns have been added to a simple Milestone Chart showing tasks and deadlines. These columns are the *Percent Complete*, which is an estimate, and *Earned Value,* which is the product of task budgets with their corresponding *Percent Complete* figure. This shows us how much of the budget for each task has been earned. We can then look at the total earned budget in relation to the total project budget to produce an overall Percent Complete (or *Total Progress*) for the entire project. In this example status, our Riparian Areas project is 85% complete.

The assignment of Percent Complete to a given task can be extremely subjective. Some tasks, such as collecting vegetation/soils data (perhaps as training sites for a satellite image classification) are straightforward to estimate. Suppose the scope defined that we would visit 50 sites, and to date we have visited and gathered data for 30 sites. This task is therefore 30/50 or 60% complete. Other tasks, though, can be much more difficult to gauge progress. Tasks such as writing a software application or a final report, for example, don't have such an easily-quantified target for completion, and thus rely on a subjective estimate made by the writer.

Our Sensitive Ecosystems Inventory Update project (from Module 2) fits this category. Although we know how much work we have done (e.g., the number of disturbances we have digitized), we cannot really know now much disturbance remains to process. We might look at the proportion of polygons or mapsheets which have been completed, but this will be an approximate estimate only. The reason we lack confidence in such an estimate is that disturbance relating to human activity will not be uniformly distributed over the landscape. Areas we have not yet assessed might be subject to greater urbanization pressure, for example, so although we might have examined half of the polygons, we have not digitized half of the disturbance because the greater proportion of the disturbance is yet to be examined. This is a common problem in estimating percent complete.

Some general guidelines may be used to assist with the estimation of progress. Several are defined below:

50-50 Rule: When a task is first begun, 50% completion is assumed. When the task is complete, the remaining 50% is earned. This is an extremely popular method, since it does not require the effort of trying to gauge how much of the work has been completed.

0-100 Rule: In this case, no credit for a task is given until the work is complete. This is an extremely conservative way of estimating. One problem with this method is that the project seems to be always behind schedule until the end of the project, when actual progress seems to suddenly catch up with planned progress. This technique is not terribly effective for small projects with very few tasks, because it cannot show progress well.

Best Estimate: For smaller projects with fewer tasks, it is often necessary to quantify progress more finely than 0-50 or 0-100. In such cases, the technician actually performing the task is asked to estimate, to the best of their abilities, the degree to which a task is complete. This method is obviously extremely subjective and a function of the personalities and outlooks of the team members involved, but it is necessary if a finer estimate of progress is required.

Proportional Expenditure: In this method, we divide our actual time invested, or budget spent, by the planned time or budget. This ratio becomes our Percent Complete. Although this allows a fairly concrete numeric value for progress, it does not truly examine progress because it looks only at expenditure, not at scope completion. This method would only be effective on projects where one is extremely confident in the time estimates for tasks, because it does not measure the disparity between work completed and time invested.

However, even with a reliable percent complete estimate, this simple earned value only shows us our scope status; a percent complete for the each task and the project as a whole. By also examining expenditures, we can look at both scope and budget together.

Table **14** shows the same table as above, but with expenditures as well.

Table 14 Earned Value with Budget Status

Task	Deadline	Budget	Percent Complete	Earned Value	Spent	Budget Status
Acquire Airphotos	11-Jan-07	$ 5,750.00	100%	$ 5,750.00	$ 4,800.00	$950.00
Scan Airphotos	18-Jan-07	$ 1,750.00	100%	$ 1,750.00	$ 1,600.00	$150.00
Acquire Basemap	18-Jan-07	$ 2,750.00	100%	$ 2,750.00	$ 3,400.00	-$650.00
Georeference Airphotos	25-Jan-07	$ 1,750.00	100%	$ 1,750.00	$ 2,300.00	-$550.00
Define Rules	25-Jan-07	$ 4,200.00	100%	$ 4,200.00	$ 4,500.00	-$300.00
Digitize Riparian	09-Feb-07	$ 3,500.00	85%	$ 2,975.00	$ 3,800.00	-$825.00
Calculate Statistics	16-Feb-07	$ 3,000.00	40%	$ 1,200.00	$ 700.00	$500.00
Final Plots	16-Feb-07	$ 2,250.00	60%	$ 1,350.00	$ 1,000.00	$350.00
Final Report	19-Feb-07	$ 550.00	0%	$ -		$0.00
		$ 25,500.00		$ 21,725.00	$ 22,100.00	-$375.00

Total Progress = $21,725 / $25,500 = 85%

Two additional columns have been added to those presented in the previous example. *Spent* is the actual expenditures, including fees, materials and other disbursements, for each task. This may require significant accounting capability to deliver these numbers in a timely manner. *Budget Status* is the difference: *Earned Value* – *Spent*. This latter column tells us whether we are ahead or behind budget for each task, and for the project as a whole. For example, Task 1 (Acquire Airphotos) is under budget by $950, while Task 3 (Acquire Basemap) is over budget by $650. The entire project is slightly over budget, being over by $375.

3.4.3 Earned Value Graphs

We now have a reporting mechanism which examines Scope and Budget status. The last remaining major control variable to include here is Schedule. We will examine a technique where the earned value for a project at a given point in time is compared with the time at which a similar amount of expenditure was planned to occur. The difference between these two times tells us our schedule status.

To perform this comparison, we need to build an expected expenditure graph. To do so, we plot planned expenditure vs time to produce a simple curve. Expenditures for most projects follow the “S”-shaped graph shown in Figure **Klaida! Dokumente nėra nurodyto stiliaus**

teksto.-29. The rate of spending is low early in the project (as noted by the fairly flat blue line), then climbs dramatically in the middle half or more of the project. This can be seen by the sharp increase in the expenditure line through the middle portion of the project timeframe. Toward the end of the project, the rate of spending declines, and the curve flattens once again. This "S" shape illustrates the process of slowly mobilizing a large project team, then as the bulk of the work is completed, a small number of people will "wrap up" outstanding tasks such as documentation while most project team members cease to work on the project.

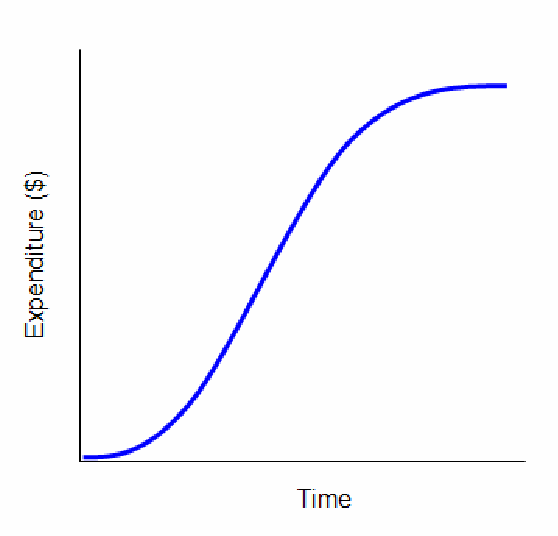

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**-29 Typical Project Expenditure Curve**

To build an expenditure curve such as this, we will make a small modification to our Earned Value table. We will add three new columns, headed *Cumulative Budget, Cumulative Earned* and *Cumulative Spent* and the result shown in Table **Klaida! Dokumente nėra nurodyto stiliaus teksto.**-15 below. These columns simply calculate cumulative versions of existing columns.

Table Klaida! Dokumente nėra nurodyto stiliaus teksto.**-15 Earned Value Table with Cumulative Values**

Task	Deadline	Budget	Cumulative Budget	Percent Complete	Earned Value	Cumulative Earmed	Spent	Cumulative Spent	Budget Status
Acquire Airphotos	11-Jan-07	$ 5,750.00	$ 5,750.00	100%	$ 5,750.00	$ 5,750.00	$ 4,800.00	$ 4,800.00	$950.00
Scan Airphotos	18-Jan-07	$ 1,750.00	$ 7,500.00	100%	$ 1,750.00	$ 7,500.00	$ 1,600.00	$ 6,400.00	$150.00
Acquire Basemap	18-Jan-07	$ 2,750.00	$ 10,250.00	100%	$ 2,750.00	$ 10,250.00	$ 3,400.00	$ 9,800.00	-$650.00
Georeference Airphotos	25-Jan-07	$ 1,750.00	$ 12,000.00	100%	$ 1,750.00	$ 12,000.00	$ 2,300.00	$ 12,100.00	-$550.00
Define Rules	25-Jan-07	$ 4,200.00	$ 16,200.00	100%	$ 4,200.00	$ 16,200.00	$ 4,500.00	$ 16,600.00	-$300.00
Digitize Riparian	09-Feb-07	$ 3,500.00	$ 19,700.00	85%	$ 2,975.00	$ 19,175.00	$ 3,800.00	$ 20,400.00	-$825.00
Calculate Statistics	16-Feb-07	$ 3,000.00	$ 22,700.00	40%	$ 1,200.00	$ 20,375.00	$ 700.00	$ 21,100.00	$500.00
Final Plots	16-Feb-07	$ 2,250.00	$ 24,950.00	60%	$ 1,350.00	$ 21,725.00	$ 1,000.00	$ 22,100.00	$350.00
Final Report	19-Feb-07	$ 550.00	$ 25,500.00	0%	$ -				$0.00
		$ 25,500.00			$21,725.00		$22,100.00		

For example, the cumulative budget for task three contains the sum of the budgets for the tasks one, two and three rather than simply the budget for the third task. These cumulative columns allow us to plot Budget, Earned Value and Spent against time to produce curves similar to that shown in Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**-29.

We now can create a graph with time along the X axis, and expenditure on the Y axis. The three data series represented will be the Cumulative Budget, Cumulative Earned and Cumulative Spent. Figure **Klaida!** Dokumente nėra nurodyto stiliaus **teksto.**-30 Example Earned Value Graph shows the resulting graph. It is not the perfect "S" curve discussed previously, due to the fact that it is a short project with a small team but it does exhibit a similar shape.

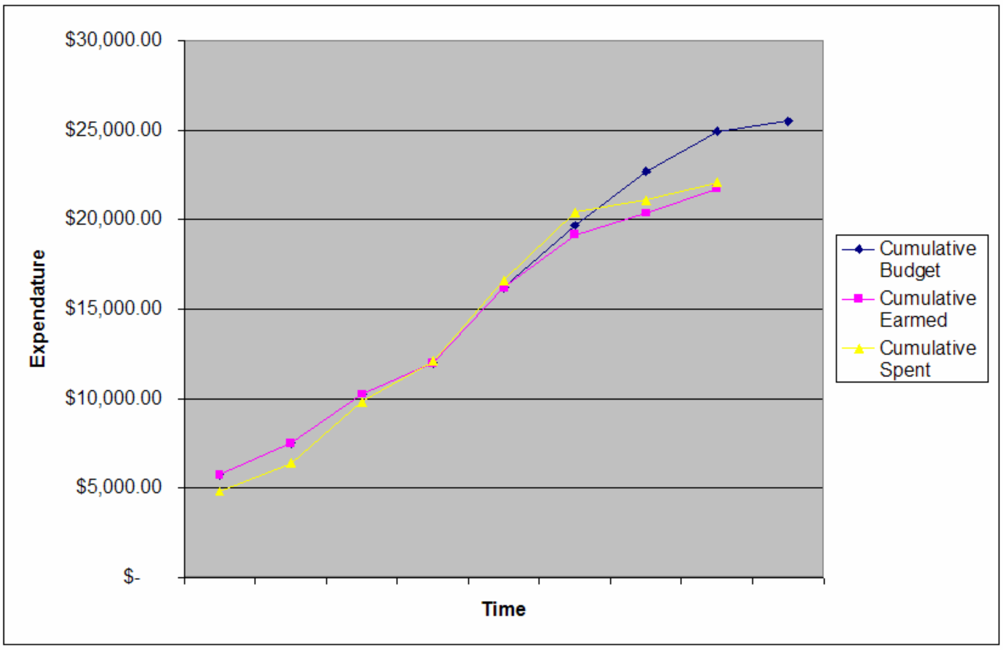

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**-30 Example Earned Value Graph**

There are a number of things we can determine by examining this graph. If the total value of the work completed is in balance with the planned rate of expenditure, all three lines in the above graph will be congruent. Where either the project is going better or worse than planned, these lines will begin to separate. For example, where the yellow line (Cumulative Spent, or Actual Cost) is below the blue baseline (Cumulative Budget, or Planned Value), costs are running lower than projected, so the project is under budget. In Figure Klaida! **Dokumente nėra nurodyto stiliaus teksto.-30** Example Earned Value Graph, the yellow line begins below the blue line, but crosses at the fourth plotted point and begins to be above the blue line. This indicates that while we began our project below budget, after the 25th of January (the deadline for the 4th task) we began to go over-budget.

In general we can identify three "variances", or differences between these lines, from such an earned value graph:

Cost Variance (CV): This is the difference between how much value we have earned and the value we have actually expended, and it tells us our budget status. In our graph above, this is the difference between Cumulative Earned (also called Earned Value, or EV) and Cumulative Spent (also called Actual Cost, or AC). A negative number for EV – AC means an overrun; we have spent more than we have earned.

Time Variance (TV): This is the difference between the time taken to earn a certain level of expenditure and the planned time to earn the same value. The difference between the planned curve and the earned curve will be negative if we are behind schedule, that is, that we have taken longer to earn a given value than we had planned.

Schedule Variance (SV): This is a measure of how much we have earned (EV) relative to the amount we planned on having spent at the same time in the project. The planned expenditure is our Cumulative Budget, and may also be called Planned Value (PV). Again, a negative schedule variance (EV – PV) tells us that we are not spending resources as fast as we had planned.

There are other measures which can be calculated, including some measures which attempt to create a combined index from both schedule and budget status simultaneously. However, the measures above are usually sufficient for the small-scale GIS projects we have described.

Examining our graph in Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**-30 Example Earned Value Graph, we can calculate these variances. Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**-31 shows an annotated area of our graph, showing the cost variance calculation for February 16, 2007.

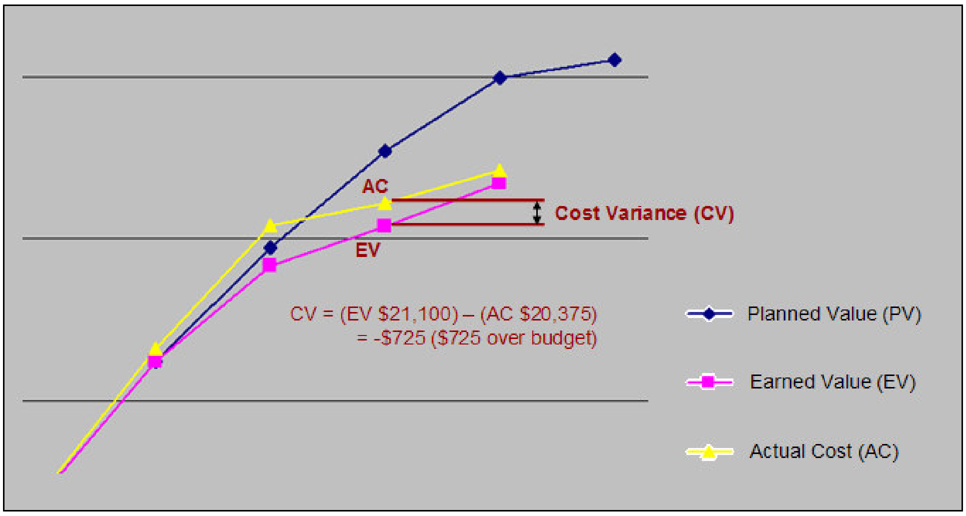

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**-31 Expanded View of Cost Variance**

As discussed above, the cost variance, or the amount we are over or under budget, is the difference between the Earned and Actual curves. Here we discover that we are $725 over budget. Similarly, we can look at the difference between the Earned and Planned curves to see the status of our schedule. Figure **32** shows an expanded view of the Time Variance calculation using our graph.

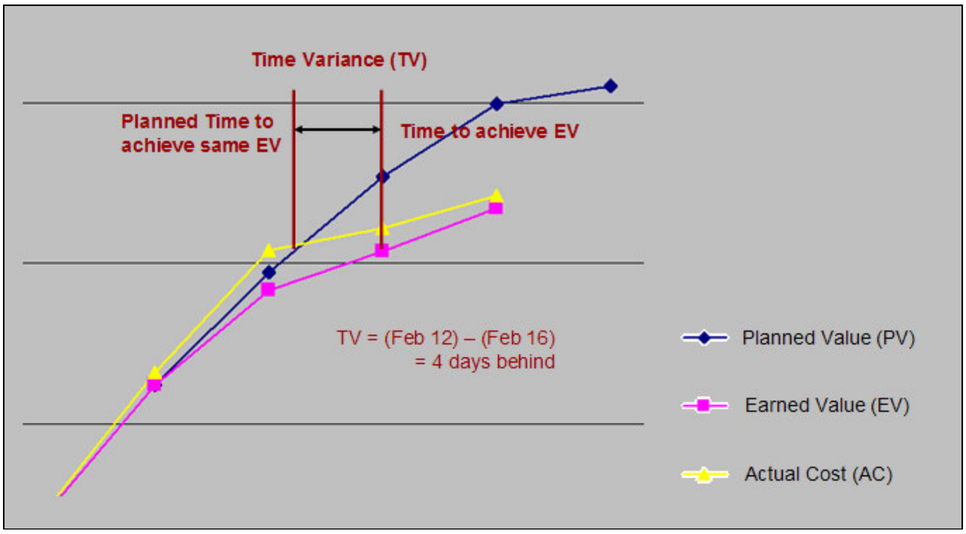

Figure 32 Expanded View of Time Variance.

In this case, we discover we are approximately 4 days behind schedule, since the work we have completed as of February 16th was planned to have been completed by February 12th.

3.4.4 Conclusions

Earned value graphs can tell a project manager a significant amount about the performance of the project team. We generally compare earned value and actual costs to our planned value, or baseline. Any deviations from this baseline indicate deviation from how we planned the project to progress; whether we are within budget or on schedule.

This method tells us historically how the project is performing, but can these graphs be extrapolated forward in time to predict performance? The answer is likely “No”. Productivity on a given task isn‘t consistent throughout the task, so extrapolating a level of productivity forward is not effective. Productivity on a given tasks tends to have an “S” curve too; it takes time to mobilize to complete a task (due to learning curve effects), and productivity declines toward the end of a task because people tend to put off difficult tasks until the end, and rework is discovered as we near completion of a task.

All Earned Value methods rely heavily on both reliable estimates of progress, and accurate and timely accounting (expenditure) figures. In some cases both of these may be questionable, in which case any earned value analysis will necessarily be flawed as well.

GIS projects, by their nature, can be difficult to monitor. The primary reason is that the product is intangible. One cannot claim a bridge is 90% complete if there is not 90% of the bridge there. However, it is easy to claim that a GIS analysis or custom application is 90% complete, even if there are no visible outcomes. Additionally, due to the diverse nature of GIS activities, many GIS projects are one-off, with experience gained in one project being of little help in another. Finally, the technology changes very quickly in GIS. Most large GIS projects employ new technology, making it difficult at times to utilize methods from past projects.

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4 Module 4: Enterprise GIS

4.0.1 Introduction

GIS may be integrated into the workings of an organisation in many ways. In Module 1 we introduced the concept of the *scale of integration* of GIS in an organisation. We introduced the idea of Project-Based GIS, Departmental GIS and Enterprise GIS as examples of increasing integration of GIS in the daily workings of an agency. In this model, we will consider planning for an Enterprise GIS.

When the decision is made to bring GIS into a large organisation, the goal should not be to simply automate some of the mapping tasks which are currently performed manually or with isolated departmental GIS. It should be to improve efficiency, provide up-to-date information to all departments and reduce redundancy. In effect, integrating GIS into the workflows of the organisation should be viewed as an opportunity to make significant changes to the way business is currently conducted and the way data are currently stored and used. The enterprise GIS is an organisation-wide resource.

Enterprise GIS is about sharing data efficiently and providing access to spatial technology. Much of the effort in implementing such a GIS is in the organisation of data and the creation of necessary outputs. However, it also entails addressing necessary changes to policy, procedures and management. Enterprise, or corporate, databases require cooperation between participating parties. While redundancy may be reduced by having a single version of a shared dataset, a single corporate entity must take responsibility for maintaining both its currency and its quality where perhaps this was not the case in the past. Internal procedures for maintaining the integrity of the shared data may offset any perceived loss of control that sharing information may create.

Implementation of an enterprise GIS may result in:

- Reduction of redundancy: Centralised data storage means that a given dataset (e.g., land parcels) are stored and updated only once.
- Consistency: More importantly, centralised data storage means that information is maintained by a single party. Irregular maintenance, where several copies of the same data are being updated sporadically by several departments, usually means that there are not just several copies of data, but several different copies of data. Enterprise GIS reduces or eliminates this problem.
- Efficiency: Depending upon the level of automation currently existing in an organisation, users may find that GIS is capable of producing information products far more efficiently than previously possible. Especially if manual mapping methods are still in use, GIS can produce significant savings in the time it takes to do a particular job.
- Better decision-making: Information from many different departments or functional areas may be brought together in a uniform format, with the likely result that better, more informed decisions may be made.

4.0.2 Module Structure

In Module 2 we examined planning for a GIS project. This applied to making use of GIS technology to create new data, solve analytical problems or present spatial data graphically. In this module, we will examine planning for a different type of GIS project. Here the GIS project is to bring GIS into a large organisation. Some of the terminology is similar, but the techniques are quite different.

Project-based GIS planning has its roots in Project Management, while implementing a GIS is more related to Systems Analysis and Design. Here we are creating a Geographic Information *System*, so systems analysis is the basis of the planning effort. The majority of the body of research in this area is typically the domain of Computer Science, but the specialised nature of GIS requires expertise in this area as well. We will continue to examine this topic from all perspectives – the general process as you might find in a Computer Science reference, and the more specific techniques and considerations which are directly applicable to GIS.

GIS is an area which has advanced quickly. We currently have readily-available software applications which are relatively easy to use, and which include extremely strong capabilities. Application development tools such as Computer Aided Software Engineering (CASE) and integrated programming environments allow rapid development of applications and database structures. Many standard datasets are freely available or available with minimal expense (when compared with the cost of creating these data). Given these factors, one might reasonably ask why we need a complex and time-consuming planning process prior to beginning implementation of an Enterprise GIS.

Thomlinson (2003) states that this is clearly not the case; significant experience in the field suggests that the absence of planning leads to failure. Lack of planning is identified by many authors as the primary reason for the failure of a GIS installation. Not only does planning ensure that you create a GIS which meets the needs of your agency, but it ensures that expectations are clear for developers, managers and those who fund the process.

Implementation tasks such as purchasing equipment or creating databases and applications are time-consuming and expensive undertakings. Placing emphasis on low-priority or unnecessary aspects of a GIS implementation because managers failed to plan for development means the agency is losing money and time, and failing to live up to the expectation that GIS can make business functions more efficient. The goal of these planning stages is to understand the business functions of the organisation, leading to clear articulation of the data, functional needs and priorities for development. With these things identified, it is then possible to make estimates of schedule, cost, staffing and equipment requirements which are based on solid research rather than supposition.

Several of these activities are similar to those discussed as part of the project management and project planning modules; this is because project management requires thorough project planning. There is obviously some overlap between this module and its predecessors.

This module will examine planning for an enterprise GIS by presenting the following three topics:

1: Planning

2: Analysis

3: Design

This Analysis-Design structure follows the SDLC we defined in Module 1, and is consistent with most Computer Science / Information Technology (IT) implementation methodologies. Some GIS references (e.g., Thomlinson, 2003) do not adhere to this standard decomposition, but rather present a series of steps without regard to whether a given task is considered analysis or design. The structure of this module seeks to cover all the necessary GIS-related material, but presents it within the framework commonly found in IT methods. The goal is to present for students a balanced approach which addresses the needs of both computer scientists and GIS professionals.

As with all examples presented in this course, the notations are suggestions only – many methods of documentation and modeling are available and students are encouraged to explore different methods.

4.1 Planning

4.1.1 Introduction

The entire contents of this module – the work which must be done prior to implementation – can be considered planning. However, this topic addresses the planning which must occur before embarking on the detailed analysis and design stages. Fundamentally, it is a review of existing strategic documentation, and a proposal outlining the process to move forward with detailed planning.

There are two primary goals of this initial level of planning, which are intimately linked: to gain support for GIS throughout the organisation, and to gain commitment to move forward with the larger-scale planning effort of analysis and design. GIS planning, when done in a thorough manner, is a time-consuming process. We need a commitment from senior management to proceed with this process, and fund the necessary staff time or consultant fees.

4.1.2 Strategic Planning

To plan an effective GIS, one must ensure that the objectives of the GIS implementation support the strategic goals of the organisation. The beginning point for planning a GIS should include an examination of any existing strategic plan and vision for the future of the agency. Where such documentation does not exist, it may be necessary to interview upper-level management to determine the goals of the organisation. To demonstrate that the objectives of the GIS are complimentary with the corporate objectives, it may be necessary to discuss both of the following:

Define the current state:

- High level view of the organization.
- Description of current and anticipated future situation
- Primary applications, or the main core business of the organization
- Data currently in use: sources, maintenance, restrictions on their use, etc.
- Current systems architecture: servers, network, desktop environments
- Staffing: number of employees by department, particularly relating to technical positions
- Business challenges: organizational, regulatory
- Technology challenges: editing volumes, archiving
- Constraints: financial, staff, skills, timing, systems

Define the proposed changes:

- Users of the new system
- Integration with other existing or planned systems

- Benefits to the organization
- Criteria for success
- Major components of the solution
- Components in each of the planned phases
- Proposed schedule for all phases
- Internal resources required
- Necessary contract support
- New hardware & software

This allows decision-makers to understand the breadth of the project. They should gain an understanding of what tasks will be performed, and over what time frame.

4.1.3 Feasibility

It is not possible to do a formal cost-benefit analysis this early in the project, since we do not have a clear understanding of what needs to be done. The analysis stage, to follow, will examine the requirements of this new system, and the design will specify the solution in detail. At this time, however, we cannot state with any confidence whether the costs are outweighed by the benefits.

A preliminary feasibility evaluation may be done during initial planning, however. We can consider this from three standpoints: an external scan of similar organisations to gauge the likelihood of our success based upon other similar projects, a preliminary economic feasilbility, and a cultural feasibility assessment.

One of the most effective forms of feasibility study is the external scan. External agencies of a similar size, or that serve a similar business function which have implemented GIS should be approached to learn from their previous experiences. We should determine whether similar implementations were successful; whether they enjoyed the benefits that were forecast and whether estimated timelines proved realistic. We should consider the hardware and software selected by these organisations to determine whether these choices are applicable in our situation. Finally, we should consider the influence of a central governing body (if applicable); have standards been set nationally, for example, which might affect our implementation, and whether there is any proposed legislation which might alter the case for GIS.

Economic feasibility is difficult to assess at this time, without a detailed description of the work that is about to begin. We cannot judge the cost of the overall project, but we can assess the ability of the organisation to fund the greater planning that must be done prior to constructing the GIS. According to Thomlinson (2003), planning for a typical city or regional government implementation of GIS will take 4 – 8 months, with a total effort of 6 to 7 person-months. The leader of the GIS development effort will devote 70% of his or her time to the planning process. In addition, staff from each department that will participate in the planning process (at least one employee from each participating department) will expend 2 to 6 days in helping define the new system. If the organisation does not have the financial resources to support this level of planning, it is not feasible to proceed with GIS implementation. Planning is a vital part of the implementation and cannot be omitted.

Organisational and cultural feasibility reflects the degree to which the organisation can accept and utilize a GIS implementation. All workplaces have their own culture, and GIS must fit within that culture. If the new applications and procedures vary dramatically from those currently in use, there is a risk that the organisation will not effectively use the system. Issues which affect the level of risk might include:

- Significant modification of longstanding work procedures
- Fear of change in job duties, or loss of employment due to automation
- Potential shifts in responsibility or power within the agency due to the new system
- Low computer competency within existing staff

4.1.4 Conclusion

One of the results of this initial planning stage should be a proposal document. The proposal should document the factors defined above, and attempt to quantify a schedule and budget for the planning stages that will follow. This document is then forwarded to senior management for review.

This is the first decision-point of the implementation process. If support is simply not adequate, if financial resources are such that the larger planning effort is unattainable, or if the experience of similar organisations has proven that the implementation is unfeasible, then the conclusion should be to terminate the project at this point. If, however, funding is in place, decision-makers are clear about what needs to happen next, and the organisation as a whole is prepared to embrace a new technology, then the real work of planning the GIS can begin.

4.2 Analysis – System Requirements

4.2.1 Introduction

With approval to proceed with the larger planning process, we can now move into the Analysis phases of development. In the standard Systems Development Lifecycle discussed in Module 1 of this course, the result of the Analysis phase was a System Requirements Document. The analysis phase may be itself referred to as a **Requirements Analysis**.

In very broad terms, the requirements definition seeks to determine:

- What are the business processes and operations performed by the organisation?
- How should these processes be performed, or what steps are necessary to complete these processes?
- What information is necessary to perform these processes or operations?

The objective of this analysis stage is to gain a thorough understanding of the workings of the organisation, and thus what the GIS must be able to do. In some methodologies, this process of gathering information about the necessary functionality of a new system is called the **Needs Assessment**, while the documentation of these needs is the Requirements Analysis (e.g., Chrisman, 1997).

Traditional systems analysis suggests that there are several means of gathering the information necessary for a requirements analysis; these are outlined below.

Review of Existing Documentation: This is often the starting point for the analysis stage of the lifecycle. It allows an analyst to fairly quickly gain an understanding of what is done in the agency, particularly if the analyst is not a part of the organisation and so has little background with the GIS application area in question. Documents reviewed will include procedural manuals and existing forms, maps or reports. These documents will form the basis of future discussions or questionnaires. Existing documentation is also helpful during interviews which may take place. They may serve as a vehicle to facilitate or focus discussion on specific tasks or outputs.

Questionnaires: These are useful for collecting information from a large number of stakeholders, or from stakeholders which are widely distributed geographically. They are limited, however, in that they cannot be used to address open-ended questions, such as "what do you do?", or "what information do you use?". They tend to be more effective when addressing close-ended questions such as "how many times in a month do you run the landuse summary report?", or "on a scale of 1 to 5, how important is it to be able to see what a subdivided lot looked like in the past?". Questionnaires have a role to play, but in isolation cannot effectively help define processes and techniques.

Interviews: Interviewing stakeholders is the most effective way to gain an understanding of business functions (Satzinger, et al., 2000). With this method, the analyst meets with individuals or user groups to discuss data and processing requirements. A key aspect which should be examined during these interviews is exception conditions. Analysts need to consider the non-standard cases, such as "what happens if the subdivision request form arrives with no signature?". These errors and exceptions are often important considerations for software application development and database design.

The drawback of interviews is that they are expensive. It takes time to discuss business processes thoroughly enough to develop a system requirements document, often several people are involved in a given interview, and there are many people or user groups to interview.

Observations: Wherever possible the analyst should be allowed to observe staff performing their duties. One could think of this as a short training course in how to do a few key jobs in the organisation. It allows the analyst to view firsthand the procedures employed, the data used and any potential stumbling blocks or bottlenecks in the process.

The effectiveness of these methods is described below in Table 16 Comparison of Analysis Methods (adapted from Dennis, et al, 2006).

Table 16 Comparison of Analysis Methods

	Document Review	Questionnaire	Interview	Observation
Depth of Information	Low	Medium	High	Low
Breadth of Information	High	High	Low	Low
User Involvement	Low	Low	Medium	Low
Cost	Low	Low	Medium	Low-Medium

As mentioned, these techniques are employed in any systems analysis effort. GIS is slightly different than many other system implementations, in that there is an element of education involved. While most potential users of a new system have a fairly good grasp of what database or accounting systems can do, it is common that the user community will not have a clear understanding of what GIS is and what they are capable of.

To help bridge this gap, Thomlinson (2003) suggests a **Technology Seminar**. This would be an opportunity to gather those departmental employees who will be involved in the analysis stage to ensure they understand the process. Topics covered would include an overview of both GIS and the planning process. In this way, users may be more prepared for the discussions which will occur in the individual interviews. There may also be a preliminary discussion of the business functions of the departments and an identification of the primary datasets, providing an opportunity for the analyst to quickly gain an understanding of the major goals and functions of the organisation.

Case Study

In order to better illustrate the process of identifying and documenting system requirements, a case study will be used. The selected case is fairly simple, to allow our examples to remain easily documented and understood by the student. This implementation would be classified in the realm of a Departmental GIS, rather than a true Enterprise GIS, but in the interest of clarity we will scale back the example to something more manageable.

As an example we will examine a government agency primarily concerned the classification of shellfish growing waters based on the sanitary and bacteriological water quality conditions of the area. Their primary objective is to protect the public from the consumption of contaminated shellfish by ensuring that bivalve shellfish (oysters, clams, mussels and scallops) are harvested from waters of acceptable sanitary quality. To accomplish this goal, they conduct ongoing sampling of nearshore tidal waters and freshwater sources (e.g., streams, farm runoff, sewer outfalls) draining into tidal waters. Where water quality is found to be unsafe, our organisation has the authority to issue a harvest closure for specific areas of the coast until such time as the water quality becomes safe once again.

They currently use a variety of software applications. Map production is performed using scanned marine navigation charts and drawing software such as Corel or Powerpoint. Reporting and data entry/edit is performed using an MS Access database application which maintains sample water quality data. A small amount of spatial data maintenance is performed using outdated DOS-based GIS software. We wish to create an integrated GIS environment to manage all of these data and integrate many manual steps into an automated process. The user community for the GIS implementation will be in the order of 10-15 staff members, including technicians, field biologists and administrators. We will call our agency the Shellfish Monitoring Branch in discussion throughout this module.

4.2.2 Data Requirements

Documenting the data requirements of a GIS is a significant portion of the overall requirements process. The articulation of the information used and produced by the new GIS will form the foundation of the System Requirements document. As a result, discussion and documentation of data should be our starting focus.

For each dataset identified during interviews, document review or via questionnaires, a description should be prepared which summarises the characteristics of the data and their function. Information summarised in this process may be supplied by external agencies, produced and maintained by the organisation itself, or be derivative data created as part of some processing function. In very general terms, these data may be characterised as Inputs and Outputs.

The starting point for our documentation of data requirements should be the outputs, or the information products that our new GIS must produce. The following should be defined for each information product identified:

- Product Name: a simple descriptor of the output.
- Requested By: either the department or specific employee who identified the information product. This will allow the analyst to quickly determine who to contact for further details.
- Output Requirements: an example of the map or tabular output that the user or department requires. During interviews, users should provide the analyst with a sketch of the output they need the system to generate. If the output is a map, it should be clear as to the data layers necessary and the output scale. Figure **Klaida!**

Dokumente nėra nurodyto stiliaus teksto.-33 shows an example of a *Shellfish Closure Map* for our Shellfish Monitoring Branch implementation. This cartographic output is created for each area of the coast that is closed for sanitary reasons. These large-scale maps are then published and placed on a website to inform the public about shellfish closures.

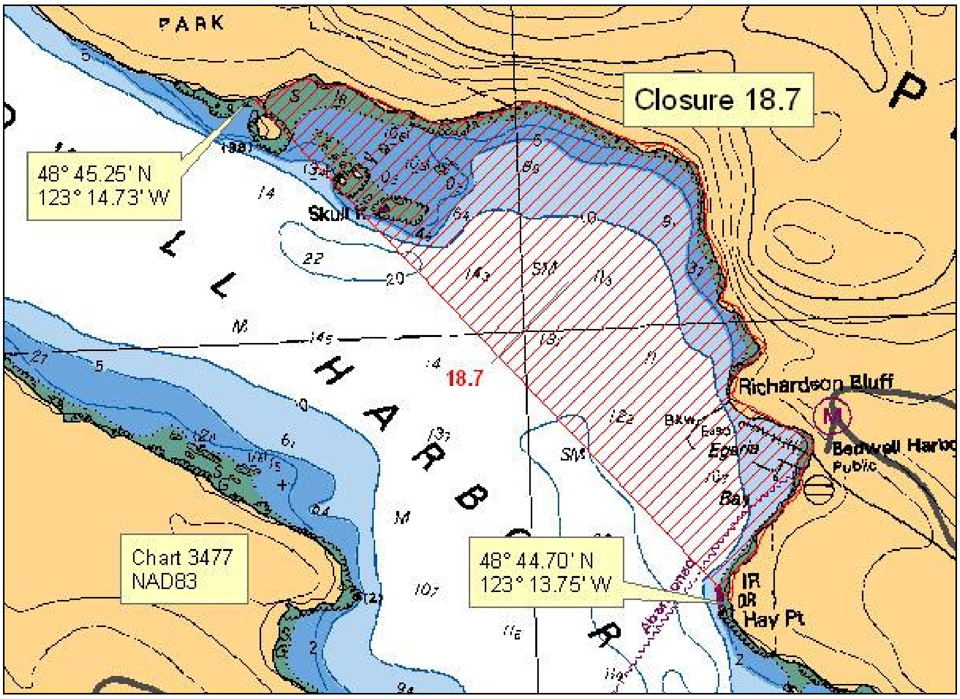

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**-33 Example *Shellfish Closure Map***

For tabular output, all necessary columns and calculations should be clearly represented. Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**34 shows an example tabular output *Marine Daily Report* required for our Shellfish Monitoring Branch. It shows sample values such as fecal coliform, salinity and recent precipitation amounts for a selected set of sample points. These are the samples used to determine whether each area of the coast is safe for shellfish harvest.

Marine Daily Report

REPORTING CRITERIA

***NOTE: Depth Samples are excluded**

***NOTE: Most recent 15 samples selected.**

Sector: QC02
Survey: All
Sample Type: Water
Tide State(s): High-Slack, Ebb, Low-Slack, Flood
Station(s): Include Stations from following list:
QC032,QC034,QC036,QC039,QC042,QC044
Fecal Coliform: The Report includes only values >= 0 and values > 43 are circled.
Time Period: All

Precipitation Criteria for:
Prev 24hr: All
Prev 48hr: All
Prev 72hr: All
Prev 5d: All

Sector	Station	Survey	Date	Time	Tide State	Depth (m)	FC/100ml MPN	Salinity (ppt)	Precipitation Amounts (mm) PREV 24hr	PREV 48hr	PREV 72hr	PREV 5d
QC02												
	QC032											
		1356	10-Aug-99	0940	Flood	0	2	32	-	-	-	-
		1356	09-Aug-99	1200	Flood	0	8	30	-	-	-	-
		1356	08-Aug-99	1355	Ebb	0	8	32	-	-	-	3.6
		1356	07-Aug-99	1325	Ebb	0	<2	31	-	-	-	13.9
		1356	06-Aug-99	1135	Ebb	0	2	31	-	-	3.6	13.9
		1356	05-Aug-99	1010	Ebb	0	2	32	-	3.6	13.9	13.9
		1356	04-Aug-99	1610	Flood	0	<2	31	3.6	13.9	13.9	13.9
		814	14-Jul-92	1500	High Slack	0	<2	32	0.8	1.6	1.6	7.6
		814	12-Jul-92	1340	High Slack	0	2	32	-	5.0	6.0	6.4
		814	10-Jul-92	0910	Flood	0	4	30	1.0	1.0	1.4	2.0
		814	09-Jul-92	0850	Flood	0	2	32	-	0.4	1.0	1.0
		814	08-Jul-92	0855	High Slack	0	<2	30	0.4	1.0	1.0	1.0
		452	27-Jun-90	1740	High Slack		350	30	1.0	1.6	1.6	1.8
		452	26-Jun-90	1705	High Slack		2	31	0.6	0.6	0.6	0.8
		452	25-Jun-90	1455	Flood		<2	31	-	-	0.2	0.2

Figure Klaida! Dokumente nėra nurodyto stiliaus teksto.**34 Example** ***Marine Daily Report***

- Frequency of Use: an estimate of the daily, weekly or monthly frequency with which this information product will need to be created. This information is very helpful in prioritizing development of the GIS.

  Our Closure Maps, for example, need to be generated as an entire set (one map for each closure), twice per year. There are approximately 300 shellfish closures, so the annual requirement for this function is 600 uses.

- Input Data Requirements: All information products will require some sort of input to be produced. In most cases these will be datasets that must be maintained and used to perhaps produce several information products.

  For each input, we will need to consider:

  - Does the organisation currently maintain digital data which may reasonably be used as an input for the information products? If not, do they exist in a form which may be converted to a useable, digital format?
  - Who is the custodian - are these data created and maintained by our organisation, or purchased from external agencies?
  - How current do they need to be? For example, can we still effectively use data that are two years old, or do the data need to be updated more regularly? Tied to data currency is data **volatility** – how quickly these data will become obsolete. Relief or elevation data, for example, will change very slowly in the vast majority of situations, but land parcels will change constantly.
  - What is the cost of updating these data, or purchasing regular updates?
  - What is the scale of these data?

For example, the *Shellfish Closure Map* requires the data identified in Table **17** to complete.

Table 17 Data Inputs for *Shellfish Closure Map* product

Input	Custodian	Update Requirement	Update Cost	Scale
Scanned Nav Charts	External (Federal Agency)	Annually	n/a Freely available under data sharing agreement	Variable
Closure Polygons	Shellfish Monitoring Branch	6 months	Low update cost due to low volatility and small number of closures. Est. annual cost: < $2,000	Variable – digitized using largest-scale Nav chart available for the area in question.
Planimetric Data	External (Provincial Agency)	Every 2 years	n/a Freely available under data sharing agreement	1:20,000

- Logical Linkages: Any connections between existing or proposed data structures or systems.
- Current Cost of Production: What it currently costs to produce what will be in future created using the GIS. This estimate is based purely on how long it currently takes to do the job, plus any necessary expenses. Create an annual cost estimate based on the one-time cost times the number of times this process is necessary during a year.

  As an example, consider the closure map shown in Figure **Klaida! Dokumente nėra nurodyto stiliaus teksto.**-33. A single map such as this must be created for each closure, twice a year. The process is currently labour-intensive. The correct digital navigation chart must be manually located, exported to a picture format such as JPG and brought into a drawing package such as Corel Draw. There the map will be created, but in the absence of real-world coordinates and distances. The closure polygon must be manually drawn, and where a radius from a point pollution source is involved (quite frequently), the distance must be scaled from the navigation chart manually and measured using drawing units. If coordinates are to be labelled, these too must be manually scaled from a navigation chart. Granted, closures which remain in effect for long periods need not have their corresponding map redrafted each year, but the process of creating a new closure is exceedingly slow. Taking this situation into account, an estimate of 1 hour per map has been made. Table **18** Costs Associated with Closure Map Production shows the annual costs which are based on this estimate.
- Projected Benefits: The estimated cost of producing the same deliverable using the GIS, plus any other less tangible benefits of using a GIS to perform the task.

  When producing this same product in the GIS environment, much of the time-consuming work will be eliminated. The selection and integration of navigation charts is automated, and measuring distances and coordinates in the GIS may take seconds. Realistically, one of these closure maps could be made in minutes, but to be conservative, 15 minutes has been estimated. This results in a cost savings of $11,250 per year.

There are other benefits associated with the move to GIS as well. One of the reasons the closure maps are created twice a year is that is impractical to create them more frequently due to the time required. If the time necessary is now one quarter what it was using a manual method, perhaps it is possible to more frequently update closure maps.

Table 18 Costs Associated with Closure Map Production

	Hours	Cost
Labour	300	$7,500
Materials		$0
Subtotal		$7,500
Number Per Year		x 2
Annual Cost		$15,000

The possibility of more frequent updating of closures may have far-reaching consequences. The public would have access to a set of closures which is based on more recent water samples, and would be less likely to consume unsafe shellfish. While it is rare that people die from shellfish contamination of the sort this agency monitors, it is common for people to become very sick. The potential for reducing public health problems and a corresponding reduction of costs in a public healthcare system, plus a possible reduction in legal proceedings due to contaminated shellfish make this a very attractive solution.

When studying data products and inputs in an Enterprise setting it is important to pay particular attention to movements of data between departments or offices. Many large organisations make use of similar basemaps on which to build their own thematic layers. For example, within city or regional governments, a land parcel map often forms the basis of other cartographic products and data creation efforts. Where this situation is true, the analyst should consider this duplication and ways to improve efficiency. For example, in one North American city government, the same land parcel map was being used and separately maintained in 17 different instances[1]. In such a case, changes to the parcel map were being repeated 17 times, and in all likelihood, many of these 17 versions would be in different states of update. Simply by designating a custodian responsible for the parcel base maintenance and effectively sharing this information among the 17 departments, data quality will be improved and less effort wasted on duplicated work.

4.2.3 Functional Requirements

To produce an information product, there must be some level of processing, or a series of steps necessary to produce the information. These steps may be considered the functional requirements of the GIS. Obviously, data and functionality are not such discrete things in a

[1] Dangermond, J., and Freedman, C. *Findings Regarding a Conceptual Model of a Municipal Database and Implications for Software Design*. In *Seminar on the Multipurpose Cadastre: Modernizing Land Information Systems in North America*, ed. B.J. Niemann, pp. 12-49. Madison: University of Wisconsin – Madison. Institute for Environmental Studies, 1984. As cited in Chrisman, 1997.

system as is implied by two separate discussions. In many analysis methodologies, the two will be considered together, but for the sake of clarity they have been separated here.

They are separated because there are cases where GIS functionality has no tangible output; it is simply processing which helps the user do things more quickly. In such a case, we have a functional requirement which is not formally tied to an information product. For example, in our Shellfish Monitoring example, it was noted that the scanned marine navigation charts used as a basemap are of variable scale. Areas of constriction or marine traffic congestion require a larger scale map than an area of the coast which is not subject to significant marine travel. As a result, coastal areas are represented at a variety of scales. One functional requirement of the Shellfish Monitoring GIS implementation is that the GIS should be able to determine the most appropriate chart to use as a backdrop from a potentially large number of overlapping charts of differing scale. This small application which implements the decision-making process and chart loading process is not part of the processing to produce any given information product, but is more an automation of a common manual task. This automation simply makes a technician's job easier.

Another reason to separate the discussion of data and functionality is that documenting or modeling of functionality and data are traditionally separate in systems analysis. The section following addresses these methods of documenting requirements. Functionality may also be referred to as **Behaviour** or **Processing** in other discussions of the topic. We will examine both types of functionality in this topic: processing necessary to create the information products identified earlier, and processing which is necessary to maintain data or applications, automate repetitive tasks, and any other functionality which produces no tangible output.

For each information product identified, the processing necessary to create it should be documented. A step-by-step description should be made of both the manual and automated tasks required to create the product. It may also be useful to document any dependencies between functions, or processing which is required to perform some larger task.

Examples of two functional definitions are presented below. Table **19** shows the steps necessary to select a set of Marine Sample Stations (locations where water samples are taken) using a Sector polygon (an administrative area).

Table 19 Example Summary for *Select By Sector* Function

Processing Step	Data Required	Functionality	Dependencies
User selects a Sector (administrative area) polygon	Sectors (administrative areas)	Select by Pick, or Attribute Query	None
User invokes Select by Sector function	Sectors Marine Sample Stations	Spatial Query	None
New selection set of marine sample stations is created from those samples within the sector	n/a	n/a	n/a

Table **20** shows an example of the steps necessary to create the information product *Marine Station Daily Report*. An example of this report appears in Figure Klaida! Dokumente *nėra nurodyto stiliaus* **teksto.34** Example *Marine Daily Report* above. This functional summary is of additional interest because it illustrates the idea of a function dependency. The *Marine Station Daily Report* is created for a set of selected Marine Station points. One possible workflow is to use the *Select by Sector* function defined above to make the selection of Marine Sample Stations prior to generating the report.

Table 20 Example Summary for *Marine Station Daily Report* Function

Processing Step	Data Required	Functionality	Dependencies
User selects one or more Marine Sample Station, either by station attribute query, select by pick, or select by sector	Marine Sample Stations Sector (administrative area) (optional)	Select by Pick, or Attribute Query	*Select by Sector*
User invokes reporting mechanism for selected Marine Sample Stations	Marine Sample Stations	Create Report	None
Marine Station Daily Report is generated	n/a	n/a	n/a

4.2.4 Modeling and Documenting Requirements

We have probably learned quite a bit about how our organisation works during our interviews, document reviews, etc. All of this information needs to be documented for review and to serve as the foundation of the design. Specifications need to be informal and understandable by non-computer scientists in order to allow for user validation, but at the same time documentation needs to also be precise enough to ensure that it unambiguously describes the business processes and data. All documentation should be in a domain-specific vocabulary, using terms and descriptions that are familiar to those within the organisation.

Thomlinson (2003) adopts notation similar to the tables identified above, and these can be pedantic and long-winded if they are to be detailed enough to clearly define the requirements. There is a saying in English that a picture is worth 1,000 words – the more we can represent graphically, the less must be written in words. Systems Analysts often use a more visual diagramming approach than we have been using so far. A set of models, or representations, are created to depict the user requirements. Different notations are used to describe data structures, software behaviour and user interaction.

Systems are complex and hard to understand. Models can make certain aspects more clearly visible than in the real system. They serve to express the ideas of the analyst, communicate with other people and to reason about the system (detect errors, predict qualities). Some computer-based modeling tools, such as Computer Aided Software Engineering (CASE), can even generate parts of the real system (programming code, database structures) when the design is complete.

We will look at several diagram types to assist in documenting system requirements. These diagrams are part of the Unified Modeling Language (UML). UML is a recently-developed (1997) standard notation that helps developers specify and document models of software systems. UML includes 12 diagram types, as summarized in Table **21**.

Table 21 UML Diagram Types

Structural Diagrams	Behavioural Diagrams	Model Management Diagrams
Class Diagram Object Diagram Component Diagram Deployment Diagram	Use Case Diagram Sequence Diagram Activity Diagram Collaboration Diagram Statechart Diagram	Packages Subsystems Models

There are far too many diagram types to effectively learn within the scope of this course. To allow students to get a sense of how these diagrams are used, however, we will investigate two of the diagram types in detail: Class Diagrams and Sequence Diagrams.

Class Diagrams

The most commonly-used diagram type, especially as UML relates to GIS technology, is called a Class Diagram. Class diagrams seek to model the characteristics of things in our database, and the relationships between them. An Object, in class diagram, is a concept, abstraction or thing that has meaning for an application. For example, in a GIS database, an object might correspond to a land owner, a water pipe, or an ecosystem. Object Classes are groups of objects that share common characteristics, or attributes. An object is an instance of an object class. For example, all land owners together are the object class Owners, and John Smith is an object instance within that class. The central thing in a Class Diagram is, not surprisingly, the Object Class. In an older notation called an Entity-Relationship Diagram (ERD), classes were referred to as Entities. You may still find ERD notation used, so this terminology is included for reference.

A class diagram delineates the classes and relationships which will be present in the completed system. A generalized class diagram is usually the starting point of an analysis phase. Classes are represented in a Class Diagram with a box, as shown in Figure **35**.

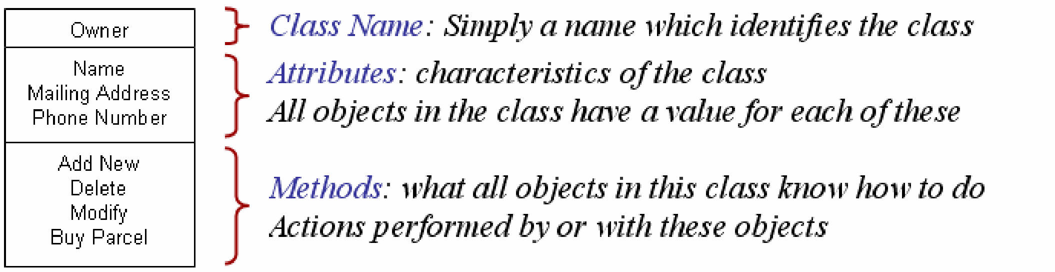

Figure 35 Class Symbol in the Class Diagram

The class box is divided into three panes. The top pane simply provides a name for the class. The middle pane holds any Attributes, or properties, of this class. Figure **35** shows example attributes of an Owner class, but similarly a Water Main class might have attributes such as Diameter, Pipe Material, and Date Serviced. The bottom pane holds any Methods associated with the class. These are actions that may be performed involving this class. To a certain extent, we can begin documenting system behaviour using methods. Methods are usually more of interest to programmers than database designers, since they end up being implemented using programming tools. It is common for early Class Diagrams to omit methods altogether and concentrate on describing the data. In such cases the bottom pane would be empty, or simply not part of the class "box". If you've worked with Object-Oriented programming before, you'll be familiar with the terminology for Object, Property and Method.

Relationships between classes are also represented using Class Diagrams. In UML any kind of relationship is called an **Association**, and is represented simply by a line between the two classes. The association usually has a name, so that it may be referred to in discussion, and a **Multiplicity**. Multiplicity defines the number of objects in one class that are related to those in another class. In an ERD, an association is called a **Relationship**, and multiplicity is called **Cardinality**. Figure 36 shows an example of an association between land owners and the parcels of land they own.

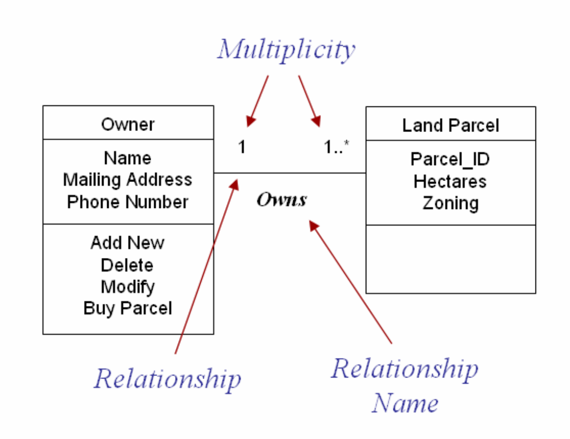

Figure 36 Relationship Symbology in the Class Diagram

The connection between *Owners* and *Land Parcels* is explicitly stated in the diagram using a line which connects the two classes. A meaningful name "Owns" unambiguously tells us the nature of that relationship. We know that this line represents the fact that a *Land Parcel* is "owned" by an *Owner*.

The complexity lies in the Multiplicity notation. The possible values for a multiplicity notation are presented below in Table **22**.

Table 22 Class Diagram Multiplicity Notations

Notation	Alternative Short Form	Description
1..1	1	One and only one

0..1		Zero or one
0..*	*	Zero to any positive integer; Zero or more
1..*		One to any positive integer; One or more
n..m		Any positive integer from n to m; More than one

The multiplicity of an association is read in two directions, which is why there are two notations on the association line between Owner and Land Parcel in Figure **36**. The association has the notation “1” on the left side, and “1..*” on the right side. If we read this relationship from left-to-right, we include the right-hand multiplicity (the “destination” multiplicity). Translating the 1..* notation to the English description in Table **22**, the association reads “Owners own one or more Land Parcels”. This explicitly states two things: owners have to own at least one land parcel, and owners may own more than one land parcel. The former restriction might be present simply because there is no point storing an Owner in our database if they do not own anything. The latter restriction accommodates owners of several land parcels. Reading right-to-left, we include the left-hand multiplicity notation (“1”), and it would read: “Land Parcels are owned by one and only one owner”. Note that the abbreviated notation “1” is the same as “1..1”. Again, this tells us two things: A land parcel must have an owner, and a land parcel cannot be owned by more than one person.

This is where the analysis of the Business Rules, or the way the organization works or processes data come into play. If the agency had a need to store owners even after they sell their last parcel of land (i.e., they no longer own any land), then the parcel (right) side multiplicity cannot be 1..*, since 1..* indicates that owners must own at least one parcel. We must change this notation to read 0..1 to accommodate the possibility that owners may own zero land parcels.

Similarly, if it were possible for parcels to be owned by several people, we need to make another change to the diagram. The owner (left) side notation can no longer read “1”. The one tells that each parcel is owned by one and only one owner, which is no longer true. We must change the multiplicity to 1..*, meaning that parcels still must have at least one owner, but more than one owner is permitted. One can see that very small changes to the multiplicities make a big difference to the types of situations which will be permitted in the final database.

Figure **37** shows an example of a more complex class diagram which might be applicable in a jurisdiction which is responsible for property taxes. It includes a new Class, called Assessment, which would include things which determine the value of the land parcels. It might store the type of assessment (land or improvements/buildings) and the resulting value. The multiplicities have also been changed for the Owns relationship.

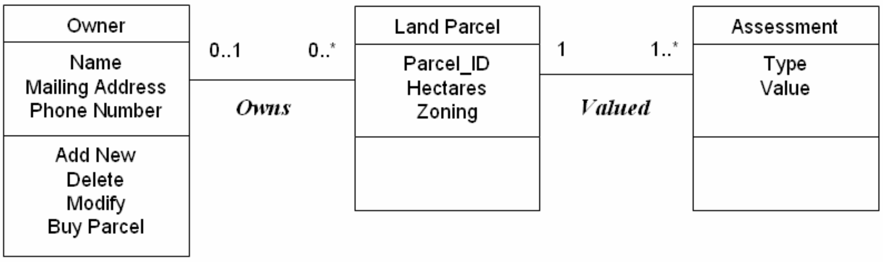

Figure 37 Example Class Diagram

To read this diagram, again we will have to read both directions, for each association. For this diagram, we will have 4 English interpretations of what this diagram tells us:

- Owners may own zero or more parcels; they don't have to own anything, but they can own several parcels.
- Land parcels may be owned by zero or one owner; parcels may have no owner (perhaps this represents government-owned lands), or they can have a single owner.
- Land parcels are valued using one or more assessments; every parcel must have at least one assessment value, but there may be several. For example, value may be determined by examining the value of the land itself, but also the value of any structures or other improvements to the land. A parcel with two buildings would then have three Assessment records: one for the land itself, and two more for the two buildings. A parcel always has at least one assessment record, because the land itself always has value even if there are no improvements.
- Assessments value one and only one parcel; a given assessment value can only be applied to a single lot.

You may have noticed that in both cases (reading left-to-right, then right-to-left), these notations told us two things: the minimum number of related instances, and the maximum number of related instances. These are called the minimum multiplicity and the maximum multiplicity, respectively. The minimum multiplicity is the number of the left of the dots, and the maximum multiplicity is on the right of the dots. Figure **38** shows the minimum and maximum multiplicities.

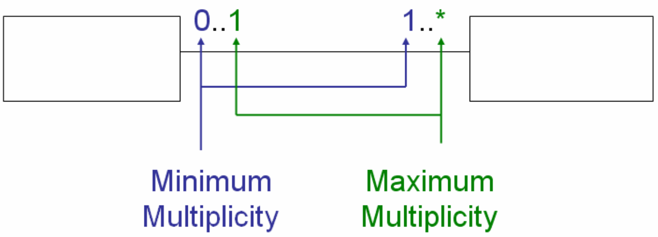

Figure 38 Minimum and Maximum Multiplicity in the Class Diagram

The minimum multiplicity can be thought of as a mandatory/optional flag. A minimum multiplicity of zero means that an object *doesn't have* to have a relationship with the other class. A minimum multiplicity of 1 means an object *has* to have a relationship with at least one instance in the other class.

The Maximum Multiplicity can be read to determine the broad categorization of the relationship. The three types of relationships encountered in data modelling are:

- **1:1** One to One
- **1:M** One to Many – can also have M:1, but it's functionally the same
- **N:M** Many to Many – may also be denoted as M:M

In the case presented in Figure **38**, the two maximum cardinalities are 1 and *, so we read this to be a 1:M relationship.

At this very generalized level of abstraction, we don't use any other values than 0, 1 and * for our multiplicities. Some students have asked how we represent the situation where we can relate one instance in one class to from 1 to 5 instances in the other class. This type of restriction is getting quite detailed – we'd handle this when we implement the database, and use what is called a *constraint* to force the maximum multiplicity (number of related records) to be five. At this level of abstraction, however, we are forced to state the multiplicity as 1..*, rather than 1..5. Remember, the data descriptions during the Analysis stage are meant to describe the business needs of the organization, not the needs of the database that data will end up being stored in. This generalized abstraction is called a **Logical Data Model**, and seeks only to describe the categories of information stored and the relationships between categories.

When we begin a detailed design of the data model, we will produce a **Physical Model**, which defines how the logical model translates into tables, rows and columns in the completed database. We will discuss physical models in the Design topic of this module.

<u>Sequence Diagrams</u>

There are a number of UML diagrams used to describe the interaction and behaviour of a new system. Many of these are based on the concept of a **Use Case**. A Use Case represents the steps in a specific business function. As it relates to the methodology discussed in this module, a Use Case corresponds closely to the steps to produce one of our Information Products. An example of a Use Case in a city government might describe the process of approving a property subdivision.

One method of documenting a Use Case is to create a **Sequence Diagram** for it. A sequence diagram graphically shows the classes (from our class diagram), the movement of information (called **Messages** in a sequence diagram) and the timing of events. It shows the sequence of interactions between people and the objects in the database. An annotated example of a sequence diagram is presented in Figure **39**.

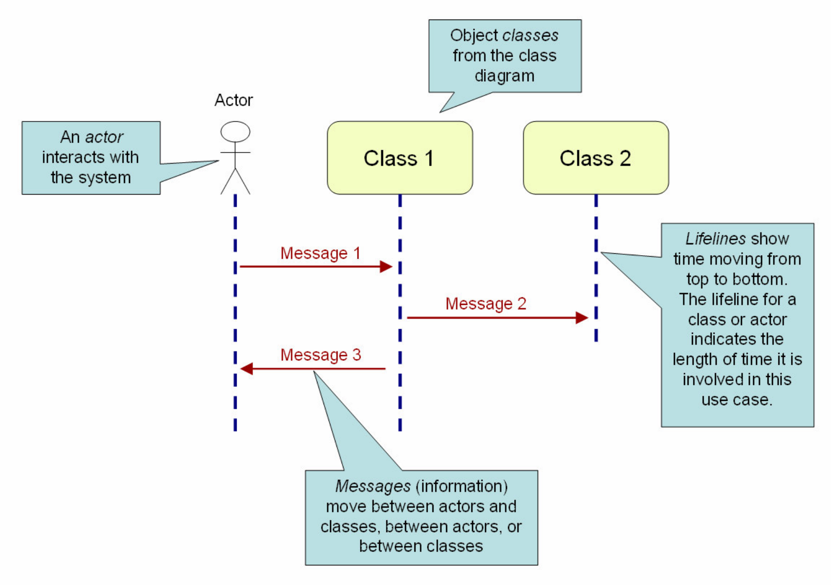

Figure 39 Symbology used in the Sequence Diagram

Sequence diagrams present those people and object classes involved in each use case along the top, generally with people, or actors, on the left and classes on the right. The diagrams then present the passage of time from the top of the page to the bottom.

The following elements are present in a Sequence Diagram:

- Classes: A class is represented as a rectangle with the class name inside, and drawn at the top of the diagram. Classes are the same as the classes we define in our Class Diagram.
- Actor: An actor is a person with a role to play in the Use Case. It may be a direct user of the system, such as a payroll clerk, or an external player who interacts indirectly with the system (by communicating with a user, for example). An Actor is given a role, which defines the capacity in which they interact with the system. Roles might include Database Administrator, Data Entry Clerk or Planner.
- Lifelines: A lifeline is a dashed line running vertically underneath an actor or class. It represents the time during which the object above it can interact with the other objects in the use case. Time flows from top to bottom, so messages higher on the lifeline occur *before* those below.
- Messages: A message is identified using a horizontal arrow identifying the sender and the recipient of information. The name of the message can describe the message intent or content.

As an example, let us examine our Shellfish Monitoring implementation. We could define one Use Case to be the process that is followed to create a new Shellfish Closure. Figure **40** shows the sequence diagram for this use case.

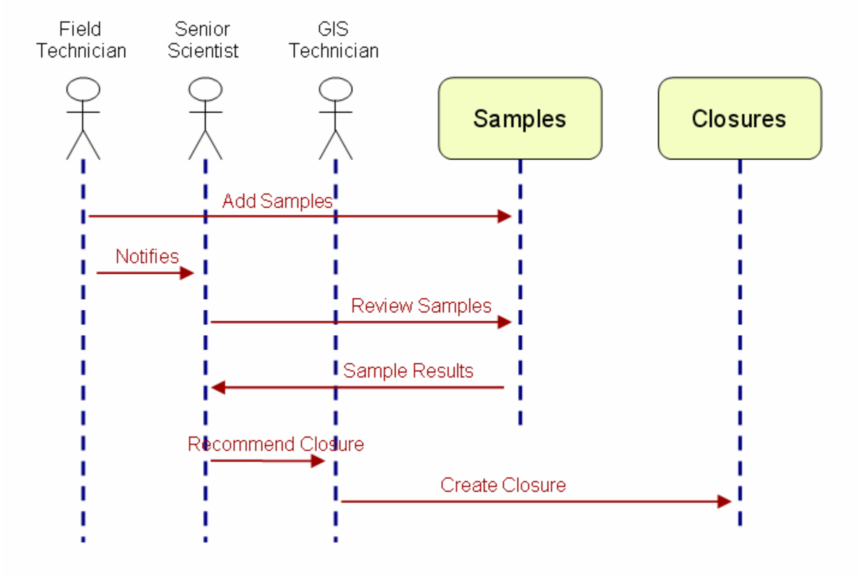

Figure 40 Example Sequence Diagram for the Shellfish Monitoring Example

Reading the sequence diagram, we can gain a reasonable understanding of the process. The first action taken (the top message in the diagram) shows the field technician entering sample value into the samples database upon return from collecting water samples in the field. They then notify the senior scientist (who makes final decisions regarding water quality safety). The senior scientist reviews the new samples, and if appropriate, recommends a new closure based on the findings. Where there is a new closure, a GIS technician is given the task of digitizing the new polygon. The interesting thing about this particular use case, is that there is almost as much communication between the actors as there is between actors and data classes. One can quickly see that this process is as much a procedural use case as it is an automation one.

4.2.5 Non-Functional Requirements

With our data, processes and products clearly documented, we can turn our attention to putting it all together in a single document, often called the **Requirements Specification**. Here we include the data and functional requirements we defined in earlier steps, as well as a number of non-functional requirements. Non-functional requirements are such things as data conversion, hardware and training.

Data Conversion

Depending upon the existing level of automation in the organisation, there may be a significant effort necessary to convert data into a form which is useable by a GIS. In city or regional governments, for example, much of the data will exist in paper maps, paper reports or files and digital databases which utilise a variety of formats and application software. In other cases, data inputs may be identified which are not currently utilised by the organisation. In all of these cases, the level of effort required to bring them all together in a useable form must be gauged.

The analyst should always examine any existing digital datasets maintained by external agencies, and the cost of purchasing such a product, as an alternative to doing the conversion in-house. The cost and accuracy of these data should be compared with alternatives for converting existing analog data to determine which means of acquiring the data will meet the accuracy needs and minimise cost and time of conversion. Keep in mind that even when data are purchased, they must often be reformatted or edited in some manner to make them useful. Include any necessary work required of purchased data in the decision process.

For example, consider the need most local governments have for land parcel mapping. Alternatives such as those in Figure **41** may exist, where the parcel mapping may be purchased from other levels of government (e.g., federal), existing paper maps may be converted via a fairly lengthy process, or parcels may be captured first-hand via field survey. In each of these, the cost and accuracy of the resulting data will be different. The appropriate alternative will depend primarily on the accuracy requirement for the completed land parcel database, as identified during the data requirements stage. If highly accurate parcel mapping is a requirement and the lower cost options of purchasing or converting do not meet the accuracy needs, then the time-consuming and labour-intensive method of field survey may be necessary.

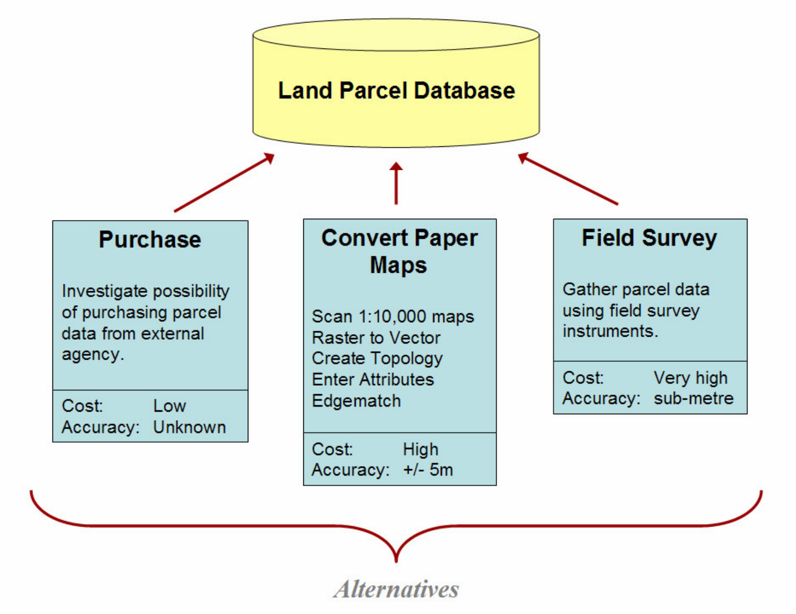

Figure 41 Possible Alternatives for Land Parcel Data

For each data input, then, a decision must be made regarding the most appropriate means of making the data available to GIS users. Considerations for choosing between data sources will include:

- Scale / accuracy (sufficient to meet requirements?)
- Spatial coverage (do these data encompass the entire geographic area of interest?)
- Conversion effort (How expensive will it be to acquire? Will it be necessary to have external contractors perform the conversion?)
- Currency (How old are the data?)

- Format (Are the data in a format that will be useable?)
- Representation (Are features represented as the appropriate type – point, line, polygon – to be useful?)

Once an approach has been selected for acquiring an input dataset, any necessary costs or processing steps should be documented.

Setting Priorities

Application development and data conversion can be expensive affairs. It is entirely possible that all of the information products and functionality identified by users during earlier steps may together cost more or take longer than we can accommodate. In addition, not all of the input datasets and processing functions can be created at once. Thus it is important to prioritise the data conversion and functionality to create both a definition of scope (what development is in or out of our implementation project) and an order of delivery.

Each requirement (either for information product generation, or for other system functionality) should be considered with many factors in mind:

- Relevance to the organisation's strategic goals
- Cost of function implementation
- Cost of acquiring the necessary input data
- Whether an alternative, less automated, process exists
- Whether several tasks rely on the same input data or processing and can be implemented together with minimal additional cost (data or function dependencies)
- Frequency of use
- Benefit to the organisation

For example, it was discussed earlier that the Shellfish Monitoring GIS implementation identified the need for the application to be able to determine which of several overlapping navigation charts of varying scales should be selected for display. This process could be performed manually, by viewing a catalog of chart extents, choosing the desired chart and manually adding the chart to the current GIS map view. While fairly time-consuming manually, if the task is not performed frequently it may not be worth automating. If this function is invoked every time a map is viewed, even a small decrease in effort for users will translate into significant savings. In this latter case this function would become a high priority for implementation.

One way to determine priorities is to create a scoring system based on those criteria which the organisation feels best reflect their business. If we were to incorporate all of the criteria listed above, a processing function which is central to the business, inexpensive to implement, having no alternative less automated method, is used frequently and is highly beneficial to the organisation would score the highest and would be placed at the top of the priority list. The results of the scoring method should be circulated widely for review before a final determination is made. A less quantitative method is to simply gather senior managers within the organisation, hopefully from all of the contributing departments, and work together to produce a priority list in a workshop format.

Requirements Document

The final step in the Analysis phase is to put all of the documentation we have amassed into a single document. This document would be suitable as a basis for issuing an RFP if external consultants are to do the system design, or as a reference document for an internal design process.

It will explicitly state the scope of the implementation, by including only those information products, functions and data conversion tasks which have been determined to be the highest priority and whose implementation will be funded as part of the current implementation effort.

4.3 Design

4.3.1 Introduction

Analysis focussed on what the GIS should do (the requirements). Design addresses how the system will be built. In the design stage, we will consider the target processing environment (e.g., hardware, software, database and network structure, user interface). Design takes the descriptions and models that were created during the analysis stage and creates models which represent the solution system. Design addresses more technical issues, and thus will require far less input from the future users. The result of the design stage should be a **Detailed Design** document.

The detailed design should address the following subjects:

- Database Design
- Applications Architecture
- Network and System Interface Design
- User Interface Design
- Hardware, Software and Staff Requirements
- Incorporation of Pilot Project results
- Cost-benefit Analysis

An Information Technology (IT) department, where present, should be included in this design stage, particularly in the planning of the network and perhaps in the database design and applications architecture. IT staff will have a firm understanding of the current technical infrastructure and configuration, and the expertise to help define what the finished configuration should look like. The depth of knowledge required to assess and design networks and system interfaces, coupled with the fact that these knowledge domains change quickly, make it unlikely that a GIS analyst will have sufficient knowledge to perform this part of the design effectively. It may be advisable to subcontract a company with significant expertise here, if IT expertise is insufficient.

Many issues are outside the scope of what can be effectively taught in this course, due to the specialized and quickly-evolving nature of the field. As a result, this topic will seek to provide an overview of the terminology and considerations at play. Students will not be experts in network configuration upon completion of this module. They should, however, have a firm enough understanding of the concepts and terminology that they can serve as an effective “bridge” between technical staff and the end-users of the GIS.

The goal, from a management perspective, is to have the Detailed Design clearly identify:

- What you are about to do
- How much it will cost
- How long it will take
- What your staffing requirements are

4.3.2 Database Design

In the Analysis topic, we discussed ways of documenting a logical data model. Here, we design the physical model – the tables, rows and columns which will become our completed database. For those not familiar with database terminology, a short introduction to the concepts and terminology of databases is presented here. These concepts will be discussed in detail during the course: *GII-05 – Geographic DBMS*.

A **database** is an organised collection of stored data that is centrally managed. Data stored in a database are arranged to facilitate efficient access and alteration. A **database management system** (DBMS) is the software that manages the information. The DBMS allows the creation, manipulation, and retrieval of information, and often manages security, backup and recovery functions as well.

The dominant database model in use today is called the **relational model**. The essential unit of a relational database is the *relation*, which is structured very much like a table. Since most database implementations make significant use of relational structures, we will concentrate our study on this model. Figure **42** shows the terminology for the basic elements of a database table.

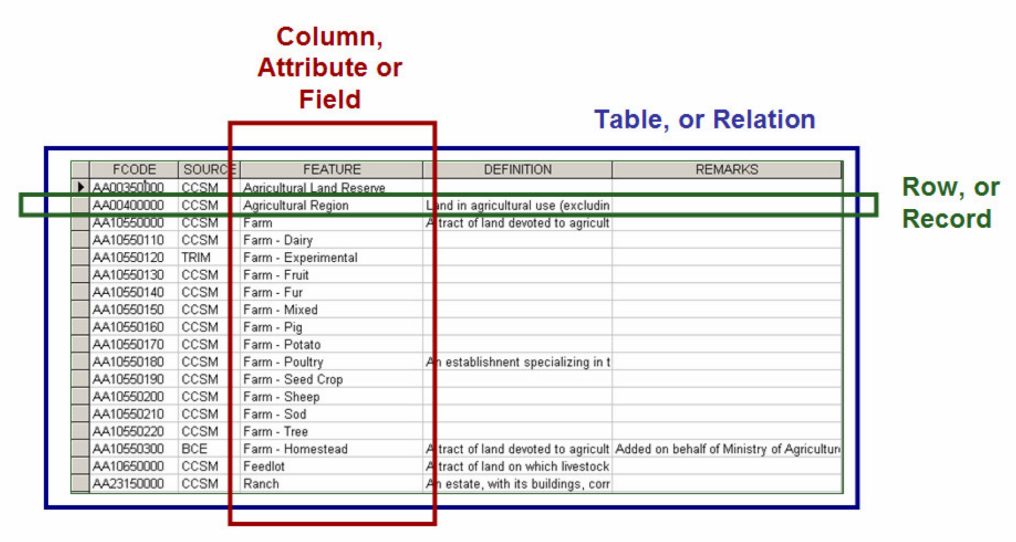

Figure 42 Terminology for Database Elements

Tables are used to store groups of similar things. For example, one table might store land parcels while another stores information about sewer pipes. A table may be considered to translate quite closely to an object class in the class diagrams we discussed in the previous topic. Also in our class diagrams were associations (or relationships) between classes. This is another responsibility of the relational database system; to manage the relationships between its tables. For example, the DBMS needs to manage the relationship between land owners and the land parcels they own.

When we create our database design, we will create what is called a **Schema**. A schema is the complete definition of the database, including descriptions of tables, attributes and relationships between tables. One could think of a schema as the database structure without all the data. Simply implementing a schema definition will create an empty structure in which to add our GIS data.

In our schema, we must define all the attributes for each table. Here we do not simply enumerate them, but define for each the **data type** (the type of information that will be stored in the attribute) and the **domain** (the range of possible values) of the attributes.

The data type of an attribute refers to what kind of information will be stored there. The simplest distinction would be whether an attribute will contain text or numbers. The data type is important because it ensures that efficient use is made of storage space. Databases encode numbers differently than text, so that a large number like 1,500,000,000 can be stored using 4 bytes of space, rather than the 10 bytes it would use if we stored each digit as a character. It also ensures that we can perform arithmetic operations on numbers, perform date calculations on date values, and scan text for patterns. If all information were encoded as a series of simple text characters, we would lose significant functionality. Most database applications (e.g., Oracle, Ingres, SQL*Server, DB2, MS Access) have slightly different data types, but all can represent the core, elementary types. Table **23** defines the general types of information all DBMS's will support.

Table 23 Generalized Attribute Data Types

Data Type	Range of Values	Storage Space Used	Example
Text	Text strings (words). Maximum string length may vary from one application to another.	1 byte per character	"John Smith"
Short Integer	Whole numbers from -128 to +127	1 byte	104
Integer	Whole numbers from -32, 768 to +32,767	2 bytes	12,453
Long Integer	Whole numbers from approximately -2.1 billion to +2.1 billion	4 bytes	1,233,420
Floating Point	Decimal numbers from -3.4×10^{38} to $+3.4 \times 10^{38}$	4 bytes	1,345,003.2345
Double Precision Floating Point	Decimal numbers from -1.0×10^{308} to $+1.0 \times 10^{308}$	8 bytes	1,234,567,434.123456267
Date/Time	Date values including time	8 bytes	December 15, 2006 11:32:03 PM
Binary	Complex binary structures storing encoded objects.	Varies by application	Images, sounds, etc.

The domain for an attribute is the range of possible values which may be stored there. For example, in a date field used to store the date a water valve was last serviced, the designer may wish to force values to fall within a given range which does not allow values which are impossible. For text values, we may wish to restrict data entry to a set of predefined values. An attribute used to store landuse might be restricted to the values "Residential", "Commercial" and "Industrial". Domains are useful for ensuring that values entered into our database conform to a reasonable set of possible values. This helps us ensure the integrity of our database.

Every table the database must have a way of uniquely identifying a single row. To accomplish this, each table has a **Key** – a field, or combination of fields, whose values occur only once in the entire table. Since the key value occurs only once, we can tell precisely which single row we are interested in. Examples of keys include student numbers, driver's license numbers and a courier document tracking number. Given one of these numbers, one could uniquely identify a single row or instance in a database.

Keys are important to relational databases because they are the means of implementing associations between database tables. For example, if we were to add a key from an *Owners* table to a *Land Parcels* table, it allows us to "look up" the owner of a parcel of land, since the owner identifier is stored right in the *Land Parcels* table for each parcel record. A key from one table that is placed in another to allow this "lookup" process is called a **Foreign Key**. In our previous example, the *Owner* key is a foreign key when it resides within the *Land Parcels* table. It allows us to determine which owner should be related to each land parcel. Figure **43** illustrates the connection between *Owner* and *Land Parcel* tables using a foreign key.

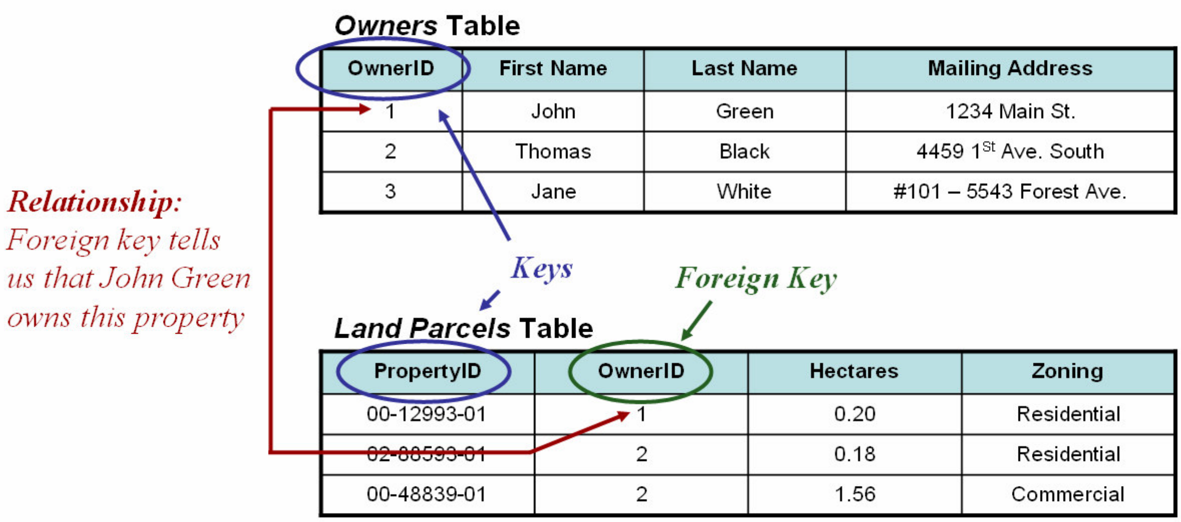

Figure 43 Illustration of Keys and Foreign Keys

The manner in which keys are stored within related tables as foreign keys varies slightly depending upon the type of relationship being represented, but the concept is universal within relational structures.

Finally, because this is a GIS implementation, we need to specify how each class of features will be represented graphically. This simply entails specifying Point, Line, Polygon or Raster for each table which will store spatial data, and an indication of the scale of the data.

Table **24** shows an example of a completed schema for a single class of features, or a single database table. It incorporates technical information such as data types and domains, but also descriptions of attributes and any relevant code values. This document serves as an overall reference for the database table.

Table 24 Example Schema for Land Use Data (Adapted from Province of British Columbia, 1995)

Dataset			Present Land Use
Type	**Scale**		**Description**
Polygon	1:250,000		Digital thematic map depicting Present Land Use at a scale of 1:250 000.
Attribute	**Data Type**	**Domain**	**Description**
TAGID	Long Integer	> 0	A unique polygon identifier associated with each Land Use polygon. The TAGID is a positive whole number. This value is the primary key used to establish the link between the polygons in the graphics file and their corresponding database attributes.
POLY_AREA	Long Integer	> 0	The total area of a Land Use polygon in hectares.
PERIMETER	Long Integer	> 0	The perimeter of a Land Use polygon in metres.
PLU_LABEL	Text (4)		A code representing the Present Land Use assigned to a Land Use polygon. This is primarily through image interpretation or image processing but may result from ancillary information such as base mapping or anecdotal knowledge.
		AGR	Land-based agricultural activities undifferentiated as to crop.
		ALP	Areas virtually devoid of trees at high elevations.
		AVA	Areas below the tree line that are devoid of forest growth due primarily to snow avalanches. Usually herb or shrub covered.
		BARE	Rock barrens, badlands, sand and gravel flats, dunes and beaches where unvegetated surfaces predominate.
		BURN	Areas virtually devoid of trees due to fire within the past 20 years. Forest less than or equal to 15% cover.
		EST	Salt water mud flats and intertidal areas at the mouth of rivers and creeks where the vegetation is influenced by frequent flooding (at least yearly).
		FO	Forest greater than or equal to 140 years old and greater than 6 meters in height. Areas defined as Recently Logged are excluded from this class.
		FY	Forest less than 140 years old and greater than 6 metres in height. Areas defined as Recently Logged (LOG) are excluded from this class.
		ICE	Glaciers and permanent snow. Depending on the date of imagery, ephemeral snow may be included in this class.
		LOG	Timber harvesting within the past 20 years, or older if tree cover is less than 40% and under 6 metres in height.
		MINE	Land used now (or in the past and remains unreclaimed) for the surface extraction of minerals or quarry materials.
		RANG	Unimproved pasture and grasslands based on cover rather than use. Cover includes drought tolerant grasses, sedges, scattered shrubs to 6 metres in height and less than 35% forest cover. Sparse forest stands are included with their understorey of drought tolerant shrubs and herbs.
		URB	All compact settlements including built up areas of cities, towns and villages as well as isolated units away from settlements such as manufacturing plants, rail

			yards and military camps. In most cases residential use will predominate in these areas. Open space which forms an integral part of the urban agglomeration, e.g. parks, golf courses, etc. are included as urban.
		WET	Wetlands including swamps, marshes, bogs or fens. This class excludes lands with evidence or knowledge of haying or grazing in drier years.
		WFRE	Fresh water bodies (lakes, reservoirs and wide portions of major rivers).
		WSAL	Salt water (oceans). Areas defined as the Estuaries land use are excluded from this class.
ELEVATION	Integer	0 – 9999	This is the mean elevation in metres above mean sea level and is based on the number of raster elevation values that fall within the polygon. This value is rounded to the nearest metre.
ELEV_MIN	Integer	0 – 9999	The minimum elevation in metres above mean sea level based on the raster elevation values that fall within the polygon. This value is rounded to the nearest metre.
ELEV_MAX	Integer	0 – 9999	The maximum elevation in metres above mean sea level based on the raster elevation values that fall within the polygon. This value is rounded to the nearest metre.
SLOPE	Short Integer	0 - 90	This is the mean of slope in degrees based on the number of raster slope values that fall within the polygon. This value is rounded to the nearest degree. (0° = flat, 90° = vertical)
SLOPE_MIN	Short Integer	0 - 90	This is the minimum slope in degrees based on the number of raster slope values that fall within the polygon. This value is rounded to the nearest degree. (0° = flat, 90° = vertical)
SLOPE_MAX	Short Integer	0 - 90	This is the maximum slope in degrees based on the number of raster slope values that fall within the polygon. This value is rounded to the nearest degree. (0° = flat, 90° = vertical)

4.3.3 System Interface and Network Configuration

Part of the design will address the mechanisms for moving information. The System Interface refers to the linking of the GIS with existing databases within the organisation. The Network Configuration refers to the manner in which information is shared between workstations, or between a central server and various client machines. The fundamental issue here is the understanding of where major datasets reside, where users of these data are located and how to connect them effectively.

In many settings, GIS is a relatively late addition to the automation of an organisation. Many local governments, for example, implemented software applications to assist with property taxation many years before exploring GIS implementations. In such a case, the parcel mapping stored within the GIS database as spatial entities may need to connect to, or “interface” with, this older, well-established taxation system. This might, depending upon user needs, be implemented as a fairly “loose” connection between GIS and taxation. Perhaps selected parcel attributes relating to land value are exported from the taxation system and imported into the GIS, to refresh land value attributes there, only once per year. Such a case is an example of one-way communication – information is taken from the taxation system to the GIS, but there is no requirement to move information in the other direction. Additionally, the infrequent nature of the update process may mean that efficient, automated processes are unnecessary. Existing import and export routines may be sufficient.

In our Shellfish Monitoring example implementation, the storage and analysis of water samples was accomplished using an existing database application. In this case, the GIS and the samples database had to function in a fairly integrated manner. Users wanted the ability to add records in the samples database by adding a point in the GIS, or to show sample points on a map in a manner which illustrated water quality found at that location from the samples database. This is an example of two-way communication between systems, and significant effort was invested in writing software which would move information back and forth between the applications. Efficiency also becomes important in this case, because unlike the taxation data example above, users were working with this connection interactively. They needed changes in one software application to be reflected in the other as they worked.

In the Shellfish Monitoring example, the ultimate goal was to integrate the samples database into the GIS at some future date, when additional funding was available. During the first phase of development, there was enough funding to ensure that the two systems could reasonably communicate, but insufficient to move all the data and functionality found within the samples database into the GIS environment. It is not uncommon for organisations, while investigating how they will allow applications to communicate, to decide that the most appropriate course of action would be to phase out the older system entirely and move everything into a more integrated data structure and operating environment.

As part of our detailed design, then, we will document the nature of the communication, including whether it is one- or two-way, the volume of data which needs to be moved between systems, the frequency of interaction and the response speed necessary. These will dictate how the communication will be accomplished. If software needs to be written to accommodate an interface, estimate the cost.

Networks allow users to access data which may be stored in several discrete locations. As part of the design, the nature of the network must be defined. GIS, by its nature, is quite different than many users of networks, in that databases tend to be massive and transactions may involve large amounts of data. These high demands upon a network may force updates to any existing network currently in place.

A **LAN** is a Local Area Network. LANs usually support high band-width communications over short distances. Data transfer rates of 10Mb/sec are most common. A **WAN** is a Wide Area Network. WANs support data transfer between locations which are geographically separated, and will often provide lower band-width communications. WANs make use of a variety of technology to move information, including telephone, satellite, and fibre-optic cable. The infrastructure for moving data is often leased from communications carriers such as a telephone network. Transfer rates vary widely, depending upon the method of connection, but transmission rates range from 56Kbps (dialup) to as high as 625 Mbps. The internet is an example of a WAN.

There are three models or architectures for distributed data handling. These are outlined below:

- File or database server, and client workstations: In this situation, data and any database applications reside on a central server. When the user performs analysis, the data are retrieved from the server to the client machine. Application software on the local, client machine does any require processing, and the results are presented on the client machine. This configuration requires that large volumes of data (particularly with GIS applications) be moved from the server to the client machine for processing, and is most effective where a high-speed LAN is present.
- Server application processing and terminal clients: Here both the data and the software applications reside on the server. When an analysis is done, the data remain on the server, the server provides the processing and the displayed result is sent to the client. The only transfers are the request from the terminal, and the display sent back from the server. As a result, this configuration results in very low bandwidth requirements, and may be appropriate where WAN bandwidth is insufficient to support the client-processing model.
- Web processing: Again, data files and applications live on the server, and the results are served back to web browsers via the internet. The resulting need for bandwidth is quite low. This configuration would be helpful if sharing data with a wide audience were more important than performance. It may require expensive server applications, and significant effort to customise the internet mapping functions.

In order to make an informed decision about necessary bandwidth, and an appropriate network configuration, each function identified in the requirements stage must be considered in light of how much data is involved and the processing intensity to solve the problem. Quantifying these things, and making an informed network decision will often require specific technical expertise which is beyond the scope of this course. Designers without significant training or experience in network architecture should seek professional assistance here.

4.3.4 Application Architecture

In software development projects, much of the detailed design effort will be expended on defining in detail how the software application will be constructed, and how the user will interact with the software. With GIS, however, much of the software and user interface work is done when a GIS software application is purchased. Remember, we're not writing GIS software, we're purchasing it and customising the applications and data structures to our needs. As a result, there is seldom a need for a detailed module-decomposition or pseudo-code (techniques for designing programming projects). Many GIS customisations or applications will be simple enough that a description of their inputs, function and outputs (as have been defined in the requirements document) will be sufficient.

There will often be a series of automation tools – software which will help string together a series of manual interactions with the GIS software into a faster, more easily run process. There might also be a need to extend the functionality of the GIS for some specialised task. The design must define how these tools will be developed. GIS customisations or automation tools might take the form of:

- Scripts, such as Python or ModelBuilder, which string together existing GIS functions. This architecture would be effective where a series of analytical steps (such as attribute query, overlay and clip) are necessary to produce a given information product. When this process is performed manually (i.e., the user initiates each analytical step, in order), two problems arise. First, it introduces the possibility for error, since users may omit a step or perform steps in the wrong order by mistake. Second, if small refinements are made to the analytical steps (e.g., changing a buffer width), it can be time-consuming and confusing to go back and regenerate intermediate results from part way through the process. Automating a series of analytical steps may not provide significant gains in performance, but it does make the analysis repeatable, easily modified and self-documenting (since the script itself documents the processing steps).

Scripts may also be useful for running batch processes, where the user wishes to perform the same set of steps on a number of data files (all the files in a folder, for example).

- Software written to run as part of an external, non-GIS application, such as code written in the Shellfish Monitoring samples database so that it can communicate with the GIS. This approach is often dictated by the system interface requirement and the interface tools and capabilities of the other system. Frequent, two-way communication between the GIS and an external system will require programming effort to implement. In some cases, programs written on the GIS "side" cannot effectively manipulate data in the external system from outside the application or database. In such cases, software must be written from within the external system to communicate in some manner with the GIS.

  For example, an external application which utilises common database applications, such as MS Access or Oracle, to store its application data will most likely not require new procedures to be written within the external system. The interfaces are well-developed and comply with Open Database Connectivity (ODBC) standards, and it is a relatively simple matter to retrieve or manipulate data in such applications from external programs.

  Applications which are highly specialised, and perhaps utilise a proprietary data format, cannot likely be accessed and manipulated by other programs (like the GIS). For example, perhaps a city engineering department uses a small, PC-based application to manage its road maintenance. The program is purchased from a 3rd party and stores its pavement management data in an unpublished file format. In this case, we cannot write code within the GIS to examine the pavement management data, because there is no standardised interface, and the file format is not documented. We must rely on the customisation tools, or the export functionality, of this pavement management system to provide the connectivity with the GIS.

- Small programs imbedded in the GIS application itself, such as those created using Visual Basic for Applications (VBA). This approach is the "middle ground" between a scripting solution as described above, and a more complex programming solution (described in the bullets following). In general, VBA would be used where the automation process is too complex for a scripting solution or where a built-in analytical tool does not exist for a specialised task. VBA may also be used to create custom interfaces (buttons, forms, etc.) and toolbars within the GIS to keep commonly-used functions together and easily accessible. Such solutions are often called **Macros**.

  A good example of this is the Shellfish Monitoring application's requirement to choose the most appropriate navigational chart from among several overlapping charts of varying scale. To do this, a program must examine how big an area the user is currently viewing (the view extent), and compare this with the extents of each raster chart. The largest scale chart which fully covers the current view extent is selected.

If the ability to extract the current view extent is not one of the pre-written processing functions (such as clip, overlay or buffer), this application cannot be implemented as a script. However, it is a very simple matter to write a VBA application which implements these processing steps. Here the code can be written as part of the GIS environment, such that a user simply clicks on a button and the most appropriate navigational chart is automatically loaded.

- Programs written in an external application development environment. Here, software is written using an environment such as Visual Studio, using a language such as Visual Basic .NET or Visual C++. Any programming language which supports the Microsoft Component Object Model (COM) may be used to write applications for the GIS. There are no limitations on functionality in this architecture. The result of such a programming effort is usually an ActiveX DLL (Dynamic Link Library) which may be loaded and run from within the GIS application. The application is externally compiled (to create the DLL), so the application source code is protected and cannot be viewed or changed by users. Such an application may be easily distributed and installed by end-users using a custom setup program.

The choice of programming language, development environment and the method of integration with the GIS application itself is often referred to as the **Application Architecture**. Designers must consider the necessary processing steps to be applied to choose the most appropriate architecture for a given processing function.

4.3.5 User Interface Design

In addition to how the programs will be developed, designers need to consider how the programs will interact with the user. This is called the **User Interface Design**. Older programs interacted with users using a series of typed commands, while most windows-based programs now make use of mouse interaction and controls such as buttons, textboxes and tickboxes. An example of the different types of controls in a user interface is shown in Figure **44**.

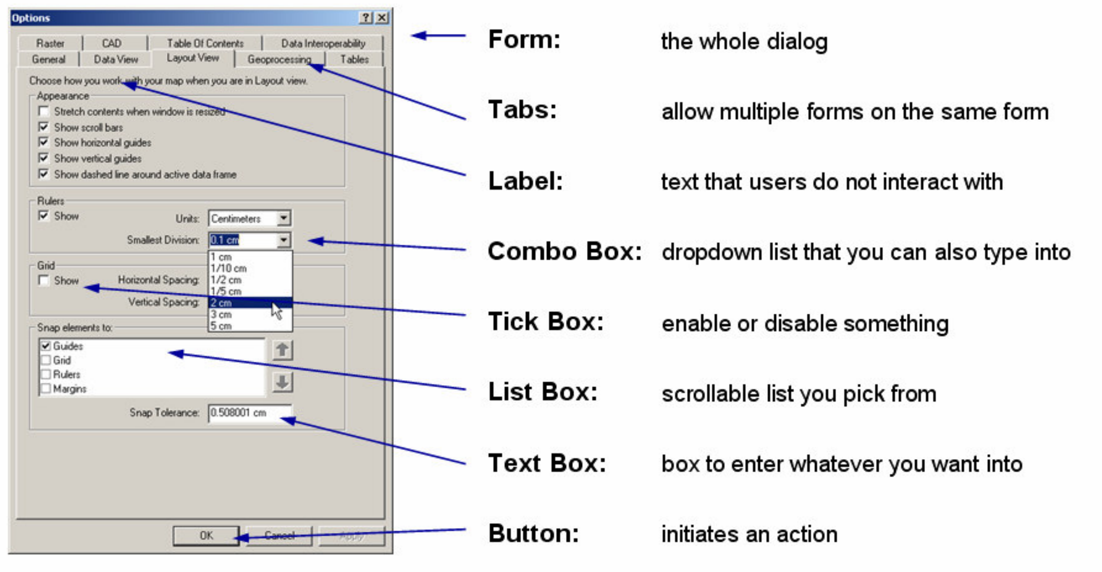

Figure 44 Types of User Interface Controls

It may not be necessary to define as part of the detailed design precisely what the interface will look like. For example, the designer would not create images showing what every form and control was going to look like. By leaving these details to the developer, it provides him or her with the necessary flexibility to complete the application.

It may be helpful, however, to translate the processing function requirements (e.g., a set of step descriptions, or a UML Sequence Diagram) into a user interface “flow”. For simple programs with very few forms, a basic diagram showing arrows between forms to indicate user navigation is sufficient. For more complex programs, a more detailed diagram might be necessary. For example, the interface for the Shellfish Monitoring GIS implementation is shown in Figure **45**. It shows the different types of user interactions (menus, forms and map interactions), and arrows show movement between interface objects.

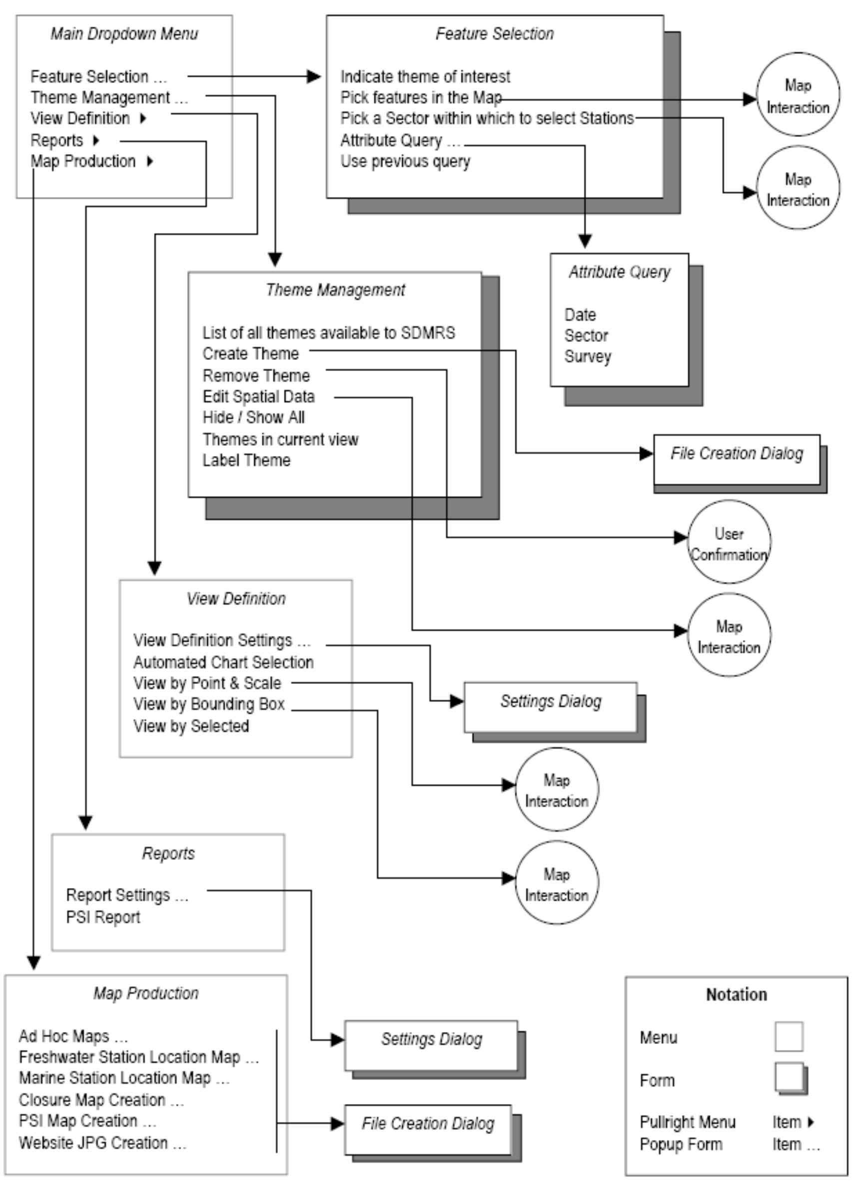

Figure 45 Example User Interface Design

4.3.6 Resources: Hardware, Software and Staff

At this stage of the planning, the design team should have a good sense of the resources necessary for both the system construction, and the post-implementation, "up-and-running" environment. The user community and the processing requirements of each user should be well-understood.

Hardware

Thomlinson (2003) recommends classifying each processing function from the requirements as requiring high intensity or low intensity computing. The concept is to develop two hardware configurations to match the two levels of processing intensity and make the selection of hardware a simpler process. High intensity requirements might be for those tasks involving either high data volumes (e.g., a calculation which requires examination of an entire dataset), or significant processing power (e.g., 3-dimensional modeling of terrain, or models involving a significant number of geoprocessing tasks). This configuration might require a fast processor and plenty of memory. GIS applications are heavy users of memory because of the large volume of data which must be displayed at any given time, and lack of memory is often the cause of poor workstation performance. If unsure, always choose more memory than you think you will need. Lower intensity requirements might involve data browsing (e.g., a machine used to answer public enquiries involving small amounts of data) or data editing (e.g., updating to attributes or spatial data). Such a configuration might require a less powerful processor and less memory. For those viewing and editing spatial data as a large part of their daily work, it is perhaps most important to include a large, high-quality monitor. In fact, many data editing stations make use of two monitors.

As part of the Analysis phase, we estimated the cost of creating each information product in the current manner, and the cost of creation using GIS. Both of these cost figures rely mostly on the time necessary to create the product. We can make use of this time estimate to get a sense of how many workstations will be required to perform the business functions of the organisation. Sum the total processing time for each task (including the frequency of use information) and group these total times by the high or low intensity of processing classification. This should give us a figure which represents the minimum number of workstations of each type required to perform the work.

Obviously this represents the barest minimum of hardware, because we do not want employees having to “line up” to use workstations, nor would staff find this an effective use of their time. This minimum figure will, however provide us with a reasonable starting point or means of validating our hardware estimates. With our staffing estimates, we should be able to estimate the maximum number of workstations necessary (i.e., one workstation per staff member participating in GIS functions).

Organisations will undoubtedly have some level of computerisation when the GIS implementation begins. Some workstations will be of acceptable performance to serve as GIS clients, and in these cases new hardware will not be necessary.

Estimating the requirements of file servers is a far more specialized task. The designer can likely gather information which will help in this assessment, such as estimates of data volumes, and response requirements, however the recommendation of specific hardware to meet these needs may require external assistance from consultants or an IT department. Estimating data volumes may be difficult without actually converting some of the data and observing the result. This will be done as part of the Pilot Project, described below. One of the main benefits of the pilot is to validate estimates such as data volume.

<u>Software</u>

Selecting the best software for an organisation can be a difficult task. In the past, GIS software applications tended to be quite different in philosophy and capability. Certain GIS vendors specialized in raster or vector analyses, or in specialised application areas such as surveying. To a certain degree, competing GIS software applications now have roughly the same functionality, with the underlying data structures and the user interface being the most significant differences. The decision regarding software is perhaps less critical today because of this. However, the designer should still exercise diligence regarding the software choice.

The most important means determining appropriate GIS software is to compare the functionality, performance and data products identified in the requirements to the capabilities of each competing software package. The application which best suits the needs of the organisation, particularly those identified as high priority, should be the leading candidate for selection.

Other significant contributors to this decision-making process will be neighbouring jurisdictions or agencies who have already implemented a GIS. They may be able to provide advice relating to the software they have purchased, and whether they felt this was a good choice or not. Discussion of their successes and failures can help with your decision-making. It might also be helpful to consider the degree to which data and expertise is currently, or is likely to be, shared between your organisation and these other jurisdictions. Adjacent City governments frequently share community planning, emergency response and land survey information, for example. If this is the case, it will be extremely helpful if both jurisdictions have the same GIS software. This does not guarantee that your functional requirements will be met, so the requirements should always be considered, but it will make data sharing easier and facilitate a sense of "user community" between the two (or more) jurisdictions involved.

Another means of evaluating different GIS software applications is to embark on a competitive process. You may wish to create an RFP from the requirements document, and request competing bids for the software installation and perhaps some of the implementation work, if appropriate. An organisation can get vendors to put forward their case as to why their software would be the best choice, and also get a very clear idea of implementation costs. A more in-depth competitive process is called **Benchmark Testing**. In a benchmark test, vendors come into the organisation and perform a series of tasks using the real datasets and their software to demonstrate its capabilities.

Your ability to attract competitive bids will be a function of how large an implementation you are embarking upon. Writing proposals and participating in benchmark testing costs the vendors money, so they will be unlikely to participate unless the potential sale is large enough. A $10,000 implementation will probably not even attract a proposal. A $100,000 implementation will receive proposals, but may not persuade vendors to participate in a benchmark test. If the implementation is very large, perhaps reaching millions of dollars in expenditure, vendors will be willing to make the investment in all manner of tests.

Staffing

Part of the detailed design should address the staffing or training needs for the implementation. The designer needs to look at the existing staff and their current capabilities, and compare that with the short- and long-term staff requirements. Short-term requirements will emphasize GIS developers; the programmers, analysts and database experts who will actually build the GIS. In the long-term, it is likely that the need for developers will decline, as the applications move into a state of maintaining existing applications and data structures, and making minor new additions, rather than a state where the organization is actively creating new applications. In the long-term, the focus should be on having a well-trained user community that can efficiently use the GIS to perform their daily tasks.

Where existing staff do not meet the expertise requirements for either the development or the long term maintenance, an organization has several choices:

1. Hire new employees: Where the skills and job descriptions are so radically different than those already in existence, an organization may wish to define and fill entirely new positions. This is particularly true for long-term needs where no such role existed before. A good example of this might be a GIS Programmer. There will always be a need to maintain the software applications and automated processes that were created as part of the implementation, and a small number of new functions should be anticipated. Depending upon the skills of existing employees, there may also be a need for GIS Managers, GIS Database Administrators and GIS analysts.
2. Contract out: Where the need is in the short-term only, such as during the implementation phase, it may be wise to hire consultants or contractors to assist. Consultants can typically mobilize a large development team faster than an organization could hire and orient their own staff. In addition, the use of consultants is a common way to redirect risk. As we have seen in the project management module, hiring contractors is one way to mitigate risk by simply having the consultant assume it.
3. Train existing staff: Where there is a long-term need for skills which do not currently exist, training can be an effective choice. This will be the case with virtually all of the users of the new GIS, since very few will have had direct experience similar technology. Training existing staff is the best choice here, because the existing staff already know the business and procedures, all they need to understand is how to translate that into using the GIS to accomplish things with a slightly different workflow. Training may also be effective if staff have similar training and require little training to bring them into the GIS arena. An example, surveyors and engineers commonly have experience with Computer-Aided Drafting (CAD). Often such experience translates easily to GIS, and significant training will not be required. Another example might be a Database Administrator currently in the IT department. Such a person might require a small amount of training to learn the specific needs of a GIS database.

All staffing requirements and decisions regarding how requirements will be filled should be documented as part of the detailed design document, for both the implementation stage and for the long-term use of the GIS.

4.3.7 Pilot Project

Once our system design is complete, we still face significant risk. Our estimates of the effort required to convert datasets or write applications may be flawed, our assumptions about database size and network loads may be incorrect, and our database design may not accommodate all the necessary analysis. A **Pilot Project** is a means of reducing this risk by validating our system design. It is a trial run of our design using a subset of the full implementation. Usually the pilot will implement a subset of the information products or functionality, and a subset of the spatial extent – usually geographically small in comparison to the entire implementation.

To a certain extent, the pilot is an exercise in trial-and-error. It is better to find problems with the design or assumptions on a small-scale project than after the entire project is complete. The pilot allows us to refine our design and estimates using the things that were learned during the pilot project. A good proportion of the pilot may serve as “Phase I” of the overall implementation, but do not plan for it. Assume much of the pilot will be discarded to avoid underestimating the level of effort required.

The pilot project serves many purposes:

1. Validate the Data Model: It verifies that the database structure we have documented will meet the needs of the organisation. The pilot will verify the ability of the database to support the functions outlined in the needs assessment, evaluate the performance of the data storage mechanisms (both the physical table structures and the file systems and server), and allow users to gauge the ease with which you can interact with the database and create new structures and data.
2. Validate Estimates: The pilot allows us to measure the actual time expended on tasks such as data conversion and programming, and to extrapolate to the larger system. This will significantly increase confidence in our ability to estimate the coming level of effort. We can also measure the resulting network traffic or system response time, to ensure our estimates in this area are accurate as well.
3. Showcases New GIS capabilities: Simply demonstrating that the GIS can accomplish the tasks and create the products defined in the requirements can effectively show progress and instil confidence in the development effort. The results of the pilot can be used to raise a level of anticipation with the project team, and those departments which will be using the GIS. The GIS team should have demonstrations ready to go, post plots and diagrams on walls and generally be prepared to show interested parties the progress made. Choosing a well-considered pilot composition may help gain the support of influential individuals or departments.
4. Speeds Up Development: Experience gained in the pilot will speed the implementation of the main project.

As with any project, we need to define the scope of the pilot project before we start. The goal is to make the pilot as representative as possible of the various tasks for which the GIS will be used. Keep in mind that we are not implementing the entire system; we need to pick a fairly small subset of the overall functionality, but one which tests as much as possible of the completed system. Try to concentrate on input data and attributes which support the very high priority functions, and those which will help evaluate spatial accuracy (such as survey monuments). Where possible, choose geographic areas or functions which are high-profile in order to better raise the awareness of the project and maintain a level of excitement about the new technology.

During the pilot project, ensure that procedures, decisions and results are documented. Maintain clear records of:

- Problems encountered during data conversion or application development
- Solutions to problems, recommendations or decisions taken
- Tests which were run (perhaps performance or data quality measurements) and their results

At the close of the pilot phase, two primary things should happen. First, any findings which result in changes to the design or estimates (budget, time, performance) should be incorporated in the design documentation. Second, the basis of a Procedures Manual should be developed which outline the most effective way to perform many of the development tasks. The pilot will teach many lessons, and these should be documented.

The final step in the pilot phase should be a review and signoff. Senior management should have an opportunity to view the completed pilot and observe many of the processing functions "in action", but also to review any modifications to the system design. They must confirm support of the ongoing development effort.

4.3.8 Cost-Benefit Analysis

With a detailed design complete, we now have enough information to estimate the total cost of our implementation with some confidence. Costs of implementation will include:

- Hardware
- Software (including annual maintenance after initial purchase)
- Salary of any new staff hired specifically to manage the GIS
- Cost of converting or purchasing all input data
- Cost of developing any custom automation tools or system interfaces
- Cost of any new server/network hardware, plus installation costs
- Cost of any new facilities necessary to house GIS equipment or staff

During the Data Requirements portion of the Analysis stage, we quantified the benefit of automation by comparing the current cost of producing each information product with the estimated cost using GIS. Adding the net benefit of each of these automation tasks together estimates an annual benefit to the organization. Where other automation benefits can be quantified, include these figures in the total benefit figure.

By comparing the total costs to the total benefits, one can gain an understanding of when the organization can expect to realize financial gains, and what level of benefit they will experience.

For example, the Shellfish Monitoring agency is performing a very small implementation. There will be some small expenditures in the first year, including the preparation of an RFP and selection of a consultant. Once development begins, there will be costs of $120,000 each year for two years, including GIS software purchase, network upgrades, data conversion and application development. Once running, however, only part of one position will be devoted to maintaining the system, and annual software maintenance will be paid. The total benefits were calculated to be $77,000, based on the information product cost-benefit analysis. Recall that the Closure Map creation alone realized an annual savings of over $11,000.

Table 25 Cost-Benefit for the Shellfish Monitoring Implementation

Year	Cost	Benefit
2005	$ 20,000.00	$ -
2006	$ 120,000.00	$ 45,000.00
2007	$ 120,000.00	$ 77,000.00
2008	$ 30,000.00	$ 77,000.00
2009	$ 30,000.00	$ 77,000.00
2010	$ 30,000.00	$ 77,000.00

If we plot the cumulative costs and benefits together, we can see several things about the finances of the GIS project. Expenditure rises steeply, due to the cost of converting data and building applications early in the project, but flattens quickly once implementation is complete. Benefits are not really felt until two or more years into the implementation, but once implementation is complete, they continue to accrue annually. In the case of this implementation, benefits overtake costs in year six, only three years after implementation is completed.

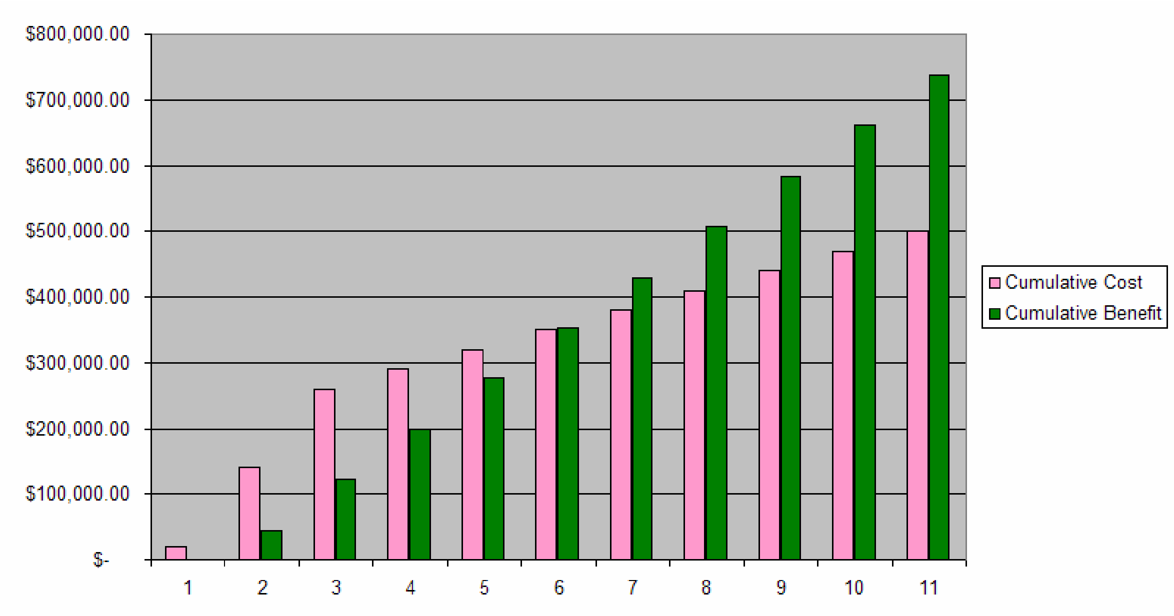

Figure 46 Cost-Benefit Graph for the Shellfish Monitoring Implementation

4.3.9 Conclusion

The result of all of this planning should be, as we have discussed, a Detailed Design document. This document summarizes all that we have discussed in this module and have learned during the analysis and design phases. We will define data structures, applications we will build, and the manner in which the data will be converted to fill our databases. We have defined the hardware, software and communications configuration. We have defined training necessary for existing staff, and any new positions which will be necessary.

In addition, this document should define the budget and timeline for all of these activities. We clearly understand the scope of what we are about to embark on, so we should be able to apply the techniques examined in module 2 to plan for the construction of our GIS.

Implementing an Enterprise GIS is conceptually a simple task, but the volume of details is what makes it difficult. Clear documentation and rigorous planning can help ensure that many of these details are not overlooked. As we have seen, the range of expertise required to understand and document areas such as databases, programming, human resources, network configurations and hardware is staggering. For this reason, implementation of a GIS is best accomplished with a team of experts. It is unlikely that a single person can effectively define solutions in all of these areas.

The core of the analysis and design process is documentation. In the course of this module, over 20 figures and tables have been presented, and we have really only looked at examples for a small number of the information products and modeling techniques. The documentation for a large GIS implementation can be huge. Sharing this information among the development team and ensuring that this documentation is safe are critical to the success of the endeavour. It may be helpful to use document management software, a database or web pages to share and safeguard these documents.

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5 Module 5: Data Management

GIS data are different than other manufactured goods in that one cannot necessarily judge their quality or applicability by their appearance. There is often an inherent belief that if a computer produces something it must be correct. GIS is capable of displaying data in a very pleasing way which may hide problems with them.

The term **Quality**, when used as an adjective to describe an object, has a variety of definitions whose general thrust is a lack of defects or problems, or a conformance to requirements. It is thought of as a good thing. We might define it as the “degree of excellence in a product, service or performance” (Veregin, 1998).

When applied to data, as in **Data Quality**, the term refers to how effective a dataset is for its intended purpose. Heywood (2002) defines data quality as “overall fitness or suitability of data for a specific purpose or … data free from errors or other problems”. Certainly datasets that are free of errors and suitable for our purpose are both valuable and useful to our organisation.

It has become widely accepted that better and more informed decisions are being made due to the use of GIS. Access to spatial data and analytical tools has meant that more decisions are being supported by GIS applications. However, decisions made on the basis of incorrect data are probably less valid than a decision made based on incomplete data and a number of assumptions. Decisions made in the absence of information must at least state assumptions and limitations. In English, there is a saying, “Garbage In, Garbage Out”. The meaning is very simple in the context of GIS: if you use inaccurate or incorrect data as an input to an analysis, the results of the analysis will also be inaccurate or incorrect. Even more simply put, the results of an analysis are only as good as the quality of the input used to create it. If we are to have any confidence in our analytical results, we must understand the level of error in the inputs and have a sense of what happens to these error levels during the necessary processing steps.

One could think of data quality in terms of a cost-benefit analysis. When making use of GIS, we often compare the cost of hardware, software, data and training to savings realised by increased efficiency and better decisions (see also Module 4, Topic 3). If business functions are not efficient or decisions are being made on the basis of poor data, the benefits of GIS cannot be seen to offset the costs.

Increasing the quality of GIS data typically increases the cost of data collection. One of the most important tasks for a GIS manager is to determine a suitable compromise between cost of collection and quality of data. Poor data structures and incorrect values can make even simple tasks such as locating data very inefficient, and inaccuracies can make business functions more costly. For example, consider the collection of locations for underground infrastructure such as water pipes, sewers, or other utilities. The cost of collecting these locations with high levels of accuracy will be expensive, and will often involve field data collection. However, significant savings may be delivered during maintenance. Sending repair crews to dig a very small hole in the correct place is far less costly than digging a large hole searching for a pipe or digging a hole in the wrong place. Additionally, there will be less interference with other properties, traffic flow and nearby utilities. The costs of incorrect decisions range from the trivial (e.g., sending an announcement that water service will be interrupted to the incorrect homeowners) to catastrophic (sending an ambulance to an incorrect address, perhaps resulting in loss of life).

Coupled with the costs associated with poor quality data is the increased probability of encountering error-related difficulties. The increase in data production in the private sector and the increase in data sharing between agencies has meant that in many cases data being used by an organisation were not prepared internally. The conditions and procedures surrounding the collection of secondary data may not be known, which casts uncertainty upon any analyses which make use of such data. Accuracy requirements are dependent upon the application, and increased data sharing will mean an increased probability that data will be put to a use which is significantly different than the intended application. Without a firm understanding of the errors or uncertainty in a given dataset, one cannot make an effective management decision regarding their suitability for your purpose.

Data quality is fundamentally a risk management exercise. The risk is that data are unsuitable for the intended purpose, and the results can range from additional cost to incorrect answers to critical questions. This material could logically be presented as a subsection to the Risk Management topic in Module 3, but it is a significant enough concern to warrant a separate discussion here.

This module will examine data quality and error in the following three topics:

1: Error types
2: Sources of error
3: Managing Error

5.1 Error Types

5.1.1 Introduction

There are several aspects to data quality. We can consider the following as different “yardsticks’ for measuring errors, or different types of error in our data:

- Positional Accuracy
- Thematic/Attribute Accuracy
- Temporal Accuracy
- Logical Consistency
- Completeness

Many of these refer to the term **Accuracy**. Accuracy can be thought of as the absence of errors, or the “correctness” of the data. Accurate GIS data represent things in a database in such a way as to be very similar to what is found in reality. Students have likely learned in previous GIS courses that information in a database can never truly represent reality; there will always be a level of abstraction or generalization when we try to represent the real world using a computer model. For this reason, GIS data can never be perfectly accurate, but it can be suitable for an intended purpose, or accurate enough for a specific analysis or visual presentation.

This implies that we can compare values stored in our database with observable reality. This may not always exist. For example, some phenomena placed on maps are subjective in their interpretation, such as a neighbourhood. One might survey people living in the area to get a sense of the perceived extents of the neighbourhood, but it is not possible to define its extents by first hand observation. Historical maps also depict past states of reality which may not be verified in a quantitative way.

5.1.2 Positional Accuracy

When dealing with spatial data, the most obvious type of error is an error in the representation of space. We can think of this spatial or positional accuracy as the closeness of the spatial information in a database, an x, y coordinate pair, for example, to its actual location. Point spatial error may be expressed in terms of error in one axis (e.g., x, y, z), or as horizontal, vertical, or total error. Figure **47** shows an example of measuring error in the three axes.

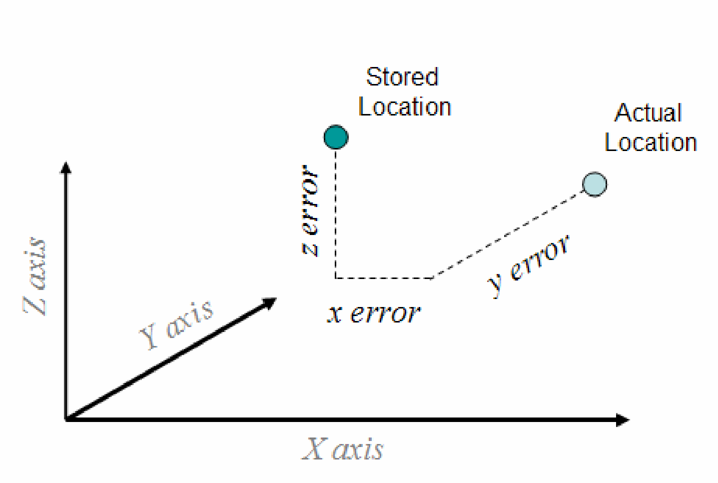

Figure 47 Point Error Measures

Line and polygon boundary errors are harder to quantify, for the simple reason that lines in a GIS can never match the subtlety of shape found in reality. When a stream, for example, is created as a line in a GIS database, that stream is abstracted, or generalized to accommodate a certain scale of capture. Some points on the line, such as the confluence of two streams, may be compared with the true location, but most of the points which define the shape of the stream do not correspond to a specific and measurable location on the earth. Figure **48** shows an example of line digitizing.

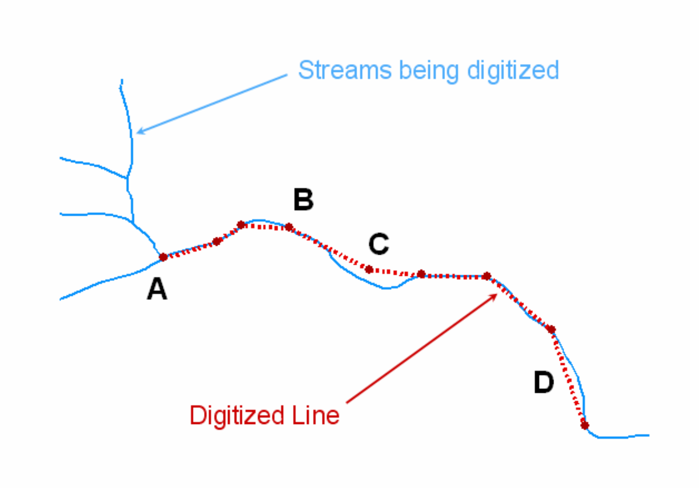

Figure 48 Line Accuracy and Digitizing

The point at location A corresponds to a specific location (the confluence of two small streams) which may be identified in space. We can assess the accuracy of this point as we would any other point data.

The point at B seems to be accurate simply because it lies directly upon the line it is trying to represent. However, if this point were moved significantly upstream or downstream (but still lying on the stream line), would it still be accurate? The answer lies in what the movement of point B does to the overall line. This type of point (e.g., B, C) is often referred to as a **Shape**

Point because it does not denote a specific, identifiable location, but merely provides shape to the linear feature. It may also be called a **Vertex** (as opposed to an endpoint Node). Shape points are somewhat arbitrary, and the data entry technician simply adds points to make the line follow the trend of the intended feature with detail sufficient for the required scale. This makes quantifying the error rate for such points extremely difficult.

Similarly, we can probably state that point C has error, since the point does not lie on the feature it is trying to represent. Again, however, the extent of this error is unclear. We could state that the error is the distance from C to the nearest point on the stream. As with B, though, there may be points up or downstream which will make the general shape of the resulting line more closely match that of the true feature than the nearest point on the stream to point C.

The label D refers to the portion of the new line which strays significantly from the true stream feature. Here it is the absence of a shape point, not the location of a shape point, which causes the deviation from the true stream location. Shape point location, as well as the frequency of shape points dictates how well a line feature in a GIS represents a line object in reality. The creation or omission of these points is part of the generalisation which is inherent in the process of representing real-world objects in a computer database.

One way to describe error in linear features is to define a buffer around the digitized line (or polygon boundary), the width of which corresponds to the level of error in the data. This buffer represents the area inside which the true line exists with some level of confidence. The buffer may not be uniform, however, since straight lines are easier to digitize accurately than complex curves, and lines with many clearly identifiable locations (e.g., street intersections) may be more accurately digitized than single lines isolated in space. Figure **49** shows an example of such an error buffer.

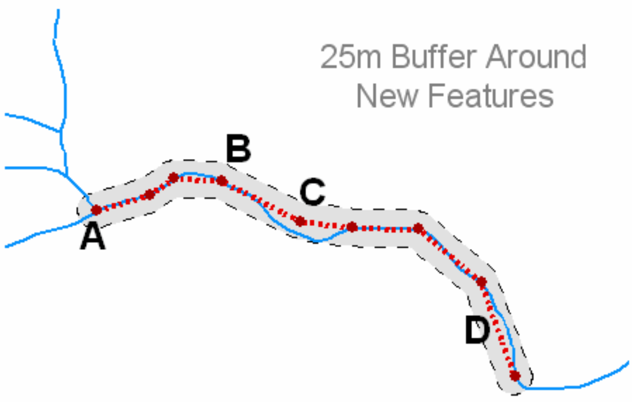

Figure 49 Line Accuracy Depicted with a Buffer

The width of this buffer is a function of data confidence. The wider the buffer, the higher the confidence one can have in that the true location of the feature lies somewhere within it. Figure **50** shows the concept of increasing confidence with buffer width. In this figure, the 70% buffer, for example, would include the area encompassed by both the 50% buffer and the 70% buffer presented. The ground unit width of a given confidence buffer, such as 90% confidence, will be a function of the scale of the data (i.e., the larger the scale, the narrower the buffer and the more confident we may be of the spatial accuracy).

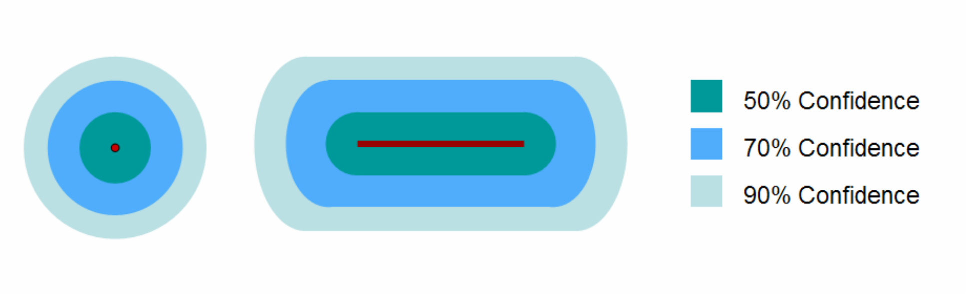

Figure 50 Position Error and Confidence Limits for Point and Line Features

Scale is the ratio of a distance on a map (between two features, or the size of a single feature, for example) to the equivalent distance on the surface of the earth. It can be expressed as a representative fraction, such as 1:50,000. This means 1 unit on the map represents 50,000 of the same units on the earth. 1:5,000 is an example of a large scale map, and represents a small area with significant detail. 1:2,000,000 is a small scale map, and represents a large area with very little detail.

GIS is largely scale-independent, since we can generate on-screen or paper maps at any scale. However, there are limits to the useable scale in practice. Problems arise if GIS data are used for analysis or display at scales significantly different than the scale of capture. The scale of capture will dictate:

- Appropriate levels of accuracy, precision and generalization; larger scales generally have requirements for higher accuracy and precision, and lower rates of generalization.
- What features can be presented; a small feature such as a building footprint cannot be represented on a small-scale map such as one depicting an entire country.
- How features will be presented; at 1:1,000,000 a city may be a point, while at 1:20,000 it may be a large polygon.

A 1:250,000 map, for example, cannot effectively be used for analysis or display at 1:10,000 for these reasons. Cities which are represented on a 1:250,000 map as a point do not become a polygon simply because you have the ability to zoom in to 1:10,000. Many features (such as a small lake) simply will not be present at 1:250,000, and positional accuracy needs will not be met.

Precision may be thought of as the exactness of measurement, or the **Resolution** of the data. In functional terms, it is the size of the smallest feature which can be represented in the database. It is tied closely to the scale of the data, since the size of the smallest thing which can be represented will vary with the display or capture scale. For example, if we assume that the smallest object a person can reasonably resolve on a paper map is 0.5 millimetres, an object of that size would be 25 metres at 1:50,000 and 500 metres at 1:1,000,000. A larger-scale map allows features to be observed better and so generally requires a higher resolution. In a raster database resolution is simply the pixel size.

While precision is usually used to describe spatial precision, as we have described above, it may also apply to attribute precision as well. Attribute resolution refers to how precisely a feature is described, or how finely it is categorized. Measuring the length of a land parcel boundary to 3 decimal places (e.g., millimetres), or storing a detailed land use categorisation such as “Single-family residential” (rather than simply “Urban”) are examples of high precision attributes.

Simply because resolution increases does not ensure that accuracy improves accordingly. It is possible to have large scale, high resolution data with poor accuracy. A satellite image with a very small pixel size, but which has been poorly georeferenced would be an example of this situation. We routinely store vector data using high precision coordinates (to the metre, for example), when their location may only be accurate to within 25 metres. Accuracy then, is commonly lower than precision for a given dataset. As resolution decreases, however, there *must* be a corresponding decrease in accuracy. A 10m pixel raster, for example, can only be accurate to within 10m.

5.1.3 Thematic Accuracy

Thematic Accuracy (also called **Attribute Accuracy**) is the closeness of the values stored in a database to the true value. Attribute values may be simply wrong, such as the incorrect street name for a particular street feature. These sorts of errors are relatively easy to detect and correct. Other attribute errors might be far more difficult to find. An elevation value, for example, which is simply inaccurate is very difficult to detect. A similar state exists for subjective classifications, where a polygon might be coded Young Forest instead of Old Forest. Thematic accuracy is not scale-dependent as spatial data is.

5.1.4 Temporal Accuracy

Where a database has a temporal component, temporal accuracy should be considered. For example, if a database stores the time period that a building is in existence, the construction and demolition dates must be considered for accuracy. Temporal accuracy is not the same as how up-to-date the data are. Temporal data may be temporally accurate, but not current. For example, a polygon defining a stand of forest may have an attribute which tells us the timber in that polygon was harvested in 2003. If the attributes are not up-to-date, we may not know that the timber stand was replanted in 2005 and is now a very young forest stand. If the timber was indeed harvested in 2003 the data are temporally correct, but out of date because the replanting is not yet recorded. Temporal accuracy is important for historical applications.

5.1.5 Logical Consistency

Logical Consistency refers to the presence of contradictions in the data. Errors in logical consistency may take two forms:

<u>Spatial Consistency</u>: This refers to the way spatial data interact, and may thus be characterised as topological consistency errors. Simple examples would include the presence of topological exceptions such as undershoots or dangles. Most GIS applications have tools to help find and fix such errors, but there are a number of inconsistencies which can occur in a spatial database which do not explicitly violate such elementary rules.

For example, consider the following situation. Seismic lines are very long, narrow clearings made in the forest to allow oil and gas exploration equipment to take samples at regular intervals along a search grid. These lines may be several kilometres in length, and criss-cross areas with petroleum resource potential. Clearcuts are fairly large areas of forest which are cleared in order to harvest the trees.

The question, from a GIS database perspective, is whether a seismic cutline which passes through a clearcut is really there. One might argue that a narrow clearing of forest cannot exist within a large clearing, and that the seismic lines should stop as they enter a clearcut and start again on the other side as they enter forested land again. Logical Consistency errors may result if different technicians within the same organisation, for example, were to digitize these features differently. If one operator ensured that seismic lines were broken and removed where they interacted with clearcuts, and another operator simply digitized the seismic line passing through the clearcut, inconsistency in the database would exist. If an analytical model were to calculate the amount of cleared land, for example, it might double-count areas where seismic lines pass through clearcuts.

Another example of spatial consistency relates to street network topology. Inconsistency might exist if in some parts of the network connecting streets are broken with a common, connecting node (point) placed at the intersection, while in other parts of the network road features simply cross in space, with a new intersection node not present. Note that this latter situation presents a problem for network analysis, in that the software does not consider lines to intersect unless they are connected to a common intersection node. Lines which cross in space without a connecting node are considered to represent situations such as an overpass, where vehicles cannot pass from one street to another at this intersection.

Non-Spatial Consistency: These errors are inconsistencies relating to the attributes in a GIS. Errors could be procedural, where we compared population density in two countries, but the population data for each country was collected in different years. Errors can also be contradictions between stored values, for example if a table stored area, population and population density, but the values could not be reconciled.

5.1.6 Completeness

Completeness errors refer to things that are missing from the database. It can refer to the presence or absence of entire feature classes necessary for some purpose, but is more likely to refer to individual features which have been omitted from the database.

5.2 Sources of Error

The discussion above provides a summary of the types of error that may exist in GIS data. These errors may arise in a number of different ways, and understanding the source of such errors is the foundation for reducing and managing error in your data. The following is a summary of how errors are introduced into datasets.

5.2.1 Obvious Errors

Currency:

There are a number of obvious reasons that data may be inaccurate. The first is that the data are simply out of date. The need to update data will certainly be a function of the nature of the phenomenon being mapped. Soils and terrain data, for example, are fairly slow to change and we may be able to use such information without update far longer than a more dynamic dataset such as landuse or a transportation network.

Old data will mean that features have physically changed, been added or removed since our last update. In addition, however, Burrough and McDonnell (1998) suggest that we must deal with the possibility that the nature of the entire dataset may have changed. Data may be currently collected to different specifications (i.e., minimum polygon size, or definition of classification), or to different standards. Frequently data providers (e.g., a central government agency responsible for production and maintenance of a specific dataset, such as landuse or planimetry) will, in the process of updating a dataset, change the way the data are collected or delivered due to better data processing technology or changing data requirements of their customers. In such a case, the utility and applicability of the new, updated data may be entirely different than the older version of the same data.

Spatial Extent:

Another source of obvious error is simply the spatial extent of the data. If the necessary data do not cover the entire geographic area for which we require them, any analysis will be necessarily incomplete. It is common that studies involving a large area of interest may have partial coverage with very high-quality, large scale mapping. In some areas, however, the only available data may be smaller scale and far less accurate. In such a situation, analysts must decide whether to generalize the large scale mapping (or simply discard them and make use of the small-scale mapping) so that a uniform dataset may be used, or whether to collect additional data at the necessary scale so that the large scale dataset exists for the entire area of interest. It is not recommended that a study proceed with mixed-scale data, because any analytical result will be inconsistent and comparisons across the study area cannot be effectively made.

Scale and Generalisation:

This latter example brings us to our last obvious problem with data, that of scale. We have discussed in the section above that larger scale data typically have better spatial resolution and more detailed attributes. Because of this, it is important to match the scale of the data with the requirements of the analysis or display. Using data that are at too small a scale for the intended purpose results in inaccurate spatial data, and perhaps attribution which does not support the necessary functionality. Using data which are too large a scale introduces a heavy burden on system performance caused by spatial and attribute detail which may never be used. This latter consideration is becoming less of a concern, since the performance of many modern workstations and the storage and retrieval abilities of current databases mean that additional spatial detail, for example, would not reduce system performance appreciably.

For example, Figure **51** shows the use of 1:250,000 coastline features (red lines) at a display scale of 1:10,000. This coastline would not be appropriate for such a scale of analysis or display because at this scale the 1:250,000 features have insufficient spatial resolution, causing linework to appear blocky and positional discrepancies of over 40 metres to be apparent.

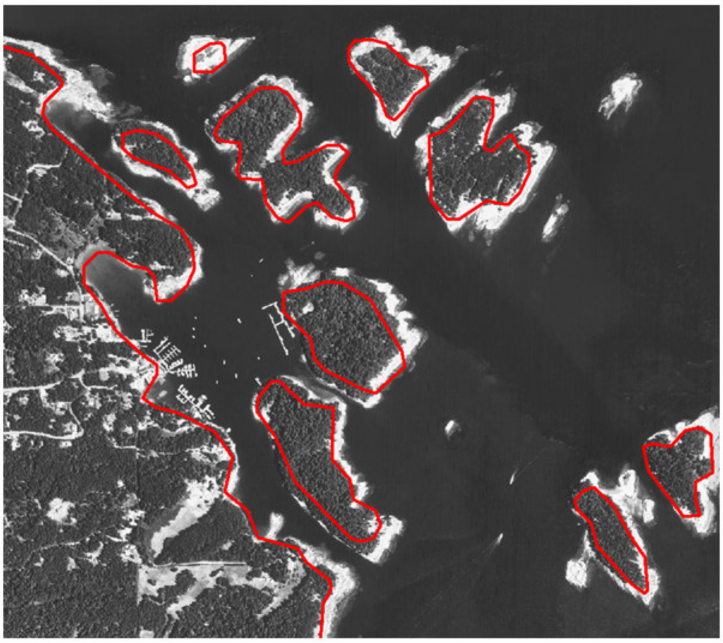

Figure 51 Generalisation of Spatial Data

It was earlier mentioned that the smallest feature a person can effectively resolve is approximately 0.5 mm on a paper map. This is typically true for line-following as well – a digitizing operator may be expected to stray from a line by up to a similar distance while digitizing. This 0.5 mm is a good rule-of-thumb for the expected error in spatial data due exclusively to the limits of resolution and generalisation during data capture (Longley et al, 2005). Table **26** summarises this uncertainty for many common scales. This is merely an approximation of the true error, but it is simple to calculate and should give users of GIS data an easy method for understanding the possibility of error in their data where explicit metadata is unavailable.

Table 26 Uncertainty Due to Scale

Scale	Expected Uncertainty
1:5,000	± 2.5 m
1:10,000	± 5.0 m
1:20,000	± 10 m
1:50,000	± 25 m
1:250,000	± 125 m
1:1,000,000	± 500 m

5.2.2 Measurement Error

Data in a GIS database are created using measurements of some kind. Attribute values such as elevation, soil pH and water temperature are measured in the field using specialized instruments. Spatial data are created by measuring coordinates from a paper map, or measuring on the earth using surveying or GPS equipment. All of these measurement techniques are ways error can be introduced into a database.

Instrument Error:

Equipment used to make measurements may be a source of error. A device used to measure ocean depth and salinity which is not correctly calibrated cannot provide reliable attribute values. When digitizing paper maps, error will be introduced by the resolution of the digitizing table. High quality tables may be accurate to within 0.075 mm, while lower-quality tablets may be accurate to approximately 0.25 mm (Chrisman, 1997). While this error rate is small in relation to other error sources, at a small scale such as 1:250,000, a 0.075 mm error would result in positional errors approaching 20 metres. When digitizing paper maps, additional error may be introduced by the media (the map) itself. Paper maps may shrink or stretch with use and changes in humidity. Reproduction, such as photocopying, further distorts maps. If possible and where accuracy is critical, a stable media such as mylar should be used as a substitute for paper.

Operator Error:

The above error sources are small, however, in relation to errors introduced by the operator. When entering attributes, operators may misinterpret the feature and enter an incorrect value, such as entering "Deciduous", when the forest stand is in fact primarily "Coniferous". There will also be blunders, or typographic errors resulting in incorrect data values. A small error in entering a street address may result in a geocoding movement of several blocks, or a typographic error entering the height of a stand of forest might result in an error of several orders of magnitude.

When digitizing, operator errors include generalizing features too much for the required scale of the data, and errors from inattention or involuntary muscle movements. Figure **52** shows examples of some common digitizing problems.

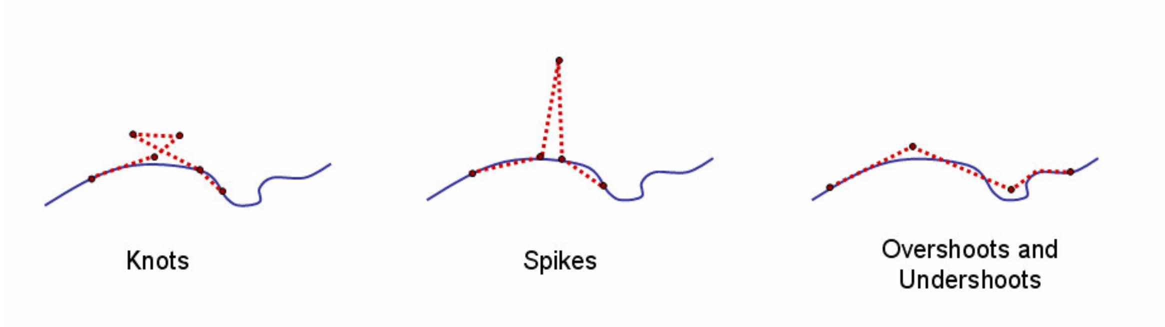

Figure 52 Examples of Digitizing Errors

Compilation Error:

Even if operators could perfectly convert a paper map into a digital version, errors are introduced because the source document (i.e., the map) has errors. Error in the source document is called Compilation Error. The choice of map projection, spheroid or datum will alter the nature and distribution of error on a paper map. The generalisation errors we have discussed previously exist with paper maps as well, since the original cartographer had to abstract the natural world to place the information on a map. There are additional problems with paper maps as well, where “cartographic license” was exercised to improve the readability of the map. For example, where a railroad runs parallel to a road, the cartographer may physically move one or both of the features so that the reader can clearly distinguish two line types, even though at small scales the two lines should be virtually coincident.

5.2.3 Processing Error

Topological Cleanup:

Lines and polygons, as digitized, frequently have minor errors such as gaps or overshoots which prevent the formation of proper polygons or line networks. Such topological errors may be corrected by automated processing which eliminates duplicated lines, closes gaps and removes sliver polygons without manual intervention. To perform this processing, the GIS software is supplied with a **Tolerance**, which dictates the magnitude of change which may be performed. For example, a linear dangle (or overshoot) which is less than this tolerance may be eliminated automatically, or gaps in a polygon boundary less than the tolerance may be automatically closed. Figure **53** shows two examples of this topological processing.

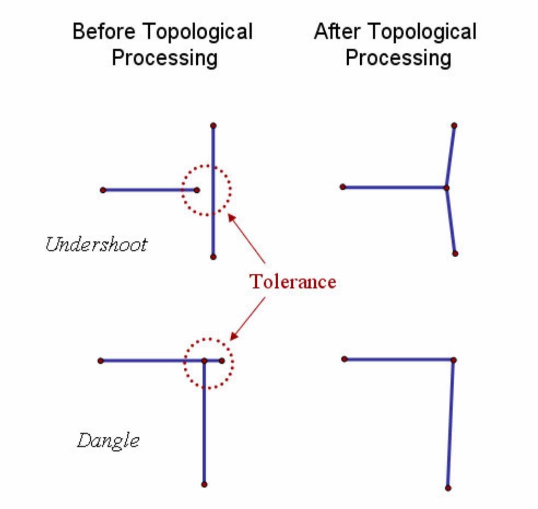

Figure 53 Example Topological Processing

The choice of a tolerance is critical to the quality of the finished data. A tolerance which is too small will result in many of the topological problems being unchanged and significant manual intervention will be required. A tolerance which is too large, however, will result in significant problems with the data. Problems include the loss of small polygons, the removal of gaps and dangles which were intended, and the generalization of line or boundary shape (i.e., the removal of too many shape points).

Recently, data were supplied for a project by a government department responsible for base mapping production and maintenance. The data they supply is the standard 1:20,000 base for most GIS work in this part of the world. It includes features such as hydrology, transportation features and terrain. These data are subject to a rigorous quality assurance process, and are supposed to meet published and detailed accuracy standards. The data which were delivered, however, had been topologically processed with a very large tolerance, most likely after the dataset had passed all quality testing. The result of a large tolerance is a dataset which is virtually useless for analytical purposes, certainly at the intended scale of 1:20,000. Figure **54** shows the intended data, and the data which were delivered.

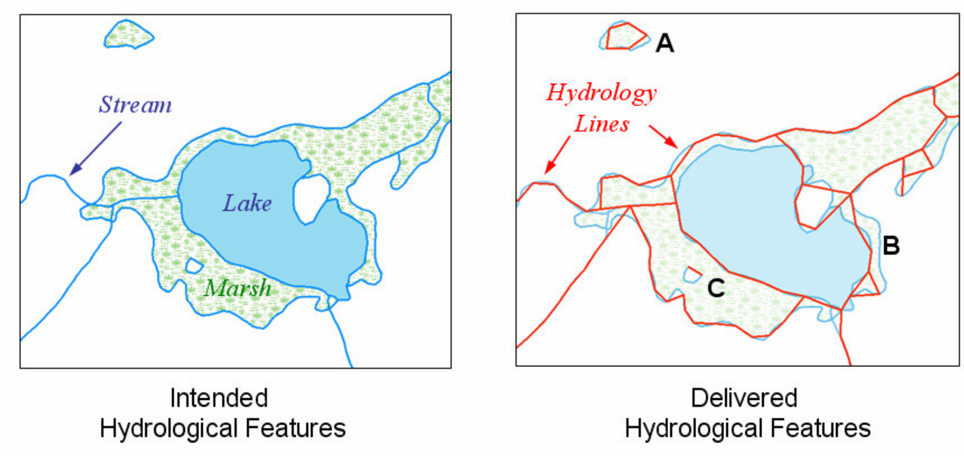

Figure 54 Errors Resulting from Topological Processing with a Large Tolerance

The image on the left (Intended Hydrological Features) shows the dataset as one would expect, depicting lakes, marshes and streams. The data which were delivered, however, were much different. The image on the right shows the delivered hydrology in red. One can immediately see the massive changes to the data resulting from the removal of far too many vertices. The small wetland at point A is an example of the error resulting from lost shape points. While significant, the feature is still topologically relevant in that it is still represented by a closed polygon. The perimeter of the lake at B is supposed to be almost surrounded by a large marsh feature. In this case, the topology has been significantly altered, now indicating that the lake has no marsh along the eastern edge. The narrow marsh feature has been "pinched off" entirely. The small void in the marsh at C is supposed to represent an elevated area which is not marshy, or a small island in the wetland. The topological processing has collapsed the small polygon into a short line. Again, this is a significant error in that the polygon (or void in the polygon) has become a linear feature, which will cause topological problems in the future.

This example obviously represents a blunder on the part of someone handling the data before it was released, but it effectively demonstrates the dangers of topological processing. To minimize data loss during such processing, a conservative tolerance should be selected. The online Help for the ArcGIS software suggests a tolerance 10% of the estimated data accuracy. If, for example, a dataset were accurate to +/- 25 metres, a 2.5 metre tolerance would be appropriate, and would ensure that unintended changes to the data are avoided.

Vector to Raster Conversion:

When converting vector data to a raster structure, additional error will be introduced. Simply by the nature of the raster data structure, it cannot accommodate the precision that appears in a vector system unless the cell size is unrealistically small. Taking a discrete point and encoding it as a raster cell means we lose the precise location of the point, and only know that the point lies somewhere within the cell. Similarly, a discrete boundary composed of a smooth line will become "stepped" in the raster structure, and the subtlety of the line's shape will be lost. This is to be expected, and an inherent tradeoff with the raster structure.

Data Classification:

Similarly, reclassification of data may introduce loss of precision, if not error. Even a common and simple process such as classification of numeric data for display in a choropleth map reduces precision. In addition, the manner in which the data are classified alters the resulting spatial pattern, and perhaps the perception of the data on the part of the reader. Figure **55** shows an example of the classification of Black Bear habitat ratings in two different ways.

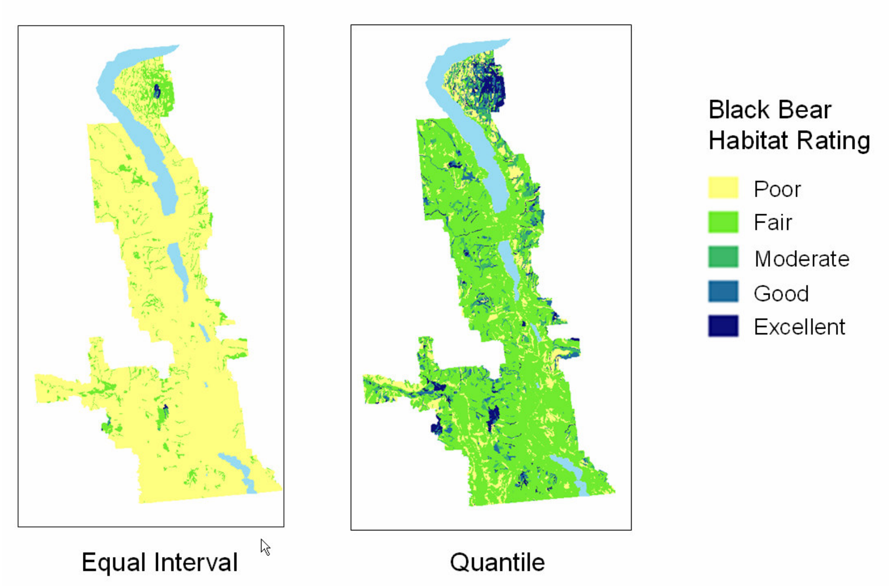

Figure 55 Effect of Classification Method on Perception

To make these maps, a numeric score from 0 to 100, calculated based on landuse and vegetation communities, is classified into a series of nominal categories (poor, fair, etc.). The equal interval method ensures that the size of each class interval is the same, while the quantile method ensures that the number of polygons with each classification is equal. The results are markedly different, with the equal interval map implying that this area is generally very poor for bears, while the implication of the quantile map is that this area is generally quite good. In addition to altering perceptions of the data, classification removes the precision of the data by classifying a ratio value into a nominal category. This same process may also apply to the classification of raster data and remote sensing imagery.

Polygon Overlay:

The polygon overlay operation is another source of errors in spatial data. When two sets of polygons are overlain very small sliver polygons (or spurious polygons) are often created. This is particularly true where a boundary was digitized in both polygonal datasets, but due to limitations of the digitizing process the boundary was not digitized in precisely the same manner in each dataset. While it is true that as scale increases (i.e., at larger scales) the *area* of the resulting slivers declines, it is likely that the *number* of slivers will actually increase, since larger scale data will often have an increased number of shape points defining curved lines.

5.3 Managing Error

5.3.1 Introduction

This module has so far examined the characteristics and sources of error. Given that uncertainty will always exist in our data, this topic will address ways to manage this error, hopefully to minimize the impact on the business functions of an organisation. The significance of error in data depends upon application, or the use that each dataset will be put to. For example, consider the following three application areas.

A marketing study may rely on geocoding of addresses and establishing relationships with socioeconomic variables. An inaccurate or incomplete street network will mean that less than 100% of the addresses can be placed on the map, but likely the study can still move forward with a smaller sample size. The impact in such a case is fairly minimal.

A forestry application may seek to model the volume of wood to be harvested based on characteristics such as stand height, species and tree diameter. Errors in this sort of model may result in a financial loss – work crews may harvest the wrong areas, and the subsequent volume of timber may be less than estimated.

An emergency vehicle routing application makes use of a detailed street network to dispatch police, fire or ambulance services to necessary locations. Errors in the topology of the street network, or errors in addressing may cause delays in emergency service response that could result in loss of life. Here error is intolerable.

One can see that the requirement for data accuracy can be variable. The marketing organisation may be perfectly happy with 70% accuracy in the street network. The timber modeling agency will demand greater accuracy, but 90% accuracy may be an acceptable level of risk. Emergency vehicle routing will likely require error rates approaching zero. Determining error rates that are acceptable is fundamentally a risk management issue. As we discussed in Module 3 of this course, risks must be weighed and possible mitigations considered.

5.3.2 Error Management Strategies

Some very basic actions on the part of an organisation can greatly reduce the impact of data errors.

1. <u>Set standards for procedures and data</u>. We need to recognise that error is inherent in our data, but error can also be magnified and new errors introduced by the processing we perform. A detailed discussion of standards is beyond the scope of this module, but in general standards may dictate the way in which data are created, the nature of the final product, the required metadata and even the symbology used to represent a dataset. Standards may be a product of the organisation (i.e., internal standards), an external government agency or a professional organisation. Organisations such as the Federal Geographic Data Committee (FGDC), in the United States, produce standards for many common data applications including Cadastral Data Content, Vegetation Classification, Soils Geographic Data and Environmental Hazards. Similar organisations exist in many countries.

Standard ways of doing things ensure a consistent data product. If data are to be used and shared both internally and externally, they need to be created and processed in a consistent manner, and in a way which minimises problems with the data. For example, one should document best practices for data creation (e.g., minimum polygon size, conventions for data classification, acceptable levels of generalisation while digitizing) and intermediate processing (e.g., topology cleaning tolerances, coordinate transformation procedures). If external standards do not exist, internal ones should be written; establish operational rules, and follow them.

Tied to standard process and product definitions is training. Ensuring that data are consistently and correctly created requires that all operators are familiar with the standards. A short course, attended by all technical staff, is a fairly small investment compared with the cost of repairing data which were incorrectly created or processed with an incorrect procedure. The goal is to provide a consistent dataset which minimises unnecessary error. Consistency implies **Repeatability**, where the same set of results would be obtained if the same capture and analysis methods were applied by another party. If the capture or analysis is not repeatable, then there can be little confidence in the result generated.

2. Document the process and products. Documentation serves two purposes during data production or analysis. First, it is a means of tracking the process and ensuring that all necessary steps are completed for a given dataset. Second, it serves to record all processing which has been performed on the dataset in the past, and provides important information for consumers of the finished data.

   In a complex production environment, where potentially many different operators are working with many different datasets (perhaps a large dataset is divided into mapsheets), it is a good practice to record the status of each dataset as it passes through the necessary processing steps. This might take the form of a “checklist”, with each processing step (e.g., registration (record RMS error), digitizing, topological processing, attribute entry, reprojection, check plot, etc.) identified and space to record when each step is complete. This ensures that no processing steps are omitted, and provides an audit trail if difficulties are found at a later date.

   When a dataset is complete, either as output of an analysis, or as a newly created dataset, the **Lineage** of the dataset should be recorded. Lineage refers to the history of activity relating to this dataset, from their source to their present state. Include any source data, capture methods, processing steps, known errors or problems and the software used to create the data. This information lets any future users of the data (or even you, several years later!) gain a sense of the overall quality and any potential problems.

3. Measure and test products. Much of error management requires that users have an understanding of problems with the data. Data inputs, new primary datasets and analysis results should all be examined to determine their level of error. Specific methods for measuring error are presented in the section which follows.

As part of an overall Quality Control (QC) program, checking of data products should be built into the processing steps for the data. Identify key points in the processing of data where data is most likely to have error introduced, such as digitizing, reprojection or polygon overlay. QC efforts can then be concentrated on these specific points in the process to measure data quality. Figure **56** shows an example of a simple data processing flow with inspections built in.

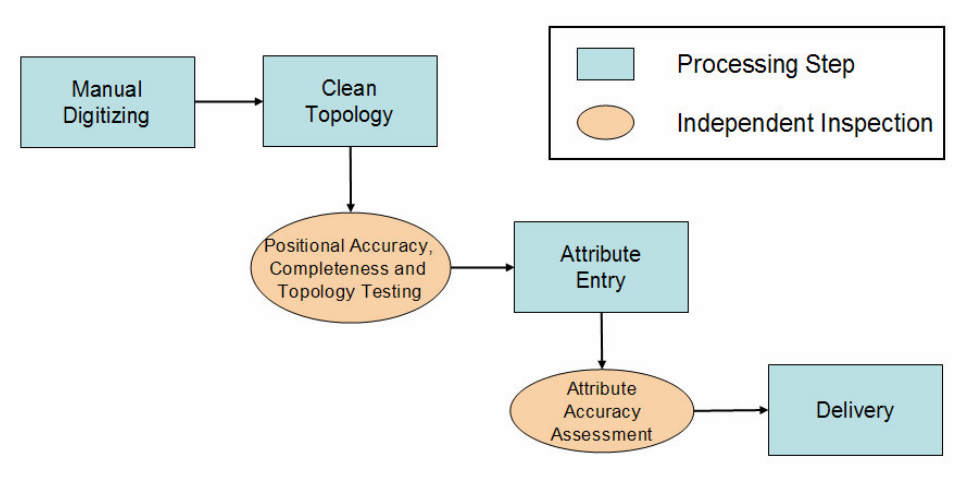

Figure 56 Example Production Flow with Quality Checks

It is usually effective to have an independent inspector review the data. This may be second operator not involved with the data processing, or an external agency to perform the inspection.

4. Report uncertainty of results. This is really an extension of #2 above (Documentation), but when a final dataset is delivered, either as the result of data collection, conversion or as an output of analysis, the expected error for the data should be noted. Ideally, every layer in the GIS would have confidence limits, both spatially and for attribute values.

   In addition, results should reflect the uncertainty of the data. For example, if the area of a polygon is calculated to be 1,426.453 square metres, the implication is that the data are accurate enough to support calculated results to the 3rd decimal place. If this is not the case, presenting 3 decimal places is **False Precision**. False precision is simply the presentation of a result in a manner that implies better precision than is actually the case. An area of 1,426.4 implies accuracy to 0.1 m, 1,426 implies 1 m accuracy. Present results in a form which matches the precision of the data. If our area calculation is only accurate to +/- 10m, we should round to the nearest 10m, so the area should be shown as 1,430 square metres.

5.3.3 Quantifying Error

To make decisions regarding acceptable error levels, users of data need to have a sense of the quality of each dataset. There are a number of techniques for assessing the quality of data, ranging from the simple and qualitative, to sophisticated statistical measures.

Qualitative Assessments:

The simplest method of assessing data is visual inspection, and this should always be a part of any alteration to the data. Obvious oversights or omissions should be apparent and may be corrected. For digitizing efforts, one can plot the resulting data at the same scale as the source document and overlay the two on a light table. Again, gross errors and omissions should be apparent.

Another simple method of checking digitized data is to “double digitize” a sample of the mapsheets. By having a second operator digitize the same map, the two resulting datasets can be compared. The number of polygons produced, the total area of an attribute class, line lengths and other characteristics of the two maps may be compared to determine if large discrepancies exist. This method tends to be an expensive way to locate errors because some of the work must be done twice.

One might also examine the size of undershoots, gaps and overshoots prior to topological cleanup. These measures will give the inspector a fairly good idea of consistent error in the map. It will not address omissions and blunders, however.

Attributes may be quickly examined using summary statistics and histograms. Often typographic errors will produce values which are inconsistent with the true values. For example, an extra digit accidentally entered would produce an elevation value incorrect by factor of 10 (e.g., 144 m instead of 14 m). Such errors will show up as outliers in histogram, or using summary values such as Maximum and Minimum.

Quantitative Assessments:

The basis for quantifying coordinate error is the Root Mean Square (RMS) error. The RMS measures differences between coordinate values on a map and the coordinates of the same feature derived from an independent, higher-quality (e.g., larger scale) data source or from ground-truthing. The RMS error may be calculated as shown in Figure **57** (Chang, 2006).

$$\text{RMS Error} = \sqrt{\frac{\Sigma[(x_i - x'_i)^2 + (y_i - y'_i)^2]}{n}}$$

Figure 57 Root Mean Square Error Calculation for Coordinates

Here, x_i, y_i are the coordinates of the ith point to be checked in the GIS dataset, x'_i, y'_i values are the coordinates of the ith check point (true position), and *n* is the number of points being checked. The RMS error is a standard method of quantifying horizontal error, and standard acceptable RMS values for data of a given scale are published by organisations such as the Federal Geographic Data Committee (FGDC) in the United States.

For example, consider a small set of example points. We have digitized five points in our GIS, and determined the true locations of these points (by using larger-scale mapping, or field checking the points with GPS or survey equipment). Figure **58** shows such a set of points.

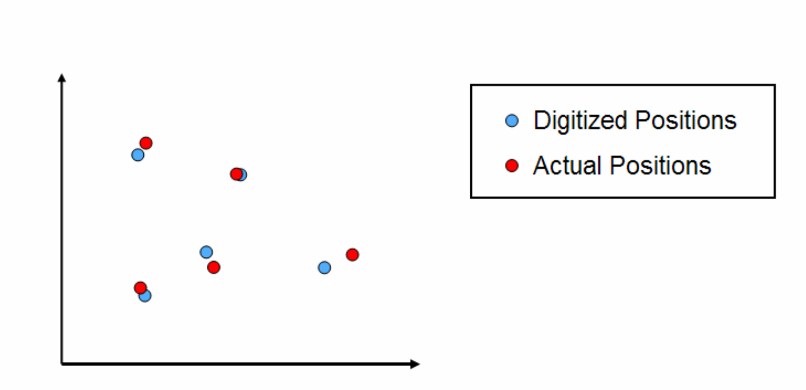

Figure 58 Example Data Points and True Locations

The table below shows the RMSE calculation for these points. The calculation is shown as it might be determined using a spreadsheet application so that each step of the calculation is visible. The RMSE value of 0.3 gives us a single measure of the accuracy of our digitized dataset.

x	y	x'	y'	x - x'	y - y'	(x - x')²	(y - y')²	(x - x')² + (y - y')²
1.1	1.0	1.0	1.1	0.1	-0.1	0.01	0.01	0.02
2.0	2.0	2.2	1.7	-0.2	0.3	0.04	0.09	0.13
0.9	3.1	1.1	3.3	-0.2	-0.2	0.04	0.04	0.08
1.4	2.8	1.3	2.8	0.1	0.0	0.01	0.00	0.01
3.2	1.8	3.6	2.0	-0.4	-0.2	0.16	0.04	0.20
							Sum:	0.44

$$\text{RMS Error} = \sqrt{\frac{0.44}{5}}$$

$$\text{RMS Error} = 0.30$$

Figure 59 Example RMSE Calculation

The RMS calculation may also be applied to quantifying the error of numeric attribute values. Instead of comparing x and y coordinates of the dataset against the true locations, we may compare the attribute values in the dataset to the true attribute values. This approach is often taken when quantifying error rates in elevation data, but the same technique could be applied to error rates in any numeric attribute. For example, we might alter the RMS error calculation above to read as shown in Figure **60**.

$$\text{RMS Error} = \sqrt{\frac{\Sigma(v_i - v'_i)^2}{n}}$$

Figure 60 RMS Error Calculation for Attirbutes

In this case, v_i and v'_i are the encoded attribute value for the i^{th} observation and the true attribute value for the i^{th} observation, respectively.

Confusion Matrix:

Error rates for attributes which utilise nominal classes, such as landuse or ecological classifications cannot be calculated using the RMS method. These classes can be checked using a cross-tabulation of encoded and actual classes at sample locations. This produces a classification error matrix, or a **Confusion Matrix**. Table **27** shows an example of such a matrix for a simple landuse classification.

Table 27 Sample Confusion Matrix for a Landuse Classification

	AG	BU	FO	FY	LOG	URB	Row Total	User Acc.
AG	**21**					1	22	95%
BU		**23**	1				24	96%
FO		3	**42**	3		1	49	86%
FY			1	**27**			28	96%
LOG					**11**		11	100%
URB	2					**36**	38	95%
Col Total	23	26	44	30	11	38	172	
Prod. Acc.	91%	88%	95%	90%	100%	95%		93%

The row and column headings are landuse classification codes. AG is agriculture, BU is burned, FO is old forest, FY is young forest, LOG is recently logged (harvested) and URB is urban. The column headings down the left side correspond to the landuse classifications as entered by the producer – the person who created the data. The headings along the top correspond to the correct landuse classifications. The numbers in the middle of the table represent the relationship between how a given classification was originally made and the correct value for that class. A number of random sample locations are selected, and for each one of these samples, both the classification assigned and the true classification are noted, and one is added to the intersection of the appropriate row and column. Those bold numbers along the diagonal represent correct classifications – where the assigned classification and the correct classification are the same.

For example, consider the row with the heading AG (agriculture). The row total here (at the far right of this row) is 22, so the original operator (the “producer”) classified 22 of the sample locations as agriculture. The figure 21 in the AG row and AG column indicates that 21 of those 22 agriculture classifications were correct. The 1 under the column heading URB (Urban) indicates that one of these 22 points was encoded as agriculture when the correct value was urban. At the far right of this row, under the heading “User Acc.” (User Accuracy), the accuracy for those sites classified as agriculture is noted as 95%. This is calculated by dividing the 21 correct agriculture classifications by the 22 total times the producer made an agriculture classification. Similarly, we can see that the producer classified 28 of the sample locations as FY (young forest). Of these 28, 27 were correct, and one should have been classified as FO (old forest). The accuracy for these young forest classifications is 27 / 28, or 96%.

Examining the column data, we can see how the data should have been classified at a glance. For example, of the 38 sites which should have been classified as URB (Urban), 36 were correctly classified, one was incorrectly classified as agriculture, and one was incorrectly classified as old forest. The Producer’s Accuracy row at the bottom tells us how accurately a given landuse has been classified. For example, the Urban landuse was correctly identified 36 out of a possible 38 times, or 95% correct.

Finally, the overall error rate for this sample can be quantified by adding all the bolded numbers in the diagonal (the correct values) and dividing this by the total number of sites checked. The overall accuracy for this sample is 160 / 172, or 93%.

The distinction between user and producer’s accuracy is subtle, and confusing to some students. We can consider them as the accuracy relative to what is on the ground (the true value) and what is on the map (the value as encoded in the database by the producer). The User’s Accuracy is the proportion of a landuse identified on the map that is correct. For example, if there were 100 agriculture polygons on the map, we could estimate that 95 of them are correct, based on the sample confusion matrix above. The Producer’s Accuracy is the proportion of a landuse on the ground which is correctly identified on the map. For example, if there were 100 agricultural areas in reality, we could estimate that 91 of them would be correctly identified on the map.

5.3.4 Error Propagation

One of the primary functions of a GIS is to produce derived information which is the result of combining two or more existing datasets. We have so far discussed the presence of error in any single GIS dataset, but we also need to concern ourselves with how the errors in each dataset interact when we combine layers in a typical GIS analysis.

For example, consider a Habitat Effectiveness Model. This model seeks to determine the reduction in effectiveness of a given animal’s habitat due to human disturbance on the landscape. It requires two inputs. The first is a habitat layer, where the raster grid or a series of contiguous polygons is assigned a score from 0.0 (habitat has no value) to 1.0 (habitat is optimal) indicating the value or suitability of each area as habitat for our animal. The second input is a measure of disturbance on the landscape. A 0.0 score for disturbance indicates the maximum level of disturbance, while 1.0 indicates no disturbance at all. Both of these layers are themselves created using a series of inputs and processing steps, but for the sake of simplicity, we will simply discuss the interaction between these two.

To complete the model, the two layers are overlaid, and the habitat and disturbance values are multiplied. In this manner, habitat becomes a 0.0 (no value) whenever it is multiplied by a 0.0 (significant) disturbance. Areas with no disturbance (1.0 disturbance score) have no change to their habitat rating. Areas with a 0.5 disturbance will have their habitat rating halved. In this manner, we can quantify the total degradation to habitat.

We are very confident of our disturbance map, and have determined through field checking or other independent evaluation that it was accurate to +/- 0.1 (a 10% variability). The habitat map is perhaps more subjective, or was determined from smaller-scale mapping, and we are less confident in this data. The habitat data is accurate to +/- 0.3; a 30% variability.

The question remains: how confident can we be in our final output? How does the output error rate relate to the error rates of the inputs? Does the result get better, or worse?

Significant study has been invested in these questions, and the results indicate that the way in which errors propagate relates to the way in which the layers are combined. For example a multiplicative model, such as our Habitat Effectiveness model above, produces error in excess of the worst accuracy of the input layers. In our Habitat Effectiveness, then, the resulting dataset would have accuracy *worse* than +/- 30%. Additive models, however, produce error rates better than the most accurate dataset.

Burrough and McDonnell (1998) review mathematically the error resulting from various ways of combining two spatial layers. The results are summarised below in Table **28**.

Table 28 Error Propagation in Various Combination Methods

Combination Method	Error Rate of First Input	Error Rate of Second Input	Error Rate of Output Layer
Addition	10%	12.5%	8%
Subtraction	10%	12.5%	70%
Multiplication and Division	10%	12.5%	16%
Squaring input (exponent 2)	10%	n/a	20%
AND operation	10%	12.5%	≤ 12.5%
OR operation	10%	12.5%	≤ 10%

In addition, if there is a correlation between the two input layers, the effect is to magnify the error in the resulting dataset. In a situation where there is 100% correlation between the two input layers, and additive model will produce error as high as the sum of the two errors. Using the values from the table above, perfectly correlated inputs would increase the error for an additive model from 8% to as high as 22.5%.

There are several ways of modeling error propagation. For example, so-called Monte Carlo methods (which rely on chance, hence the name) use the statistical distribution of error in each map layer to incorporate a random variation in each layer which is proportionate to the error rate of the layer. The analysis is then run. A new, random variation is added to each layer and the analysis is repeated, perhaps as many as 100 times. Averaging the resulting 100 outputs allows a mean and standard deviation to be computed for each grid cell or map region. In this way, one can examine both total error for the map, but also regional variation due to error rates.

Below are a number of guidelines for developing models, which will help reduce the overall error in the resulting data:

- Where possible use additive models
- If you cannot add, multiply or divide
- Avoid taking differences or raising variables to powers
- Keep the number of factors as small as possible; dropping layers which contribute very little to the model results may actually increase the quality of the model results because there are less combinations of layers
- Avoid intercorrelated variables
- Understand the error in your input layers; identify the largest source of error in the model and work to improve that dataset

5.3.5 Sensitivity Analysis

Frequently in GIS applications, modeling techniques or processing steps are utilised which require the mathematical or logical combination of map layers. We have seen that this combination may cause propagation of existing errors to the analytical results. However, we also need to understand how variation in the model inputs will affect the output of the model. The process of checking how the model reacts to such variations is called Sensitivity Analysis.

Sensitivity may be thought of as the model's response to subtle changes in either the inputs or the model parameters. We can examine sensitivity of:

- The input layers; how does the model respond when the values in an input layer change?
- The weights; how does the model respond when the weight applied to a given layer changes?

The concept, when examining input layers, is to isolate each layer and examine how the model reacts to changes. It allows us to determine which layer is contributing most to the model results, to observe the effects of error in a given input layer, and to consider the effects of increasing or decreasing data precision.

For example, consider a complex model which assists planners in locating a new industrial development. We would like to choose a site which minimizes both environmental impact and construction cost. The inputs to such a constraints model might include such information as slope, geology, wildlife habitat, road access, rare or endangered plant communities and privately owned land.

One useful way to utilise a sensitivity analysis in this case is to use the full observed range to test the sensitivity of the model to each layer. Let us assume that the slope layer in our constraints example has three values: flat, gentle and steep. In such a model, flat land is better to develop on, since construction costs are much higher on steep slopes. We can test the sensitivity to the slope layer by setting the entire input layer to the best possible class present in the data, in this case “flat”, and rerunning the model. We then set the entire slope layer to the worst possible class present in the dataset, (e.g., “steep”) and run the model once again. The difference between the true model results and these two test cases tells us how much variability will occur in the model in response to the maximum and minimum possible slope values currently within the study area.

If we perform this analysis for each input layer, we will have a fairly good grasp of how the model behaves *for this particular dataset or spatial extent*. This is an important distinction, because although it should be simple to look at a model and determine which input layer *theoretically* contributes the most to variability in the model results (by the weights, or mathematical combination methods, for example), the characteristics of the specific dataset may mean that in *practice* a different layer dominates the model.

Consider our constraints model. If the model were structured such that the largest weight was applied to the slope input, one would expect that the slope layer would dominate and lend the most influence to the model. If the entire study area is flat, however, functionally the slope has no influence on model results at all. The influence of a particular layer is related, naturally, to the mathematics of the model, but also to the variation of values within the study area. Layers with little variability over the study area will not contribute significantly to the model regardless of the mathematics.

In practice, only a small number of layers, perhaps 2 or 3 of the 8 or 10 inputs to our constraints model, will have a significant impact on the model results. It is important that we know which these are in order to defend the methodology effectively and be able to understand where the major sources of error in our model are.

Sensitivity analysis may also be performed to examine the affects of error or uncertainty in the inputs. For example, if a Digital Elevation Model (DEM) were one of our model inputs, and the accuracy of the elevation values was expressed as +/- 5m, we could use this value (5m) to observe the effect uncertainty in elevation has on the model. We might subtract 5m from every elevation value and rerun the model, then add 5m to all elevation values and run the model again. This would show us the potential change to the model based on the possible error in the DEM. If we ran the model with every layer decreased by its accuracy, then again with values increased by the accuracy value, we could establish a confidence interval for the overall model results.

One other application of sensitivity analysis is to determine the most cost-effective resolution for the inputs. We can run the model with differing resolutions to quantify the effect on the model results due purely to change in resolution. We can then address the question of what resolution is necessary for the project. Would the increased cost of collecting extremely high resolution data be justified by a significant improvement in the model results? Will inexpensive, small-scale mapping for a given layer provide sufficient precision in the model results? These questions may be answered by applying sensitivity analysis.

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