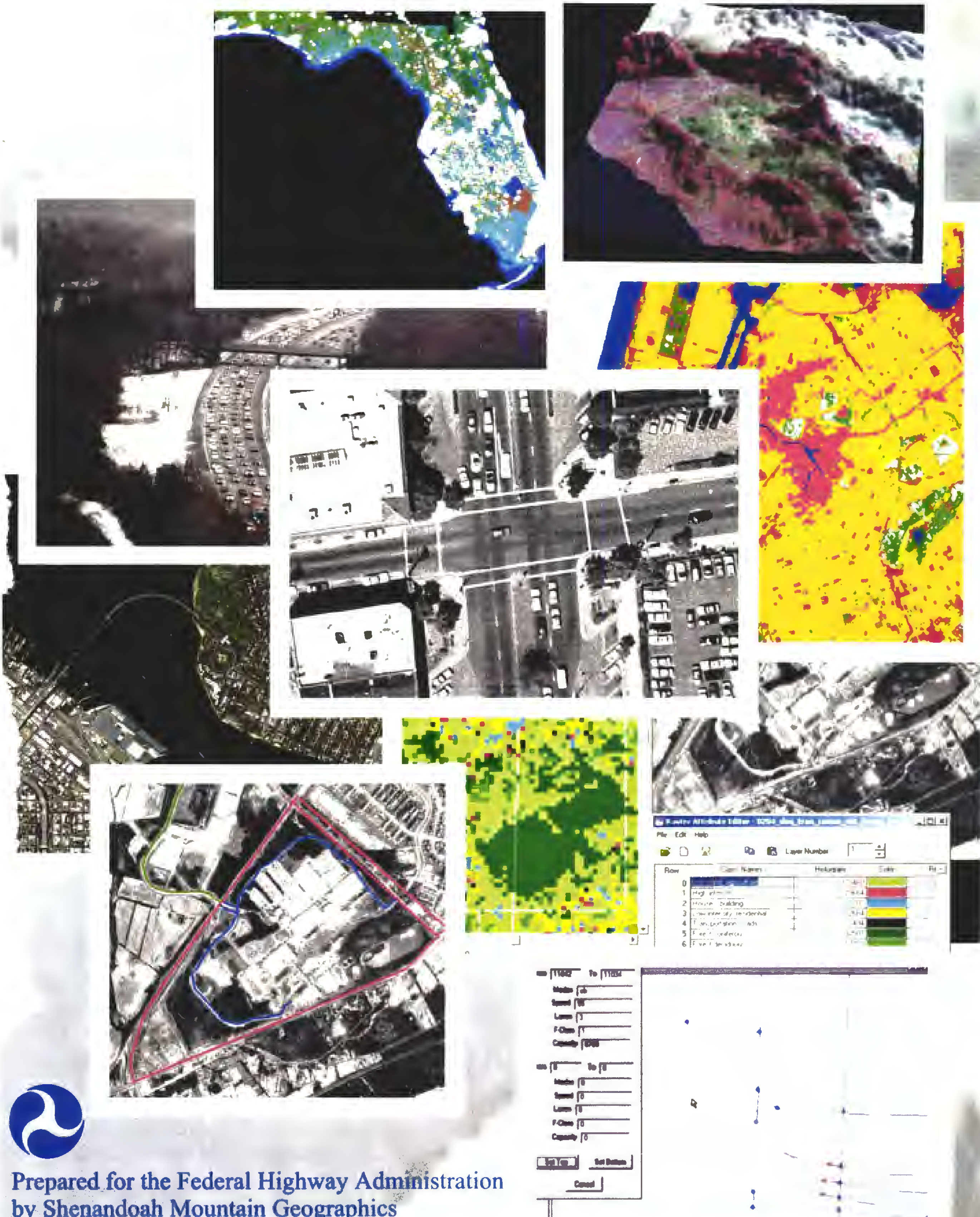
The Use of Imagery in Transportation Planning: A Guidebook



Prepared for the Federal Highway Administration
by Shenandoah Mountain Geographics

The Use of Imagery in Transportation Planning: A Guidebook

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Executive Overview

Effective transportation planning requires current, accurate geospatial information about the transportation infrastructure, associated interrelationships between the land use and demographics, and the ways that the land uses and demographics interact with, and use the transportation infrastructure. The increasing need to gather this information across diverse functions, scales, and ownerships has resulted in wider and more efficient use of remote sensing, geographic information systems (GIS), and associated technologies.

This guidebook provides information on taking measurements of objects from a distance, or remote sensing, and its uses in transportation planning. The guidebook provides background information on the key concepts of remote sensing, uses of remote sensing in specific transportation planning activities, and steps to integrate imagery-based products of remote sensing into a GIS environment for use by transportation planners. The guidebook is designed to assist a range of transportation planners—from those with little prior knowledge of remote sensing and GIS technologies to those with a number of years of practical, hands-on experience in use of the data and technology.

The guidebook is organized to present overview information on remote sensing followed by specific applications of imagery uses in transportation planning. The four chapters of Section I provide an overview of the technology and introduce important concepts that provide a foundation for understanding the applications. The chapters in Section II define six broad applications of imagery to support transportation planning. These chapters are supported by examples from metropolitan planning organizations (MPOs) and State Departments of Transportation (DOTs). Selected topics are presented in a set of video training modules, titled "Integrating Remote Sensing with Transportation Planning," which are being distributed to MPOs and state DOTs in separate shipments.

The appendices contain additional useful information, including a discussion of data acquisition, classification hierarchies, a summary of the selected literature, and references for additional reading. The appendices also contain the current list of remote sensing coordinators that can and should be used as the first line of resources to assist your remote sensing activities.

The guidebook was prepared by Shenandoah Mountain Geographics, Incorporated during a Phase II Small Business Innovation Research (SBIR) program, under contract DTRS-57-98-C-00089 with the Volpe National Transportation Systems Center of the US Department of Transportation. The Office of Environment, Planning, and Realty within the Federal Highway Administration provided technical oversight during the contract. The guidebook is based on textbook material, numerous references to scientific literature, and the results of several development and demonstration projects conducted by MPOs and State DOTs around the country.

Introduction and Background

Previous efforts using imagery related to transportation have pointed out the utility of satellite data for its broad regional coverage, its timeliness, and its multispectral content. But the conclusions from previous applications have also indicated the need for increased spatial resolution to enable identification of smaller features, thereby providing increased utility to transportation planning applications. High-resolution, commercial imagery satellites with sub-meter spatial resolution capabilities are now available to support planning activities on demand, with no need for lengthy aerial acquisition planning. The data from current high-resolution satellites offer the benefits of high resolution, spatial accuracy, timeliness, and broad area coverage that have not been available to commercial satellite imagery users in the past.

Planning activities that required high-resolution imagery have, until recently, relied on aerial imagery sources. Both aerial and satellite capabilities now provide high resolution data that will further augment and transform analysis and applications that use imagery, including transportation planning. This guidebook describes how remotely sensed imagery in digital form can be used to support activities related to transportation planning. Emphasis is placed on imagery that can be analyzed digitally and that can be integrated into a GIS. These data are an important source of information for regional assessments, project and corridor studies, and for small area analysis.

Highways and transportation facilities are major contributors to the quality of life in communities and can be a major factor affecting the quality of the natural environment, especially air quality. The Federal Highway Administration (FHWA) works with its partners through initiatives in planning, environment, analytical models, new technologies, and research to ensure that highway facilities balance local, regional, and national concerns with the natural environment and add value to the community.

FHWA has been supporting State, local, and regional efforts of integrating imagery into the transportation process since 1997 through the development of case studies and by sponsoring regionally-based imagery seminars and workshops. This imagery program complements FHWA's Research and Technology Program that established several goals in its support of State, regional, and local governments. A planning research program was created to develop cost-effective methods for State, regional, and local governments to evaluate transportation alternatives and to develop and disseminate improved planning methods to enhance the understanding and analysis of land use, transportation, and environmental relationships. An environmental research program was created to contribute to an enhanced human and natural environment with improved tools and technologies for assessing highway intermodal impact on communities and ecosystems in terms of air quality, noise, wetlands, hazardous waste sites, water quality, historic preservation, and archeological and other resources. Finally, a technology transfer program was developed to enable research results to be put into practice quickly to be widely publicized to benefit the Nation's transportation system. FHWA views training as an effective procedure for implementing changes resulting from advances in technology as well as addressing needs related to a shrinking and changing highway workforce.

Remote Sensing Resources within US DOT

FHWA Resource Locator

FHWA expertise is a partnership of FHWA offices across the country. The ***FHWA Resource Locator*** is a network of FHWA specialists to serve its customer's needs by sharing knowledge, providing technical assistance, and moving new and innovative technology into practice.

Office of Planning, Environment, and Realty

FHWA's ***Office of Planning, Environment, and Real Estate*** views imagery to be an important data source for planners at State Departments of Transportation (DOTs) and at metropolitan planning organizations (MPOs). FHWA has: 1) supported the development of case studies with selected DOTs and MPOs, and 2) has offered and presented, at several US locations, an imagery training workshop that provided background on remote sensing and applications of remote sensing in transportation planning. This Guidebook also signifies FHWA's support of integrating imagery into the transportation planning process at DOTs and MPOs.

NHI

The ***National Highway Institute*** (NHI) offers training programs addressed to transportation employees at all levels of the federal, state, and local government; industry; universities; and the international community. NHI has a specific course offerings on remote sensing and GIS: Applying Spatial Data Technologies for Transportation Planning.

RSPA

In 1998, the Transportation Equity Act for the 21st Century (TEA-21), authorized the Secretary of Transportation to carry out a Commercial Remote Sensing Products and Spatial Information Technologies Program in cooperation with NASA. The goal of the program is to validate commercial remote sensing products and spatial information technologies for application to national transportation infrastructure development and construction.

The ***Research and Special Programs Administration*** (RSPA) of the U.S. Department of Transportation (DOT) has implemented the ***National Consortia on Remote Sensing in Transportation*** (NCRST) in partnership with leading academic institutions, service providers, and industry to develop, study, and implement remote sensing applications in transportation. The program is designed to serve long-term research for education and workforce development and near-term technology applications to transportation practice. The program combines NASA research expertise in remote sensing with DOT expertise in technology assessment and application to transportation practice.

BTS

The ***Bureau of Transportation Statistics*** (BTS) chairs the Ground Transportation Subcommittee (GTS) of the Federal Geographic Data Committee (FGDC). GTS promotes the coordination of geo-spatial data collection and standards for ground transportation related activities. The Subcommittee goal is to establish mechanisms for the coordinated development, use, sharing, and dissemination of geo-spatial data for ground transportation financed in whole or in part by Federal funds.

The geospatial data sets distributed by the Bureau of Transportation Statistics depict transportation facilities, networks, and services of national significance. Databases are designed to be used with other data, including imagery, in GIS software packages to locate transportation features and provide a framework for transportation network analysis.

Objectives of Guidebook

This guidebook is intended to provide both a theoretical and a practical base. The guidebook begins with a discussion of fundamental concepts related to remote sensing, including topics on planning, acquisition, and analysis. The guidebook then presents several practical applications of imagery for transportation planning, including a compendium of image-based studies undertaken by metropolitan planning organizations (MPOs) and other transportation researchers that have used imagery. The specific objectives of the guidebook are to:

- discuss key concepts related to remote sensing,
- provide specific examples on the use of imagery in activities supporting transportation planning,
- identify procedures for effective project management, and
- provide information on integrating the imagery and the derived products into GIS.

Scope of Guidebook

This publication is intended to be a basic reference for transportation planners who are either considering digital imagery for transportation planning or for those that have access to digital imagery and plan to use it for an on-going project. The guidebook is a collection of concepts, ideas, and examples of what is possible with current technologies. It is designed to introduce important terms and ideas, and also to present key applications of imagery in the transportation planning process. Terms appearing in boldface can be found in the Glossary. Terms appearing in boldface italic can be found in Appendix E.

There are several applications of imagery within the transportation planning process. This Guidebook describes several, but not all possibilities, along with suggestions for further reading. The reader is encouraged to refer to the literature summary in Appendix C and to use the references listed in Appendix D for further information on ideas and operations described in the text. This guidebook, along with the video modules "Integrating Remote Sensing into Transportation Planning," were developed to provide an introduction to remote sensing and associated technologies. Technical advice and literature is available from remote sensing coordinators listed in appendix E. Training on more technical aspects of these technologies and their applications is also available through several commercial firms. FHWA appreciates comments on the utility of this guidebook.

SECTION I
OVERVIEW AND CONCEPTS

Chapter I
Using Remote Sensing for Transportation Planning

The Context of Imagery in Transportation Applications

The ***San Diego Association of Governments*** (SANDAG) has used various digital image products since 1990 to update components of its regional transportation database. SANDAG concludes that the use of imagery data has greatly increased its modeling accuracy and travel demand forecast reliability. SANDAG has found that as the spatial **resolution** of the imagery increases, more information becomes available to the analyst, along with a reduction in the uncertainty associated with the imagery interpretation.

SANDAG analysts and planners have used imagery, in conjunction with other data sources, to align highway and rail networks, code network attributes without field review, delineate better traffic analysis zones, and code zone connectors that more accurately represent the way in which trips are referenced to the model network. Imagery data have also been used to identify land use change, update the vector land use database, and verify land use assumptions which drive the trip-generation component of travel demand modeling.

What is a GIS ?

A geographic information system (GIS) is a collection of software and data, such as maps and images, used to analyze and view geographical relationships between and among the data. According to the Environmental Systems Research Institute (ESRI), a GIS combines layers of information about a place to give you a better understanding of that place (Figure 1-1). A GIS can link data sets together by common locational data, such as addresses, which helps departments and agencies share their data. By creating a shared database, one department can benefit from the work of another—data can be collected once and used many times. What layers of information you combine depends on your purpose—finding the best location for a new transportation facility, performing environmental assessments, and planning routes for transit service are just a few examples..

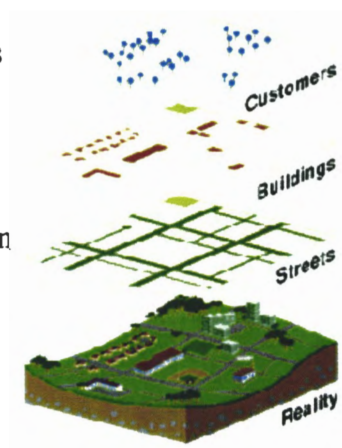

Figure 1-1 Examples of layers in a GIS
Courtesy ESRI

Survey research suggests that 25 percent or more of jurisdictions across the country are in the process of developing a GIS based on tax

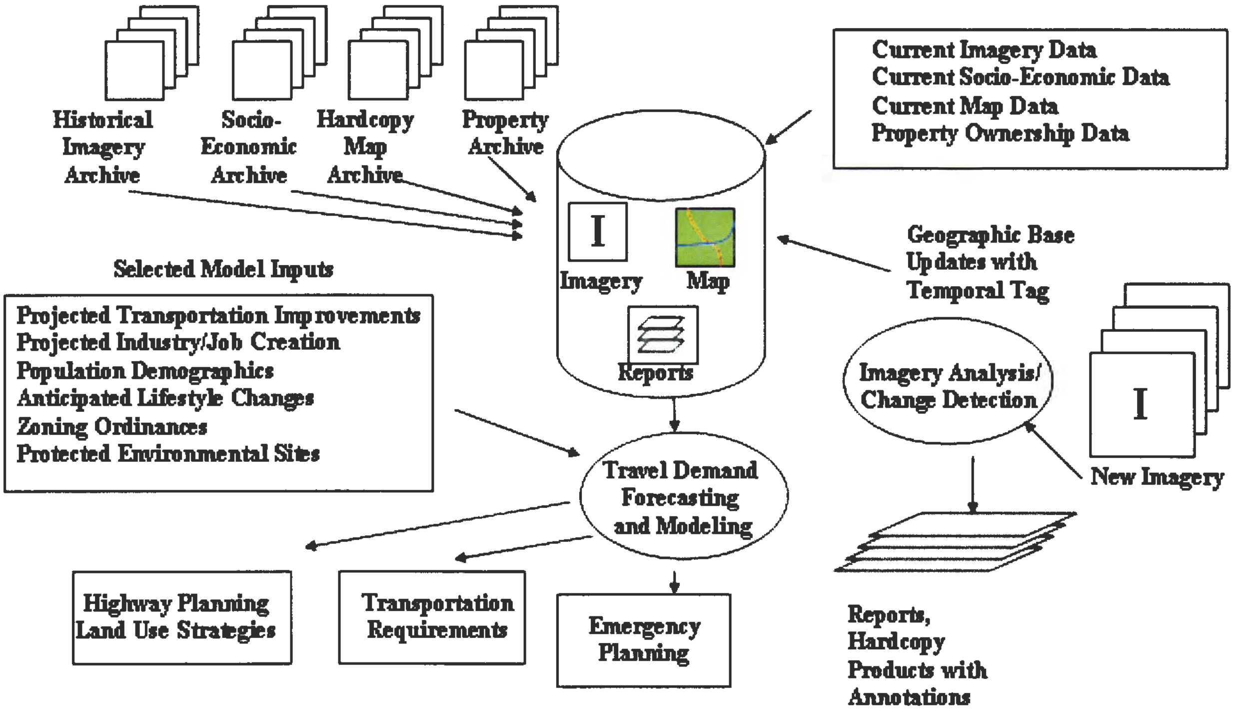

Figure 1-2 Context of Imagery in a Transportation GIS

assessor parcels, including most cities with populations greater than 100,000. (Moudon and Hubner; Crane; Huxhold; Kollin, et. al.).

What is the Role of Imagery in Transportation Planning ?

A transportation GIS contains numerous data layers, including socio-economic archives, map archives, property archives, and imagery archives, as well as current socio-economic data, current maps, current property boundaries and attributes, and current imagery (Figure 1-2).

Imagery data provide information on the form and substance of objects within a given geographic space. Unlike map information, imagery is not generalized or representational. Instead, imagery represents the actual characteristics of the landscape. The exact representation

Regional Information Systems

Metro, Portland's MPO, provides a broad range of services to 1.3 million residents in three counties and twenty-four cities surrounding Portland, Oregon. Metro's Regional Land Information System (RLIS) contains more than 100 data items, including land use, undeveloped land, zoning, urban growth boundaries transportation data, and political boundaries that are registered to a geographic basemap and which has linkages to the counties' tax assessor parcels.

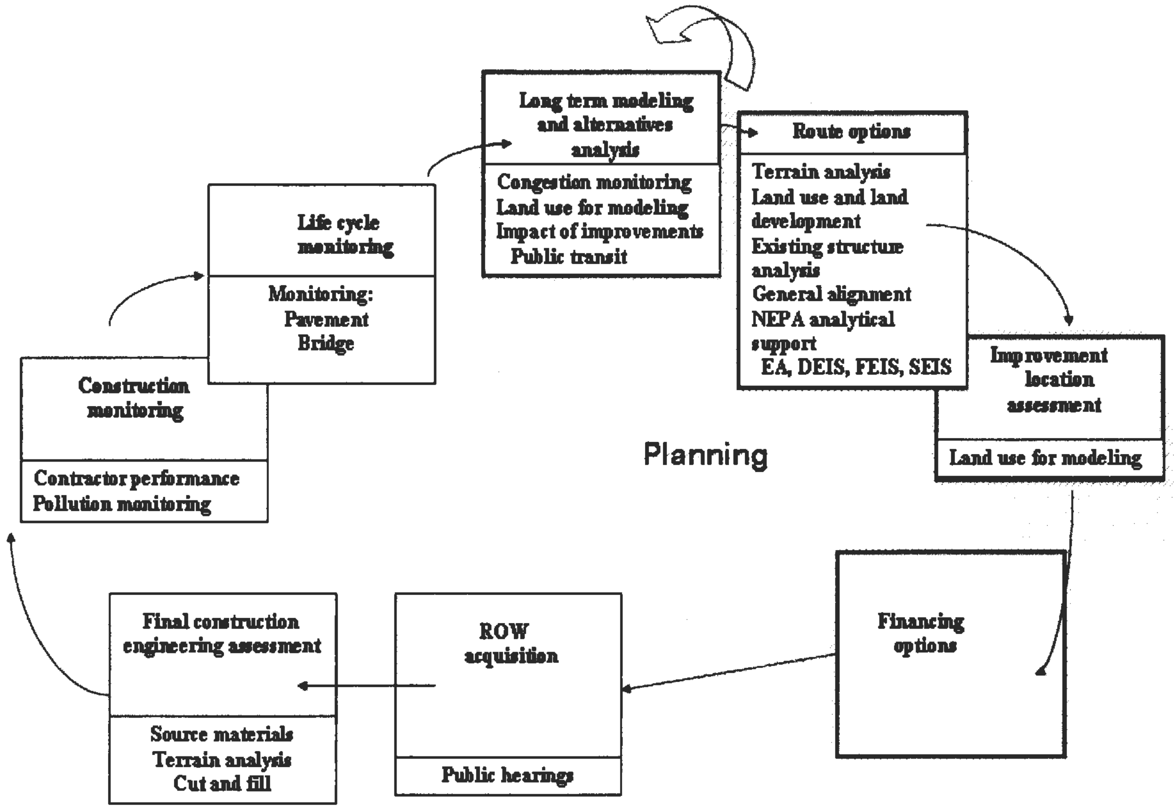

Figure 1-3 Applications of Imagery in Transportation
Based on Stover and Koepke; Dickey

depends on the characteristics of the sensor that collects the imagery. The interpretation of the imagery characteristics depends on several things—the most important being the expertise of the imagery analyst.

As new imagery is acquired, it is analyzed and compared to other information in the GIS. The analysis can take several forms, but likely will include an assessment of the changes that have occurred since the latest information in the GIS. The imagery can be annotated to highlight changes, and reports can be generated that discuss the impact, if any, of the changes. Lastly, data objects in the GIS database can be updated to denote their new location and new attributes. Objects can also be identified as being no longer present, based upon the outcome of the imagery analysis.

There are several applications of imagery to support transportation planning and program development. The transportation planning process (shown as a gray hatched pattern in Figure 1-3) is an on going process that looks forward in measured time increments (usually 20-25 year into the future), but which can be viewed as a process consisting of several discrete planning windows. The long term modeling and alternatives analysis portion of the planning process includes an assessment of the following items:

- the transportation network to be modeled;
- census data, including characteristics of the population and the number of vehicles using the network; and
- travel surveys that depict the number of household and individuals; as well as a trip log of where they travel and how they chain together their trips that can be used for extrapolation to similar demographic clusters within the population; and
- the financial aspect of the project, including costs.

Imagery data can be used to support long term modeling and alternatives analysis in a 10-20 year, long-term planning window. Imagery supports the assessment of the size and nature of environmental and other impacts resulting from facility improvements. Impact analysis can also include the changes to housing and business locations that are likely given a new facility improvement. Imagery provides information to support analysis of congestion patterns as well as for land use to support travel demand modeling.

Imagery can also support the analysis of route options through terrain analysis, land use analysis, inventory analysis, and by supporting the environmental assessment to ensure that the improvement meets federal and state regulations. Once a corridor has been selected, imagery can support the development of land use for modeling anticipated impacts.

Imagery also supports the program development associated with infrastructure improvement. Presentation graphics can be used to support public hearings. Imagery can also be used to support terrain analysis, analysis of raw materials to support construction, and cut and fill analysis in the final engineering assessment.

During construction, imagery can be used to monitor sediment runoff and to assist in monitoring contractor performance. Finally, imagery can be used to monitor bridge and pavement condition during the lifecycle monitoring phase.

Chapters 5 through 10 in Section II present six broad applications of imagery that support transportation planning:

- presentation graphics;
- analysis of urban form and growth;
- land use, land use change, and forecasting;
- socio-economic data analysis;
- support to travel demand modeling; and
- corridor/project management.

Figure 1-4 Color infrared imagery of a transit station and surroundings
Image Source:USGS DOQ

These six applications can be further segmented into site-specific, corridor-specific, and regional applications.

Site-Specific Analysis

Interchange and transit station analysis

Imagery can be used to support analysis of point and small area features such as interchanges and transit stations. Figure 1-4 shows a rail transit station to the west of Washington, DC. Imagery analysis can be used to determine attributes of the facility, to measure features associated with the facility, to show surrounding parking and road access, to show surrounding land use, and to measure changes from one time period to another.

Project and Corridor Analyses

Alignment of new road

Remote sensing and GIS support planning and development of new corridors and services including bike paths and walking paths. In addition, remote sensing and geospatial data support the planning and development of new intermodal facilities, such as truck and rail staging facilities.

Regional Analyses

Land use, travel demand

The ***Office of Planning, Environment, and Realty*** has developed a toolbox of analytical methods for testing the regional impacts of transportation and land use policies. The toolbox is designed for use by metropolitan planning organizations (MPOs), state departments of transportation (DOTs), and other analysts who wish to assess a range of impacts in regional transportation and/or land use planning.

The toolbox includes techniques ranging from sketch-planning methods and GIS-based analyses to integrated urban models. In contrast to project-level analysis techniques, the methods are primarily designed for analyzing the impacts of a regional transportation plan, regional land use scenarios, or other policies applied on a region-wide basis.

Remote sensing data sources can be used to support the acquisition of regional land use data. These land use data can be hierarchically categorized to support specific projects or can follow established land use hierarchies that have been developed by organizations such as the ***US Geological Survey***, state, and regional governments.

Regional land use can be used to support the travel demand modeling process. In addition, these land use data can be used in land use forecasting techniques, which can, in turn, provide input data for travel demand models.

How Can Imagery Support Transportation Planning?

Imagery, of course, is only one component of the data and applications that are needed to create a regional information system to support transportation planning. But imagery provides the following benefits to the transportation planner:

- a stable geographic/geometric base,
- timeliness of coverage and update, and
- broad area coverage providing a comprehensive, regional perspective.

Imagery Comes with a Price

The potential utility and timeliness of imagery data must be a factor in the decision-making process associated with imagery acquisition to support internal projects. As you will discern after reviewing the following chapters, there are many applications of imagery in the transportation planning process. While this guidebook promotes and encourages the use of aerial and satellite imagery in transportation projects, the reader needs to understand the complexities and costs associated with this data source.

The current costs of high-resolution imagery will force most users to be selective in coverage, either in geographic extent, or by forcing them to update their imagery base only every other year, for example. A planning organization may choose to stratify its region into zones of priority when developing its strategy for imagery acquisition. Some planning organizations collect higher-resolution imagery in urban areas and somewhat lower resolution imagery over areas outside the urban boundaries.

Vacant Land Inventory

Portland's Metro maintains and updates its vacant land inventory on an annual basis using aerial photography. Tax parcel maps are digitally overlaid on the imagery to support imagery identification and analysis. Metro estimates that the vacant land update for its region takes two technicians approximately two months.

Once received from an imagery vendor, imagery data do not provide the same level of initial utility as other data sources, such as data from the US Census. Value-added processing is required to transform these data into information products. These value-added products often provide greater utility to the transportation planner than the original imagery.

Many MPOs and State DOTs may not have staff with imagery expertise. Expertise will likely have to come from the existing GIS staff, since these staff are already familiar with hardware and software and with geographic concepts. These staff may require additional training on imagery concepts and applications to enable them to effectively utilize imagery.

Chapter 2
Remote Sensors and Remotely Sensed Data

Remote sensing platforms range from outer space (satellites) to low altitude sensors (Figure 2-1). Each level provides a different perspective and new information.

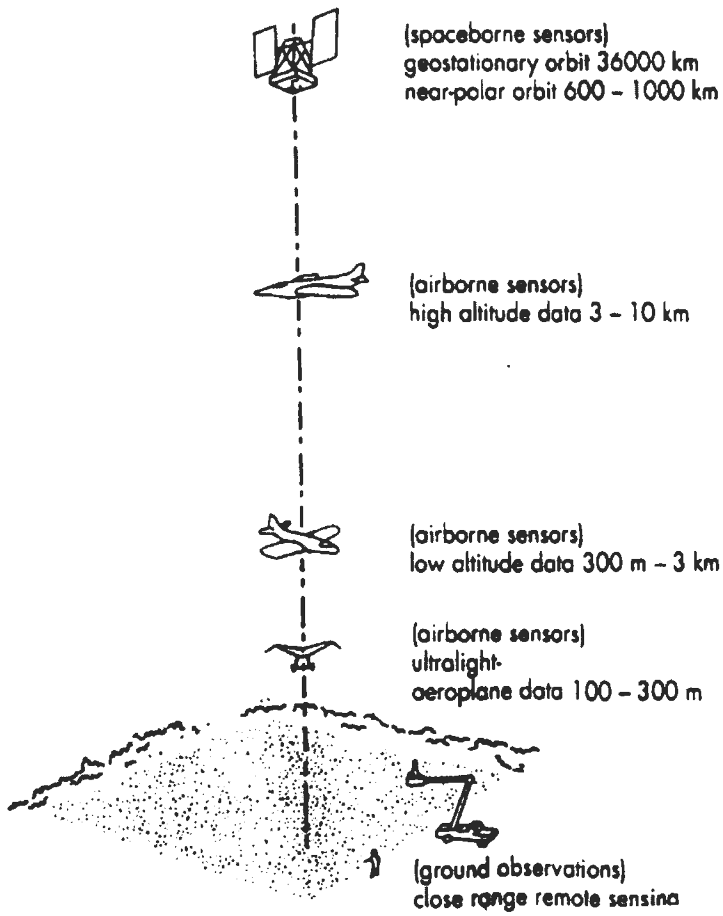

Figure 2-1 Imagery can be acquired at many altitudes
Courtesy Lillesand and Kiefer

With the wide variety of remote sensing tools available, choosing the proper data source for mapping transportation facilities and associated features can be difficult. Both photographic and digital systems have limitations. Characteristics often used to describe and compare these analog and digital systems are grouped into four different types of resolution: spatial, spectral, radiometric, and

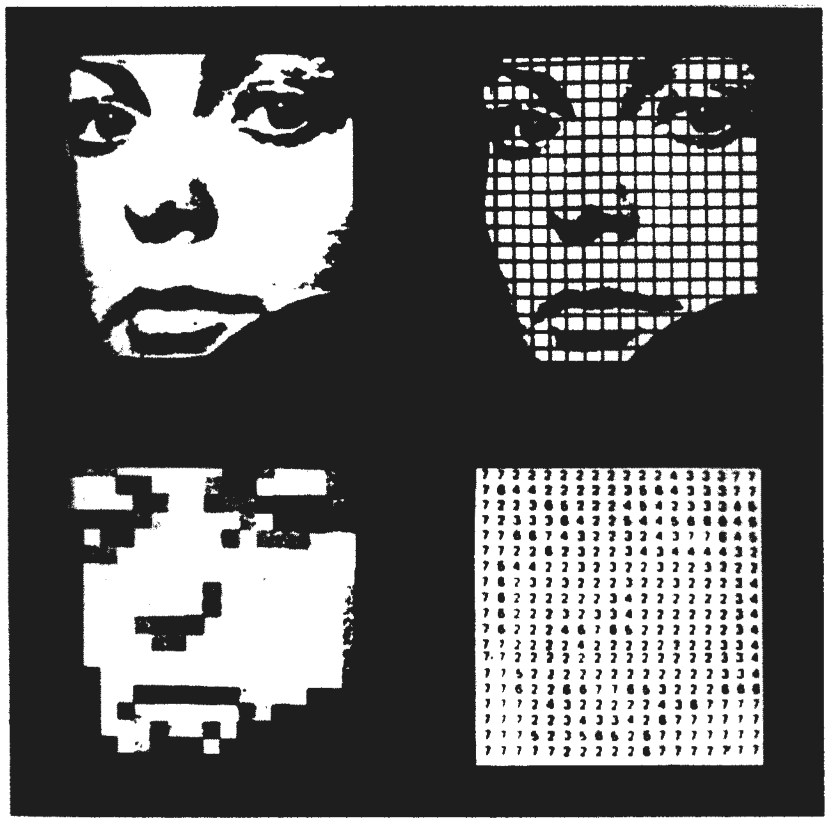

Figure 2-2 Digital conversion of an image into picture elements or pixels
Courtesy Thomas IL, Benning VM, Ching NP

temporal. Note that in common usage, the name of a particular **sensor** can also refer to the image data obtainable via that sensor. For example, "TM" (short for Landsat Thematic Mapper) may refer to either the sensor or the data generated by the sensor. Similarly, resolution is commonly attributed to an image and the sensor that provides the image data.

Resolution

Spatial resolution is a measure of sharpness or fineness of spatial detail. It determines the smallest object that can be resolved by the sensor, or the area on the ground represented by each **pixel.** For digital imagery, spatial resolution roughly corresponds to pixel size as illustrated in Figure 2-2. Spatial resolution is often represented in terms of distance (e.g.,1 meter, 30 meters, etc.). Note that the smaller the distance, the higher the spatial resolution of the image.

The Imagery Resolution Assessments and Reporting Standards (IRARS) Committee published in March 1996 a reference document to guide the spatial requirement for imagery acquisition. For one meter imagery, the IRARS standards state that an analyst can detect individual lines painted on paved roads, aprons, and parking lots. At approximately one foot resolution, an analyst can visually detect manhole covers.

Spectral resolution is a measure of the specific wavelength intervals that a sensor can record (see Appendix A for additional information). For example, while normal color photographs show differences in the visible region of the electromagnetic spectrum, **color infrared** (CIR) photographs and some digital sensors can provide information from both visible and infrared (IR) regions of the spectrum. For digital images, spectral resolution corresponds to the number of spectral bands, and the range of sensitivity within each band.

Radiometric resolution is a measure of a sensor's ability to distinguish between two objects of similar reflectance. Radiometric resolution can be thought of as the sensor's ability to make fine or "subtle" distinctions between reflectance values. For example, the Landsat Enhanced Thematic Mapper (as discussed on page 24) has a radiometric resolution of 256 (stored as 8-bit data), while Ikonos imagery has a radiometric resolution of 2,048 (stored as 11-bit data). ETM can identify 256 different levels of reflectance in each band, while Ikonos can differentiate 2,048; thus Ikonos imagery potentially can show more and finer distinctions between objects of similar spectral reflectance.

Temporal resolution is a measure of how often the same area is visited by the sensor. Unlike the three types of resolution discussed above, temporal resolution does not describe a single image, but rather a series of images as they are captured by the same sensor over time. While the temporal resolution of satellite imagery depends on the satellite's orbit characteristics (Figure 2-3), aerial photography

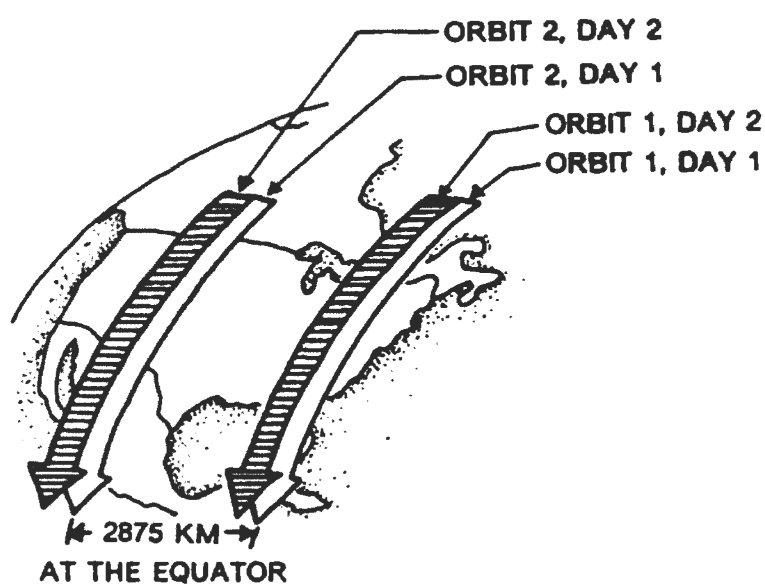

Figure 2-3 Landsat orbit characteristics constrain its temporal resolution
Courtesy Campbell JB

obviously requires special flight planning for each acquisition.

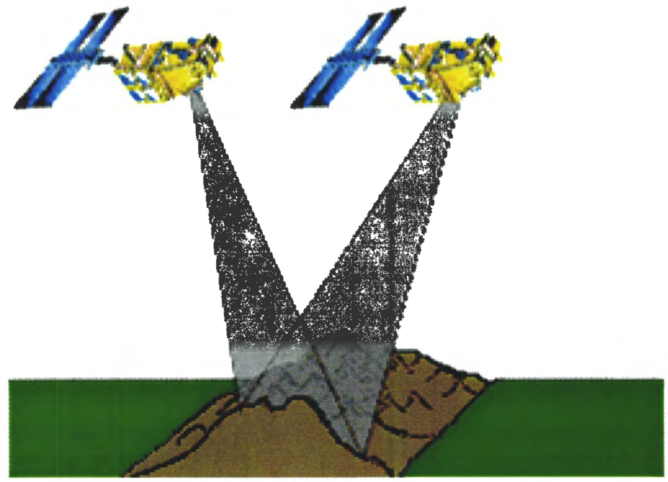

Figure 2-4 Several satellites have pointable sensors
Courtesy CCRS

Temporal resolution for satellite imagery is represented in terms of the amount of time between satellite "visits" to the same area (e.g., 3 days for Ikonos). Note that certain satellites have pointable sensors, which provide these satellites with greater revisit capabilities when compared to satellites without pointable sensors (Figure 2-4).

Resolution and Image Accuracy

An increase in any type of resolution results in a higher probability of correct identification or classification of an object (Jensen and Toll, 1982). Relationships between spatial and spectral resolution tend to be inversely related. This tradeoff must be considered when planning a mapping project. For example, while a particular sensor may have high spectral resolution, its spatial resolution may not be adequate to identify objects critical to the project.

While resolution determines the size of the ground sample unit, image accuracy refers to the conformance between sampled points on imagery and their true location on the ground. The ***USGS National Map Accuracy Standards*** have been established to provide users with a convenient method of identifying the quality of imagery.

Image Processing

In addition to the inherent resolution of the acquired data, certain image processing functions can influence the usefulness of the data. Image preprocessing, enhancement, and classification are some of the more frequently performed image processing operations. Image preprocessing and enhancement operations are designed to improve the spatial positioning of the data and detectability of objects or feature classes. Image classification is the process of assigning pixels of an image to categories or classes, generally based on spectral reflectance characteristics. Usually, the objective of image classification is to obtain a thematic map such as a land cover map. Refer to Chapter 4 for more information on image processing operations in the context of a remote sensing project.

Interpretation Elements

Shape
Shape refers to the geometric configuration associated with the object. Representative shapes include oval, rectangular, and linear.

Size
Size refers the dimension of the object and usually denotes a comparison to other objects in the image for reference scale. If the precise **scale** of the image is known, size (both length and area) can be measured using digital or manual tools.

Tone
Tone refers to the gray shades or color shades present in the image. Dark tones are associated objects that have low reflectance and light tones are associated with objects that have a high reflectance. Differences in tone between adjacent objects create objects and background, and permit identification of, and differentiation between, objects.

Contrast
Contrast refers to the apparent range of tones in the image. Images with dark areas, light areas, and a large number of gradations between are labeled as areas of high contrast, while images with few gray tones are labeled as areas of low contrast. Areas of high contrast permit greater differentiation between objects and thus provide more capabilities for object analysis and identification.

Texture
Texture refers to the interrelationships of tones within an image. When adjacent objects in an image have greatly contrasting tones, a speckled pattern develops, which yields an area with rough image texture. Areas of similar tone create smooth texture; inversely, areas of great differences in tone create rough texture.

Pattern
Pattern refers to the spatial arrangement of geometric shapes within an image or a portion of the image. Patterns often allow easy identification of objects. Orchards and mobile home parks are two examples of object classes that have distinctive, imagery-observable patterns at most resolutions.

Site
Site refers to the placement of an object in context to its surroundings. An object's location in proximity to other objects in the environment often provides clues to support attribution and identification of the objects. Proximity to highways or rivers is an example of site.

<u>Seasonality</u>
The time of year the imagery was recorded effects the imagery characteristics and the items that are available for interpretation. Seasonal factors include leaf-on/leaf-off (for vegetation), snow, solar angle, and water levels in lakes, ponds, rivers, and streams.

Interpretability

The interpretability of an image is dependent upon several factors. First, the interpretability is dependent on the requirements of the analysis. An analysis task involving the differentiation between land and water is generally more simplistic than an analysis that requires the identification of specific attributes associated with a road network and all residential and commercial building footprints with associated area estimates.

The scale of the imagery also influences image interpretability. Generally, larger scale imagery, for example imagery with scale of 1:1200, is more interpretable than smaller scale imagery, for example imagery with scale of 1:125,000. This fact generally holds since larger scale imagery generally portrays objects that are more easily discernable and recognizable when compared to similar objects in smaller scale imagery.

The resolution of the imagery affects the interpretability of the imagery since imagery with smaller pixel sizes generally portrays more natural representations of objects. This is especially true with objects that are smaller than the dimension of the pixels. The reflectance values from small objects are averaged throughout large area pixels, resulting in a generalized representation of those objects in low resolution imagery.

The photographic tone or color contrast of the object against the background also affects the interpretability of imagery. Objects that are adjacent to each other and that are the same color or tone will appear as one object in an image unless there is some other distinguishing characteristic, such as shadow, that allows the objects to be differentiated.

Access to, and use of, collateral sources, such as maps, guidebooks, and other images, generally supports and enhances image interpretability. Likewise, image analysis tools, as well as the sophistication of the tools (e.g., desktop ruler versus advanced software), can support the analysis and enhance the interpretability of imagery.

Finally, the experience and skills of the analyst influence the interpretability of imagery. Image analysts gain an appreciation for object features, tones, and spatial patterns over time that enhance their ability to analyze and identify objects and features in imagery.

Interpretation Keys

A basic element of the imagery analysis process is the identification of representative examples of pure, discrete land uses for use in comparison with other portions of the image. Imagery interpretation keys provide utility to both manual and computer-assisted imagery analyses.

A great deal of research has been performed on surface material reflectance and on the development of land use keys. Keys are often not applicable to multiple images in multiple geographic regions, due to differences in sun elevation, atmospheric conditions, seasonal effects, terrain effects, and the fact that building materials vary from region to region.

Figure 2-5 illustrates a land use key for residential and ommercial/office land use types. The images labeled A represent 1- meter resolution **panchromatic** imagery; those labeled B represent 4-meter resolution **multispectral** imagery.

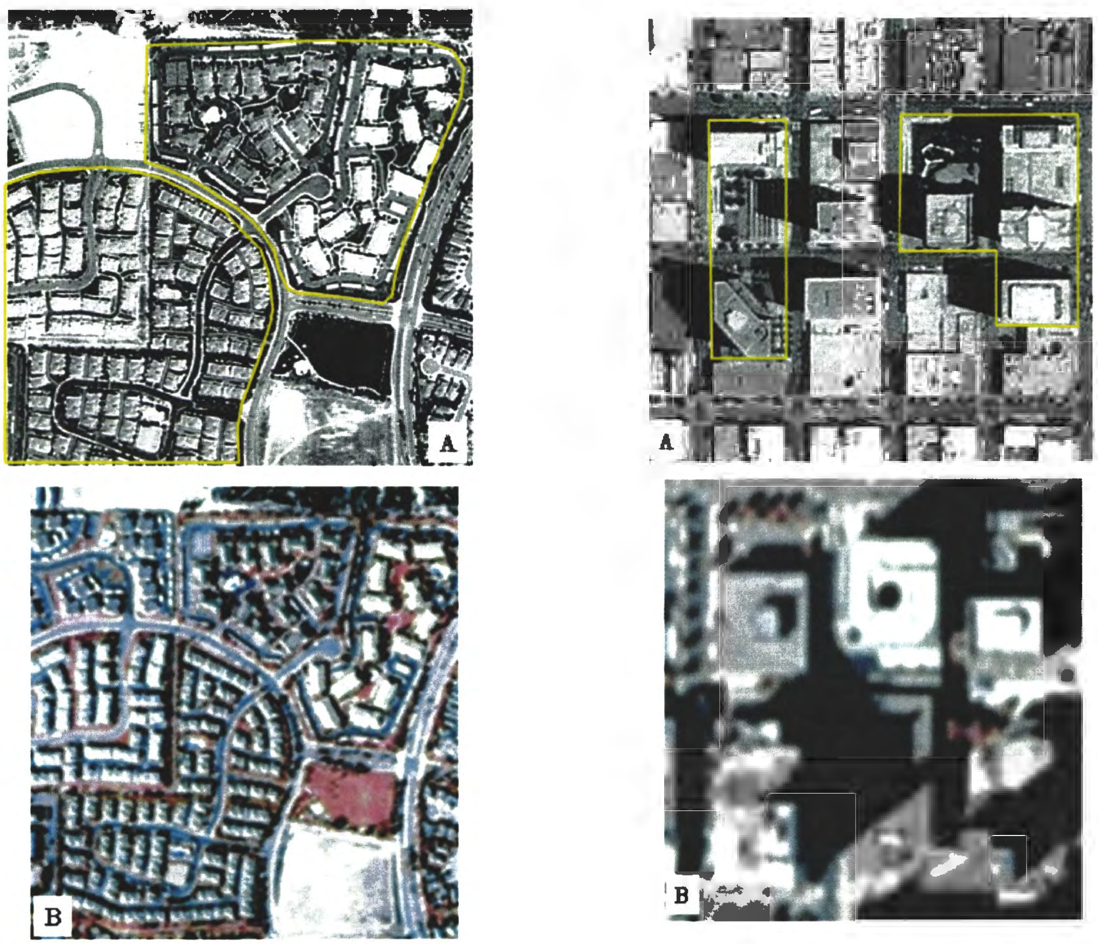

Figure 2-5 Residential and commercial/office land use keys using (A) 1-meter resolution and (B) 4-meter resolution image chips

Provided by San Diego State University

Descriptions of Commonly Used Image Data

Landsat

The first Landsat satellite was launched in 1972 and marked a new era in commercial remote sensing. The first three satellites had a multispectral scanner (MSS) sensor with a resolution of 80 meters. Landsat 4 and 5 had a Thematic Mapper (TM) sensor with six 30-meter resolution multispectral bands and one 120-meter resolution thermal infrared band. The current Landsat 7 satellite has a 15 meter resolution panchromatic band an enhanced Thematic Mapper (ETM) sensor that has six 30-meter resolution multispectral bands and one 60-meter resolution thermal infrared band.

SPOT

The first SPOT satellite was launched in 1986 and continues to operate as of the writing of this guidebook in 2002. SPOT 1, 2, and 4, all operational, have a sensor with three 20-meter resolution, multispectral bands and one 10-meter resolution panchromatic band. SPOT 5 provides 2.5 meter and 5 meter resolution imagery over wide swaths (60 x 120 km).

IRS

The first IRS satellite was launched in 1998 and had sensors with resolutions of 36 and 72 meters. The third IRS satellite, IRS 1C, has a sensor with one-5 meter resolution panchromatic band, four 23-meter resolution multispectral bands, and one 70-meter resolution thermal infrared band.

SPIN-2

SPIN-2 imagery is a film-based, 2-meter panchromatic product that is digitized and orthorectified. SPIN-2 offers 2-meter and 10-meter imagery and digital elevation models of areas throughout the world.

DOQ

USGS **digital orthophoto quadrangles** (DOQs) are digital image files derived from aerial photography (typically black-and-white, but sometimes color or color infra-red). The photographs are scanned and processed to create a georeferenced and planimetrically accurate digital image. This processing, or rectification, removes the distortion in the scanned photo caused by the camera lens, topographic relief, tilt of the airplane, and other factors. The production of an orthophoto also requires accurate ground control and an elevation model of the area (see Appendix A).

Orthophotos combine the image characteristics of a photograph with the geometric qualities of a map. The primary digital orthophotoquad (DOQ) is a 1-meter ground resolution, quarter-quadrangle (3.75-minutes of latitude by 3.75-minutes of longitude) image cast on the Universal Transverse Mercator Projection (UTM) on the North American Datum of 1983 (NAD83). The geographic extent of the DOQ is equivalent to a quarter-quadrangle plus an **overedge** to support tonal matching for mosaicking and for the placement of the primary (NAD83) and secondary datum corner ticks.

Ikonos	Space Imaging launched Ikonos, marking the first successful launch of a high resolution commercial satellite. Ikonos has a 1-meter panchromatic band and four 4-meter resolution multispectral bands.
Quick Bird	Digital Globe offers the highest resolution satellite imagery available commercially. Quick Bird was launched in 2001 by Digital Globe and provides 0.61-meter (2-foot) resolution panchromatic (black and white) and 2.44-meter (8-foot) multispectral (color) imagery. Quick Bird will collect an industry-leading 16.5-kilometer (10.3-mile) swath of imagery that enables greater collection of large areas.
OrbView	ORBIMAGE's OrbView-3 and OrbView-4 high resolution satellite imagery will be useful for mapping existing infrastructure and planning the construction of roads, buildings, dams and other objects.
ASTER	The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument that is flying on the NASA Terra satellite. Launched in 1999, Terra is part of NASA's Earth Observing System. ASTER provides 14 spectral bands in varying spatial resolutions of 15, 30, and 90 meters.

Chapter 3
Determining Appropriate Uses for Imagery

When Should One Consider Using Imagery

How does one know whether to use imagery for a particular project? As noted in chapter 2, there are several different kinds of imagery available. The spatial, spectral, temporal, and radiometric resolutions of the various image types offer many options and will strongly influence a decision. Additionally, factors such as season, atmospheric conditions, and geographic location can also affect the feasibility of an image classification.

Some reasons for choosing imagery include situations where:

- resource or study areas are large or inaccessible,
- existing data sources, including aerial photographs, are outdated,
- existing inventories do not cover entire area of interest,
- inventories are outdated or infrequent,
- inventories lack consistency or assessment of accuracy,
- existing data lacks spatial component,
- existing data is not in digital form for GIS, or
- change detection over time is necessary.

In addition to these reasons, managers should consider the following issues:

Level of required detail. The level of detail in the map should be defined in the **classification hierarchy** (see Appendix B). The classification hierarchy is the list of classes or the legend needed for the project. For example, a 1:12,000-scale aerial photograph will provide detail not found in a Landsat satellite image.

Size of resource area. It may not be cost-effective to purchase and classify aerial or satellite imagery for a large project area where a high level of detail is needed. There are times, however, when classification may be cost-effective, such as when imagery coverage is already available.

Project-specific circumstances. Individual project-specific circumstances may strongly influence the decision to use a particular technology. For example, a severe time constraint or very large geographic area may require the use of low resolution satellite imagery. In such instances, modification of the ideal project classification hierarchy may be necessary to accommodate the technology.

What Factors Affect the Results of an Image Classification

Besides differences in satellite and aerial sensors, several factors can affect the results of a land cover classification from satellite imagery. For example, the use of **ancillary data** (secondary data that supports the interpretation and analysis of the imagery data) could increase the **accuracy** of the thematic land use map derived from imagery. Ancillary data of poor quality might actually decrease the accuracy of the resulting analysis.

The geographic location of an image can also affect the type and accuracy of information derived from it. For example, in the Pacific Northwest or other areas where vegetation is usually dense, the imagery sensor observes mostly vegetation. However, in drier areas, background such as rock and bare ground can overwhelm the vegetation information so that the sensor is less successful in detecting this information. High resolution imagery might be preferable in such a case.

How Can One Choose an Appropriate Data Type

As discussed in Chapter 2, important factors that can affect the classification of imagery include:

- type of imagery used (Landsat, SPOT, DOQ, etc.);
- type and quality of ancillary data, and method of incorporating it in the classification process;
- geographic location of the image;
- time of year image is acquired—seasonal land cover differences may be important;
- atmospheric conditions at time of data collection;
- time and money available for processing and field work;
- experience of the image analyst; and
- analysis methods and classification hierarchy.

Any of these factors alone or combined could affect the outcome of a project using digital imagery. Therefore, it is not possible to generalize about the appropriateness of imagery for all mapping projects.

The best way to decide whether imagery (or any other data source) will meet the project's needs is to gather as much information about previous work done in the area or areas similar to it. Before gathering additional data, it is wise to complete an inventory of existing data sources. There may be existing data that will suit the needs of the project.

Factors such as computer processing time also must be calculated when choosing types of imagery. An increase in spatial resolution will increase the processing time required for interpreting the information. Also, imagery with higher resolution requires more storage space on computers for a given area. For example, an image with 10-meter pixels would require significantly more time to process than a lower resolution 30-meter pixel image, given the same area. Likewise, the ten meter resolution imagery requires nine times as much storage space for a single image when compared to the 30-meter resolution imagery of the same geographic coverage.

This is a list of steps that should be taken before using imagery in a mapping project:

Step 1: To formulate realistic goals for a remote sensing project, become familiar with the best and worst possible scenarios, and aim for something in between.

Step 2: Define the classification hierarchy (discussed in Appendix B). The information needs of the mapping project should drive the decision to use a particular imagery data source and technology.

Step 3: Do a literature search for similar projects completed in your geographic area or one with similar characteristics.

Step 4: Scrutinize results (accuracy assessments) of past projects. Take a close look at individual class accuracies as opposed to overall accuracies (see chapter 4).

Step 5: Consult expertise in universities, research units, and/or other agencies. Appendix E provides a list of remote sensing and technical contacts.

In addition to the above steps, a pilot project is an excellent means of testing the technology as well as for developing a sound methodology. Completion of a pilot project is highly recommended when the team is unfamiliar with using digital imagery. Thorough testing of the technology by taking a project from start to finish for a smaller geographic area will answer questions that were not thought of and will bring project expectations in line with reality.

Chapter 4
The Imagery Analysis Project

This chapter provides an overview of the remote sensing project that is designed to ensure the effective management and technical execution of a mapping project that involves the use of digital imagery and GIS technology.

Setting Up the Imagery Analysis Project

Managing a GIS/remote sensing project can be a complex undertaking involving both human and technical resources, multiple data types, and numerous logistical as well as analytical considerations (Figure 4-1). Remote sensing projects can get quickly out of control for many reasons, including:

Project Challenges

- overestimating what the technology can accomplish;
- underestimating the difficulties associated with large data sets

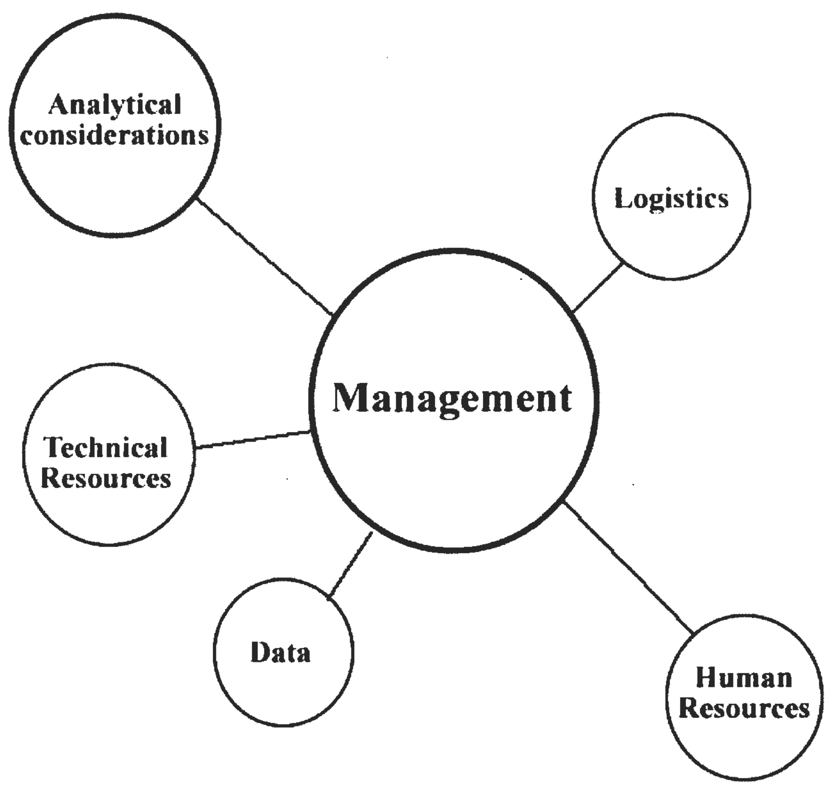

Figure 4-1. Management issues associated with a remote sensing project

and multiple data base layers;
- not knowing when products are adequate for intended project purposes;
- underestimating the work needed to combine data sets of varying scales, accuracies, and origins;
- underestimating the time needed for multidisciplinary approaches to problem solving;
- underestimating the need for training/experience with current software; and
- fascination with the technology at the expense of accomplishing project goals.

Strong project management is essential to prevent these issues from becoming problems. While no project manager can be expected to know the technology inside and out, the manager should know and practice the time tested management techniques that follow.

Project Management

Project management is the planning, organizing, and managing of resources (personnel, equipment, time, money, and data) to accomplish a defined objective. Successful project management requires:
- a clear definition of project objectives,
- identification of all tasks needed to reach the objectives,
- proper allocation of resources to accomplish tasks, and
- constant monitoring of task accomplishments and resource expenditures.

Gathering Information

It is important that the project manager begin the job by gathering general information about the requirements of the planned project. Information gathering activities may include the following (based in part on Hewitt and Koglin):
- user needs,
- data requirements,
- analytical needs,
- processing system and storage requirements, and
- identifying the staffing needs for the project.

Drafting the Project Plan

It is often said that while a perfect plan will not guarantee success, the lack of a plan will guarantee failure. The **project plan** must be the manager's first priority, and should be maintained and updated as a written document throughout the project life span. At a minimum, the project plan should contain the following four elements:
- an abstract or overview,
- a technical design,
- a schedule, and
- a budget.

The **abstract** should be designed for distribution to interested parties, including the public, cooperators, potential funding sources, and upper management.

The **technical design** should clearly and specifically:

- state project objectives and identify output products,
- state the methods and data sources to be used,
- break the workload into identifiable tasks,
- allocate hours and type of personnel by task,
- allocate equipment (including hardware and software) needed by task,
- identify material and services needed by task,
- assess risk by task and provide fallback plans for high risk tasks,
- state the data structures, formats, and conventions to be followed, and
- include a quality control process.

In the technical design, the breakdown of tasks is particularly important. Tracking individual tasks is much easier than trying to manage the whole project at once. The task breakdown is also used to monitor progress and budget.

Assessing risks and formulating contingency plans are also important to the technical design. Typical risks for remote sensing projects include:

- problems related to using new or untried technology and/or data sources,
- the chance that data for certain geographic regions is not available,
- chances of delay in receiving data,
- budget and schedule overruns,
- problems related to the logistical challenges of fieldwork, and
- failure to meet specified accuracy standards.

The **project schedule** is constructed from the technical design as follows:

- start with the time needed for each task as listed in the technical design;
- determine which tasks are concurrent, and which tasks depend on the completion of other tasks;
- consider the availability of personnel;
- consider constraints related to fieldwork, access to computers, and availability of data;
- include time for contingency plans; and
- develop the final schedule.

The **project budget** is calculated by assigning costs to each task identified in the technical design. Be sure to include salaries, travel costs, equipment and material needs, and required outside services.

The technical design, schedule, and budget of a project are interrelated in such a way that a change in one may necessitate a change in the others. Project planning is an iterative process. If the initial schedule, as dictated by the technical design, misses a deadline, then the technical design must be altered, perhaps by adding personnel or using different methods. The budget may then need adjustment. Alternatively, if the initial budget exceeds the allotted funds, a different technical design may be needed.

Coordinating Elements of the Project Plan

The project manager must understand the relationship between technical design, schedule, and budget. When unexpected problems occur (and they almost always do), the manager must know the effects on timing and budget of any changes in the technical design.

Project managers should be aware that certain aspects of digital image classification are particularly crucial to reasonable project planning. The **classification hierarchy**, for example, has the single largest effect on the methods, cost, and success of a remote sensing project. Therefore, the project manager must ensure that the project methodology matches the classification hierarchy, and that the hierarchy is realistic for remote sensing. (For a review of the importance of the classification hierarchy, refer to Appendix B.) Accuracy assessment also must be carefully considered in project planning in order to produce useful and verifiable results, and to set guidelines and standards acceptable to project analysts and managers.

Using proven techniques reduces the risk of time and budget overruns. However, many projects require that the team use unfamiliar approaches or develop new ones. Difficulties often arise when the project manager waits until late in the project to try out a new technique. A small pilot project that takes a new methodology from start to finish will reduce the risk associated with new technology.

Project Monitoring

The project plan defines tasks and assigns resources (personnel, equipment, money, data) to those tasks. During the project monitoring phase, the manager must compare actual task accomplishment and resource expenditures to planned accomplishments and expenditures. The project manager's day-to-day responsibility is to allocate and manage resources as needed to keep the project on track. The project manager manages and monitors the project through regularly scheduled progress reports, budget reports, and daily activity logs. The manager should also institute a "no surprises" policy with the team:

any issue that could affect the technical design, budget, or schedule must be reported immediately. Without this, the manager can quickly lose the ability to adjust the plan to accommodate change—sometimes with unfortunate results.

Continuous quality control is an important part of project monitoring. The quality control plan for the project should:

- clearly state acceptable standards of work, agreed to by the users and the project manager;
- identify potential sources of error for each task;
- prescribe actions to eliminate known sources of error;
- assign responsibility for quality control for each task; and
- be reviewed during project wrap-up.

Digital Image Processing

Once the objectives of the research have been determined and once a project plan is in place, the digital analysis portion of the project is initiated.

Preprocessing

Most imagery, and especially most commercial imagery, has been pre-processed prior to its release to the research and applications community and to the general public. Still significant data pre-processing is required for most image data.

Data Import

Most geographic information systems and image processing packages provide tools to import imagery. This step is often necessary to support data management and indexing within the software or to convert generic image formats, such as tiff, into internal formats to support geographic indexing and faster operational processing.

Reprojection

Many planning agencies use a standard datum and projection for all geographic data. Reprojection functions convert images from one datum and projection to another datum and projection. Several GIS and image processing packages now reproject geographic data "on-the-fly" as the data is being read from disk and displayed on the computer monitor, which may lessen the impact on agencies to reformat each of its new data sets as they are integrated into the GIS.

Registration

Some imagery data may require registration with data currently in an existing GIS. Imagery registration is the process that conforms an input image to a reference source (an image or map). The decision point on whether to register imagery to your base map or to register your base map to your imagery will require time, and must be approached with caution, since it could result in re-registration or reprojection of all of your existing data.

Imagery registration is not available in some GIS packages; an image processing package is required (Figure 4-2). Imagery registration requires identification and selection of unique points that are identifiable in both input and reference sources. The resulting registration error is dependent on the number of **ground control points** as well as their spatial distribution (Orti; Fonseca, _et_. _al_.).

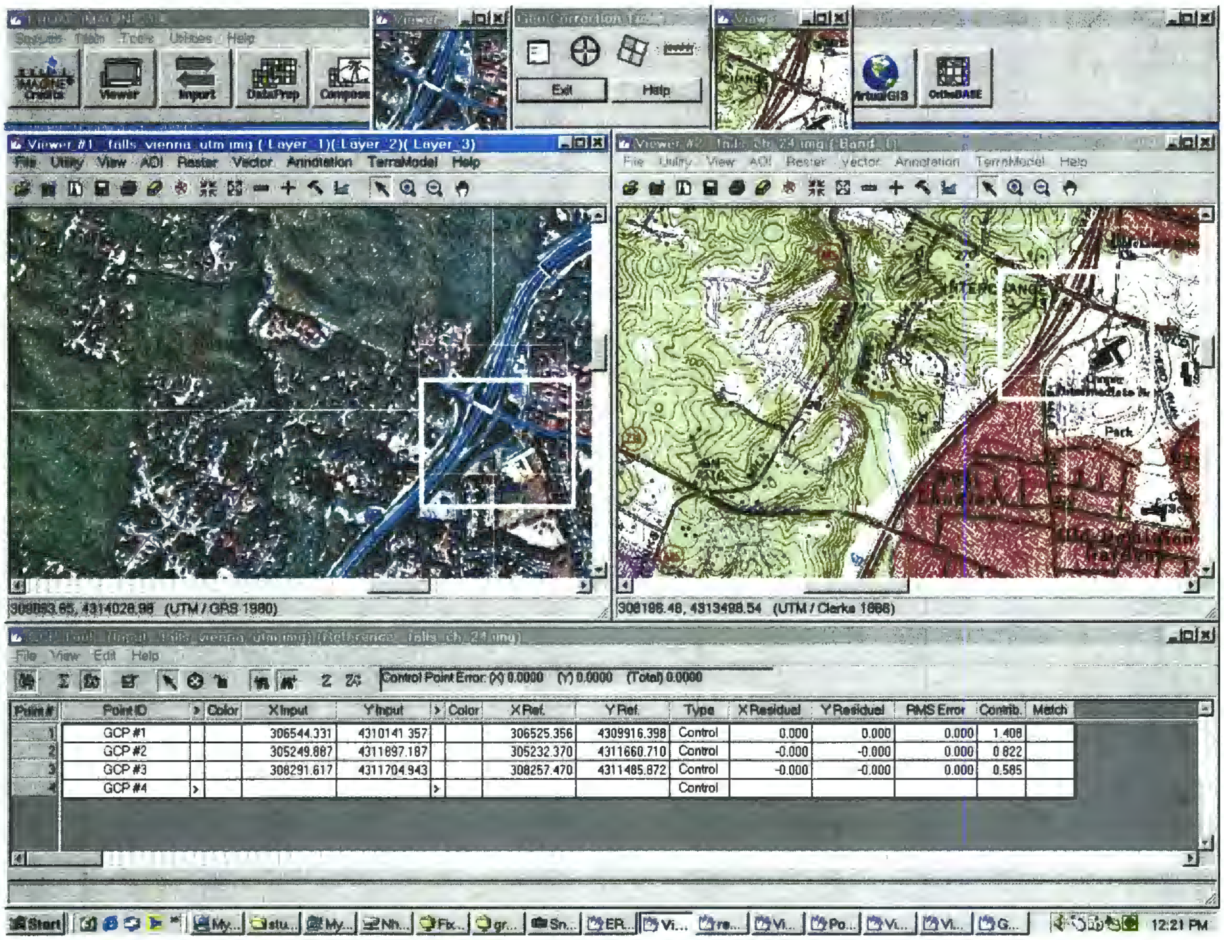

Figure 4-2. Imagery to map registration using points identifiable on both sources

Image Registration

During the 1995 SANDAG land use update, analysts determined that locational errors in SPOT imagery were generally found to be 10 meters or less. Polygon layers in SANDAG's GIS contained errors of 25-100 meters. For this reason, SANDAG used SPOT imagery in 1995 to serve as a base map to update vector layers and to register with other GIS layers in the regional database.

IRS 5 meter resolution of Baltimore-Washington Airport
Imagery source: Space Imaging

Landsat 28.5 meter resolution of Baltimore-Washington Airport
Imagery source: Space Imaging

Merge product of Baltimore-Washington Airport
Figure 4-3. Resolution merge enhances the spatial resolution of low resolution multispectral imagery

The goal of imagery analysis is the discrimination of objects and features into recognizable shapes and patterns to discern meaning. The analyst has many semi-automated and automated tools to assist in the discrimination process.

Imagery enhancement spans a range of processes and functions, ranging from simple gray scale enhancement to complex multiple image resolution merge functions. Enhancements are performed on imagery to support manual, semi-automated, and automated analysis.

Gray scale and contrast enhancements are used to sharpen distinctions between objects and their background. This form of enhancement is available in both low-cost picture processing software and in professional imagery processing software.

Image enhancement also includes functions that match the brightness **histograms** between two or more images. Such enhancement is often necessary to standardize the overall image brightness and contrast before conducting pixel by pixel comparisons, such as **change detection**, between two or more images.

Resolution merge functions merge a single, high resolution, panchromatic image with a lower resolution multispectral image (Wald, et. al.; Chavez, et. al.). The resulting image retains the multispectral characteristics of the original multispectral image but has increased spatial resolution, as shown in Figure 4-3.

Transformation

Functions such as band ratios, tasseled cap, and principal components transform an original image into a synthetic image with different dimensions and different characteristics. The most straightforward of these transforms is the band ratio, whereby the pixel values of one image spectral band are divided by the corresponding values of a second band. Band ratios have been found to reduce effects of topography in imagery and have been used to accentuate vegetation-related characteristics.

The tasseled cap transform was originally developed to assist in the understanding of important agricultural crop phenomena. This transform provides information on vegetated, as well as non-vegetated regions and can be used to provide insight and identification of urban boundaries.

The principal components analysis transform creates a new image in which the new bands minimize intra-band correlation. Principal components analysis identifies the optimum linear combination of the original image bands that account for variation of values in an image. Most of the original data content within the image is expressed in the first few bands of the principal components image, thereby reducing dimensionality of the image and minimizing space for the image.

Classification

Image classification is a mixture of art and science. Classification converts a continuous image with numerous, possibly several hundred, gray scales into an image with fewer discrete values that may reflect surface material and/or land cover differences. The resulting **accuracy** of the classified images needs to be measured and understood before using the classified product as a decision-making tool.

Supervised vs. Unsupervised

Both supervised and unsupervised classification requires knowledge of specific objects and land use types within the scene. In supervised classification, samples that correspond to specific objects and land use types, referred to as training sets, are identified in an image. Statistics, both spectral and textural, can be calculated for each of the training sets during training set formation. The goal of training set formation is to create maximum statistical separation between object types. Once training sets have been identified, the remaining pixels within the image are classified into the most likely training set category, based on comparison of that pixel with training set statistics. The supervised classifier can become confused when training set categories have overlapping statistical characteristics, since an image pixel with properties similar to the overlap area could be placed into an incorrect object class (Figure 4-4).

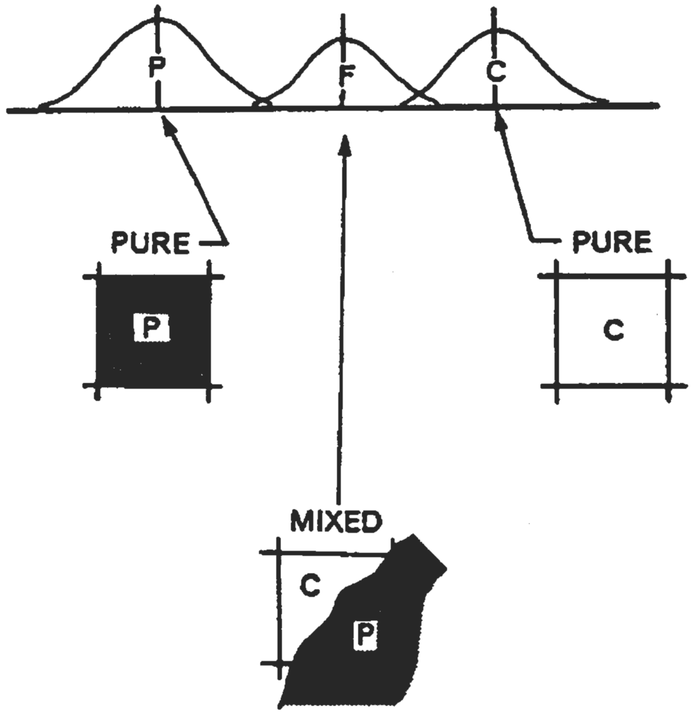

Figure 4-4 Graphical concept of mixed training sets which can result in classification errors

Courtesy Campbell JB

Unsupervised classification segments the image into a predetermined number of classes specified by the analyst, based on spectral and textural characteristics of the image. The final and most difficult step in unsupervised classification is the generation of land use through the transformation, and often aggregation, of the computer-generated classes into land use categories. The image analyst performs this step using personal expertise supported by ancillary information. As the analyst identifies a pixel associated with a specific object or feature class, all pixels with similar characteristics in the image will be grouped into that feature class.

Mixed Pixels

Mixed pixels result when two or more objects or feature classes are present in a single pixel (Figure 4-5). Mixed pixels often occur at the edges of large parcels or along linear features. The resulting pixel is not pure in the sense that a specific object or feature class is not represented in its pixel value. Mixed pixels create confusion during the classification stage since the classifier, based on the mixed pixel's statistics, may have characteristics of none of the pixel's constituent components and could assign an input pixel to either the wrong category or to a new, undefined category.

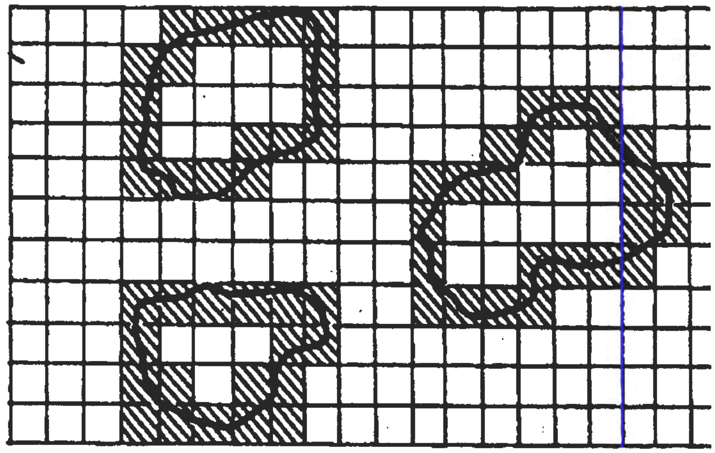

Figure 4-5 Mixed pixels often occur at the boundaries of features
Courtesy Campbell JB

Scattered occurrences of small land use parcels may produce special problems because they may be represented only by mixed pixels. At the other extreme, high resolution imagery may provide such an abundance of spectrally pure pixels so as to confuse classification of land use classes, such as residential or commercial, into several composite classes, such as driveway, grass, landscaping, and others.

Accuracy

While it may seem so at times, the classification process is not magic. **Accuracy** defines the relative correctness of a classification and measures the agreement between what is known to be correct and what is classified as being correct. Classification accuracy is based on the characteristics of the imagery and the analytical process used in classification. Accuracy is influenced by the quality of the data used to support:

- training set identification (supervised), or
- analyst matching of object or feature classes with spectral clusters (unsupervised).

Accuracy is also influenced by the purity of:

- the input training sets (supervised), or
- the object(s) or feature class(es) (unsupervised).

In general, accuracy is increased as the sample size is increased. As a result, the remote sensing project manager needs to balance the costs associated with collecting samples for accuracy analysis versus the confidence that results from classification (Dicks, et. al.).

Analysis

Analysis is that portion of the project where the planner or image analyst attempts to derive information from the raw imagery, the processed imagery, and imagery that has been integrated with other data sets, such as raster and vector maps and tabular attribute data. The quality of the results and the associated accuracy of the analysis justifies the costs associated with acquiring and processing the imagery.

Several specific items could culminate from this step, including:

- simple presence or absence of an object,
- object identification and location,
- calculation of area associated with a feature class or with feature classes, and
- complete land use assessment.

Change Analysis

Change detection is a specialized form of image analysis that compares one date of information with another date to determine and assess the nature and degree of change (Ridd, *et. al.*). Image change analysis is performed by comparing a historical image with a more recent image by subtracting pixel values of one from the other.

In addition to use of the raw image subtraction, two different image transform techniques—principal components and tasseled cap—are widely used to enhance each of the input images in the analysis. When these transforms are used, additional computer resources and time are required, of course, when compared to use of the raw imagery only. But the pre-processing transformations can provide additional discrimination of objects and features classes to support automated and manual visual change detection and analysis.

Vector Digitization

One final step that can be taken in the imagery analysis project is the extraction of vector lines and polygon boundaries from the imagery (Figure 4-6). Most image processing packages provide the capability to digitize vectors and store them in industry standard formats for use and further processing in GIS.

Project Wrap-up

Too often, remote sensing projects are completed, published, and forgotten. This is partially the fault of project managers who failed to involve the users throughout the project or did not actively plan for the distribution and use of final products. If potential users are not familiar with existing data or how to use it, they will probably not use it. Therefore, a primary goal of the project wrap-up is to prepare the data for future use. The manager should budget time at the beginning of the project for publications, awareness briefings, data distribution costs,

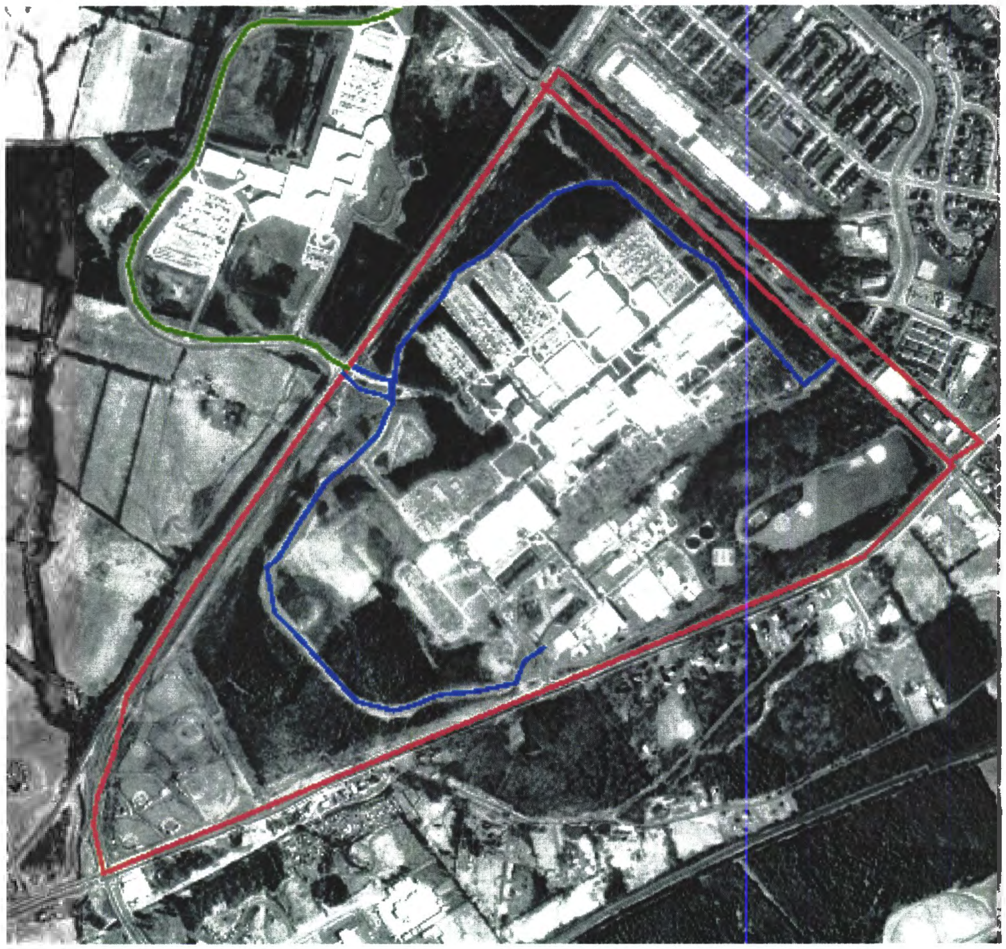

Figure 4-6 Many software packages allow vector editing over imagery providing capabilities to overlay and maintain boundary files, such as this TAZ

and **metadata** creation costs needed at project completion. The manager must also plan a suitable archive for the project. A general rule is to save enough data and documentation so that a reasonably knowledgeable person could use the archive to reproduce the project in all its steps—from raw imagery to final classification. It is also essential to archive a replica of any final products.

Since remote sensing and GIS are still relatively new technologies, others will benefit from a written final project report. This should include an overview of how the project proceeded and an indication of whether it was on schedule, within budget, and why. It should also discuss successes and failures, including descriptions of any new techniques used and advice on working around the problems encountered. In other words, a final project report that is useful for future projects will answer these questions: What was learned? How were problems solved? Which approaches worked best and were most efficient?

Data Preparation and Project Implementation

Imagery analyses were performed to support the ***Southern California Association of Governments*** (SCAG) and the ***San Diego Association of Governments*** (SANDAG). During the first step of the computer-assisted, visual analysis each of the input data sets was registered to a common projection space. The Landsat TM imagery, the USGS MRLC data, the land use digital data, and the Tiger/Line block files were re-projected to UTM Zone 11, NAD83 conform to SCAG projection specifications. The Ikonos imagery, the USGS MRLC data, and the Tiger/Line block files were re-projected to State Plane, feet, Zone 3401 to match SANDAG projection specifications. The DOQ imagery was resampled to create images with ground sample distance that matched the Ikonos 1 meter resolution imagery.

The Landsat TM images were sharpened with the haze removal function of Erdas Imagine. Next, the 1993 image was registered to the 1999 imagery using the common control points in each of the images. Finally, the spectral range of the 1993 color infrared imagery was adjusted to correspond to the 1999 imagery by using a histogram equalization technique developed by the San Diego State University.

Imagery analysis was performed using both panchromatic and multispectral imagery. TM bands 4,7,3 were displayed as red, green, blue using Erdas Imagine. The Erdas Imagine Blend/Fade tool was used to perform visual comparison of the multi-date imagery. Changes observed in the manual visual analysis were marked as areas of interest and were converted to ArcInfo vectors using the vector module of Erdas Imagine. The vector coverage that depicted change was segmented into eight classes—agriculture, vegetation, cleared/vacant, commercial/industrial, water, reservoir, and earth construction—based on the observed land use class in 1999. These areas were then analyzed against the land use data sets.

MRLC land use data was analyzed with respect to current land use using imagery and the map-based land use data sets. The analysis focused on the accuracy of the classification as well as the level of detail present in the MRLC when compared with the high and low resolution imagery and map-based land use data sources.

After the visual analysis was performed, additional semi-automated image change analysis was conducted to verify the techniques for broad-scale application within the larger SCAG and SANDAG planning areas, and to develop a path for subsequent automated analysis using imagery and vector-based map sources.

SECTION II
APPLICATIONS AND CASE STUDIES

Chapter 5
Presentation Graphics

Imagery provides visual information that illustrates the location and spatial relationship of cultural objects and their natural surroundings. As such, a simplistic yet powerful application of imagery is the use of imagery as presentation graphics. Imagery can be used to produce large, poster-sized displays to support information the planner is presenting during public hearings, including improvement location assessment, corridor placement, financing, and right-of-way planning.

Figure 5-1 Imagery is a powerful medium for public displays

Imagery also is a powerful medium in publications, whether small or occupying a full page. Imagery provides the visual evidence that can add credibility to textual descriptions.

Figure 5-2 depicts a notional strategy of imagery acquisition to support analysis of a planned transportation corridor outside Washington, DC. The red rectangles in the figure represent approximate locations of the transportation corridor. The magenta rectangles represent areas where medium resolution imagery is required to support broad land use analysis. The yellow rectangles represent areas where high resolution imagery is required to support detailed analysis.

The image in the background of Figure 5-2 provides a broad, regional overview of the Washington, DC metropolitan area. Presentation graphics as an application is quite straight-forward and requires only imagery and a drawing package to support creation of the overlaid graphics and text. Imagery supports this graphical application by providing to the viewer the land uses and natural features that may influence the final placement of the transportation features.

Imagery can be integrated into PowerPoint and video presentations. The presentation can include both the original tiff files obtained from the imagery vendor as well as screen shots of the imagery as it is being processed in geographic information system and image processing software applications.

Processing

The creation of presentation graphics often requires very little analytical processing. Imagery can be downloaded from the web or can be extracted from a distribution CD. Once the imagery is acquired, the planner can manipulate small image areas with low-cost desktop tools to cut, crop, and perform minor visual enhancement. The resulting images can then be placed in a document or can be output to a high quality printer.

Overlay Registration

Imagery can be integrated with other geographically referenced data using specialized geographic information system and image processing software to support overlay registration and display. This process requires a modest level of analytical processing and can be used to overlay data such as road networks over the image base for graphical display.

Figure 5-2 Imagery provides a contextual backdrop for vector graphics

Visualization

Imagery can also be integrated with **digital elevation model** data and rendered into three dimensional forms using special purpose software to create simulated terrain fly-overs and fly-throughs.

Figure 5-3 shows a perspective using a Landsat image draped over elevation data acquired by NASA's shuttle radar topography mission (SRTM) during a February 2000 Space Shuttle mission. The image shows the Tehachapi Mountains in the right foreground, the city of Ventura, California on the coast at the distant left, and the easternmost Santa Ynez Mountains forming the skyline at the distant right.

Figure 5-3 Landsat data draped over SRTM elevation data
Courtesy NASA

Chapter 6
Analysis of Urban Form and Growth

Imagery provides a convenient data source to assess and analyze the urban form. Imagery also provides the capability to monitor the urban form over time, allowing the assessment of growth and change. Figure 6-1 shows two Landsat TM images of the western portion of Riverside County, California, located to the east of Los Angeles. The Landsat image on the right is overlaid with City Lights data, distributed by the ***National Oceanic and Atmospheric Administration*** (NOAA). City Lights data are acquired by a thermal infrared sensor and depict urban areas as bright, white patches. The City Lights sensor provides a clean depiction of the generalized urban/rural boundary.

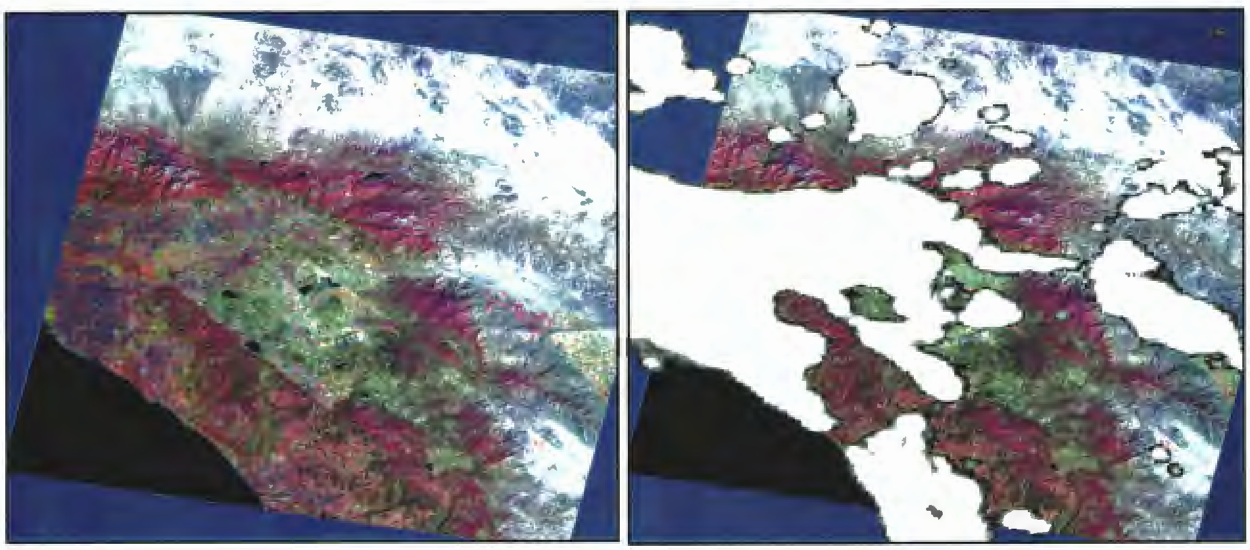

Figure 6-1 Landsat TM imagery and Landsat TM imagery overlaid with City Lights illustrate urban differentiation in southern California

Defining the Urban Boundary

Urban growth boundaries (UGBs) are a means of controlling and managing growth and have been required or are authorized for use in six states (Knaap, 2000). In the Oregon system, UGBs encompass the inventory of urban land and reflect the areas that have already been developed and those areas that are developable. Areas that cannot be developed, for example because of some natural constraint, are also identified.

Oregon's system requires that enough land must be maintained within the UGB to support growth for a twenty-year period. Assessments on the availability of land, which provides a measure of the rate of change for the period, are taken every five years.

Portland's Metro uses a raster-based data model and specialized GIS software (known as GRID) for certain geographic analyses. Metro's regional forecast can be allocated to very small area estimates. This capability has enhanced Metro's ability to analyze various regional growth concepts, employment and housing capacity. More recently, the GRID data was used to distribute future employment and household growth over the entire region to study urban growth and the need to expand the Urban Growth Boundary (UGB).

An increasing number of jurisdictions have tax parcel-based GIS capabilities. These GIS efforts provide the capabilities to monitor land supply and capacity monitoring (LSCM) in an effort to manage urban growth.

A survey taken from October 1997 through March 1998 (Moudon, *et. al.*) indicates that LSCM efforts are predominantly:

- led by the public sector;
- are regional in scope;
- address primarily medium- to long-term supply and capacity prospects;
- involves the collection, maintenance, and analysis of large, complex data sets, with elements ranging from aerial imagery to infrastructure networks to parcel-specific land records;
- are sporadic rather than continuous, whereby land supply and capacity are analyzed for a specific time period, but are often not tracked over time to support a good understanding of trends;
- are oriented toward single family and vacant land uses, have limited treatment of employment based uses, multiple or mixed uses, and lands available for infill and redevelopment;
- give piecemeal consideration to environmental factors;
- serviced land is generally limited to transportation; and
- future assumptions are often based on the status quo projections.

Urban Growth Boundary (UGB)

Metro updates its inventory of vacant land for the 461 square mile UGB on an annual basis through the analysis of GIS layers and aerial photography. Metro estimates that it spent approximately $44,000 to support staff time, computer time, plotter supplies, and aerial photography during the two months that was required to complete the vacant land inventory.

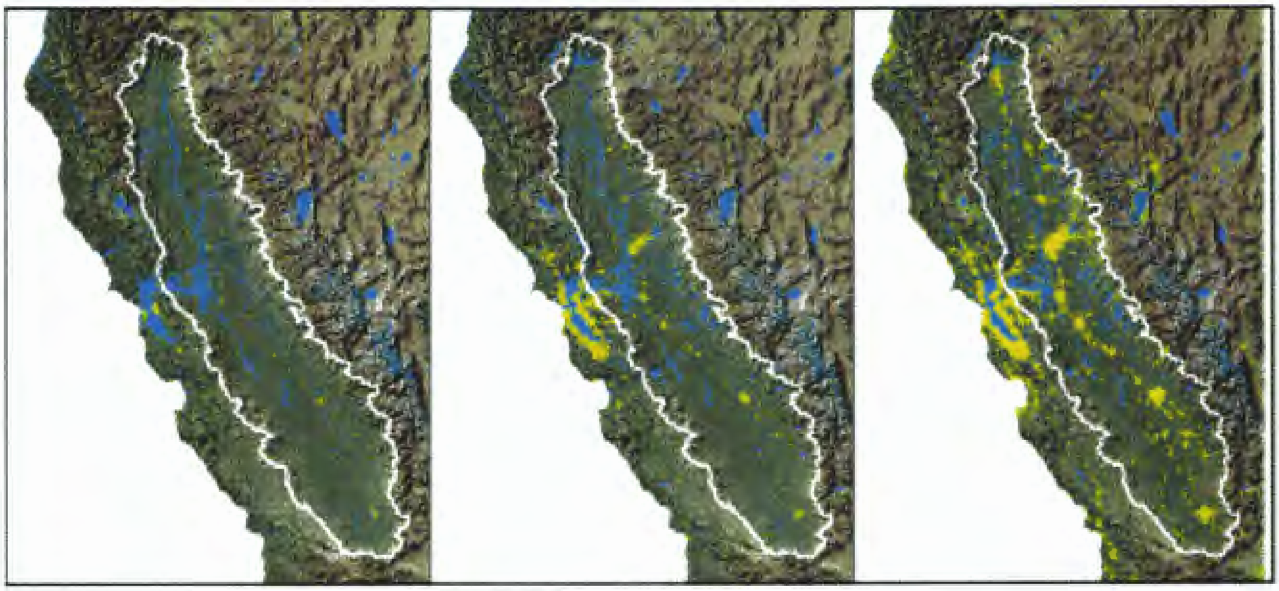

Figure 6-2 The USGS urban dynamics program has developed models of growth (yellow) for the San Francisco Bay Area

Courtesy USGS

Urban Dynamics

The US Geological Survey developed the Urban Dynamics program to analyze land use change in urban environments. The goal of the analysis is to provide a historical perspective of land use change and an assessment of the spatial patterns, rates, correlation, trends, and impacts of change. Figure 6-2 provides graphical depictions of urban change during three distinct time periods.

Imagery can be the basis of monitoring and assessing the nature and significance of changes around a specific point or within a region. Changes can be identified and monitored using either multiple dates of imagery or by comparing imagery against map data within a GIS.

Figure 6-3 provides a visual depiction of change at the edge of what is now the informal urban boundary to the west of Washington, DC. The figure shows three time periods—1962, 1989, and 1995—of Exit 47 of Interstate 66 approximately 25 miles west of Washington, DC near Manassas, Virginia. Similar to many places 25 miles from an urban center in 1962, this area was quite rural. Residential and limited commercial growth is evident in 1989. The 1995 image shows increased commercial development including big box retail stores and an extensive strip development on the primary arterial.

Monitoring and Assessing Urban Boundary Change over Time

Once a boundary is identified and defined, updated imagery, as it is acquired, can be used to support long-term monitoring of changes associated with the boundary. This monitoring process requires careful geographic registration between the imagery and the map boundary data.

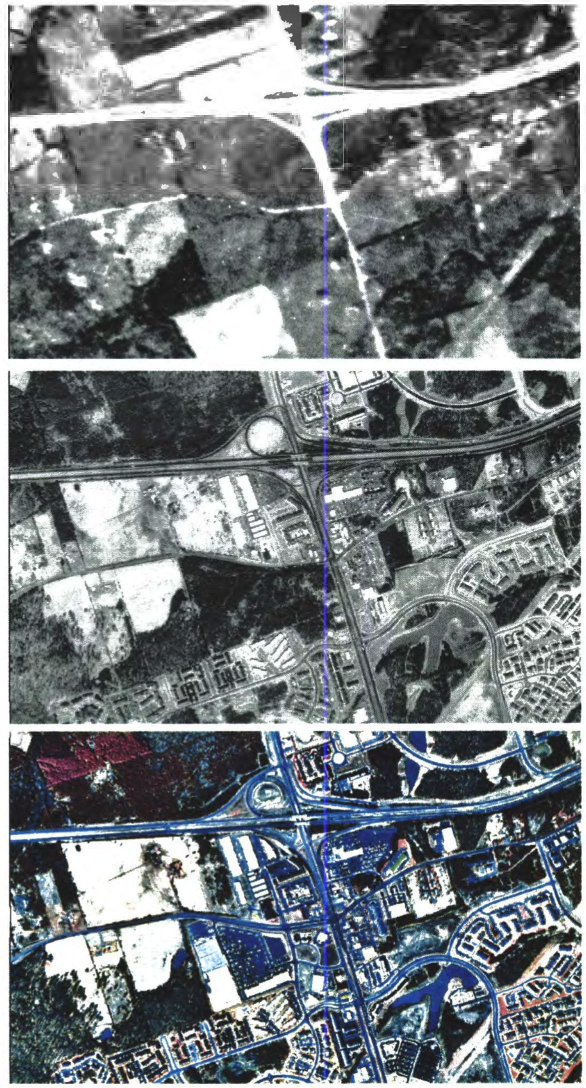

Figure 6-3 1962, 1989, and 1995 imagery of Manassas, Virginia locale
1995 imagery Courtesy VARGIS

Future Visioning

Residents, business leaders, political officials, and planners have analyzed growth patterns and land consumption in northern Utah as part of the Envision Utah Quality Growth Strategy (Coalition for Utah's Future).

The Envision Utah process identified six goals that guided the analysis:

- enhance air quality;
- Increase mobility and transportation choices;
- preserve critical lands, including agricultural, sensitive, and strategic open lands and address the interaction between these lands and developed areas;
- conserve and maintain availability of water resources;
- provide housing opportunities for a range of family and income types; and
- maximize efficiency in public infrastructure investments to promote the other goals.

Envision Utah, in conjunction with its private citizens, business, and political stakeholders, developed a set of strategies to guide the implementation of the before-mentioned goals:

- promoting walkable development (encouraging new and existing development to include a mix of uses with a pedestrian-friendly design);

- promoting the development of a region-side transit system (which could utilize buses, bus ways, light rail, lower-cost self powered rail technology, commuter rail, and small private buses) to make transit more effective and convenient;
- promoting the development of a network of bikeways and trails for recreation and commuting;
- fostering transit-oriented development (housing and commercial developments that incorporate and encourage various forms of public transportation);
- preserving open lands by encouraging developments that include open areas and by incentivizing reuse of currently developed lands;
- fostering mixed-use, mixed-income, walkable neighborhoods to provide a greater array of housing choices.

A Quality Growth Efficiency Tools Technical Committee analyzed growth issues related to demographics, economics, transportation, air quality, land use, water availability, and infrastructure costs. The Technical Committee produced a concept map that encompassed six layers:

- constrained lands (steep slopes, wetlands, developed, and government-owned);
- critical lands (open space buffers and development buffers);
- infrastructure (highways and transit);
- centers and corridors (commercial and industrial centers)
- newly developed lands (new land committed to urban use between 1997 and 2020); and
- redevelopable lands (land with existing development and low improvement values).

Analysis completed during the review process focused on intensifying land uses by reducing the average residential lot from 0.35 acres to 0.29 acres and promoting infill in urbanized areas to ease the pressure to develop new lands.

Activity Center Delineation and Validation

The Metropolitan Washington Council of Governments (MWCOG) used high resolution imagery collected in 2000 to define and further delineate activity centers within the greater metropolitan Washington, DC planning region. Constituent government agencies within MWCOG provided MWCOG with activity center polygons that represented areas of present and future residential, commercial, and/or industrial importance to the region. These activity center polygons were overlaid on high resolution imagery to validate the location and shape of the boundaries and to provide the planner with real-world, tangible evidence of the land use mix within, and surrounding, each of the polygons.

Chapter 7
Land Use, Land Use Change, and Forecasting

Federal guidelines require that proposed transportation actions be conducted in the context of current development trends. Further, planning and analysis of a proposed facility must identify state and/or local land use plans and policies that will be impacted. Most land use decisions in the United States are made at the local level.

The planner has specific objectives in mind when analyzing the impact of transportation improvements. These objectives force the planner to segment the planning area into discrete, project-significant land use categories. Once established, the land use categories provide a framework for analysis over time. Land use data include those objects and features that supply information on population, households, and employment at a small geographic area level. Land use data provides a description of the physical area of land and any built structures used in support of such activities.

All urban planning and monitoring systems have an inventory of the land by type as the basis for analysis (Knaap, et. al.). Land use, including vacant or developable, totally unavailable, partially unavailable, or redevelopable, is a key data type and can be determined through imagery analysis and other geospatial data sources.

The link between land use and transportation is well established, but the reverse linkage is less so, partly due to the length of time that it takes for such effects to occur and the associated lack of empirical data (Mackett). The linkage between land use and transportation is portrayed in Figure 7-1.

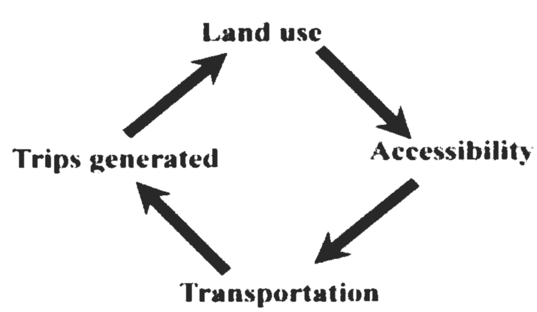

Figure 7-1 Linkage between land use and transportation
Courtesy Mackett

The Clean Air Act Amendments (CAAA) of 1990, the Intermodal Transportation Efficiency Act of 1991 (ISTEA), and the Transportation Equity Act for the 21st Century (TEA-21) are relatively recent federal laws that require a linkage between transportation policy and land use analysis. The implementation of ISTEA and TEA-21 has resulted in greater attention to regional land use policies (Lupa, *et. al.*).

ISTEA and Land Use in Metropolitan Planning

ISTEA authorized federal highway and transit funding programs and recognized the changing development patterns, the economic and cultural diversity of metropolitan areas, and the need to provide metropolitan areas with more control over transportation at the regional level. ISTEA identified transportation planning as a key strategy to improve the system and investment decision-making.

ISTEA established sixteen metropolitan and twenty-three statewide planning factors that formed the framework for a more integrated planning process to better meet the needs of all constituencies. ISTEA also provided explicit linkages to the air quality objectives put forth in the Clean Air Act Amendments of 1990, and led to the enhancement of models that measure and forecast both travel demand and air quality.

Land Use

In the Twin Cities of Minneapolis-St. Paul, the Metro Council MPO is authorized by State statute to prepare and adopt a comprehensive development guide consisting of policy statements, goals, standards, programs, and maps prescribing the orderly economic development of the metropolitan area. The guide includes directions for land use, parks and open space, airports, highways, transit services, and public buildings.

TEA-21's seven general planning factors

The Transportation Equity Act for the 21st Century (TEA-21) consolidates ISTEA's sixteen metropolitan and twenty-three statewide planning factors into seven broad areas to be considered in the planning process:

- support the economic vitality of the metropolitan area, especially by enabling global competitiveness, productivity, and efficiency;
- increase the safety and security of the transportation system for motorized and non-motorized users;
- increase the accessibility and mobility options available to people and for freight;
- protect and enhance the environment, promote energy conservation, and improve quality of life;
- enhance the integration and connectivity of the transportation system, across and between modes, for people and freight;
- promote efficient system management and operation; and
- emphasize the preservation of the existing transportation system.

The consideration of land use is implicit in TEA-21's general planning factors. MPOs are required to consider projects and strategies that will support the economic vitality of the metropolitan areas and increase accessibility and mobility options available to people. The explanatory materials for TEA-21 make clear that "...metropolitan planning organizations are encouraged to consider the interaction between transportation decisions and local land use decisions appropriate to each area."

Travel model issues

Travel demand modeling is part of the continuous monitoring of the transportation network and infrastructure. The transportation planner uses models to forecast, estimate, and predict the interactions between transportation, economic development, and environmental concerns. These models are complex, data-intensive formulations of assumptions that are founded on the spatial organization of residences, employment locations, and locations of commercial activity. The planners use these models to review the results of various land use scenarios and the requirements for transportation improvements. Various researchers have included land use as a variable in their travel demand modeling (Lupa, *et. al.*).

Surveys of MPO Use of Land Use in Travel Models

A 1995 study of thirty-five MPOs (Porter, *et. al.*) showed that:

- eleven used Disaggregate Residential Allocation Model/ Employment Allocation Model (DRAM/EMPAL) or a variant, often in conjunction with less formal methods, such as local review:
- twelve reported using some other type of model, usually developed in-house;
- nine reported basing land use projections primarily on information assessments of development trends and local conditions; and
- three reported doing no land use forecasting though one of these was in the process of developing a model.

More recently, the ***Travel Model Improvement Program*** (TMIP) summarized case studies at five MPOs that represent the best of the practice in their use of land use forecasting in travel demand models (Parsons, 2000). Each of the MPOs highlighted —Portland, Seattle, San Diego, Dallas, and Longview Texas—use GIS data as the basis of their land use forecasting.

The Longview MPO in east Texas uses a **Delphi Process** to incorporate land use into its travel demand modeling, while the other four—Portland, Seattle, San Diego, and Dallas—use more traditional quantitative methodologies. These four MPOs use heavily modified versions of DRAM/EMPAL, in conjunction with custom models to allocate the results to local geography.

BTS Supports Data Standardization

According to the Bureau of Transportation Statistics, data on land use impacts of transportation are required to understand the relationship between public policy and the ability of transportation to serve businesses and the public. BTS states further that there is a need to classify land uses by type of economic activity within developed areas and a need to develop a vehicle to collect land use data on a national scale (US DOT, BTS).

USGS MRLC

Several standards are available to provide frameworks for developing land based classification standards (see Appendix B). The US Geological Survey (USGS) Multi-Resolution Land Characteristics (MRLC) program is founded on the premise that there are a range of requirements that support the need for land cover and land use data (Vogelmann, et. al.). The MRLC provides data at three scales—1:2,000,000, 1:100,000, and 1:24,000—for uses ranging from global change research, to regional land management, and finally to detailed urban infrastructure mapping.

The MRLC uses the USGS Anderson land cover classification as the primary system for classification of land cover units. For the 1:100,000 products, data are classified into fifteen categories, including water, residential, commercial/industrial, agricultural, natural vegetated areas, wetlands, and rock/sand.

The MRLC 1:100,000 scale program represents provides broad regional data for land cover analysis and change assessment. The data represents some of the best, if not the best, data available for broad area land use planning and analysis within the United States. The classification hierarchy is tailored to the physical landscape. In addition, detail is generalized, especially in urban areas, due to the broad regional extent of the dataset. Notwithstanding these two factors, however, the MRLC represents a high quality land use product to the transportation planner.

The MRLC also has a 1:24,000 scale component, but only a few selected cities are represented. The MRLC 1:24,000 provides the appropriate resolution that is needed by transportation planners, but still, the land use categories associated with the MRLC are not well suited to transportation planning applications.

Tax Assessor Parcels

An increasing number of local jurisdictions are developing parcel based GIS (PBGIS) as a means of managing urban growth and as a means of tracking tax assessment. These data offer the planner a rich source of detailed information on land value, building value, and land use. These data are created with the primary purpose of identifying and assessing land value and building value per parcel. It is important

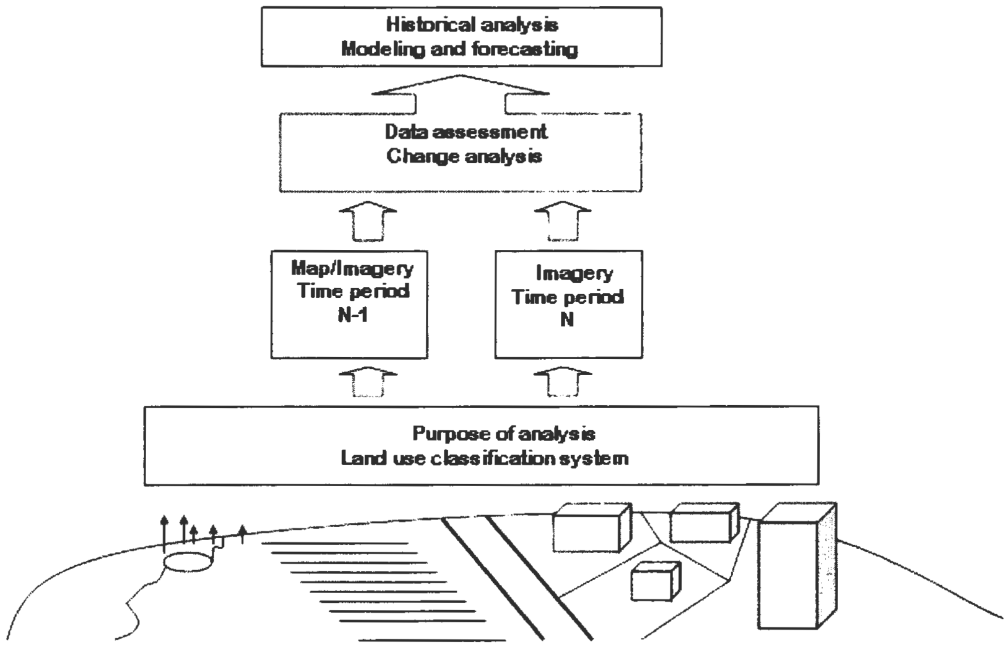

Figure 7-2 Path from imagery to modeling

to note that land use codes associated with the parcel data are often miscoded or coded using a land use classification hierarchy that is not consistent with transportation planning. Further, parcels are generally classified as vacant only if the entire parcel is vacant (Knaap).

Path from Imagery to Modeling

Imagery can support forecasting and modeling activities (Gallimore, _et_. _al_; Parrott, _et_. _al_.; Stow). Historical maps and imagery provide a base from which new imagery and associated information can be integrated to support change analysis and trend analysis. These historical trends and changes can be integrated as variables in the land use and travel demand modeling activities (Figure 7-2).

When engaged in land use analysis using imagery sources, the analyst must take into account the resolution of the sensor, the size of the features within the area of study, and the aggregation effects of these features into cultural/physical constructs known as land use categories. Land cover and land use maps from imagery sources are compiled by discriminating statistical differences between land cover categories.

A recent report published by the Florida Department of Transportation states that additional research is needed to explicitly document the role of remote sensing in determining land use and changes in land use (Transportation Planning Services).

Urban Land Use Change Typically Progresses through Several Observable Changes

Land under development generally progresses through imagery identifiable changes:

- initial clearing of land,
- construction, and
- landscaping.

The analyst has many semi-automated and automated software and analysis tools to assist in land use discrimination using imagery and ancillary data sources, as was discussed in the section on Digital Image Processing in Chapter 4. These tools provide the analyst with a means to discern statistical differences in land cover that can be mapped to known land cover categories using high resolution data sources.

Even with the assistance of sophisticated software tools, however, it is often difficult in an image analysis project to form land use data through the transformation, and often aggregation, of the land cover classes into culturally-relevant land use classes.

Imagery-Derived Land Use Change Product

An image change product reflects differences in land cover and land use between two dates of imagery. The image change product reflects changes in corresponding **pixel reflectance values** between the two images. Precise geographic registration of the two images is required to prevent offsets in shared pixel locations from producing slivers, which could be identified as change rather than as points of misregistration.

SCAG Land Use Change Study

A recent study performed for the Southern California Association of Governments (SCAG) concluded that between 1993 and 1999, approximately 1.9% of the study area converted to a cleared/vacant land use (Figure 7-3). Within the study area, 97% of the acreage that converted to cleared/vacant by 1999 converted from 1993 forest and grassland categories (Table 7-1). Analysis of the progression of cleared/vacant land use class shows that 2,679 acres, or 86% of the changed urban/residential land use in 1999 was classified as cleared/vacant in 1993. This preponderance of conversion of cleared/vacant land use could support forecasting trends in urban/residential growth based on availability of cleared/vacant land. Imagery analysis provides one means of providing the baseline change data to support such forecasting.

In the SCAG analysis, new residential growth was evident in several areas in proximity to Interstate 15, the main transportation corridor in the area. This residential growth is observed as expansion of pre-existing residential areas as well as infill within pre-existing areas. In several areas, pre-construction clearing was evident in the earlier 1993 imagery and housing was present in the year 1999 imagery. In other areas, new housing was observed in year 1999 imagery where there were no signs of construction in 1993.

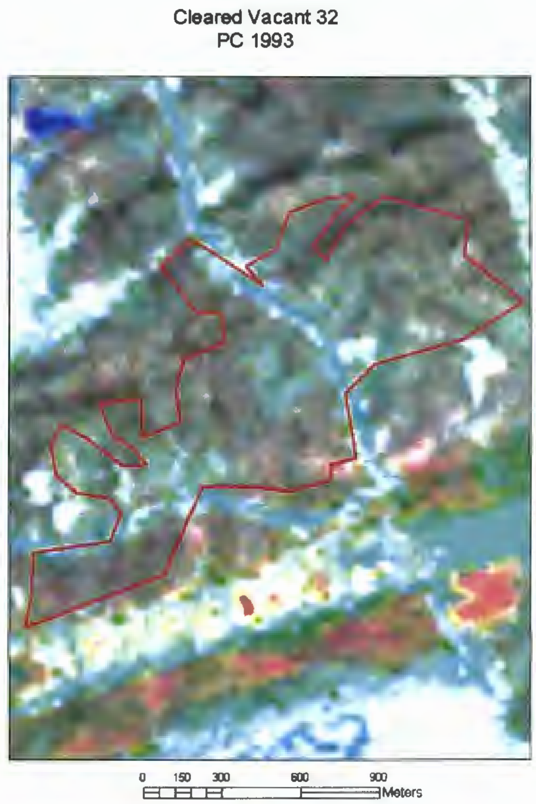

Figure 7-3 An example showing low resolution Landsat TM forested (1993) to cleared (1999) transition class

1999 Cleared/Vacant Class		1999 Urban Residential Class	
1993 Image Class	Area (acres)	1993 Image Class	Area (acres)
Forest	2,238	Cleared/Roads	265
Grassland	875	Cleared/Vacant	2,679
Mixed Forest	254	Forest	23
Mixed Grassland	1,184	Mixed Forest	39
Water	121	New Houses	95
Total	4,673	Total	3,101
% of Total Study Area	1.9%	% of Total Study Area	1.2%

Table 7-1 Selected summary statistics for SCAG land use change analysis. For each 1999 land use class, the table shows the 1993 land use component that changed

SANDAG Land Use Change Study

In a study undertaken for SANDAG, visual imagery analysis of the DelMar area showed eleven general areas and 35 specific sub-areas where change was noted between 1996 and 2000 (Figure 7-4) . Two additional areas that represented representative land cover classes within the study area were chosen where no change was observed. Figure 7-5a and 7-5b illustrates a sub-area that changed from cleared/ vacant to under construction/residential between 1996 and 2000, as observed during the visual imagery analysis. Figure 7-5c provides an example of the Tasseled Cap Image Change image that shows the land cover change from 1996 to 2000 as charcoal gray/black.

Table 7-2 provides the imagery change assessment, based on manual techniques, for each of the general areas that are shown in Figure 7-4, as well as the assessment of correspondence with parcel change data

Table 7-2. Imagery, Parcel, and Comprehensive Land Use Change Assessment

Area ID	Imagery assessment	Parcel Agreement	Comprehensive Land Use Agreement
1	560 potential houses	no	no
2	6 houses	no	no
3	700 new houses	partial	yes
4	2,500 potential houses	no	partial
5	10 new commercial buildings, 48 condo buildings, and remaining developable parcels	no	yes
6	500 new houses	partial	yes
7	60 new houses	no	yes
8	58 new houses	no	partial
9	No Change	yes	yes
10	8 new buildings, 7 acres parking lots	partial	yes
11	25 acres of new buildings, 15 acres of new parking	no	yes
12	No Change	yes	yes
13	New road intersection and access road	partial	partial

DelMar Ikonos 2000

Figure 7-4 . Change areas identified during SANDAG high resolution imagery analysis

Imagery Source: Space Imaging

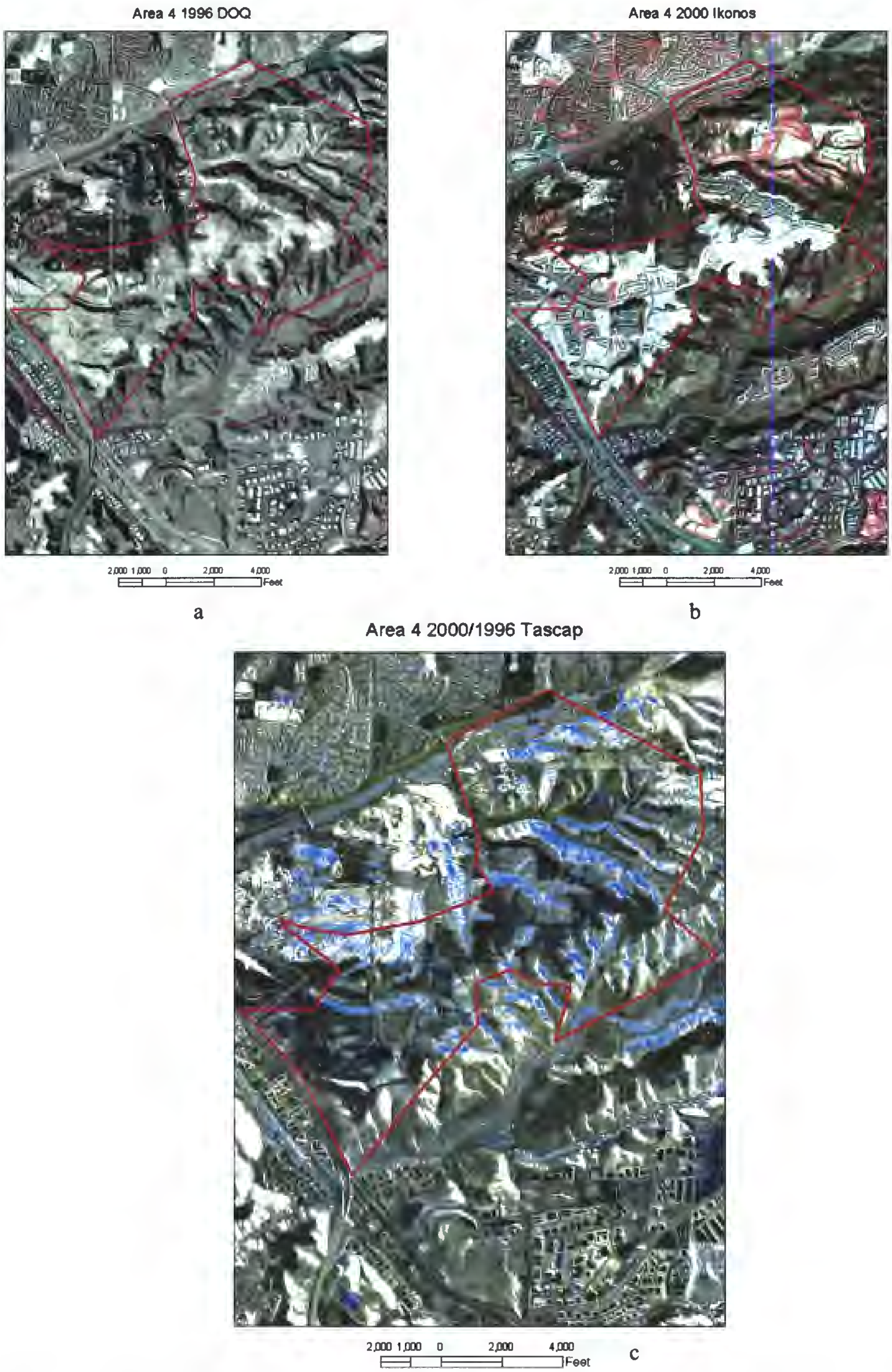

Figure 7-5 Example of high resolution image change product path, with original images above and image change image showing change in dark gray and change boundary in red.

and comprehensive land use change data. Table 7-2 shows that the tax assessor parcel data reflects partial change in only four of the eleven change areas that were identified using imagery. The parcel data accurately reflects the two areas where no change was observed using imagery. Parcel change data does not reflect the change identified in imagery in seven of the change areas.

In contrast, the SANDAG comprehensive land use data correctly reflects change in six of the eleven change areas and reflects partial agreement in three other change areas. Two change areas identified in imagery are reflected as not having changed in the comprehensive land use data set.

Land Use Change in a Chinese City

Wu studied land use change in metropolitan Guangzhou, China from 1987 to 1992. Parcels were segmented into two classes: those experiencing land use change and those not experiencing land use change. For those parcels where change was noted, land use was classified broadly into five categories:

- industrial;
- residential;
- commercial;
- government, institute, and community facilities; and
- under construction.

Aerial photography was used to identify land uses. Land use change was identified by overlaying sequential aerial photographs that were registered to a common coordinate space. Socio-economic data were added to these land use photographs and were registered to a parcel base.

Generally, Wu found that commercial change areas were concentrated within a 3 mile radius from the city center. Residential change areas were located mainly around the main urban built-up area. Industrial and construction change areas were widely scattered in the metropolitan area.

Chapter 8
Socio-Economic Data Analysis

Urban areas evolve and change over time. Imagery provides key information on cultural objects and natural features and is a useful tool for identifying changing demographic patterns. Imagery, both alone and in conjunction with ancillary data sources, provides information on the types and intensities of activities taking place at specific sites.

Type of Use

Imagery analysts convert image pixel reflectance values and the corresponding tones or colors into meaningful features that have natural and cultural significance. As we discussed in Chapters 2 and 3, the imagery analysis process is influenced by several factors, including the scale and resolution of the imagery as well as the experience of the analyst.

One goal of imagery analysis is to classify features important to the project into meaningful categories, allowing assessments of:

- number of features,
- attributes associated with the features,
- area(s) of the feature(s) and feature class(es), and
- change over time.

Relevant feature categories, in the form of a land use hierarchy (discussed in Appendix B), are important to support not only the goals of the imagery analysis project but also the goals of the transportation planning project. The breadth and depth of the land use hierarchy that can be analyzed using imagery depends on the spectral and spatial characteristics of the imagery, the scale of the imagery, and analyst expertise.

Many imagery objects and features provide direct or surrogate information with socio-economic significance. High resolution imagery provides details on size of parking lots, square footage of commercial and industrial buildings, and presence of new construction. Imagery also provides residential housing unit counts, presence of swimming pools in back yards, size of residential lots, and area calculations of residential houses and housing subdivisions.

Development associated with highway and road frontages and interchanges can often provide indications of strip commercial development. Likewise, residential housing developments have distinctive patterns and textures and can be used to measure the extent of residential development.

Figure 8-1 shows a mixed residential housing area consisting of apartment buildings, garden apartments, and townhouses. This high resolution image allows an analyst to estimate the number of parking spaces, the number of residents, and the likely traffic flows on adjacent roadways that result from the residential complex.

Figure 8-1 High resolution imagery showing mixed residential complex
Image Source: USGS DOQ

Figure 8-2 shows land use (on the left) and high resolution imagery (on the right) for a semiconductor manufacturing complex in Manassas, Virginia. The white buildings within the complex stand in contrast to the forested area within the triangular roadway that surrounds the complex. Agricultural land uses are observed to the west of the complex, residential development to the northeast, and a ball field occupies the lower left portion of the image.

Low resolution imagery can also support analysis on the type of use. Figure 8-3 illustrates low resolution, color infrared, Landsat TM imagery for the same region that is illustrated in Figure 8-2. First, the ball field is a bright pink triangle towards the center of the lower left quadrangle. Buildings that are associated with the semiconductor complex are observed as white objects in the center of the image. The pink and blue mottled features in the lower right and upper right portion of the image show residential areas, and reflect the diversity of material types such as driveways, houses, and lawns. Coniferous

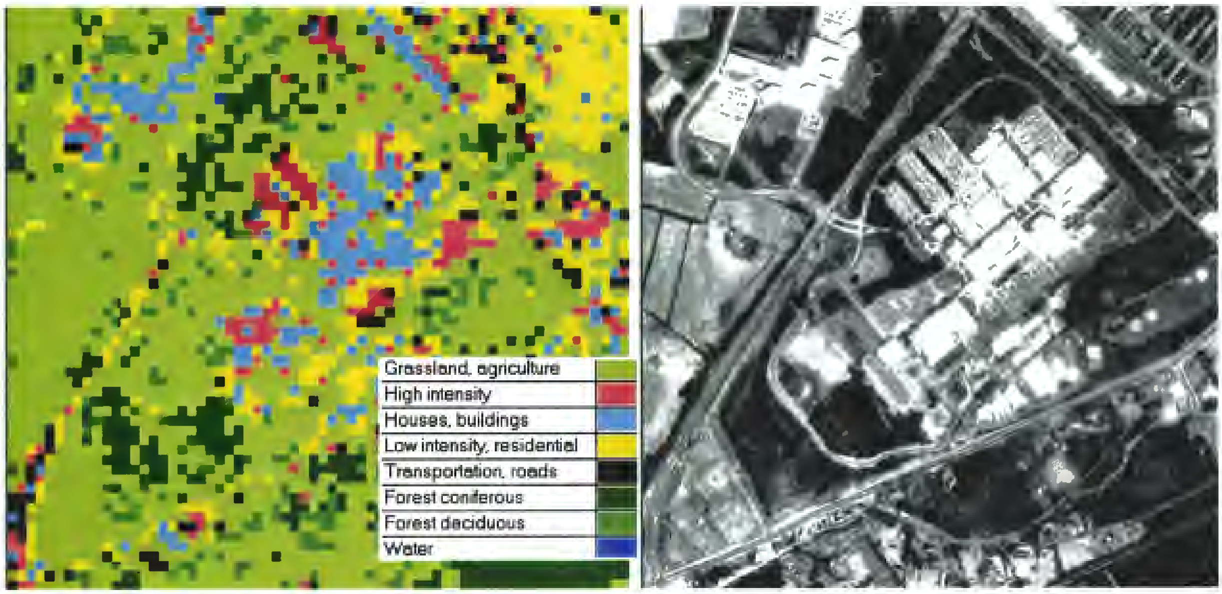

Figure 8-2 Land use and high resolution imagery showing region surrounding a semiconductor manufacturing complex in Manassas, Virginia

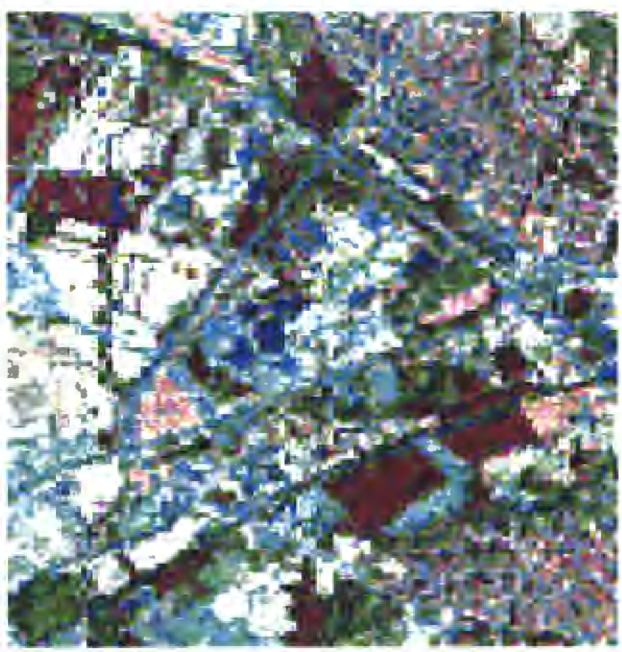

Figure 8-3 Low resolution Landsat TM imagery showing region surrounding a semiconductor manufacturing complex in Manassas, Virginia

vegetation shows as bright red rectangular features, resulting from the strong response of healthy vegetation in the infrared portion of the electromagnetic spectrum. The agricultural areas to the west of the semiconductor complex show as a light pink, reflecting the dormant vegetation state of the agricultural fields in this image that was acquired in the early spring.

Given that imagery can support the identification and characterization of type of use, area-based measures and statistics can be generated to reflect intensity of use. The most common area boundary used in transportation modeling is the **transportation analysis zone** (TAZ).

Density of development has been found to affect travel demand (Putman, 1980; ITE). New construction of a tract of single family homes, or infill development within existing residential development changes the density of a TAZ. Changes in density within the TAZ have also been found to induce other changes, both in population density and in employment.

Imagery provides crisp representations of density of development and intensity of use. Figure 8-4 shows USGS DOQ imagery in which three distinct residential development patterns are illustrated, from cluster-spaced, to cul-de-sac, to traditional grid.

Superimposition of the TAZ on imagery allows an analyst to calculate descriptive statistics on type of use and intensity of use. These descriptive statistics should prove useful to the derivation of density of development and intensity of use from imagery to support travel demand modeling.

Figure 8-4 High resolution USGS DOQ imagery showing three distinct residential land use densities

Land Use and Transportation Planning

The New Orleans Regional Planning Commission (NORPC) has developed a Central Business District (CBD) Land Use and Transportation Plan for Metairie, a suburb of New Orleans located on the west bank of the Mississippi River. The plan addressed existing conditions and community concerns within the project area, then formulated the land use and transportation plans around those concerns. Development of the plan was supported by the use of 1-meter resolution aerial photography obtained from the Louisiana Digital Orthophoto Quarter Quadrangle project.

The project team used the aerial photography to assist in the development of both the transportation and land use components of the plan. The aerial photos were utilized to establish the existing right-of-way through the CBD and collect profile information including:

- number of lanes;
- sidewalk locations;
- crosswalk locations; and
- overall corridor width

The aerial photography was also used when identifying new connections (roads, alleys, sidewalks, and paths) to the existing transportation system. Off-street parking locations near developments sites were also verified and inventoried from the aerial photography. The photos provided a comprehensive view of the area allowing the project team to view any physical impediments to the new connections such as vegetation or buildings.

The use of aerial photography in the plan also provided the capability to perform a general temporal analysis. The plan identified several market trends and forces in the Metairie CBD. Comparing aerial photography flown in 1998/1999 to corresponding aerial photography from 2000/2001 supported preliminary land use trend analysis of the area.

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Regional Planning Commission | Jefferson Parish Government

Comprehensive Area Planning Pilot Program
Metairie CBD Land Use and Transportation Planning Study
RPC Task A(1)

BURK-KLEINPETER, INC. BKI Job 10012-01 December 2001

Figure 1

Metairie CBD Project Area
Jefferson Parish, Louisiana

Long-Range Planning

The Massachusetts Highway Department (MassHighway) completed a twenty-year plan for two small, but growing, communities—Hudson and Marlborough. The study performed by Mass Highway utilized a variety of tools including aerial photography, GIS, traffic analysis and simulation software, and design software. The study used 1/2-meter resolution panchromatic aerial photography.

The planning study undertaken by MassHighway consisted of five phases. In the foundation phase, an interagency group was developed to establish goals and objectives for the plan, identify the study area, and select criteria for evaluation. Various data, including aerial photography, was presented to the interagency group.

Traffic, accident, environmental, and land use information was gathered to assess current conditions for the plan. This data proved to be useful in determining the feasibility for proposed improvements.

After assessing the current conditions, MassHighway developed a variety of alternatives based upon future traffic forecasts. Each alternative was examined further for traffic, safety, neighborhood impacts, environmental impacts, business considerations, and costs. Traffic was analyzed using simulation software. The simulations showed that even though the study intersections had an adequate level of service and queue length, bottlenecks could still occur.

The plan developed by MassHighway for Hudson and Marlborough was successful. Three significant conclusions were drawn from the study. First, a twenty year plan is an important tool to manage growth. Second, transportation changes can effectively be modeled using micro-simulation software. Third, aerial photography in combination with GIS overlays can provide the public with a view of the benefits and impacts proposed alternatives can have on adjacent properties.

Chapter 9
Support to Travel Demand Modeling

The Transportation System

Travel demand models are used to forecast the level of usage of the transportation system as a function of population centers, socio-economic composition and employment characteristics of the surrounding community, and the characteristics of the transportation system itself. Travel models evaluate the effect of public investment in highway and transit systems, and likely impacts resulting from changes in future land use, including residential, industry, and shopping district location. Thus, given certain assumptions about population growth or other socio-economic change, these models forecast the transportation requirements to satisfy travel demand and minimize travel cost.

An important data sources for these travel demand models include the demographic, employment, and land use data forecasts. Forecasts are made once data on these variables are gathered and the results are tabulated at the TAZ level.

Network Collection

Portland Metro has used GIS to support the integration of Census Tiger/LINE road network data with attribute data that was stored in its travel modeling package. GIS scripts were also developed to support collection of road attribute and turning pocket data from imagery. The resulting data was part of the data developed to support the Travel Model Improvement Program (TMIP) and Metro's installation of the TRANSIMS modeling package.

Data Collection

Key Land Use Types

Imagery provides information on a number of land use types that are important to travel demand modeling:

- residential land, both urban and rural;
- percentage of single and multi-family structures;
- commercial land;
- industrial land;
- vacant, buildable land;
- land under construction, and
- total land.

Network Coding

Imagery data also provides useful and, if acquired in a timely fashion, current information on road location, width and capacity attributes, surface condition, and construction status. Once imagery is loaded into the system and registered with other data sources, center line road and TAZ data can be derived either:

- by digitizing the arc-node information directly off of the screen using the mouse as a digitizer, or
- through the use of semi-automated road extraction algorithms.

These data can be associated with GIS line features (Figure 9-1) and integrated as a functioning component of GIS.

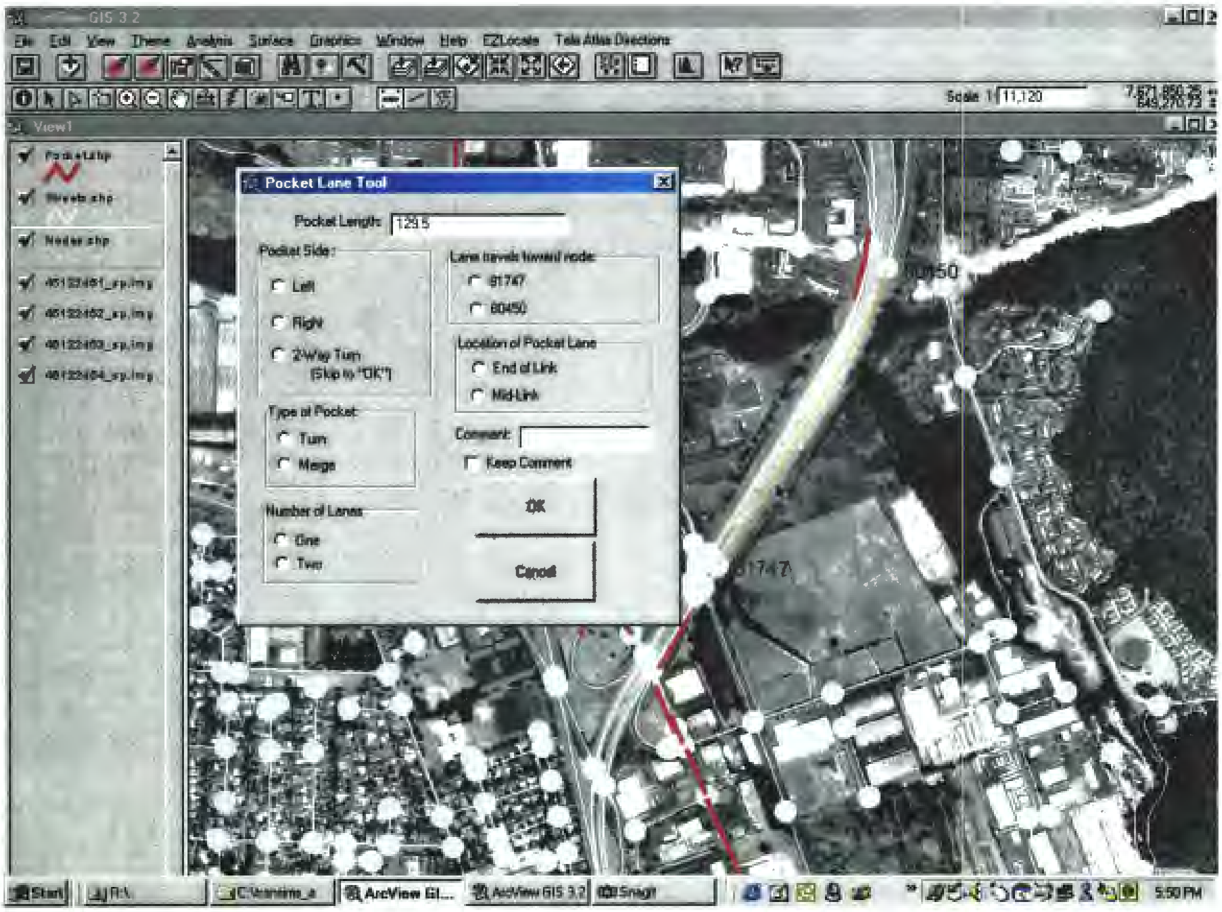


Figure 9-1 GIS portrayal of road network data and a highlighted (yellow) link with which to associate attributes

Software extension developed by: Portland Metro

Data Models

FGDC Transportation Data Model

The Federal Geographic Data Committee (FGDC) Ground Transportation Subcommittee is sponsoring the development of a conceptual data model standard for representing road segments digitally as unique geo-spatial features which are independent of any cartographic or analytic network representation. These road segments will form the basis of a National Spatial Data Infrastructure (NSDI) framework road data, and for establishing relationships between road segments and attribute data.

Travel Model (Network) Data Model

Network data for travel demand models consists primarily of nodes and links. Associated with each of these elements are all relevant attributes, including assignment results and user defined attributes. Networks can be built for different modes, such as highway and transit. Travel model data are often generalizations of the network that is being modeled and may exclude minor network features, depending upon the level of analysis and objectives of the planning activity.

Zonal Boundaries

Transportation analysis zones (TAZs) are generalized views of the land surface based on road, street, and census block networks (Figure 9-2). The majority of current implementations of travel models have the TAZ as the standard unit of data aggregation. The centroid of the zone is used as the point of reference to adjoining zones.

Most travel demand models are based on TAZs, and thus accurate portrayal of the TAZ boundaries affects the model output. Several researchers have used GIS to form TAZs in metropolitan areas (Baass; Bennion, et. al.; Anderson). With the increase in the use of GIS systems, large, generalized TAZs are shrinking into smaller and smaller units.

Imagery provides a mechanism to establish boundaries for new TAZs or redefine boundaries for old TAZs, especially when used in conjunction with other data sources such as US Census data.

Imagery and remote sensing offer to the transportation planner a means to derive detailed information on land use type and

Imagery Applications for TAZs

SANDAG uses imagery to support both land use classification and network applications, including counting number of lanes, lane configurations, intersection controls, and functional configuration of the link. Network editing is performed in ArcInfo. SANDAG uses a macro to convert the ArcInfo vectors into a TranPlan modeling network. SANDAG notes that the differences between one foot resolution and one meter resolution makes a substantial difference in providing capabilities to count lanes and in the identification of crosswalks and other transportation and demographic features. SANDAG codes approximately 84 land use categories to develop person trips in its transportation planning model. SANDAG also uses imagery to connect access links to the network from the centroids of transportation analysis zones. SANDAG loads one to four links per zone and then loads the volume of traffic for the zone at that point.

Figure 9-2 Transportation analysis zones (TAZs) in white overlaid on 1 meter DOQ imagery surrounding the Tyson's Corner, VA activity center (in red).

Image Source: USGS DOQ
TAZ, Activity Center Source: MWCOG

intensity. The difficulty that the transportation planner faces is how to best use the remote sensing data to derive information aggregated at the TAZ level.

Special Generator Surveys

The land use system supplies the travel demand model with location and estimates of volume associated with special generators, including major employment centers, large scale residential developments, and major investment sites. Imagery provides a broad, pictorial view of the landscape associated with a special generator. As such, the transportation planner can determine special travel-related characteristics that may be induced by the special generator, allowing the planner to update specific network links accordingly.

Figure 9-3 shows a comparison between a Thomas Bros. map and an IRS 5-meter resolution panchromatic image of FedEx Field, the home

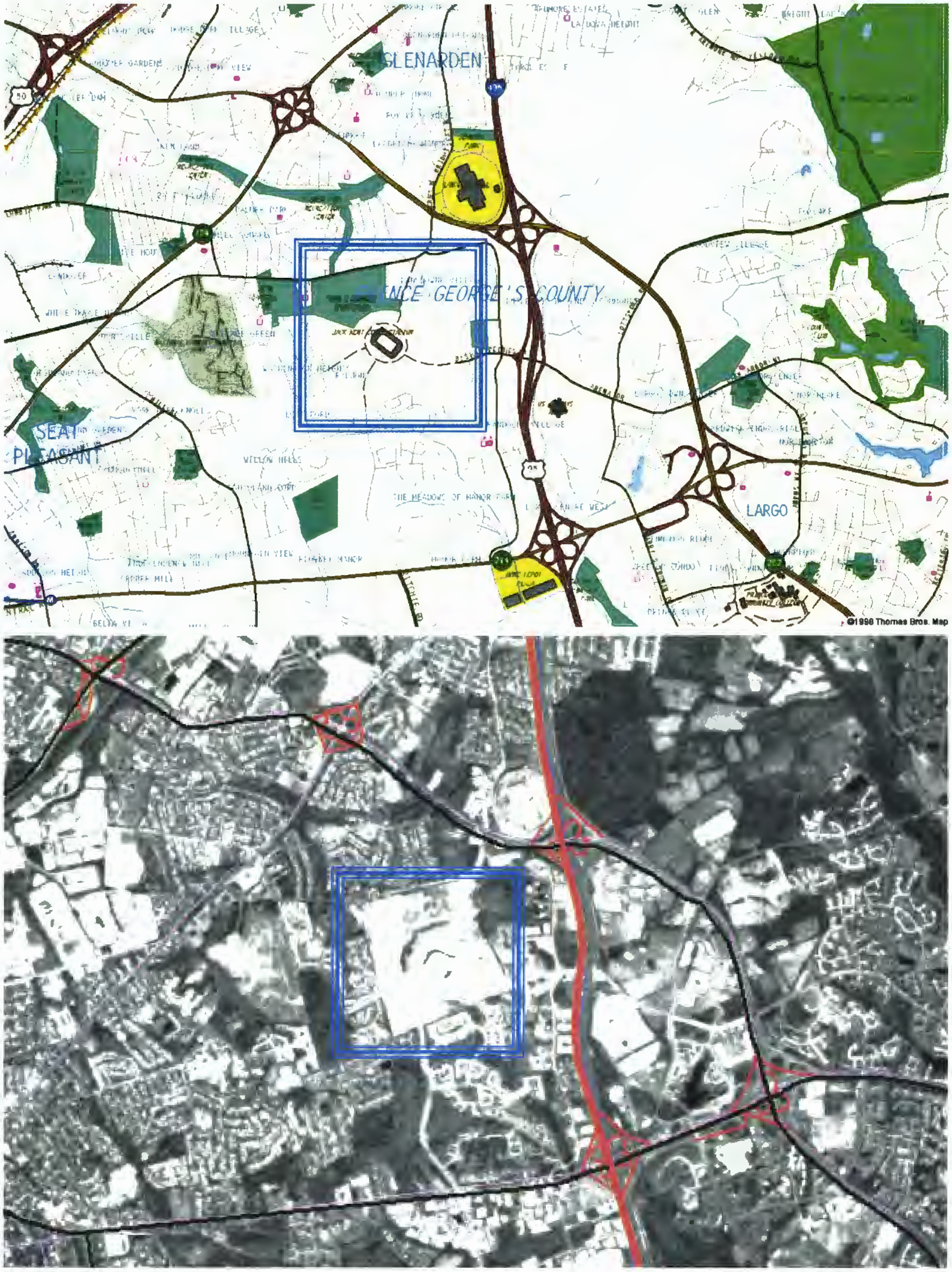


Figure 9-3 Thomas Bros. Map and IRS 5-meter resolution image showing area surrounding FedEx Field (in blue square) in Prince George's County, Maryland.

field of the Washington Redskins. The map and the imagery depict the relationship between the stadium, transportation features, and existing commercial and residential areas. The map shows residential street networks while the imagery shows the housing patterns in detail. These two data sources provide the planner with adequate information to support the analysis of likely travel impacts resulting from stadium events.

TAZ-Up

The Baltimore Metropolitan Council (BMC) used imagery to support the update of its TAZs based on 2000 Census block geography (TAZ-Up). The Census Bureau requires that TAZ boundaries conform to clear, identifiable boundaries, such as roads and power lines. BMC used imagery to illustrate that each of its TAZ boundaries did, in fact, conform to the Census guidelines.

The TAZ-Up process required less than thirty days.

Network Data Update and Maintenance

Accurate, current imagery can support validation of existing network data. GIS and image processing software provide capabilities to overlay existing network data on imagery. GIS and image processing tools allow analysts to update and maintain the physical assets associated with networks as well as the spatial location and accuracy associated with the networks. Before maintenance of these networks begins, the MPO and State DOT must decide if historical views of the data are required, and if so, how to implement and fulfill such requirements.

The planner needs to understand that changes made in the data will be permanent and all future analyses will reference the changes. If the planner has requirements to view historical versions of the data, adequate care and procedures need to be followed to permit timestamps to be associated with the data.

The planner will be faced with the dilemma that historical data will reference not only previous physical networks, but may also refer to historical networks with inaccurate detail that has been edited and cleaned during more recent version releases. As practitioners that work with spatial data will attest, digital data maintenance and update procedures usually update network changes as well as clean up spatial and attribute information associated with the networks.

Traffic Congestion

The Maricopa Association of Governments (MAG) evaluated the validity of estimating stopped delay using aerial photography. Stopped delay is the time a vehicle spends motionless waiting to pass through an intersection. The average stopped delay per vehicle can then be used to determine the level of service (LOS) for an intersection.

MAG staff chose to use aerial photography in addition to machine traffic counts as the primary method of determining the LOS at specified intersections. Detailed traffic counts from ground observers were collected at four intersections as a method to check the accuracy of the aerial photography data. Each intersection was flown to capture aerial photography for two consecutive days from 4pm to 6pm, resulting in 24 aerial photographs (see figure below) per intersection covering 5-minute intervals between the two days. From these photos, MAG staff counted the number of vehicles stopped at each of the four intersections and calculated queue lengths at through and right turn lanes.

Each of the intersections was also monitored using traffic count machines for a period of 48 consecutive hours and aggregated into 15-minute intervals. The machine counts provided the total volume of vehicles at each intersection.

Ground observers also collected data simultaneously at the four intersections. The number of stopped cars was counted every 5 to 20 seconds to enable calculation of the queue length using the collected data.

The results of the analysis supported the use of aerial photography and machine counts as a method of estimating LOS for intersections. It is also noted that the aerial photography is beneficial since the visual record from which the data is derived is permanent.

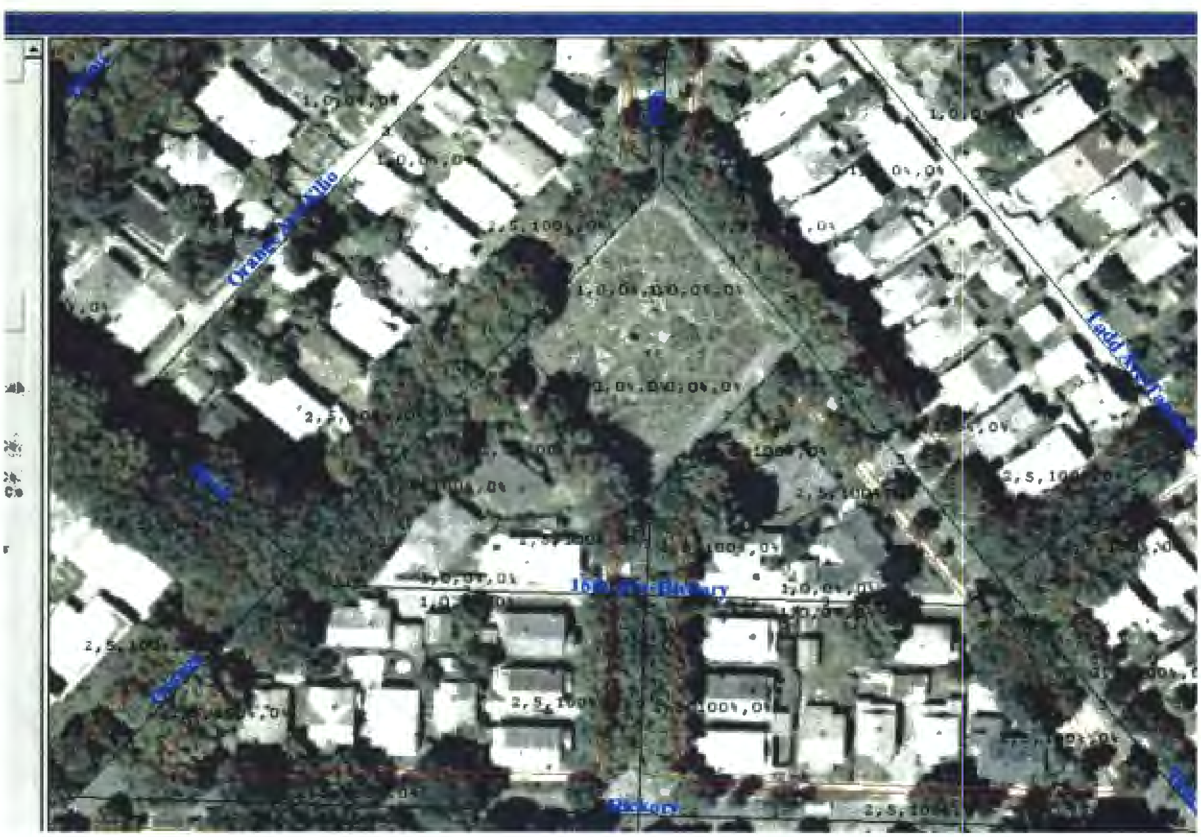
Regional Pedestrian Access to Transit Program

Portland Metro is currently working to locate and inventory all sidewalks and crosswalks within its region as a part of the Regional Pedestrian Access to Transit Program. The ultimate goal of the program is to provide an adequate means for pedestrians to reach public transit stops and stations.

Aerial photography flown in 2000 and 2001 was used to inventory sidewalks. The images served as the primary data source for the project. The minimal resolution established for identifying sidewalks from the imagery was 2-feet. However, the photos flown in 2001 had a 1-foot resolution, allowing for a clearer view of features on the ground.

Several problems were encountered while relying on the imagery for data collection. A majority of the photos lacked the contrast necessary to distinguish between features during interpretation. This was attributed to the low levels of sunlight during the summer of 2000. Additionally, tree canopies and other vegetation concealed many of the sidewalks and paths in the photos. Problems in air photo quality for several areas required additional data gathering, including a series of field observations.

The results of the project produced a series of data sets portraying sidewalk information. The figure below shows an attributed street centerline, as well as the locations of the sidewalks. The figure illustrates the interpretation problem due to obscuration from tree canopies.



Chapter 10
Corridor/Project Management

Corridor planning typically includes alignment studies, environmental evaluations, conceptual mitigation plans, drainage design, roadway design, and public presentations. Corridor planning provides the ability to link sustainable land use and transportation planning in order to manage and protect public investments in the transportation system.

Imagery data provide useful base map data for locating, identifying, and overlaying information in the alternatives analysis and in the selection of a corridor, its construction, and its maintenance (Figure 10-1). High resolution imagery provides

Figure 10-1 Alameda corridor surrounding Long Beach, California
Image courtesy: NASA JPL

Freight Planning in the Alameda Corridor

Researchers at the Jet Propulsion Laboratory and at Tetra Tech ASL are integrating imagery sources with various ground-based information, including land development parcels and truck traffic models, to develop a corridor analysis tool (CAT). The CAT will include features for urban planning, engineering design, and siting operations monitoring, and environmental and economic impact analyses for projected regional growth.

precise information on housing characteristics and, combined with other information, can provide information on property value and likely impact resulting from a transportation enhancement.

Once a corridor is designed and constructed, the planner maintains an awareness of corridor volumes, roadway capacity, and transit characteristics. Imagery can support congestion analysis, status of road construction and road closures, and can help maintain an awareness of facility condition.

The perspective of viewing the landscape from an aerial perspective, whether from satellite, airplane, or balloon, has been used to support environmental assessment and land use studies since its use in the Civil War in the 1860's. Imagery can support the transportation planner through its use as a data source in the environmental assessment process, from initial development of wetland delineation maps to supporting the development of environmental impact statements. The scientific literature on applications of imagery to support environmental analysis is rich and varied. Suffice it to say that imagery can be used to support the assessment of impacts of transportation decisions on habitats, ecosystems, and communities.

Congestion Monitoring

The Metropolitan Washington Council of Governments (MWCOG) performed an aerial survey in spring 1999 of over 300 miles of freeways in the metropolitan Washington, DC area. The aerial survey was conducted during morning and evening rush hours as a primary component of MWCOG's congestion management system. Congestion for each roadway that was studied was computed by determining the number of passenger cars per lane per mile and then converting into average travel speeds and travel times.

TPB News, January 2000.

Environmental Analysis

Investments in transportation should enhance community and social benefits and should improve the quality of the natural environment by reducing highway-related pollution and by protecting and enhancing ecosystems. FHWA provides specific guidance to field offices and project applicants in ***Guidance for Preparing and Processing of Environmental and Section 4(f) Documents (FHWA Technical Advisory T6640.8A)***, dated October 30, 1987.

Imagery can support the Environmental Assessment (EA) that helps the Federal Highway Administration and the sponsoring local Highway Administration determine if there is a need for a complete environmental impact statement. Imagery can support the requirement to include good quality maps and exhibits as part of the EA.

Imagery can also be used to support the identification and demarcation of economically and environmentally sensitive locations or features in the proposed impact area (e.g., neighborhoods, elderly/minority/ethnic groups, parks, hazardous material sites, historic resources, wetlands, etc.).

EA and EIS

The most commonly encountered impacts for highway projects that can be illustrated and studied using imagery include:

- land use impacts,
- farmland impacts,
- social impacts,
- relocation impacts,
- economic impacts,
- considerations relating to pedestrians and bicyclists,
- noise impacts,
- water quality impacts,
- wetland impacts,
- water body modification and wildlife impacts,
- coastal barrier impacts,
- floodplain impacts,
- wild and scenic river impacts,
- coastal zone impacts,
- threatened or endangered species impacts,
- historic and archeological site preservation impacts,
- hazardous waste site impacts,
- visual impacts, and
- construction impacts.

The construction, use, and maintenance of transportation features have direct and indirect impacts on wetlands and other aquatic resources which are regulated under Section 404 of the Clean Water Act.

GIS and imagery provide data resources and tools to transportation planners and to wetland managers to ensure the most efficient and effective approaches to mitigate transportation impacts on wetlands. These tools provide the capability to build consensus for policy and regulatory decisions.

Wetland Mapping

Researchers used high-resolution hyperspectral image data and high resolution **LIDAR** to support detection and mapping of wetlands in a project jointly funded by US DOT/RSPA and NASA and managed by Mississippi State University. Techniques were developed to provide a surrogate process that closely approximated determinations made as part of conventional wetland assessments.

NCRST Publication
NCRSTE_TG003

Environmental Streamlining—TEA-21 Section 1309	In response to ***Section 1309 of TEA-21***, FHWA implemented a coordinated review process, termed environmental streamlining, for construction projects that require environmental assessment. Simply stated, environmental streamlining consists of establishing realistic project development time frames among the transportation and environmental agencies involved in a project, and then working to meet the agreed upon time frames. GIS data development, including imagery acquisition and analysis, provides one means to coordinate activities between all project stakeholders. Shared imagery and geographic map layers between the interested agencies could serve to minimize project duplication and reduce time in project execution.

Transportation Corridor Planning

An urban corridor plan was developed for a high traffic area known as the Mason Street Transportation Corridor in Fort Collins, Colorado. The goal of the urban corridor plan was to identify alternative transportation methods to relieve current traffic congestion, provide multi-modal connectivity, and suggest enhanced development areas. The corridor plan is complimented by the use of aerial photography for community input, visual communication, and video simulation.

The aerial photography was flown specifically for use in the corridor plan. The 1/2-foot resolution photography covered a 1 mile swath along the 5 mile corridor and served as the base for the CAD and GIS overlays.

College Avenue is the backbone North-South arterial in the urban core of Fort Collins. Fort Collins planners realized that the College Avenue corridor was reaching its capacity and that widening the existing corridor would displace businesses and place a large fiscal burden on the city. An alternative solution to the congestion of College Avenue was to enhance the corridors in close proximity. Fort Collins planners chose to study the Mason Street corridor due to its proximity to the College Avenue Corridor.

Mason Street is characterized by diverse land use and activity, including the Historic Old Town district, Colorado State University, and multiple retail and business centers. The plan developed for the corridor addressed pedestrian traffic, bikeways, the existing rail system and bus routes. Community volunteers utilized aerial photography, which was displayed at a local mall, to enlist community comments and suggestions to the existing transit system. Several conceptual designs and alternatives were proposed and overlaid on the aerial photography to allow the public to see both existing conditions and proposed developments such as dedicated transit lanes, bikeways, and transit routes.

A series of computer simulations showing each alternative and major intersection were developed as an additional component of the corridor plan. The simulations were developed by integrating aerial photography with traffic volume estimates for the year 2020 to illustrate and portray current structures and activities on either side of the roadway.

Glossary

Abstract—one of the four recommended sections of the project plan. The abstract provides a clear, concise overview to allow decision-makers and public citizens to understand the main elements of a project.

Accuracy—denotes the relative position of features on a map or in imagery with respect to their actual position on the ground. Accuracy is usually determined by comparing a statistical sample of points on a map or in imagery with their ground positions using survey techniques.

Ancillary data—in imagery analysis, ancillary data are map, image, and demographic sources that provide the analyst with contextual information and which support interpretation and analysis of the imagery.

Change detection—in traditional image processing literature, change detection is the comparison of historical imagery with more current imagery with the intent of locating the position and determining the nature of change. Several techniques have been described in the scientific literature, including use of raw imagery, as well as use of principal components and tasseled cap transformations.

Classification hierarchy—a taxonomy that allows a planner, researcher, or scientist to both differentiate objects that are being modeled and to provide each of the objects with specific descriptions to provide a means to share research methodology and results.

Color infrared—a form of imagery that includes at least portions of the visible region of the electromagnetic spectrum as well as at least portions of the near infrared region of the electromagnetic spectrum. When combined in this fashion, color infrared imagery provides distinct land-water interfaces as well as enhanced vegetation discrimination due to the nature and properties of the infrared energy.

Congestion monitoring—use of imagery to determine the volume, speed and truck/car statistics of traffic in a selected geographic location or corridor. Monitoring can be limited by the nature of the sensor, its time of collection, and its repetitive visits over the area being monitored.

Delphi process—a planning process that uses the local knowledge of a broad cross-section of people to build a consensus forecast.

Digital elevation model—gridded data files that provide average elevation data within each cell, and which, when viewed as a whole, provide a representation of the earth's terrain surface. The cell resolution of DEMs affects the degree of generalization of the surface that is being represented. The cell size of USGS digital elevation model data is 30 meters.

Digital orthophoto quadrangle—a form of imagery made popular by the US Geological Survey which is now a standard in the industry. The DOQ is imagery collected by a sensor that has been processed to correct for distortions in the imagery that are related to sensor acquisition and terrain.

Emittance—energy that radiates from an object due to its specific composition. Emitted energy is composed of energy in the far infrared region, and is commonly known as heat. Emittance differs between asphalt and grasslands and often provides support to object differentiation.

Ground control points—imagery-identifiable points with known geographic, x-y (and often elevation, z) characteristics that are used as reference points in imagery to allow precise image geo-coding and registration with ancillary data sources.

Histograms—a graphical tool that allows an analyst to view the distribution of sample data points. In imagery analysis, the histogram illustrates the distribution of pixel values in an image.

Hyperspectral—refers to imagery with more than approximately ten and up to several hundred specific spectral bands. Hyperspectral imagery provides a broad array of digital values for objects and feature classes that may provide unique spectral signatures from which reliable discrimination can be achieved from other objects and feature classes.

ISODATA clustering—also known as unsupervised classification, this clustering technique segments an input image source into a user-defined set of classes based on the numerical and statistical characteristics of the input data source. Each of the output data clusters may denote a land cover or object data type.

LIDAR—short for light detection and ranging, lidar is an experimental system that is nearing operational use in transportation applications. The lidar laser system is mounted on an aircraft and measures high-detailed elevation data with resolutions from one to 15 meters and vertical accuracies to 15 centimeters.

Metadata—according to the Federal Geographic Data Committee, metadata is "data about data" and describes the content, quality, condition, and other characteristics of data.

Mixed pixels—phenomena that results when the spectral values of a pixel reflect more than one object or feature class. This phenomena may result in a statistical manifestation that reflects neither of the input classes and can result in object misclassification.

Multispectral—refers to imagery in which a sensor has acquired data in multiple electromagnetic regions, or spectral bands. These multispectral bands can be analyzed to differentiate between objects or feature classes. Imagery that has been acquired in more than approximately ten bands is termed hyperspectral.

Overedge—the overlap region between two adjacent aerial photographs, which is used to support tonal matching and stereo compilation for multiple photographs.

Panchromatic—usually refers to black and white imagery of the visible portion of the electromagnetic spectrum.

Pixel—an individual picture element within an image which corresponds to the ground sample distance of the camera sensor and which is commonly used to refer to the resolution of the image.

Pixel reflectance values—numerical representations that depict the amount of reflectance coming from the object(s) and feature class(es) within a pixel. For eight bit imagery, this value ranges from 0 (no reflectance or black) to 255 (highest reflectance or white).

Project budget—reflects the amount of time and resources that are either available or required for a given project. The project is often broken into specific, tangible tasks and subtasks that allow for parallel development and which each have specific associated resources.

Project plan—reflects the project breakdown that is used to guide project-related activity and which assigns resources to tasks. The plan is a living document that is created before the project begins and which is maintained and updated through the course of the project.

Project schedule—assigns tasks to specific dates and time periods with the objective of completing the project within budget and on-time.

Radiometric resolution—describes the ability of an imaging system to discriminate very slight differences in energy. An imaging system that records data as one bit imagery, that is either black or white, records much different image characteristics when compared to an imaging system that records data as eight bit imagery, or between 0 and 255.

Reflectance—the amount of energy that is neither absorbed or diffused from an object. Passive sensors capture the amount of reflected energy from objects and feature classes.

Resolution—can be defined as either the ground sample distance (e.g., 1 meter, 30 meters), which conforms to the pixel size, or the smallest resolvable feature in the image.

Scale—represents the ratio of a distance on the map or image to the actual distance on the ground. For example, if a feature on an image is 2 centimeters and the same feature is one kilometer on the ground, the scale would be 2/100,000=1:50,000.

Sensor—a device capable of collecting information and performing measurements on objects from a distance. Examples of sensors include microscopes, cameras, and imaging satellites.

Spatial resolution—in general terms, spatial resolution describes how much detail in a photographic image is visible to the human eye.

Spectral resolution—reflects the number of bands and spectral range of each band within an image. Landsat 7 imagery has seven bands, three in the visible portion of the spectrum, two in the near infrared, and one in the thermal infrared.

Technical design—provides the overall technical guidance and project objectives, as well as the resources available to complete the project.

Temporal resolution—refers to the revisit period between image updates. For imaging satellites, this period is roughly equivalent to the periodicity of the satellite, that is the period of time in which a satellite views a specific piece of real estate. However, some satellites can point forward and backward, and from side to side, thereby modifying the strict interpretation of periodicity. Temporal resolution can also refer to the specific dates of imagery available for a given study area and which are available for comparison and analysis.

Transportation analysis zones—generalized regions of homogeneous land cover and/or economic activity that are the basis of travel demand modeling. TAZs are often based on census block and/or tract boundaries.

Appendix A
Data Acquisition Characteristics

Passive remote sensors record energy radiating from the Sun that is either reflected or emitted from the natural and man-made objects on the surface of the earth (Figure A-1). The energy from the Sun forms the electromagnetic spectrum, part of which is the red, green, and blue light that we refer to as visible light and which we can view with our eyes. The physical properties of the electromagnetic spectrum and the interaction with the atmosphere are beyond the scope of this guidebook, but interested readers are referred to several textual sources listed in Appendix D.

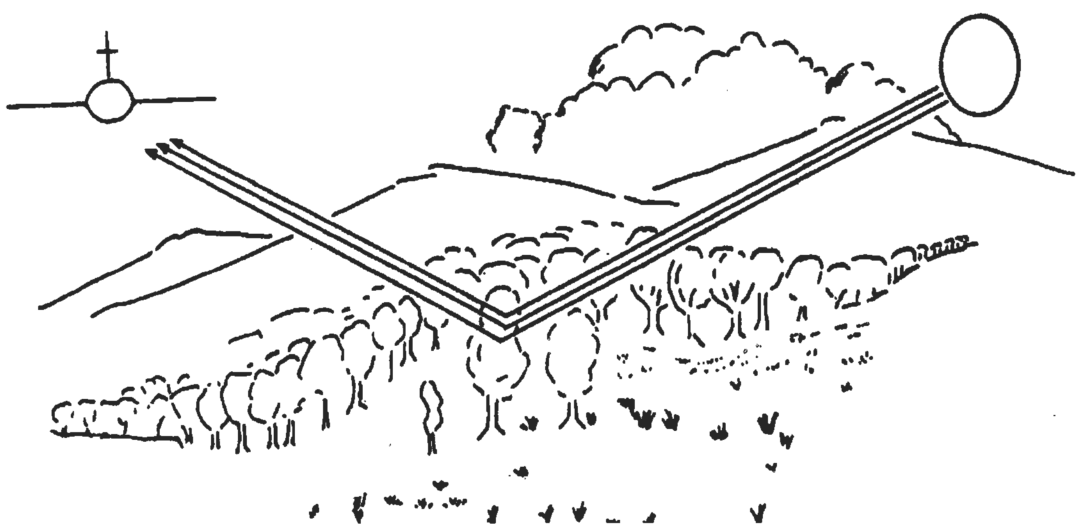


Figure A-1 Remote sensing using reflected solar radiation.

Courtesy Campbell JB

Electromagnetic Spectrum

The wavelengths of energy in the electromagnetic spectrum are commonly measured in microns, or 10^{-6} meters. Visible light is that portion of the spectrum between approximately 0.4 microns and 0.7 microns (Figure A-2). Passive sensors capture visible light that is reflected from the surface of the earth. The majority of imagery products portray this visible light as either a panchromatic image or as a color image.

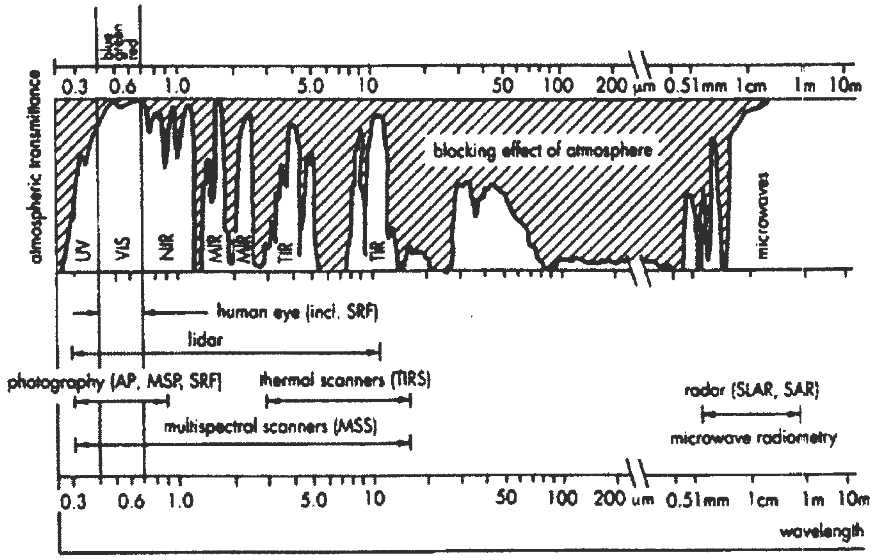


Figure A-2 Electromagnetic spectrum and remote sensing instruments
Courtesy Lillesand and Kiefer

Infrared energy, and specifically near-infrared energy, is that portion of the electromagnetic spectrum just beyond the red spectrum from approximately 0.7 microns to approximately 3.0 microns. Though not visible to the human eye, this portion of the electromagnetic spectrum can be captured with specially-designed infrared sensors. Vegetation has unique characteristics in the near-infrared portion of the spectrum and was the basis for its early use in camouflage detection since painted green surfaces reflect differently in the near-infrared when compared to leafy, green vegetation.

Spectral Signatures

The basis of imagery analysis, both manual and automated, rests on the fact that different objects have unique spectral characteristics and that sensors can detect these differences. **Multispectral** and **hyperspectral** sensors slice the **reflectance** and **emittance** from objects into specific wavelength regions which, in theory at least, form a unique spectral curve or spectral signature for each object in the scene. Practical applications of spectral signatures generally show that spectral signatures differ both over time (both day/night and seasonal) and in various geographic contexts.

Figure A-3 illustrates the six visible and near-infrared bands collected over Dulles International Airport, west of Washington, DC, as observed by the Landsat 7 ETM sensor. Note that each band provides different visible information that can support analysis and discrimination of objects and feature classes within the scene.

Figure A-4 illustrates the concept of spectral signatures by showing that different feature classes have different spectral responses in the green, red, and infrared bands. Currently, hyperspectral sensors, with

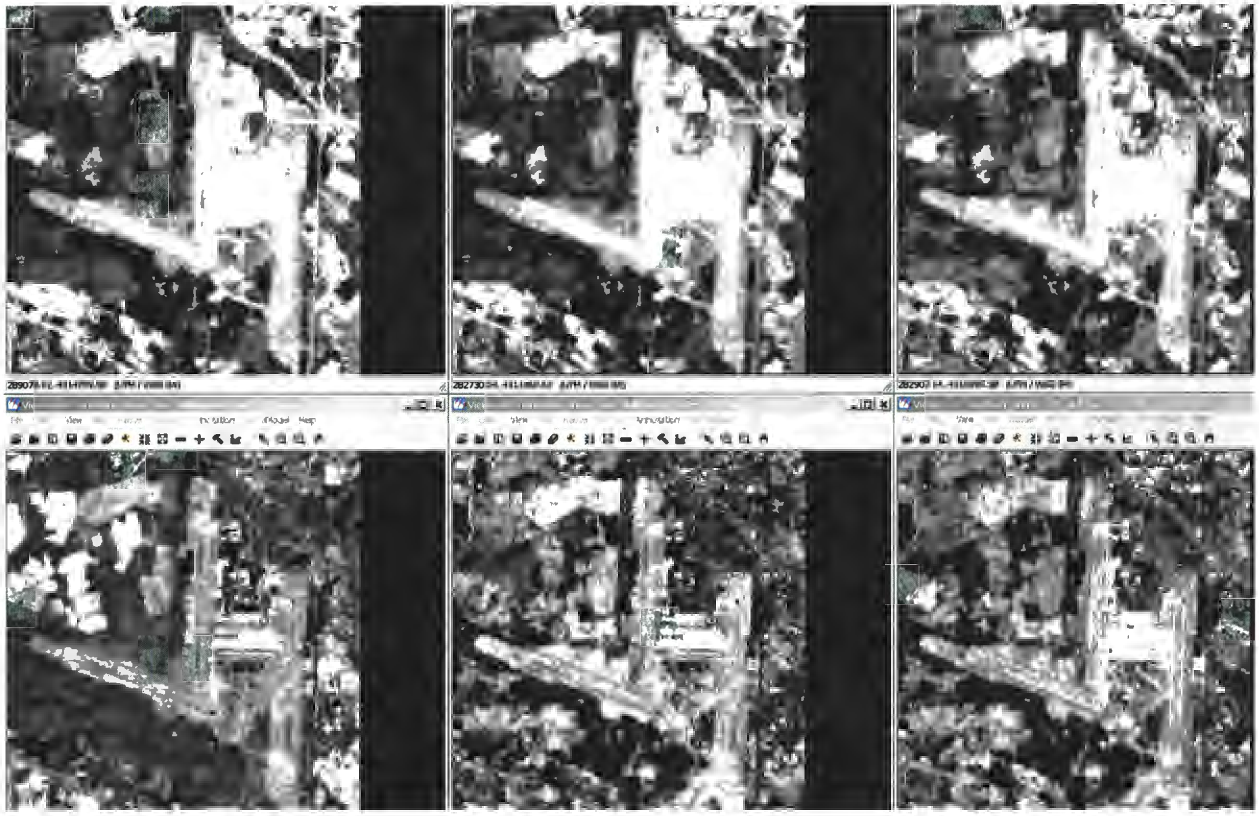


Figure A-3 Six bands of Landsat 7 imagery of Dulles International Airport.

up to 200 wavelength regions, provide even greater object differentiation and are being studied in numerous research and analysis efforts.

All imagery that is collected by a remote sensor has distortion resulting from sensor motion relative to the surface, flight characteristics of the sensor, terrain influences, and distance from the center of the image (Figures A-5 and A-6). These distortion elements can be modeled and the imagery can be corrected using both flight and terrain information. When the imagery is modeled successfully, the resulting product is termed ortho-rectified photography, or orthophotography. If integrated into a GIS, non-orthorectified photography will lead to misregistration with existing data, and could lead to measurement and location placement errors if used as a basis for measurement and data collection.

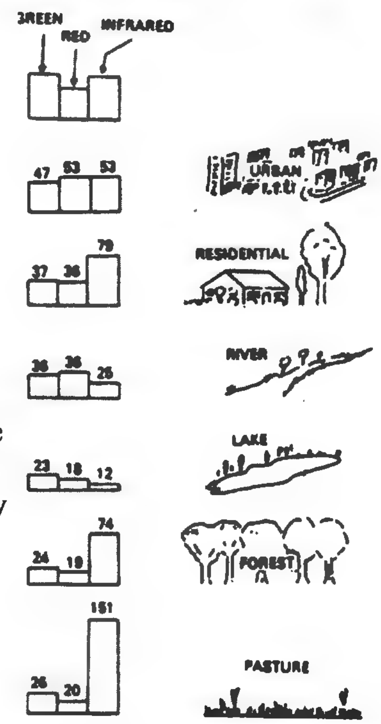


Figure A-4 Spectral signatures provide unique class and object identifiers.
Courtesy Campbell JB

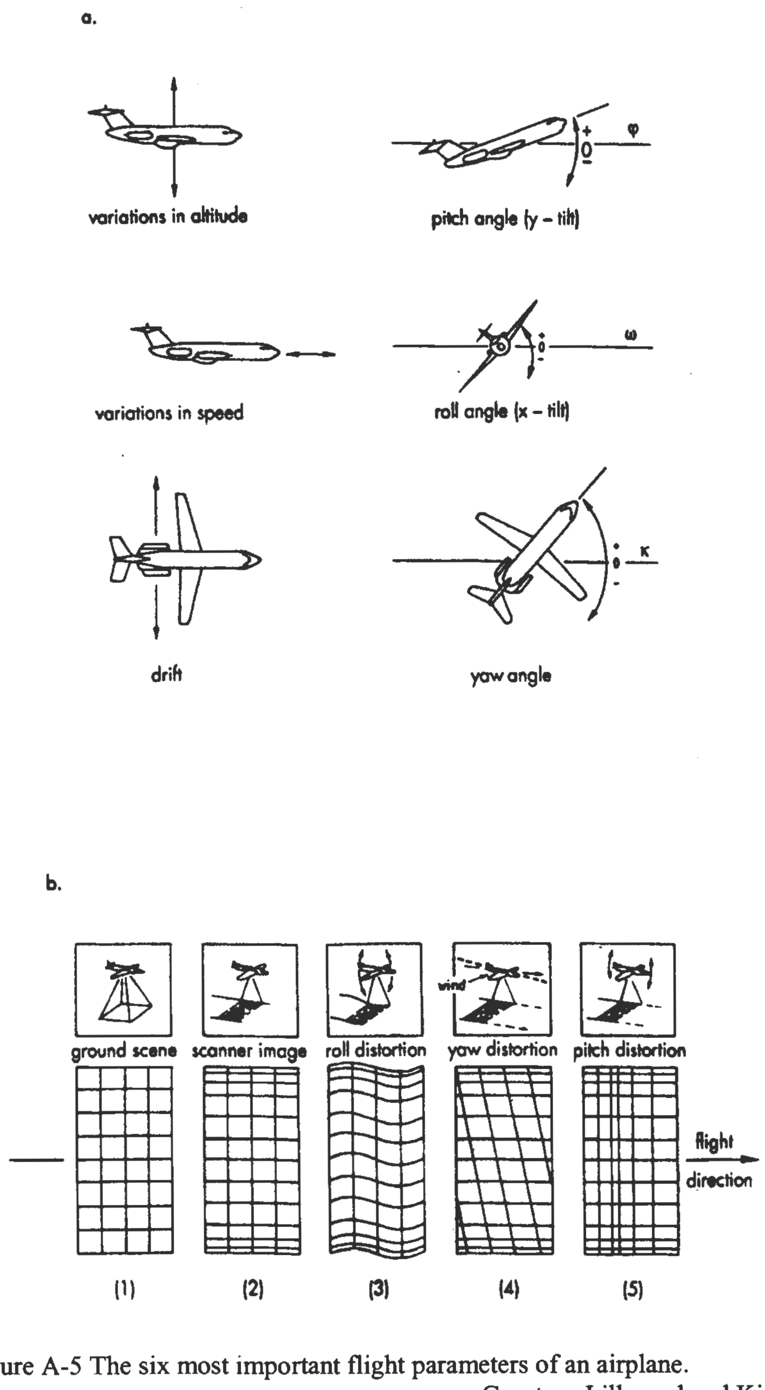


Figure A-5 The six most important flight parameters of an airplane.
Courtesy Lillesand and Kiefer (1987)

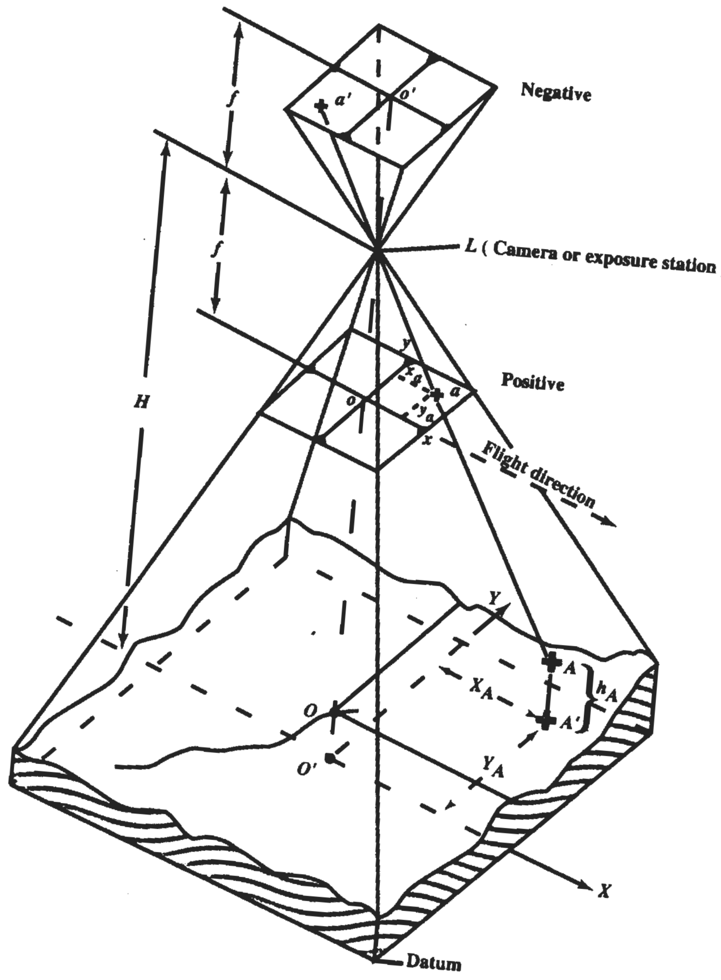


Figure A-6 Geometric orientation parameters used in photogrammetry.

Courtesy Schott

Appendix B
Land Use Classification

Land use hierarchies facilitate the segmentation of our complex world into manageable categories to permit study, analysis, and comparison. The use of a common hierarchy provides the capability to aggregate regions and permits a structured comparison between regions. Without a common hierarchy, comparative analysis between regions is made more difficult since adjacent regional planning agencies could:

- define similar land use categories with different names, or
- give similar names to different land use categories.

There is currently no single nationwide standard in use to characterize land use. Consequently, standards vary widely among local and regional planning agencies in the US.

A fundamental technical issue pertaining to imagery classification for land use applications is the creation of a viable, representative classification of discrete land uses into a land use classification system. Once established, the imagery analysis process places identifiable features into the various categories in this system, within the accuracy specifications of the particular data and the requirements of the specific project.

The land use classification task is an important preliminary step in transportation planning analysis using imagery sources. A comprehensive hierarchy is necessary to segment imagery features into a framework that satisfies transportation planning requirements. Further, consistent use of a hierarchy between and among regions facilitates aggregation and analysis of larger regions. Once an appropriate classification system has been established, several advanced forms of imagery analysis are possible.

One critical issue in any modeling effort is the typology used to aggregate and characterize the specific land use categories. This issue is especially important when using imagery data as the source of the land use analysis.

USGS Anderson

The most widely used hierarchy is the USGS classification hierarchy developed by Anderson, et. al. Anderson, et. al. state that the USGS classification system was developed to meet the following criteria:

- the minimum level of interpretation accuracy in the

identification of land use and land cover categories from remote sensor data should be at least 85%,
- the accuracy of interpretation for several categories should be about equal,
- repeatable or repetitive results should be obtainable from one interpreter to another and from one time of sensing to another,
- the classification system should be applicable over extensive areas,
- the categorization should permit vegetation and other types of land cover to be used as surrogates for activity,
- the classification system should be suitable for use with remote sensor data obtained from two different times of the year,
- effective use of subcategories that can be obtained from ground surveys or from the use of larger scale or enhanced remote sensor data should be possible,
- aggregation of categories must be possible,
- comparison with future land use must be possible, and
- multiple uses of land should be recognized when possible.

SLUCM

The Standard Land Use Coding Manual (SLUCM) developed by the Housing and Urban Development Agency in the 1960's incorporates socio-demographic context into the classification of land use types, making it useful to agencies such as the Department of Transportation.

LBCS

The ***American Planning Association's (APA) Land-Based Classification Standards*** provide a consistent model for classifying land uses based on their characteristics. The standards are based on a multi-dimensional land-use classification model.

Executive Summary

LBCS updates the 1965 *Standard Land Use Coding Manual* (SLUCM), a standard which was widely adopted for land-use classifications. Because many current applications and land-based data depend on SLUCM and its derivatives, the LBCS includes tools and methods to migrate such data.

According to the APA, the LBCS provides a consistent model for classifying land uses based on their characteristics. The model extends the notion of classifying land uses by refining traditional categories into multiple dimensions, such as activities, functions, building types, site development character, and ownership constraints. Each dimension has its own set of categories and subcategories. These multiple dimensions allow users to have precise control over land-use classifications.

Classifying land uses across multiple dimensions, in database terms, means adding new fields to the land-use database. The total number of land-use fields in the database should equal the number of dimensions, that is, every record in the database is classified in not just one land-use field, but several—one for each dimension. The number of dimensions, in turn, will depend on the purpose of the data. When the purpose of the data changes, dimensions may be added or dropped as needed. For local planning purposes, LBCS calls for classifying land uses in the following dimensions: Activity, Function, Structure Type, Site Development Character, and Ownership.

Activity refers to the actual use of land based on its observable characteristics. It describes what actually takes place in physical or observable terms (e.g., farming, shopping, manufacturing, vehicular movement, etc.). An office activity, for example, refers only to the physical activity on the premises, which could apply equally to a law firm, a nonprofit institution, a court house, a corporate office, or any other office use. Similarly, residential uses in single-family dwellings, multi-family structures, manufactured houses, or any other type of building, would all be classified as residential activity.

Function refers to the economic function or type of establishment using the land. Every land use can be characterized by the type of establishment it serves. Land-use terms, such as agricultural, commercial, industrial, relate to enterprises. The type of economic function served by the land use gets classified in this dimension; it is independent of actual activity on the land. Establishments can have a variety of activities on their premises, yet serve a single function. For example, two parcels are said to be in the same functional category if they belong to the same establishment, even if one is an office building and the other is a factory.

Structure refers to the type of structure or building on the land. Land-use terms embody a structural or building characteristic, which suggests the utility of the space (in a building) or land (when there is no building). Land-use terms, such as single-family house, office building, warehouse, hospital building, or highway, also describe structural characteristic. Although many activities and functions are closely associated with certain structures, it is not always so. Many buildings are often adapted for uses other than its original use. For instance, a single-family residential structure may be used as an office.

Site development character refers to the overall physical development character of the land. It describes "what is on the land" in general physical terms. For most land uses, it is simply expressed in terms of whether the site is developed or not. But not all sites without observable development can be treated as undeveloped. Land uses, such as parks and open spaces, which often have a complex mix of activities, functions, and structures on them, need categories independent of other dimensions. This dimension uses categories that describe the overall site development characteristics.

Ownership refers to the relationship between the use and its land rights. Since the function of most land uses is either public or private and not both, distinguishing ownership characteristics seems obvious. However, relying solely on the functional character may obscure such uses as private parks, public theaters, private stadiums, private prisons, and mixed public and private ownership. Moreover, easements and similar legal devices also limit or constrain land-use activities and functions. This dimension allows classifying such ownership characteristics more accurately.

The underlying principle of the LBCS model is its flexibility. It addresses flexibility in adapting the model to a variety of planning applications, data collection methods, data-sharing and data-integration methods, and color coding and mapping. The flexibility also makes it possible to assign new categories for new land uses, to accommodate new methods and technologies for analysis, and to customize the model for local needs without losing the ability to share data. Each of these aspects of LBCS calls for applying a variety of standards or conventions to maintain consistency in land-use classifications.

MPOs

Casual analysis of land use hierarchies used by MPOs, State DOTs, and county and local governments suggest that the Anderson land use hierarchy is the most widely used standard, but that this standard is often modified to conform to specific, regional applications throughout the United States.

Appendix C
Summary of Literature

Integrating imagery into the transportation planning process

There are few references in the published literature regarding the specific use of imagery in the transportation planning process. A few researchers and analysts have used imagery within the context of a GIS to support transportation planning. There are several references in the literature that discuss the use of imagery in applications that support various components of planning in general, but which have utility in the context of transportation planning.

Land use analysis provides the planner with information such as road networks, vegetation, residential, and commercial/industrial information. Once collected, these data provide information for use in transportation forecasting models and in subsequent GIS processing.

Spatial resolution

Jensen, et. al. (1994) state that imagery of 20-meter resolution is sufficient to provide regional information on land cover change and that 10-meter resolution data is useful for updating urban transportation infrastructure. Imagery of 5-meter resolution is necessary to identify homes, duplexes, and other residential features.

Transportation planning

Several sources in the published literature discuss the use of imagery in applications related to transportation planning. In a study performed in the Charlotte, North Carolina region Gallimore, et. al. used imagery to update land use. Several transportation networks were modeled reflecting alternative highway development projects. Traffic flows from origin to destination were predicted using a gravity model. Employment data in the study was referenced to zip codes.

An imagery analysis package was used to derive land cover and land use from Landsat TM imagery. Various classes of land use and land cover were derived including:

- water,
- hardwood forest,
- softwood forest,
- wetlands,
- urban or built-up areas,
- cropland and grassland, and
- open areas.

The study concluded that higher resolution imagery was required to derive further detail.

Regional analysis

Ehlers, _et_. _al_. used SPOT 20-meter data for regional growth analysis and local planning. In their study, various digital techniques were used to cluster the raw digital imagery data into land cover classes. These classes were aggregated into eight general land cover classes following manual imagery analysis and fieldwork investigation. Additional land cover classes were then added to the eight general land cover classes, resulting in a total of thirteen land cover classes.

Foresman and Millette discuss information that can be derived from imagery based on the scale and resolution of the imagery data. The article reviews several applications of imagery data related to planning, including land cover updating, road extraction, urban modeling, regional growth analysis, rural land use analysis, and rural-urban fringe analysis. The article states that imagery analysis to support these applications is most likely to be housed in the digital mapping office within many planning organizations. Finally, Foresman and Millette argue that standardized coding hierarchies and documentation procedures are essential for efficient use and quality assurance of spatial databases.

Treitz, _et_. _al_. discuss the application of SPOT 20- and 10-meter imagery for land cover analysis at the rural-urban fringe. Various digital techniques were used to derive land cover information from the digital imagery. The study concludes that land cover and land uses within urban areas are often composed of multiple sub-components, and digital techniques alone are often not sufficient to differentiate between various land cover classes. For example, an industrial facility may be composed of a headquarters building, a manufacturing facility, parking lots, and surrounding vegetation that results in a diversity of spectral values that can cause confusion when using digital image processing techniques.

In their study for the Bell South telephone company, Jensen, _et_. _al_. (1994) determined that capital investment forecasts require information on the following topics:

- transportation networks,
- residential housing,
- commercial and industrial complexes,
- population and demographics, and
- existing Bell South facilities.

The study performed an analysis on the utility of imagery to derive information on the first three topics.

Housing units were extracted by using band ratioing techniques, followed by other digital processing operations. The absence or presence of dwelling units was compared with the number of units summarized in Census data at the block group level. A model of residential development was then developed which provides the capability to monitor urban expansion between the decennial census, using various information including flood plain maps, land use zoning maps, lot size, and remote sensing data. Indicators of development were most often associated with change in the number of residential units.

Jensen and Toll (1982) used Landsat MSS 79-meter data to identify residential environments located at the urban fringe. In the study, it was determined that residential housing goes through several stages of development, such as clearing, subdivision, transportation, building, and landscaping. A dichotomous key was developed yielding ten stages of residential development. These ten stages were:

- original land cover;
- the area is cleared;
- the area is cleared and subdivided, and roads are paved;
- the area is cleared and subdivided, roads are paved, buildings are constructed;
- the area is subdivided, roads are paved, buildings are constructed, and the area is partially landscaped;
- the area is cleared and subdivided, dirt roads are constructed;
- the area is cleared and subdivided, dirt roads are present, buildings are constructed;
- the area is subdivided, dirt roads are present, buildings are constructed, and the area is partially landscaped;
- the area is subdivided, dirt roads are present, buildings are constructed, and the area is landscaped; and
- the area is subdivided, roads are paved, buildings are constructed, and the area is landscaped.

Landsat MSS band 5 (0.6-0.7m), which enhances the contrast between vegetated and non-vegetated regions, and texture data were used to produce change detection maps that were approximately 81% correct. Image differencing was used as the change detection method. The critical issue when using image differencing is deciding where to place the threshold boundaries between change and no-change.

Texture change maps were used to differentiate many pixels of change during various stages of residential land use development. Other land use category changes, for example from rangeland to established residential, resulted in similar textures and created confusion during the change detection analysis. In addition, confusion was experienced when comparing natural vegetation with cleared, subdivided residential parcels before housing construction was completed. However, differences in texture were observed when comparing differences between natural vegetation and fully landscaped residential development.

Change detection

A number of algorithms to assist in change detection using remote sensing data sources exist in the literature (Ridd and Liu; Macleod and Congalton; Lyon, et. al., and Jensen, et. al. 1997). These researchers have developed a framework that view land use to be an orderly process that can be mapped over time.

Wang and Newkirk discuss several techniques to assist in the detection of land use change between two different time periods using imagery data. These techniques include image ratioing, image differencing, image overlay, vegetation indexing, post-classification comparison, and spectral/temporal classification. In their study, Wang and Newkirk used image differencing to locate the areas of change and post-classification comparison to identify the nature of the change.

Stow reports that ratioing spectral bands (red and near-infrared) more efficiently detected land use changes compared to generating principal component images from corresponding bands (green, red, near-infrared). According to Stow, most of the information content related to land use change is captured when ratioing the red spectral bands of a multi-date pair. An image processing operation known as masking was used to eliminate from further analysis those areas where no change occurred.

Westmoreland and Stow performed a study with the San Diego MPO. In a conclusion that is similar to one reached by Wang and Newkirk (1987), Westmoreland and Stow conclude that land use change detection is actually two processes. The first process is the actual identification and delineation of areas of change and the second is the identification of the land use category.

Contextual classification

A critical issue in land use analysis is the consistency of update between differing dates and between different analysts. Human analysts have different experience and knowledge that often results in differing interpretations of imagery. Humans also have limits on the volumes of information that they can assimilate for the interpretation process.

Digital techniques can allow a researcher to process more data with more consistency, but such techniques have limitations as well. The greatest limitation is the issue resulting from differentiating between land use classes in urbanized areas, consisting of a composite of land cover components such as roads, vegetation, concrete, roofing, and building materials. Texture, defined as variations of image brightness in adjacent pixels, contextual information, and other collateral data sources have been shown to improve the accuracy of identifying land use classes.

Westmoreland and Stow use both manual and digital techniques to categorize digital imagery into nineteen land use and land cover classes. The classification hierarchy provided for the possibility that a change within the agriculture class, for example from corn production to fallow, would not reflect in a change in the percentage of the overall class. The digital imagery data were combined with various collateral data sources through a combination of visual interpretation, digital image processing, and GIS overlay techniques.

Data on land use of adjacent polygons were generated and were used as contextual information in land use/cover identification and change detection. This technique was inconclusive due to the large areas of both undeveloped land and land under construction that bordered most of the change areas.

The spectral signatures of buildings, trees, roads, and grass are averaged in the instantaneous field of view of an imagery pixel resulting in a broad composite signal for urban residential areas (Barnsley and Barr). As resolution increases, the individual pixels are made up of pure elements of the broad categories such as residential, commercial and industrial, resulting in a more varied spectral response from urban areas, and resulting in a more difficult classification. As a result, a number of researchers recommend post-classification spatial processing using variable sized kernel filters (Barnsley and Barr; Groom and Fuller).

Appendix D
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Appendix E
Remote Sensing and Technical Contacts

US Department of Transportation (http://www.dot.gov)

Transportation Equity Act for the 21st Century (TEA-21) (http://www.fhwa.dot.gov/tea21/)

Federal Highway Administration FHWA (http://www.fhwa.dot.gov)

Office of Planning, Environment, and Real Estate (http://www.fhwa.dot.gov/hep/index.htm)

Travel Model Improvement Program (TMIP) (http://tmip.fhwa.dot.gov)

Office of Planning, Environment, and Real Estate Office of the Environment
Document on NEPA Process and Environmental Streamlining (TEA-21 Section 1309)
(http://www.fhwa.dot.gov/environment/nepa/ta6640.htm)
(http://www.fhwa.dot.gov/environment/strmlng/baseline/)
Guidance for Preparing and Processing of Environmental and Section 4(f) Documents
(FHWA Technical Advisory T6640.8A)
(http://www.fhwa.dot.gov/legsregs/directives/techadvs/t664008a.htm)

National Highway Planning Network (NHPN)
(http://www.fhwa.dot.gov/planning/nhpn/index.html)

National Highway Institute (http://www.nhi.fhwa.dot.gov)

FHWA Resource Locator (http://highwayexpertise.fhwa.dot.gov)

Bureau of Transportation Statistics (BTS) (http://www.bts.gov)

Research and Special Program Administration (RSPA) (http://www.rspa.dot.gov)

National Consortia on Remote Sensing in Technology (NCRST)
(http://www.ncrst.org/ncrst.html)

Commercial Remote Sensing Products and Spatial Information Technologies Program in cooperation with NASA (http://scitech.dot.gov/research/remote/index.html)

Federal Geographic Data Committee (http://www.fgdc.gov)

US Geological Survey (http://www.usgs.gov)

USGS digital orthophotography specification
(http://www-wmc.wr.usgs.gov/doq/)

USGS National Mapping Program Standards National Map Accuracy Standards
(http://rockyweb.cr.usgs.gov/public/nmpstds/nmas.html)

National Aeronautics and Space Administration Remote Sensing Tutorial
(http://rst.gsfc.nasa.gov/starthere.html)

National Oceanic and Atmospheric Administration City Lights (DMSP)
(http://spidr.ngdc.noaa.gov/)

Canadian Center for Remote Sensing (CCRS)
(http://www.ccrs.nrcan.gc.ca/ccrs/homepg.pl?e)

Baltimore Metropolitan Council (http://www.baltometro.org)

Metropolitan Washington Council of Governments (MWCOG) (http://www.mwcog.org)

Portland, Oregon METRO (http://www.metro-region.org)

San Diego Association of Governments (SANDAG) (http://www.sandag.org)

Southern California Association of Governments (SCAG) (http://www.scag.org/)

Transportation Research Board (http://www.trb.org)

American Planning Association (APA) Land-Based Classification Standards
(http://www.planning.org/lbcs/index.html)

American Society for Photogrammetry and Remote Sensing (ASPRS)
(http://www.asprs.org)

Hyperspectral resources
(http://www.techexpo.com/WWW/opto-knowledge/IS_resources.html)
(http://biology.usgs.gov/hwsc)