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Geographic Information Systems

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ABSTRACT

This tutorial provides a foundation in GIS including its basic structure and concepts, and spatial analysis. Spatial Decision Support Systems are introduced, emphasizing one current model. The links of GIS to related technologies such as GPS, wireless, location-based technologies, and RFID are examined. The tutorial gives an overview of vertical-sector uses of GIS, and concentrates on a few examples in marketing and banking. GIS is a new field in business schools, and presents opportunities for research. It is derivative from about 8 to 10 disciplines, some unfamiliar to most IS researchers. Several conceptual models and research methodologies are discussed.

Keywords

Geographic information systems, spatial decision support systems, spatial analysis, conceptual models, methods

INTRODUCTION

Geographic Information Systems (GIS) access spatial and attribute information, analyze it, and produce outputs with mapping and visual displays. GIS includes spatial boundary layers and utilizes attribute data that have spatial coordinates. It consists of both a data-base and tools and models to manipulate the data and boundary information. To understand GIS, elements of geography and spatial science are necessary. GIS analysis includes numerical algorithms, statistics, and optimization. In addition, spatial tools act on the boundary layers, including union, overlay, buffering, nearest neighbor, and spatial attraction.

GIS may be regarded as a form of decision support system, often referred to as spatial decision support system (SDSS), that has a data-base, model base, and user interface to support decision makers, However, SDSS differs from DSS in its data-base, which has both attribute and spatial data; and in its model base, that includes tools for georeferencing, geocoding, and spatial analysis, which are unfamiliar to most IT faculty. An example of the latter is algorithms to analyze the overlay of two or more spatial boundary layers. Several preliminary conceptual models have been published for SDSS (Murphy, 1995; Jarupathirun and Zahedi, 2001; 2004; Huerta, Navarrete, and Ryan, 2004).

Other areas covered in this tutorial are the design of enterprise GIS systems, cost and benefits, spatial knowledge discovery and data mining, web-based GIS services, and the linkage between GIS and the associated technologies of global positioning systems (GPS), remote sensing, and location-based mobile services.

Why GIS Is Important

GIS started in the government sector, but is now rapidly growing in business. Datatech estimates that the market for the core GIS software and services in 2003 was $1.7 billion (Directions Magazine, 2003; Francica, 2004). Areas of business application are numerous, including marketing, sales, logistics, transportation, real estate, energy and power, natural resources, agriculture, and health care. Many Fortune 1,000 firms utilize GIS, although most do not publicize it. Successful corporate examples are Sears Roebuck in optimizing delivery logistics nationwide, McDonalds for site location, and the Credit Union of Texas for direct marketing. GIS use is growing worldwide including in the such developing nations as India and Mexico.

For IS researchers, GIS is significant because it improves the efficiency of transaction systems, enhances many types of decision-making, and can influence corporate strategy. Its high growth rates in industry imply that applied researchers will need to recognize and include it.

From the standpoint of academia, GIS originated in the 1960s and 1970s in landscape architecture, geography, cartography, and remote sensing (Longley et al., 2000a). During the last twenty years, it has branched into other academic disciplines notably computer science (Longley et al., 2000a), statistics and more particularly geostatistics (Getis, 2000), land administration (Dale and McLaren, 2000), urban planning, public policy (Greene, 2000), energy studies (Harder, 1999), social sciences, medicine (Khan, 2003), and the humanities (Gregory, Kemp, and Mostern, 2002). In the 1990s, it began to spill over into the business disciplines including management (Huxhold, 1991; 1995), information systems (Grimshaw, 2000), organizational studies (Reeve and Petch, 1999), real estate (Castle III, 1998; Thrall, 2002), retail management (Longley et al., 2003), and telecommunications (Godin, 2001).

In the early 21st century, some business schools recognized the importance of GIS by including it as a required course or degree emphasis; for example, elective GIS course are offered at the University of California Berkeley's Haas School of Business, and the University of Redlands' MBA emphasis in GIS (UCGIS, 2003). Several business schools established centers for GIS research, such as the Wharton Geographic Information Systems Laboratory. University College London established the interdisciplinary Centre for Advanced Spatial Analysis (CASA), which is an initiative to combine spatial technologies in several disciplines which deal with geography, location, business, and the built environment.

PRINCIPLES OF GIS

Geographical information systems (GISs) access spatial and attribute information, analyze it, and produce outputs with mapping and visual displays. An early definition stated: GIS is "an information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-referenced data, as well as a set of operations for working with the data" (Star and Estes, 1990).

A GIS consists of layers of geographic boundary files, shown in Figure 1, on the right side, which are tied to geo-referenced attributes in data tables (Figure 1, on the left side). It further has analysis and modeling tools that are based on both the attribute data-bases and the spatial boundary files. Results are output in a variety of visual and tabular displays.

COMMON GIS ANALYTICAL AND MODELING METHODOLOGIES

GIS spatial analysis techniques (Mitchell, 1999; Getis, 1999; Longley and Batty, 2003) consist of methods that are used in the analysis and modeling functions of a GIS. This section describes only a few important analysis techniques. A full treatment is available in specialized sources (Mitchell, 1999; Getis, 1999).

Buffer Analysis

In buffering, GIS software forms bands on either side of a point, line, or polygon, in order to perform analysis within the bands. A simple example would be to assign half-mile buffers on both sides of a highway, in order to query how many service stations are within the buffer.

Map Overlay Functions

Overlay consists of superimposing two or more map layers. Quite a few operations for map overlays are supported. One example is the union procedure, in which two boundary file layers are combined to result in a third output layer. The resultant layer has the identical geographic extent as the two layers that form it, and it combines the attributes from those two layers in its associated data-base. Greene and Stager (2004) demonstrate the overlay union procedure (Figure 2).

This diagram shows one layer that has census blocks and a second layer with three store trade areas. The resultant map combines all these features. The attributes of each layer are combined into an attribute data-base (not shown). The advantages of overlay procedures include the ability to combine component maps in many different ways and turn on or off layers for particular purposes. The business purpose in the example is to make available the census block attribute characteristics for the sales areas (Greene and Stager, 2004).

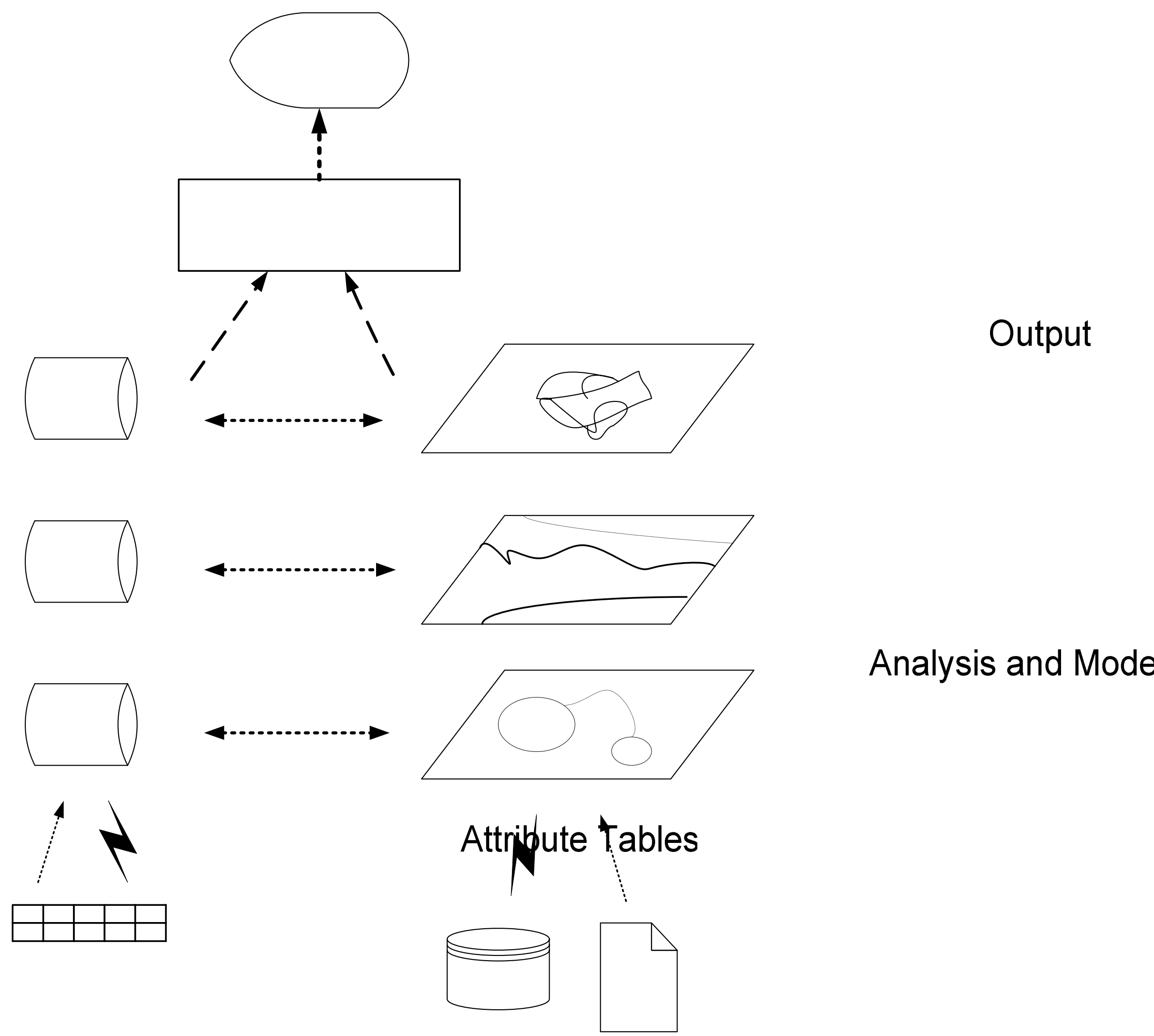
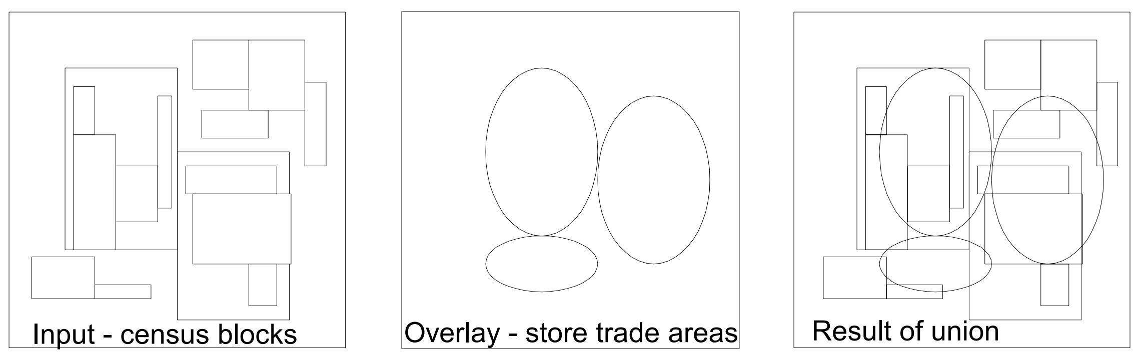


Figure 1. Design Elements of a GIS



(Source: Greene and Stager, 2004)

Figure 2. A GIS Union Procedure

Spatial Analysis

Spatial analysis techniques compare spatial features (Lo and Yeung, 2002; Longley and Batty, 2003). Spatial analysis can, for example, determine how many points are inside a polygon, how many line segments cross a polygon boundary, or how much polygons overlap each other. A practical example would be to ask how many times rivers (lines) cross a toxic waste area (polygon).

Examples of more sophisticated spatial analyses include uses for industrial specialization and location quotient analysis in an urban labor market and for trade area analysis, based on a gravity model, which can examine customers' attractions to competing consumer destinations. Greene and Stager (2004) discuss the gravity model with respect to attraction of major opera houses in northern Illinois and southern Wisconsin.

Proximity Analysis

Proximity analysis assesses how close certain map objects are to other map objects. For instance, it can determine how close the population residing in a census tract is to grocery stores.

Longitudinal Change Detection

This type of analysis seeks to compare maps over time, and assess what significant spatial changes have taken place.

Modeling and Forecasting

Forecasting and simulation models can be built with spatial data, and the results can be displayed in map form. An example is a model that projects population distribution within a county, based on starting year data. The future population distributions can be mapped, to inform businesses and the public.

Statistical Analysis

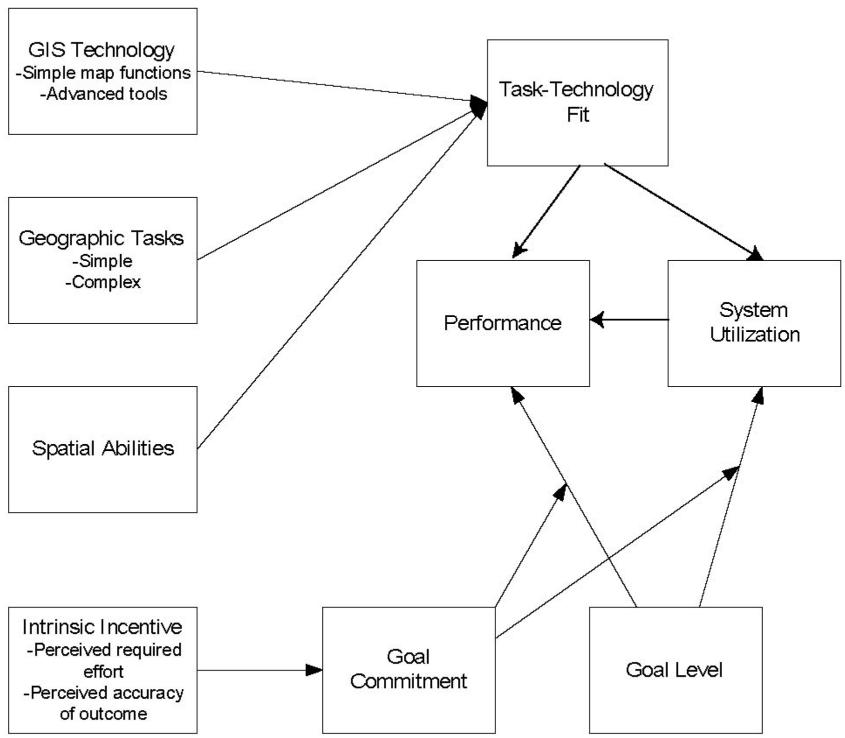
Statistical models are often used to study the relationships of certain spatially-referenced attributes to other attributes (Getis, 1999). These techniques include correlation, regression, analysis of variance, cluster analysis, and t tests. The input data, as well as the results, of many of these models can be represented as spatial displays. This allows enhanced understanding of the geographical effects and influences. Although beyond the scope of this paper, a specialized part of statistics, called geostatistics, takes specially into account spatial effects and interactions, such as spatial autocorrelation (Getis, 2000).

SPATIAL DECISION SUPPORT SYSTEMS (SDSS)

Over the past 30 years, GIS moved upward in organizational level just as conventional Information Systems moved from transaction processing to MIS to decision support systems. GIS can be applied for decision-support. This combines a traditional DSS with spatially-referenced data and spatial analysis. SDSS has spatial analytical tools that go beyond ordinary DSSs and include spatial tools. It also has advanced, specialized functions for special purposes that are both spatial and analytical including for example 3-D visualization, statistical modeling, and network analysis (Jarupathirun and Zahedi, 2004). In the literature the unique visualization features of SDSS that include the dynamic nature of map visualization, visual thinking, and the behavioral impact on decision makers (Jarupathirun and Zahedi, 2001; 2004). Given all this, how can the effectiveness of an SDSS be evaluated and tested? A SDSS conceptual model of Jarupathirun and Zahedi (2001, 2004), shown in Figure 3, includes technology, problem tasks, behavioral abilities, and the resultant task-technology fit, as well as incentives, goals, performance, and utilization. Future enhancements of SDSS may include use of 3-D, animation, and intelligent agents (Jarupathiun and Zahedi, 2004). SDSS is at the core of why GIS is essential to real-world decision makers.

COSTS AND BENEFITS OF GIS IN BUSINESS

Another area of research interest is study of the costs and benefits of GIS. In anticipating applying GIS in an organization, a crucial aspect is to examine the key factors and methods for assessing costs and benefits (King and Schrems, 1978; Obermeyer, 1999; Pick, 2004b). Cost-benefit (C/B) analysis for GIS differs from C/B analysis in non-spatial IS in two ways. First, GIS software tends to be linked with other technologies and software, such as GPS, wireless technologies, RFID, statistical software, and modeling packages. This need to link up may result in added costs as well as benefits. Second, GIS data and data management must deal with both attribute and spatial data, which influence C/B differently. Third, the



Source: Jarupathirun and Zahedi, 2004.

Figure 3. Jarupathirun/Zahedi Conceptual Model to Test and Evaluate SDSS

visualization aspect of GIS is hard to quantify and therefore adds to intangible costs and benefits. The costs and benefits are related to the organizational hierarchy of an organization. There is a long-term trend for GIS business applications to move up this hierarchy, i.e. from the operational to managerial to strategic levels. At the higher levels, benefits become more difficult to assess. A related topic considered with respect to GIS is the IT productivity paradox. The productivity paradox and value of IT investment literature can be helpful in assessing the payoff of GIS (Ahituv, 1989; Lucas, 1999; Strassmann, 1999a, 1999b; Devaraj and Kohli, 2002).

Among the challenges in GIS cost-benefit analysis is that GIS usually involves higher costs than conventional information systems because it requires considerable data acquisition and data management to obtain the needed attribute and spatial data (Huxhold, 1991; Huxhold, 1995; Clarke, 2001; Tomlinson, 2003).

Data collection for GIS is estimated to constitute 65 to 80 percent of the total cost for conventional systems development/implementation (Huxhold and Levinson, 1995; Obermeyer, 1999; Tomlinson, 2003). Further, the attribute and digital boundary data need to be linked together. These linkage tasks add to costs, relative to non-spatial IS. Another difference has to do with GIS's visualization feature (Jarupathirun and Zahedi, 2004). In this respect, GIS is comparable to a multimedia business application, which may have higher costs, due to its visual aspects. Because the benefits of visualization are predominantly intangible, the proportion of intangible costs and benefits tend to be greater than for a non-spatial information system. Another distinctive aspect of GIS is that it tends to be more linked or coupled with other software systems and technologies than is normally present in IS applications. Among the systems and technologies with which GIS is often interfaced are global positioning systems (GPS), remote sensing (Meeks and Dasgupta, 2003, 2004), marketing information systems (Allaway, Murphy, and Berkowitz, 2003), and global positioning systems (Clarke, 2003). Because of this linking together of several types of systems and technologies, the cost and benefit calculation for any one of them may be more difficult.

GIS'S LINKS TO OTHER TECHNOLOGIES

At the level of large-sized systems and applications, expanded computing power, combined with the Internet and modern telecommunications infrastructure, allows GIS to be deployed across an organizations as a worldwide enterprise system. In enterprise applications, the GIS processing is centered in specialized groups of servers that are interconnected through middleware to the client-based end users (Ray, 2004). The development of enterprise GIS resembles the trend towards enterprise resource planning systems (ERP). Sometimes they are merged; in fact, many ERP systems allow for interconnections to GIS software.

A number of other technology trends led to the expanding use of GIS. They include more sophisticated and robust GIS software, evolving data-base design, improved visualization display both hardware and software, and since 1992 the growth of the commercial internet (Longley, 2000a,b). Like other information systems applications, GIS benefited notably from the internet (Francica, 2004). As a consequence, GIS applications are available as web services, and, in some cases, a single map server responds to millions of requests per week. This area of GIS is rapidly expanding. GIS is used in location-based applications, which refers to applications where small portable devices are connected by the internet to send and receive data to and from centralized computing resources. Hand-held GIS devices such as ArcPad (ESRI, 2003), coupled with other mobile devices, support these applications.

Another group of related technologies is more specifically advantageous to GIS in business. Some of the more important ones are given in Table 1.

Technology	*Importance for GIS in Business*
Global positioning systems	GPS combined with GIS allows real-time locational information to be applied for business purposes.
RFID	Allows portable products of any type to be spatially registered and to carry data that can be accessed and updated remotely. Useful in business because its supply chains and inventories consist of goods that are moved around and can benefit by being tracked (Richardson, 2003).
Spatial features built into leading relational data-bases such as Oracle	Makes large-scale GIS applications easier and more efficient to realize. GIS software packages contain specific add-ons to link to the data-base spatial features. Applies to business because enterprise applications are mostly adopted by businesses
Mobile wireless communications	Allows field deployment of GIS technologies in mobile commerce. Useful in supporting the real-time field operations of businesses (Mennecke and Strader, 2003). Combines GIS, GPS, and wireless technologies.
Hand-held GIS, such as ArcPad	A new type of product that is equivalent to PDAs, cell phones, and other mobile devices. It contains GPS and scaled-down versions of standard GIS software. Gives businesses field flexibility in inputting, modifying, and utilizing data. Important in business sectors such as retail that have substantial field force (ESRI, 2003).
Map server software	Specialized software to support servers that deliver GIS over the internet. The software converts maps from conventional GIS storage form into versions that are coded and optimized for web delivery

Table 1. Examples of Technologies Closely Associated with GIS for Business

These associated technologies added to the momentum that increased GIS use in business.
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PRIOR RESEARCH ON GIS IN THE INFORMATION SYSTEMS FIELD

Books and journals are devoted to GIS in general (Longley et al., 2000b; Clarke, 2003) and to its practical applications in business (Harder, 1997, 1999; Grimshaw, 2000; Boyles, 2002), and to research for GIS in business (Pick, 2004a). The amount of peer-reviewed research on GIS in business is small (Huerta, Navarrete, and Ryan, 2004).

GIS in business as a scholarly field developed over the past four decades, drawing from and relating to information systems and other business disciplines, as well as to the real world. Keenan (2004) delineated the growth of this field's body of knowledge, referencing and linking together key studies in the literature. The literature and key concepts for important areas of business application of GIS include logistical support, operational support, marketing, service, spatial decision support systems (SDSS), electronic commerce, and mobile commerce (Keenan, 2004). In service for instance, the movement towards customer relationship management (CRM) systems is reinforced by GIS. Customers' spatial relationships to one another can be used to provide better service. For consumer electronic commerce, GIS supports the delivery logistics. In mobile services, GIS, combined with wireless and GPS, customizes service at the customer location. Referring to the classical Nolan stage theories of IS growth (Nolan, 1973), Keenan (2004) suggests that GIS in the business world today is entering the expansion/contagion stage. GIS will likely do well in the subsequent stage of data integration. However, due to its complexity, the data administration stage may pose problems for GIS.

To study of the extent of business GIS research for decision support during the past twelve years, Huerta, Navarrete, and Ryan (2004) examined 20 leading information systems journals and conference proceedings predominantly in information systems but with some from the GIS field. They found only 9 articles on GIS and decision support. Using a well-known model of decision support by Todd and Benbasat (2000) they classified the articles by area. They found a deficit of studies on "desired effect" and "decision strategy" (Huerta, Navarrete, and Ryan, 2004). The paucity of peer-reviewed research in the GIS-DSS area suggests an overall lack of research on GIS in business.

CONCEPTS, METHODOLOGIES, AND THEORIES OF GIS IN BUSINESS

Geographic information systems use methods and techniques drawn from many disciplines, including geography, cartography, spatial information science, information systems, statistics, economics, and business. It is typical of new fields to draw on referent disciplines, eventually combining concepts to form a core for the field. Some of the concepts and theories for GIS in business and their referent disciplines are shown in Table 2.

Concept or Theory in GIS in Business	*Referent Discipline*	*Concept or Theory in GIS in Business*	*Referent Discipline*
Spatial Analysis	Geography, Regional Science	Networking Configuration	Telecommunications
Location Theory	Geography	Visualization	Computer Science
Gravity Model	Geography	Geostatistics	Statistics
Remote Sensing	Geography, Earth Sciences	Customer Relationship Management	Marketing, Information Systems
Decision Support Systems	Information Systems	Adoption/Diffusion Theory	Marketing
Knowledge-Based Discovery	Information Systems	Market Segmentation	Marketing
Data Mining	Information Systems	CAMA and AVM Models	Real Estate
Location Based Services	Information Systems	Cost-Benefit Analysis	Economics, Business
Value of IT Investment	Information Systems, Economics	Organizational Theory	Management, Sociology
Electronic Business	Information Systems, Economics		

Table 2. Referent Disciplines for Concepts and Theories of GIS

For example, spatial analysis stemmed originally from developments in geography and regional science in the early 1960s (Fischer, 2000). It includes "methods and techniques to analyze the pattern and form of geographical objects, … the inherent properties of geographical space, . spatial choice processes, and the spatial-temporal evolution of complex spatial systems" (Fischer, 2000). A simple example of spatial analysis is the overlay, which juxtaposes two or more map layers on top of each another. The positions of spatial objects can be compared between layers; for example, highways on one layer crossing the boundaries of marketing territories on a second layer.

Spatial analysis techniques differ from ordinary data-base functions because they involve computations on spatial attributes (such as points, lines, and polygons), rather than just data attributes (such as numbers and characters). Advanced applications of spatial analysis involve elaborate spatial simulation, modeling, and visualization (Longley and Batty, 2003). This side of GIS is less familiar to scholars in the business disciplines.

CONCLUSION

There is a foundation of research on geographic information systems in business. GIS grew up in the government sector, and today is expanding in businesses. The academic research literature is stronger in the base discipline of geography and its related areas, but weaker in business disciplines. An important example of emerging research in GIS is cost-benefit analysis. The methods utilized draw on studies of information systems C-B analysis, as well as on the IT productivity paradox literature. Many referent disciplines contribute conceptual theories and concepts to the study of GIS in Business, including information sciences, geography, earth science, computer science, economics, and business disciplines. As GIS and its related technologies continue to become more prevalent and strategic for enterprises, a growing academic base of knowledge can provide useful ideas to the wider group of real-world practitioners, and vice versa. Because the academic field of GIS for business school investigators is still new, it offers great potential for research and publication.

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