1-2016

A Tutorial on Geographic Information Systems: A Ten-year Update

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Abstract:

This tutorial provides a foundation on geographic information systems (GIS) as they relate to and are part of the IS body of knowledge. The tutorial serves as a ten-year update on an earlier *CAIS* tutorial (Pick, 2004). During the decade, GIS has expanded with wider and deeper range of applications in government and industry, widespread consumer use, and an emerging importance in business schools and for IS. In this paper, we provide background information on the key ideas and concepts of GIS, spatial analysis, and latest trends and on the status and opportunities for incorporating GIS, spatial analysis, and locational decision making into IS research and in teaching in business and IS curricula.

Keywords: Geographic Information Systems, Spatial Analysis, Location, Conceptual Models, Research Methods, Ethics, IS Model Curriculum.

1   Introduction

Geographic information systems (GIS) are becoming an essential part of the information systems (IS) field. GIS provides the capability to integrate location as part of an information system. It can improve many types of IS applications through enhancing accuracy, efficiency, knowledge, and intelligence. Some GIS concepts resemble standard IS concepts, while others are not widely known in the IS field. In this tutorial, we provide background information on GIS concepts, methodologies and emerging trends, applications, research implications, pedagogy, and ethical implications to IS faculty and graduate students.

The history of GIS dates back to the 1950s when pioneers such as Waldo Tobler foresaw that combining computers and cartography together could lead to automated map outputs. GIS initiatives by national governments emerged in the mid-1960s under the leadership of Roger Tomlinson, an English geographer who moved to Canada and pioneered GIS with the Canadian Government. Likewise Esri, founded in 1969 by Jack Dangermond, originally focused on the government sector and even today mostly serves the governmental markets. Some technologies closely related to GIS, including global positioning systems (GPS) and radio frequency identification (RFID), were developed by U.S. defense agencies during the Cold War. During the past four decades and paralleling IT-industry trends, GIS batch-driven software and mainframe technology have progressed up to today's environment of servers, tablets, mobile devices, high-speed Internet, cloud hosting, multimedia, and social media. Today, mapping is available on billions of cell phones globally, and the GIS and the spatial data industry are worldwide.

1.1   Summary of Principles and Concepts of GIS

A GIS comprises spatial and attribute data, GIS software, and analysis and modeling tools. It produces visual or data outputs shared on a network or cloud, stored in a database, or displayed on mobile or stationary devices. The analysis and modeling outputs can, in turn, influence business processes and can also be shared through connections via the cloud, traditional local area networks, or by physical in-person meetings. These spatially informed business processes support business solutions that often include decision making (see Figure 1). A wide variety of users use GIS, such as GIS professionals and network specialists GIS and business analysts, executives and managers, nonprofit analysts, everyday consumers, and school children.

GIS software creates digital maps and manages their associated numerical, text, and multimedia attributes. More specifically, for 2D mapping, GIS software can be thought of as having multiple layers of map information, each layer associated with its attributes. For instance, one layer could display point locations of a discount retail chain's outlets and another layer could display highway and street patterns. In this case, the GIS user could analyze the magnitude and direction of transportation flows in proximity to each outlet. For three-dimensional mapping, the software maps objects in three dimensions; hence, the user views objects as 3D images (e.g., a building appears on the map as it would in a photograph). Likewise, there can be multiple 3D layers of different types. For example, one layer could be the external walls of buildings and a second layer could be locations of business premises in the buildings. Contemporary GIS software makes these layering operations transparent to users so they can interactively view and work on analyzing and modeling spatial relationships using analytical tools while the software manages the spatial layers.

A GIS's basic software, processes, and analysis and modeling components could reside in the cloud: here, GIS can communicate data, instructions, and messaging with each other. The components depend on assorted underlying hardware as Figure 1 shows. GIS components could also reside on mobile devices, notebooks, laptops, desktops, servers, and/or specialized devices such as car navigation systems. Through the Internet and other networking connections, multiple devices may comprise the same GIS. For example, the GIS system in one major utility firm has its geodatabase resident on eight servers and its enterprise GIS software on two servers. The servers connect over the cloud with hundreds of desktop and laptop thick clients and with over a thousand mobile-device thin clients used mostly by the utility's inspection and maintenance workers in the field. The GIS accesses spatial and attribute information, analyzes it, and produces shared outputs on the network or cloud, which mobile or stationary devices display, and stored. Surrounding these GIS elements portrayed in Figure 1 is the broader environment of the organization, the economic and regulatory context, customers, investors, and competitors.

From another perspective, one can view a GIS as aligned with a decision support system (DSS) or business intelligence (BI). Having spatial features can improve support for better and more accurate decisions. Researchers often refer to a GIS that assists in decision making as a spatial decision support system (SDSS) or spatial business intelligence (SBI) (Jarupathirun & Zahedi, 2005, 2007; Power & Sharda, 2007; Santos, Coutinho-Rodrigues, & Antunes, 2011). For example, an oil exploration company may need to decide on how to place its well sites based on 3D spatial knowledge of the subsurface geology. Traditional decision maker John may use numerical algorithms and his tacit knowledge of the ground surface to place the wells. Decision maker Sarah may use computer-supported numerical algorithms in coordination with digital mapping features of the ground and subsurface to better pinpoint and understand potential well site locations. It is likely that Sarah's spatially-assisted decision will be more accurate than John's since her including the geographical features enhances the solution.

1.2   Emerging Trends for GIS

Key emerging technology trends for GIS include more interactive and intensive Web platforms such as Web 2.0 and 3.0, GIS big data and geo-databases, mobile spatial environments, and locationally referenced social networks.

1.2.1   Shift in Spatial Web platform

The first emerging trend, the shift in the spatial Web platform to Web 2.0 and 3.0, supplants earlier Web versions that emphasized unidirectional flows from Web server to client. Web 2.0 features bi-directional flow between the server and user. For GIS, this flow implies that a thin client spatial user with an iPad can interact (with a nearly full set of commands) with powerful commercial GIS software located on a cloud server to achieve near-desktop functionality (Longley, Goodchild, Maguire, & Rhind, 2011). The interactive aspect also supports collaborative groups of users who are often at remote locations to share common access to spatial software. For instance, this interactive aspect enables users in technologically undeveloped nations to interact with powerful spatial applications residing in an advanced nation's global technology hub. Other advantages of contemporary platforms include pervasive access, Web openness if desired, metered costing, access to a wider pool of applications, and scalability. An example of spatial Web 2.0 is Environmental Systems Research Institute's (Esri's) Living Atlas (Esri, 2014a). Living Atlas transforms the traditional static atlas into a contributed set of interactive maps and accompanying applications that is centralized, cloud based, and continually updated worldwide in real time. The Living Atlas incorporates interactive maps such as earthquake faults by age, housing mortgages, and electricity rates that are updated in real time (see Figure 2). Web 3.0 allows individuals to share data much more readily and at higher volumes.
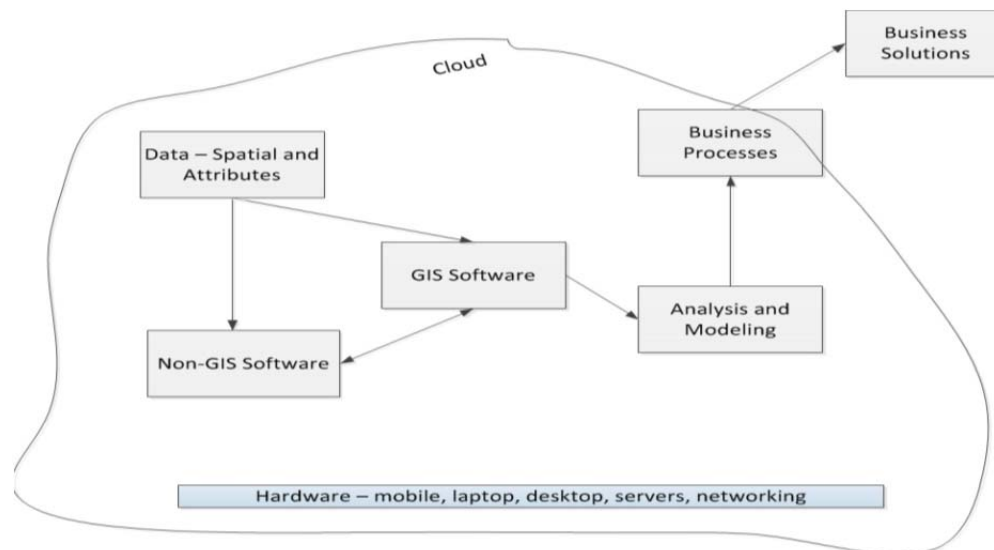

Figure 1. Design Elements of a GIS

1.2.2   Trend toward Big Data

The second emerging trend is the increased use of giant data storage that exceeds traditional databases' capability to input, output, manage, and analyze data and that often involves unstructured data (Chang, Kauffman, & Kwon, 2014; IBM Corporation, 2014). Big data has originated as a consequence of the massive explosion of Internet-based information from e-commerce, social media, billions of mobile devices, diverse multimedia, and enterprise systems. Spatial data were among the early examples of data becoming massive due to their potential coverage of the entire globe and the concomitant locational information. Often, spatial big data is unstructured, such as data that represents imagery that might come from diverse free-flowing sources such as crowdsourcing, social media, and satellite feeds. Individuals can perform big data spatial analytics through data mining, multi-processing, machine learning, trending, and other methods. One applies such methods to better understand big data's characteristics of multiple dimensions, speed, variety of data types, outliers, and unforeseen relationships. We can see an example of big data in GIS with Union Power Cooperative of North Carolina, which uses a spatial application to analyze and map massive information from their advanced metering infrastructure (Harrington & Gross, 2012). As such, this information is big data due to the high volume of data from millions of electrical meters and consumer records, its high speed since it gives near instantaneous warnings of meter problems, and the variety of data types because the data comes from meters and geographically referenced consumer data. The user's dashboard displays multiple tables and maps and pinpoints meter positions and their current status, real-time spatial patterns, and trends of power consumption.
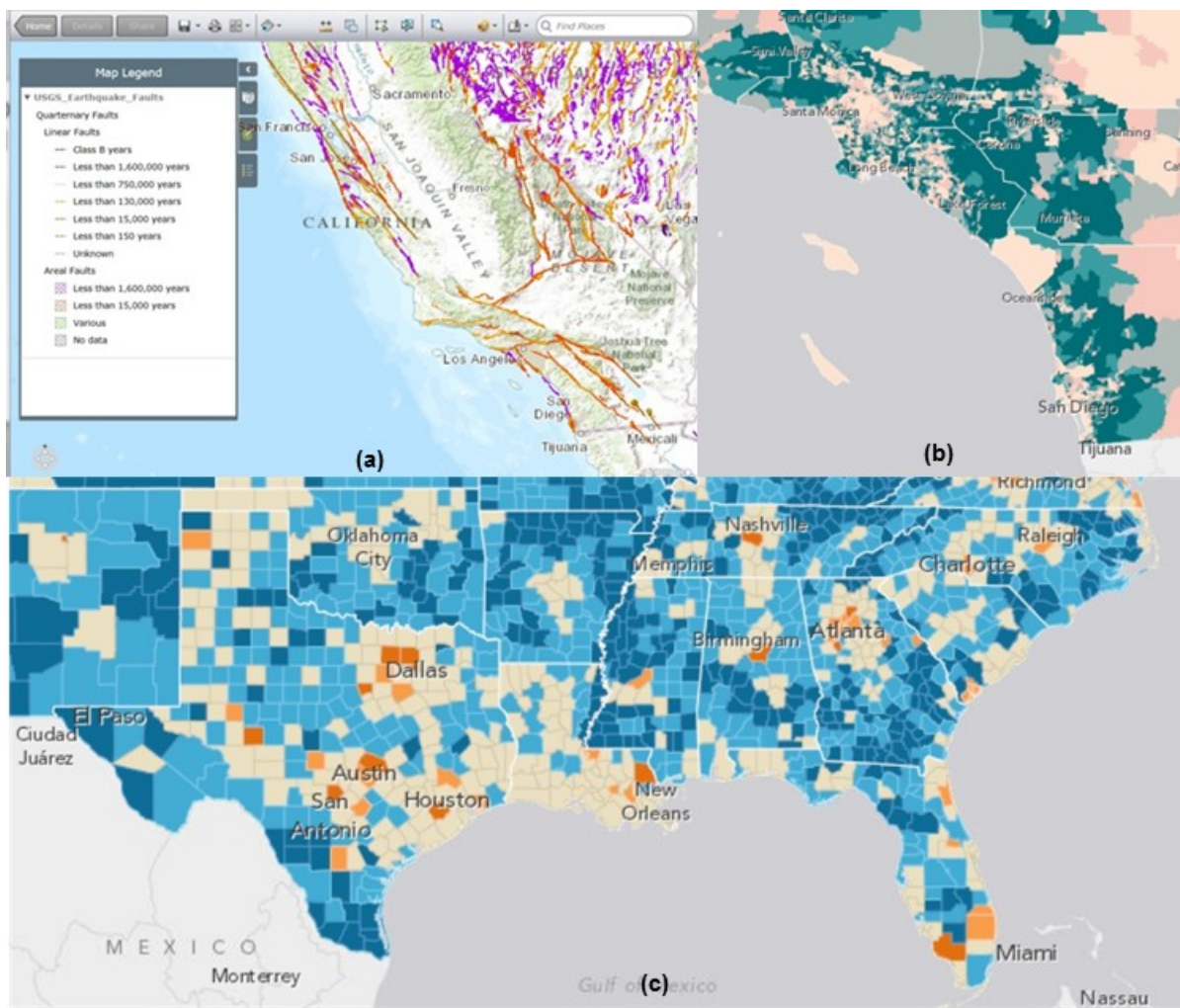
(a) Quaternary earthquake faults by age (Federal User Community), (b) Housing with mortgages (Esri, 2014), (c) Electricity rates in the south of the U.S. (Esri, 2014)

Figure 2. Esri's Living Atlas of the World (Example of Spatial Web 2.0)

1.2.3   Trend toward Expanded Mobile Usage and Locational Analytics

The third emerging GIS trend is the expansion of mobile usage and locational analytics. Powerful GIS capability is available on 3G mobile phones, and simple mapping can occur on almost all cell phones, which numbered about 6 billion worldwide at the end of 2011 (International Telecommunication Union, 2012). Most mobile phones are GPS enabled and nearly all are able to triangulate with cell towers to yield locational information that is somewhat less accurate than with GPS. The explosive growth of cell phones in the 2000s coincidentally mirrors the largest expansion in spatial technology in history. Consumers use GIS on mobile phones and wireless devices for a wide variety of business and lifestyle activities that range from determining competitors' store locations to vehicle navigation to knowing the proximity of social media friends. Several specific examples include automatically identifying emergency calls' origin, tracking inventory, using radio frequency identification devices (RFID) scanning to determine location, and using personal navigation devices (Francica, 2008). On the other hand, the spatial enablement of mobile phones raises ethical issues such as the National Security Agency's (NSA's) tracking individuals' locations (see Section 6).

1.2.4   Trend towards Growth in Social Media

The fourth emerging GIS area is growth in social media usage with large flows of geo-referenced data. This means that social media companies and outside entities that obtain social media data from providers are able to map and spatially analyze the content of these messages based on locational and time. For example, in one study, Tsou and Leitner (2013) measured the number of tweets with the "Obama" and "Romney" keywords for the largest 30 U.S. cities during the periods October 14-20, 2012, and October 28-November 3, 2012, in the run-up to that year's presidential election. They did mapping comparisons between the two periods, which showed a major shift towards Obama in most of the cities with a key factor being President Obama's concerted response to Hurricane Sandy, which occurred during the intervening week (Tsou & Leitner, 2013). In another study, Li, Goodchild, and Xu (2013) geo-referenced tweets and Flickr photos were mapped for the U.S. indicating the highest densities of these social media in the metropolitan belt in the Northeast from Boston to Washington. From analyzing socioeconomic characteristics of the tweet locations, they found that frequency of tweets was correlated with college education, graduate degree, high income, and occupation in management, business, arts, and sciences (Li et al., 2013).

1.3   GIS, Organizations, and Management

GIS management includes the well-known constructs of IS management, strategic management, operational management, human resource management and development, management of marketing and sales, cost-benefit analysis, planning, and systems development (Laudon & Laudon, 2014).

Systems development and planning are particularly important management constructs for GIS (Tomlinson, 2011). Beyond the usual systems-development steps, the technology seminar has proven to be useful in developing GIS projects. It comprises a big meeting early on with all GIS customers and stakeholders to uncover user needs and inputs, explain GIS concepts and methods, justify costs and benefits, and gain consensus on how systems development planning and implementation will proceed (Tomlinson, 2011).

Researchers have applied GIS to enhance strategic management (Tomlinson, 2011). Traditional IS strategic management principles emphasize the alignment of IT and business strategies. Researchers have empirically corroborated that organizations with business strategies and IS strategies that are not aligned run into difficulty (Hirschheim & Sabherwal, 2001). To achieve business and IT strategic alignment, there needs to be two-way functional integration between business and IT strategies and also between business and IT infrastructures (Papp, 2001). Furthermore, a successful GIS needs to be aligned with the GIS with the business's strategy (Tomlinson, 2011). A three-way functional strategic integration is a way to incorporate GIS so that it is aligned with business strategy (Tomlinson, 2011) and with information systems strategy (Pick, 2008) (see Figure 3). In practice, this model avoids misalignments such as the procurement of desktop or mobile devices that are insufficient to support current GIS needs, averts strong investment in siting new franchise facilities without investing in spatial software and systems to optimize location selections, and precludes planning for an expensive, state-of-the-art enterprise GIS system without aligning it with business and IT goals (Tomlinson, 2011).
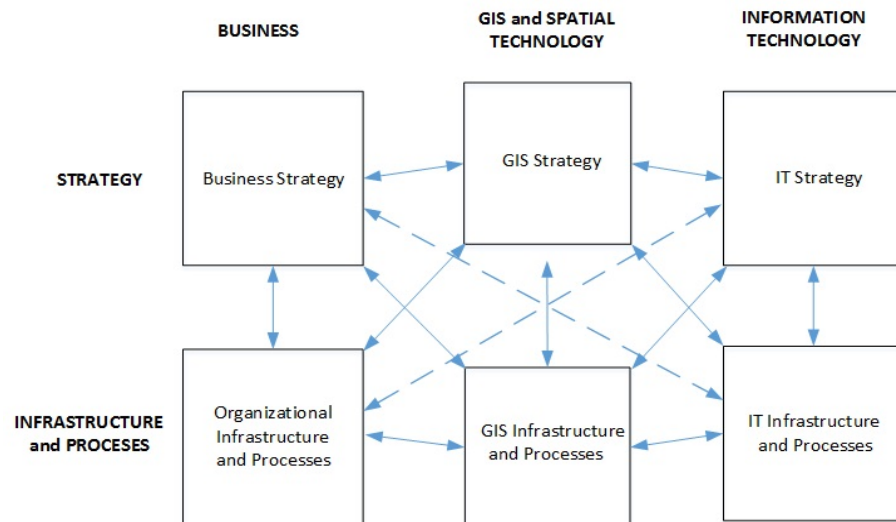
Figure 2. Business-GIS-IT Strategic Alignment Model (Adapted from Pick, 2008)

1.4 Why GIS Is Important

Oxera (2013) has estimated that the geo-services industry's revenue in the US in 2013 was $232 billion in nominal U.S. dollars of which about $73 billion was in labor remuneration for geo-services employees (Oxera, 2013). In addition, Oxera (2013) has estimated that USD$42 billion in revenue came from the satellite industry (Oxera, 2013). The Bureau of Labor Statistics (2012) has estimated that the US employs 210,000 people in traditional GIS job titles and 424,000 in all geospatial occupations. Additionally, Oxera (2013) has predicted that GIS-related jobs will to rise to 572,700 employees in 2020. Many GIS benefits spill over outside of the geospatial industry. The Boston Consulting Group (2012) has estimated the larger economic component that includes spillover for the US to comprise USD$1.6 trillion in revenue and USD$1.4 trillion in cost savings, and it has estimated that 5.3 million U.S. workers use geospatial services daily. Economic sectors of business application of GIS include marketing, sales, retail, military/defense, utilities, logistics, fleet management, building and construction, real estate, banking and finance, energy, natural resources, environment, technology, agriculture, and healthcare (Pick, 2008). Regionally, GIS use is expanding rapidly in the developing world, which includes Southeast Asia, Latin America, and parts of Africa.

For IS and business programs and IS researchers, GIS is significant because it has deep connections with decision support systems, marketing and retail systems, analytics, and big data. It can improve the efficiency of enterprise and transaction systems, support middle management, and inform corporate leaders on aspects of strategic visioning and decision making.

In summary, GIS brings the spatial dimension into business decision making to improve the efficiency and effectiveness of solutions. Many IS concepts underpin GIS. Moreover, spatial analysis involves some new concepts that do not appear as usual IS topics. Next, in Section 2, we discuss spatial analysis and spatial statistics, and in Section 3, we discuss emerging geospatial technologies. In Sections 4 and 5, we detail the expanding roles of GIS for research and teaching in IS and business. Finally, in Section 6, we examine ethical aspects of GIS and, in Section 7, conclude the paper.

2   GIS Methodologies

2.1   Spatial Analysis

Spatial analysis involves applying GIS techniques to discover patterns, trends, and relationships in locational data. Several techniques are relevant to information systems research and business decision making. Pick (2004) describes several such techniques including overlay analysis, buffer analysis, and proximity analysis. In the past decade with the development of powerful desktop development environments, existing tools have been enhanced and new techniques have become available, such as business gravity models and hot spot analysis (Mitchell, 1999, 2005; Pick, 2008). In this section, we expand the prior tutorial (Pick, 2004) by including contemporary techniques. In the discussion that follows,

we use a point dataset of hypothetical retail outlets in the State of New York Taconic Region. We drew the spatial layers from New York State's county and primary roads shapefiles (U.S. Bureau of the Census, 2012). We created the examples using Esri ArcGIS 10.2 and Esri Business Analyst Online.

2.2   Building Blocks of Spatial Analysis

2.2.1   Spatial Data Characteristics

A GIS includes spatial layers, each of which comprises geometric forms such as points, lines, and polygons. The layers are positioned exactly on top of each other (Longley et al., 2011). For instance, one layer shows points for fast food outlets and the layer underneath shows the road network. Combined together, they constitute the entire map. GIS data, also referred to as spatial data or geospatial data, primarily comprises vector data (points, lines, and polygons) and raster data (imagery). While GIS layers for continuous land surfaces or atmospheric layers may be raster (data encoded in points or pixels), business applications primarily use vector data. Three aspects of vector data are its geometry (point, line, or polygon), geographic location, and attributes that describe specific features. While map layers visualize location and geometry, attribute values describe the characteristics for each feature. Descriptive statistics can give meaning to sets of attribute values (e.g., mean and standard deviation). Figure 4 illustrates descriptive values for an attribute, the retail sales of all retail items, at 13 locations in the State of New York. We drew the data for Figure 4 from a representative spatial data set.

Simple visualization does not tell the whole story nor does it exploit the value of GIS. Many spatial analysis techniques involve comparing and analyzing geometric features (e.g., area, perimeter, distance from nearest neighbor) and analyzing geometric and attribute values together to investigate solutions that cannot be examined any other way.
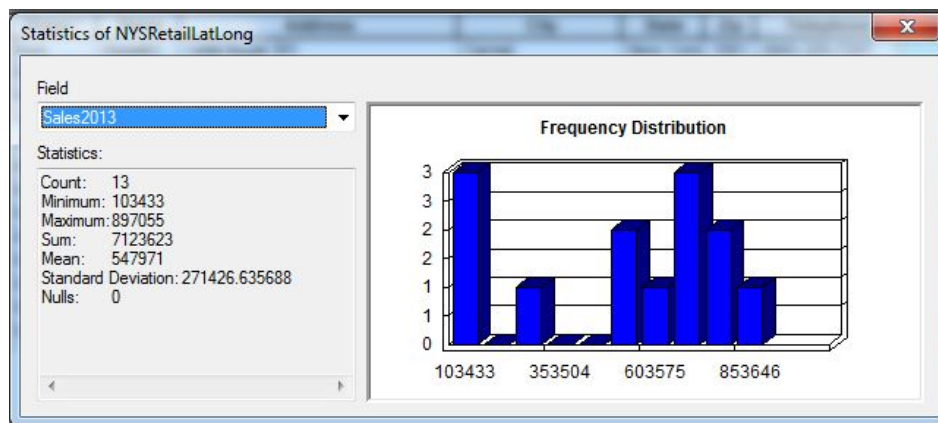

Figure 3. Descriptive Statistics

2.2.2   Map Layers and Overlays

Map overlays are an important part of spatial analysis beyond simple visualization. Superimposing two or more spatial layers gives insight into various spatial data perspectives. Multiple layers can illustrate topological relationships and different aspects of proximity via a variety of techniques including buffers, drive-time analysis, and density.

Point locations on the earth that are the foundation of the points, lines, or polygons appearing in a single layer in GIS software are based on geographic coordinates, which are uniquely defined by their values of longitude and latitude (Longley et al., 2011). For instance, the Washington Monument is located at latitude 38.8895o north and longitude -77.0352o west. Geographic coordinates determine a unique earth location. Latitude/longitude also can be identified by universal transverse Mercator (UTM), state plane coordinates (for individual U.S. states), and other coordinate systems that fall outside the scope of this tutorial (Longley et al., 2011).

A layer, which is a flat (2D) surface, is actually projected from the earth, which is an ellipsoid. There are hundreds of types of ways the ellipsoid earth can be projected onto a flat surface, which includes common projections such as Mercator, Lambert conformal conic, and state plane (Longley et al., 2011). The

Mercator projection, for instance, projects the Earth's surface on a north-south cylinder wrapped around the equator. Although the details of projections are beyond our scope here, when two or more layers are overlaid on top of each other, each layer must be in the identical coordinate system and have the same projection, and, in this manner, layers are then precisely aligned with each other.

Decision making can be further enhanced by selecting features based on both geographic (location) and attribute criteria. Using attributes to establish query criteria is similar to database queries with structured query language (SQL) logic operators. There are two common types of selection in a GIS: a great deal of analysis involves selecting spatial features based on attribute values (e.g., equal to, greater than, etc.), and location selection selects geographic features based on spatial relationships (e.g., the nearest neighbors). These two techniques when combined can enhance the power of GIS analysis by being able to explore and uncover spatial relationships.

2.2.3   Selection by Attribute

When attributes are used for selection, features are searched for those that meet some attribute criteria. For example, we performed a software query on the New York State county layer to select county features based on attributes relating to population and ethnicity. Figure 5 shows the counties of New York State and retail outlets selected by the attribute of belonging to the Taconic Region. In another instance, selection depends on the value of numeric attribute as in Figure 6, which shows those counties with less than 50,000 population in a particular year.

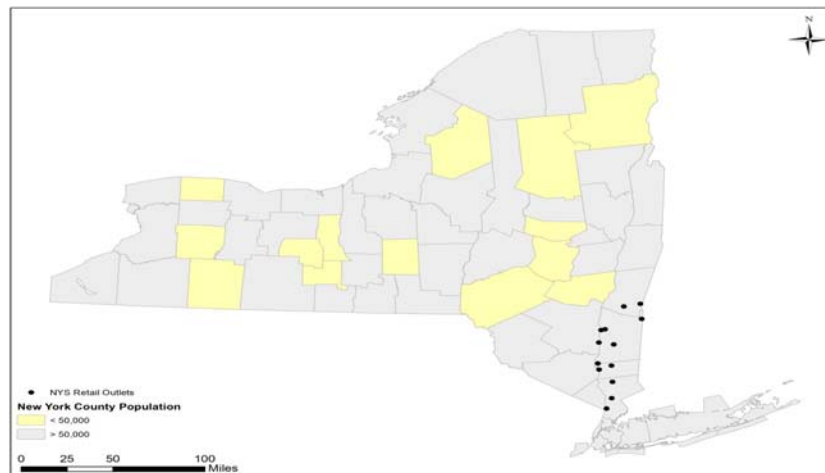**Figure 4. Retail Outlets in the Taconic Region (New York State)**

Figure 5. Selected (by Attribute) New York State Counties (Pop. < 50,000)

2.2.4   Selection by Location

We can see by looking at a map counties that have geometric relationships between geographic features on a single layer or between two or more overlaid layers. Such a selection is termed a locational selection. For example, as Figure 7 shows, we might be interested in highlighting only the counties that "contain" retail outlets (Figure 7). Other location-based queries include selecting polygons containing two intersecting geometric shapes, selecting polygons bordering a line, or selecting points in a specific distance of a polygon.

2.2.5   Geo-referencing and Geocoding

Sometimes, applications have layers (e.g., aerial imagery) that have not been associated with coordinates to correctly position them on a map. Geo-referencing is the process of assigning appropriate geographic identifiers or coordinates to an item of information so its geographic meaning can be shared among all uses of the information (Longley et al., 2011). For example, a zip code number is a geo-reference of a zip code area, while a parcel number geo-references a land parcel in a county or city. Using GPS, one can assign latitude and longitude coordinates to a geographic object. Geocoding is a technique to assign coordinates to addresses so that they can be rendered in a GIS. In the retail outlet example, we geocoded addresses, which were initially part of a spreadsheet, to produce their point locations in latitude and longitude. The geocoding algorithm in the software uses existing data sets of streets and addresses to interpolate longitude and latitude for a new address.
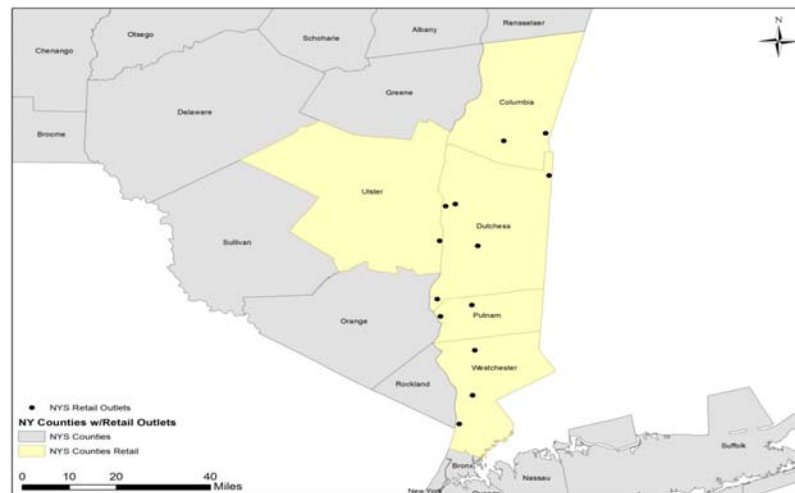
Figure 6. Selected (by Location) New York State Counties with Retail Outlets

2.2.6   Classification and Thematic Maps

Another way to look at attributes on a map is to classify features according to their attribute values and to build a thematic view. In the previous example, we looked at selecting counties according to a population criterion. A thematic view takes each spatial feature and assigns it to a category based on its value. Figure 8 shows county population classified by quintile. Specifically, for the New York State county data, other classifications could be based on ethnicity (e.g., Hispanic, Native American, etc.) or on income categories. Depending on the application, the variety in attributes is virtually limitless (e.g., political party affiliation, metropolitan status, and categories of median house prices, crimes, and energy usage.)

Figure 7. Thematic Map: Population Distribution of New York State Counties (Each Color Represents a Quintile)
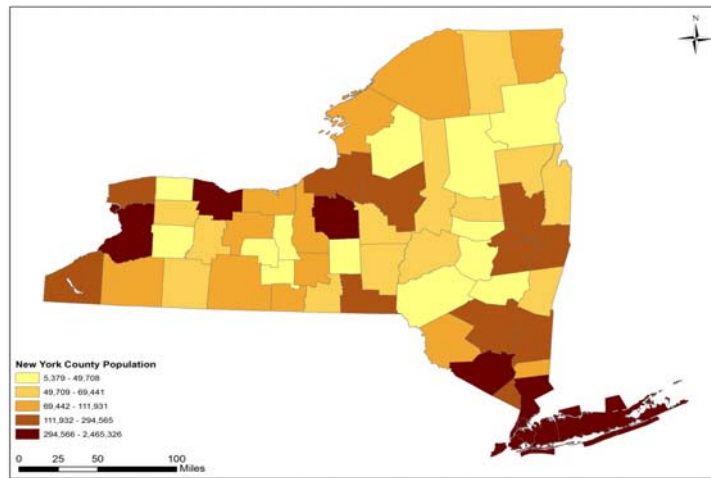
2.2.7   Proximity Analysis

Proximity analysis provides a way to identify the geographic "closeness" of features being studied. There are many ways to understand proximity ranging from simply looking at a map to statistical methods that we describe in Section 2.3.

2.2.8   Buffers

A buffer, which is a type of proximity analysis, is an area determined by distances around features and can be applied to points, lines, or polygons to identify areas that fall in or outside the buffer. In Figure 9, for example, we set 5 and 10 mile circular buffers around the points for retail outlets. In the example in Figure 9, one can see how close the buffers around the retail outlets are to a major New York thoroughfare (Route 22). Alternatively, one could create a linear buffer on both sides of Route 22.
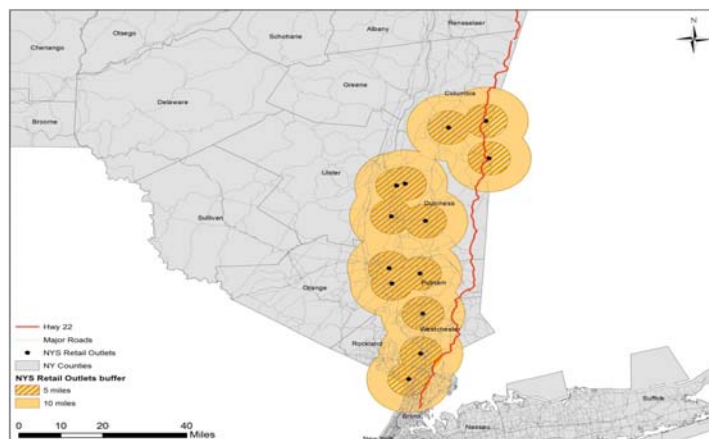
Figure 8. Taconic Retail Outlets with 5- and 10-mile Buffers Surrounding Them

2.2.9   Using Distance during Location Selection

When selecting by location, one can indicate a proximity criterion and select features that are "near" other features. Using the taconic retail outlets, one could look specifically for outlets in a particular distance of a highway. With the buffers still in place, Figure 10 selects retail outlets in 10 miles of Route 22 (the selected ones are highlighted in darker green).

2.2.10   Drive-time Analysis

Another variant of a buffer, involves incorporating roads and estimating drive times based on road criteria (e.g., speed limits and distances) to create a buffer that represents a drive time from a central point. Figure 11 shows drive-time buffers of 2, 5, and 10 minutes surrounding seven central points in New York State, north of New York City, near the Hudson River. The buffered area is often termed a service area.
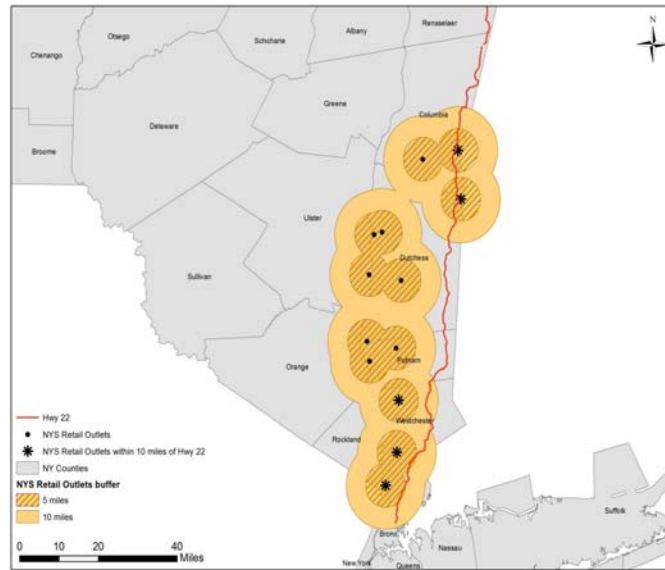
Figure 9. Retail Outlets within 10 Miles of Route 22 (Select by Location)
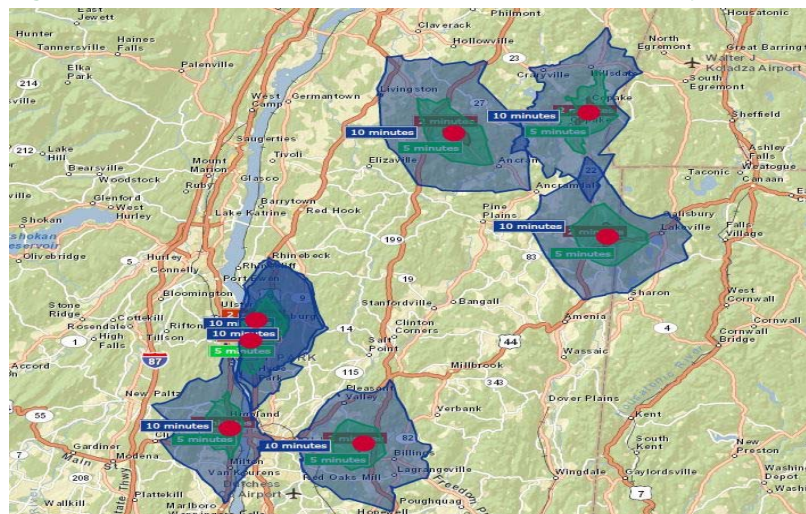
Figure 10. 2-, 5-, and 10-mMinute Drive-time Buffers around Seven Points

2.2.11   Thiessen Polygons: Creating Proximal Zones

Thiessen polygons are used to identify, for a set of designated central points and for a designated area surrounding all the central points, the boundary lines in the designated area such that any point in the layer is located in only the polygon that contains the nearest central point but no other central point. For example, if one has a number of retail outlets (i.e., central points) in a designated area and wants to market to customers that outlet that is closest to their address, Thiessen polygons would delineate, for each customer, the polygon with the closest outlet. Thus, each customer's polygon has the customer's nearest outlet located in it. Using techniques that we mention above (selection by location) and a customer address layer, one can identify the customers who are in each Thiessen polygon (i.e. proximate to each retail location). Figure 12 displays the Thiessen polygons in the designated area (in blue) for the example's retail outlets (the black dots).

2.2.12 Density

Sometimes, one needs to understand how features group together and whether there is a significant density of them or not. Computing density creates a value reflecting concentrations and groupings of entities in a specific area or geographic feature (e.g., a county). Examples would be the density of retail outlets in a zip code or point locations and densities of houses in a census tract. Figure 13 shows the density of medical device manufacturing and related establishments in Orange County, California, in 2012 with noticeable concentrations in cities such as Irvine, Santa, Orange, and Anaheim.

2.2.13 Specialized Modeling for Business Applications: Huff Modeling—Predicting Consumer Behavior

Huff (1963) defined the original Huff model (Huff, 1963) to predict consumer behavior with the underlying assumption that the probability a consumer would choose a particular retail outlet is based on the size of the retail space and the distance between the consumer's home and the retail outlet. The probability is inversely proportional to the distance and, thus, has also been called the gravity model. Individuals have generalized the model to include a variety of parameters. For instance, one can create a market profile for a single mall and use gross leasable area (GLA) an attractiveness variable. A patronage probability map surface shows the probability of a customer patronizing a selected mall positively related to the attractiveness of the mall and negatively related (inversely proportional) to the distance between the mall and the customer (Dramowicz, 2005). Figure 4 shows a Huff model that shows the probability that customers will visit store 1 in a market of three retail stores based on the population of 189 census block groups in an urban area in Mid-Western US.
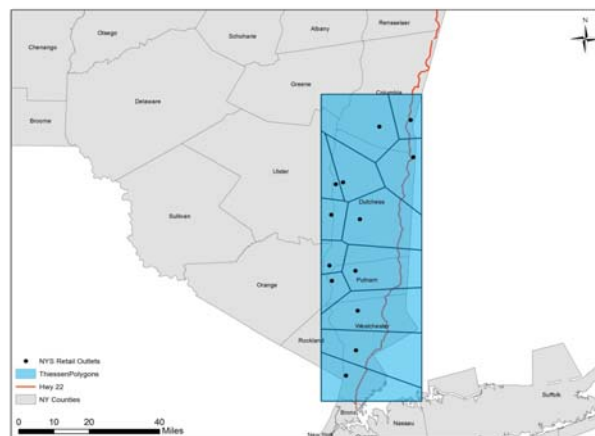

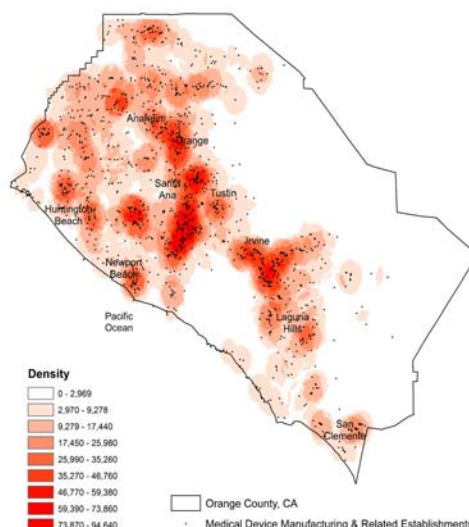**Figure 11. Retail Outlet Proximity Zones (Thiessen Polygons)**

Figure 12. Dot Density Map Showing Medical Device Manufacturing Locations in Orange County, California
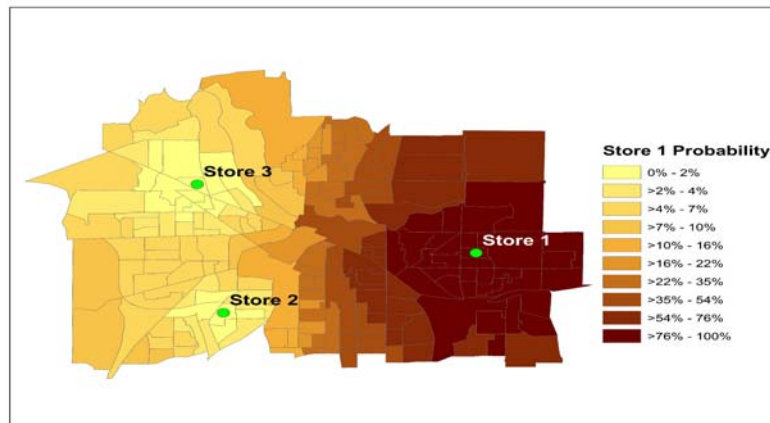
Figure 13. Example of Market Analysis with Huff Model

2.3   Spatial Statistics

Individuals commonly apply spatial data analysis to describe and explore relationships of spatial characteristics (O'Sullivan & Unwin, 2010). An example would be a simple weighting of polygons in a 2D spatial layer. For instance, one could weight a city's districts proportionately to their population. Another simple example for a layer with multiple polygons would be to define how many polygons are considered the nearest neighbor of a particular polygon. This might be based on adjacent boundaries to define "neighbors" or alternatively to define a "neighbor" as any polygon that has any portion of it in a fixed radial distance of the given polygon's centroid point (Lloyd, 2010).

Spatial statistical analysis represents data by a spatial statistical model (O'Sullivan & Unwin, 2010). These techniques include spatial cluster analysis, spatial autocorrelation, geographically weighted regression, spatial interpolation, and hot spot analysis (Lloyd, 2010; Chun & Griffith, 2013). Any of these techniques provides statistical analysis that considers the locations of sample cases in a statistical sample. For instance, ordinary non-spatial cluster analysis uses a set of attributes to organize a sample into separate clusters of cases that are internally closely related to each other based on the similarity of certain attributes. For example, suppose one performs a cluster analysis on 100 city districts to identify seven city-district clusters based on 10 economic attributes. This type of analysis would ensure that, in each cluster, districts would have similar economic attributes but that, between the clusters (districts), there would be significant economic differences. Spatially each cluster includes mostly contiguous districts, but, in some clusters, districts are spatially scattered away from each other. Spatial cluster analysis would ensure that each cluster comprises only geographically contiguous districts (Mitchell, 2005).

One applies measures of spatial autocorrelation to indicate how agglomerated or un-agglomerated polygons appear on a map. Specifically, spatial autocorrelation (SA) analyzes whether, in a given map layer of polygons, polygons tends to be surrounded by similarly valued polygons (positive SA), by randomly valued surrounding polygons (SA close to zero), or by oppositely valued polygons (negative SA). For instance, Figure 15 maps the adoption of broadband (subscribers per 100 population) for all U.S. states in 2010. For the states, spatial autocorrelation is significantly positive since polygons tend to be surrounded by similarly valued polygons (i.e., consider the consistently high values in neighboring states in the west and the consistently low values in neighboring states in the mid-south). Spatial autocorrelation analysis confirms a highly significant positive spatial autocorrelation of 0.457 when using the Moran's I spatial statistic (Longley et al., 2011; Pick & Sarkar, 2015). In summary, spatial statistical techniques provide formal quantitative ways to explore, interpolate, and test for relationships of geographic data. They are available in several widely used GIS software packages including ArcGIS from Esri and Geoda from Arizona State University.
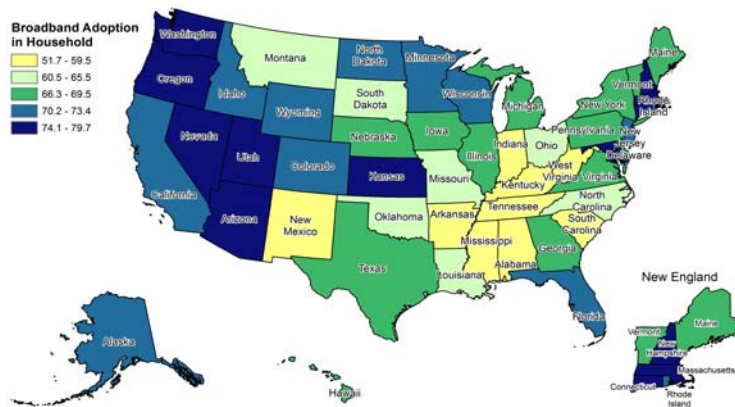
Figure 14. Example of Positive Spatial Autocorrelation: Broadband Adoption in U.S. states in 2010 (Pick & Sarkar, 2015)

2.4   Space-time Trend Analysis and 3D Modeling

2.4.1   Space-time Trend Analysis

GIS techniques commonly provide a spatial view of data at a single time point, but more applications are adding temporal components to the analysis. It is one thing to understand a situation based on a data snapshot at one point in time but quite another to compare snapshots over time to uncover longitudinal trends and changes. If the data have a temporal attribute representing different points in time, one can show temporal change by using different spatial layers for different time periods. Advanced tools provide the ability to create sliding time scales that will, interactively or through animation, display map features changing over a time period.

A good example is the public domain website Gapminder.com (Gapminder, 2014). Figure 16 shows GDP by country in 1947 and 2010, where GDP is proportionate to the size of the circle icon. One can see near the bottom, a time slider that can automatically provide an animated multi-decade sequence of change.

2.4.2   3D Modeling

Just as temporal attributes offer a new perspective, adding 3D to GIS models incorporates visual analysis and solutions that would not be otherwise possible. With tools available in some software development environments, several techniques for creating 3D models exist. One approach combines the target layer (e.g., rivers or roads) with the draping of that layer on a 3D image that contains elevation values that, thereby, renders the target layer in 3D. 3D development environments are becoming important for city planning, real estate, and transportation. If a city has been rendered in 3D, it is possible to visualize the effects of growth, add buildings, compute line-of-sight models, and examine complex changes to cities' natural environmental features.

Figure 15. (a) GDP by Country, 1947; (b) GDP by Country, 2010

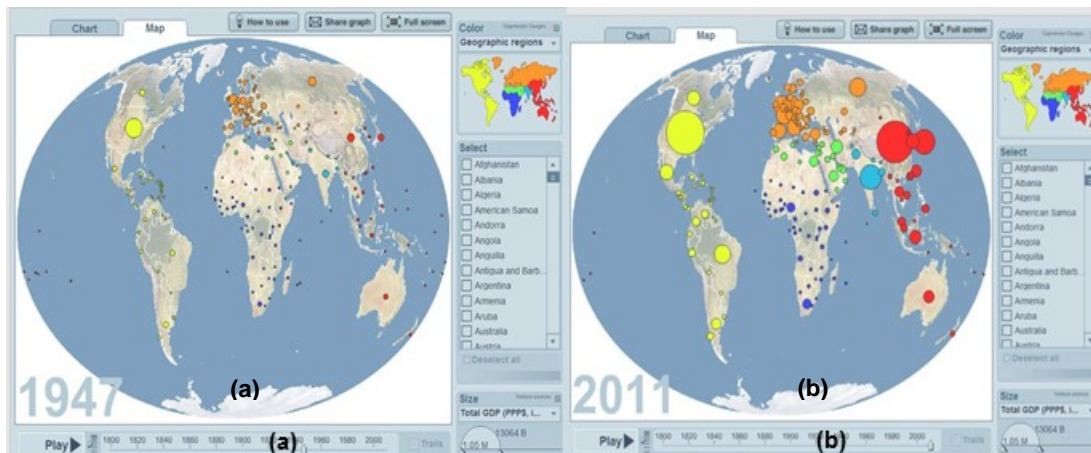In summary, GIS methodologies include spatial analysis, spatial statistics, space-time trend analysis, and 3D modeling. These methods have much in common in that they add the spatial dimension to enhance quantitative analysis by including location and spatial relationships. In this section, we provide only a snapshot of what is a large and diverse set of methods that are increasingly used in the business world as their competitive advantages become more apparent.

3 Emerging Technologies and GIS

Several emerging phenomena and technologies are introducing a new dynamic into the development of geographic information systems and applications. Of particular interest to researchers and practitioners alike is the impact these will have on developing and using GIS. In this section, we describe several of these new phenomena and technologies.

3.1 Introduction

As we mention in Section 1, GIS and its currently associated technologies (e.g., GPS and RFID, to name a few) and several emerging technologies are creating a deluge of previously unimaginable amounts of geospatial information, which will create many opportunities and challenges to capitalize on it (Carpenter & Snell, 2013). Data lifecycle management is an approach to managing the flow of data through an information system: from its initial creation and use to its final deletion. The Committee on Earth Observation Satellites Working Group on Information Systems and Services and the United States Geological Survey Community for Data Integration Data Management Best Practices (2012) have created a "living document" that is a compilation of data lifecycle models and concepts . We selected one model that the document (the U.S. Geologic Survey (USGS) science data lifecycle model (Faundeen, et al., 2013)) as a guideline for this section to best organize and understand the impact of these emerging technologies.

The USGS expects that this six-stage model will serve as the conceptual foundation on which data management best practices would be organized, aligned, explained, understood, and promoted (U.S. Geologic Survey, 2013). In this manner, we selected four of the six stages as the organizing framework for this section:

1. **Acquire:** the series of actions for collecting or adding to data holdings; includes automated collection, the manual recording of empirical observations, and the obtainment of existing data from other sources.

2. **Process**: a series of actions or steps performed on data to verify, organize, transform, integrate, and extract data in an appropriate output form for subsequent use; includes data and content organization, data synthesis and/or integration, and transforming formats.

3. **Analyze:** a series of actions and methods performed on data that help describe facts, detect patterns, develop explanations, and test hypotheses; includes data quality assurance, statistical data analysis, modeling, and interpretation of analysis results.

4. **Publish/share**: to prepare and issue or disseminate the final data product(s) of the research or program activity; includes the "raw" data, data/metadata "packages", derivative materials, and whether the publishing or sharing is human-to-human, human-to-machine, and/or machine-to - machine.

To better understand the four stages and to specifically place them in the GIS context, we discuss each in turn (see Sections 3.2 to 3.5)

3.2 Collecting Data

Collecting data is an essential part of GIS. To answer specific questions, researchers may elect to collect their own data. Spatial data are different from non-spatial data in that spatial data are geo-referenced (i.e., refer to a precise 2D or 3D location) and, as such, can be structured in many different file formats. A geodatabase is a special database type that is designed to manage these geographic datasets and various geospatial data types.

The U.S. Government has taken several steps to achieve key milestones related to transparency, participation, and collaboration that impact data collection and use (Open Government Initiative, 2009). One of these efforts (Data.gov, 2009) has been directed at making data available to the general public. As

of this writing, over 110,000 datasets are available through the Data.gov website, approximately 82,000 of which are geospatial datasets (Data.gov, 2014). At the non-governmental level, the Open Geospatial Consortium has promoted spatial data standards that help facilitate GIS data collection and use worldwide (Open Geospatial Consortium, 2014). In general, standards will be essential for emerging spatial technologies (Federal Geographic Data Committee, 2014).

3.2.1   Enabling Technologies

The technologies we describe here are the global positioning system, mobile smart phones, unmanned vehicles, and light detection and ranging (LIDAR). We include example applications that use these data-collection techniques.

a) **Global positioning system**: collecting data often involves the global positioning system (GPS). The GPS uses satellites to determine the location of a GPS receiver at any point on the globe (Grewal, Weill, & Andrews, 2007; Hofmann-Wellenhof, Lichtenegger, & Collins, 1993). In the United States, www.GPS.gov is the official website regarding GPS technologies. Applying the GPS extends into a wide variety of industries such as agriculture, aviation, environment, marine, disaster planning, and survey and mapping. As a result, data-collection techniques and technologies are frequently adapted to the specific needs and domains of interest.

b) **Mobile smartphones**: Cisco Systems (2014) has predicted that, by the end of 2014, the number of mobile-connected devices will exceed the number of people on earth and, by 2018, that there will be nearly 1.4 mobile devices per capita. As we note earlier, GPS-enabled smartphones have become an emerging method for gathering spatial data. In addition, many mobile applications use phone-based location information as part of their core functionality (i.e., locating the closest restaurant, gas station, or event). To leverage this growing number of devices, many users are collaborating to create, modify, and use spatial data for their purposes. This data-collection method is referred to as crowdsourcing geospatial data (Heipke, 2010). An interesting project in this space is Project Tango (Google, 2014), a customized hardware and software device that will make over a quarter million 3D measurements every second, update its position and orientation in real time, and combine those data into a single 3D model of the space around the user.

c) **Unmanned vehicles**: unmanned vehicles are a new data-collection technique for GIS (Humphrey, 2014). As its name suggests, an unmanned vehicle is a vehicle that is operated without direct human interaction. There are three types of unmanned vehicles: aerial, ground, and surface. These vehicles are generally enhanced with various data-collection technologies such as GPS, still-image cameras, video cameras, LIDAR, and sensors of varying types. An unmanned aerial vehicle (UAV) traverses through the atmosphere to collect spatial data and can be an airplane, helicopter, or their miniatures (Bone & Bolkcom, 2003; DeGarmo & Nelson, 2004; Patterson, McClean, Morrow, & Parr, 2011). Similarly, an unmanned ground vehicle (UGV) refers to vehicles that are capable of traveling through different types of terrain (Baca, 2012; Gage, 1995). Unmanned surface vehicles (USV) are used for gathering underwater geospatial data (Bertram, 2008; Caccia, Bibuli, Bono, & Bruzzone, 2008; Manley, 2008).

d) **Light detection and ranging (LIDAR)**: when a laser is pointed at a target, the beam of light is reflected by the surface it encounters. A sensor records this reflected light to measure a range. When these laser range data are combined with position and orientation data generated from integrated GPS and inertial measurement unit systems, the result is a dense, detail-rich group of elevation points called a "point cloud" or LIDAR data. Each point has 3D spatial coordinates (latitude, longitude, and height) and is used to generate other geospatial products, such as digital elevation models, canopy models, building models, and contours (National Ocean Service, 2014). LIDAR data are often collected by air. For example, LIDAR data can reveal both a top-down and profile view of the Bixby Bridge in Big Sur, California. Organizations use LIDAR-generated products to examine both natural and manmade environments. For the National Oceanic and Atmospheric Administration, LIDAR data support activities such as inundation and storm surge modeling, hydrodynamic modeling, shoreline mapping, emergency response, hydrographic surveying, and coastal vulnerability analysis. The U.S. Geologic Survey's Center for LIDAR Coordination and Knowledge (CLICK) provides links to LIDAR websites, an electronic library of LIDAR references on the use of LIDAR imagery—data that is downloadable for areas of the earth and a range of time points and contacts (U.S. Geologic Survey, 2015).

3.2.2 Applications

These data-collection techniques have enabled analysis and applications in many fields. Three such fields include agriculture, disaster response, and infrastructure development.

a) Agriculture (Herwitz et al., 2004). For example, UAVs in agriculture are used for crop monitoring and for damage assessment where rapid image acquisition and processing (<24 hours) at a fine-grained unit of analysis (1-10 meters) are critical for rapid decision making and intervention. In addition, knowledge-based agricultural approaches to increase farming efficiency, enhance profitability, and lessen environmental impacts drive UAV technological innovations.

b) Disaster response (Hodgson, Battersby, Davis, Liu, & Sulewski, 2014; Montoya, 2003; Tsou & Sun, 2006). At a basic level, UAVs and the high-resolution aerial imagery they can gather are used to survey which structures (e.g., public buildings, hospitals, schools) may be available for shelter after a disaster. They are also used to monitor the distribution of goods, identify temporary settlements, and help to provide estimates of displaced persons and assessments of damage and search-and-rescue activities

c) Infrastructure development (Bernard, Mäs, Müller, Henzen, & Brauner, 2013; Guo, Qingyun, Zhang, & Xu, 2008; Schall et al., 2009; Yang, Raskin, Goodchild, & Gahegan, 2010). LIDAR data's accuracy, efficiency, and cost-effectiveness support a wide variety of infrastructure development and management needs. For example, highly detailed terrain mapping is used for highway corridor planning and design. Environmental impact assessment (e.g., salt water infiltration detection, algae proliferation detection, and wildlife census counts) and infrastructure asset management (inspecting oil and gas pipelines, inspecting power lines and cables, assessing railway track beds) are also areas that benefit from the use of LIDAR data.

3.3 Managing GIS Data

Every day, 2.5 quintillion bytes of data are created—so much that 90 percent of the data in the world today has been created in the last two years alone. These big data come from everywhere: sensors used to gather climate information, posts to social media sites, digital pictures and videos, purchase transaction records, and mobile phone GPS signals. Big data are frequently geographically referenced, so one can use them in spatial analysis. Big data typically spans four dimensions: volume, velocity, variety, and veracity. For each of them, there is an opportunity to conduct spatial research to find insights in these often-emerging types of data, to answer questions that were previously considered unanswerable, and to solve some of the issues related to using this type of data. Many of these challenges will be solved by building scalable strategies for well-defined, practical-use cases. Some of these solutions will combine spatial and other emerging technologies designed for specific data-processing tasks, analysis, and interoperability (Manoochehri, 2013).

3.3.1 Enabling Technologies

a) **Apache Hadoop**: one of the main big data tools is Apache Hadoop, a framework that allows for the distributed processing of large data sets across clusters of computers using simple programming models (The Apache Software Foundation, 2014). The two core components of Hadoop are the Hadoop Distributed File System (HDFS) for storage and MapReduce for processing. Generally, one uses the HDFS as both the input and output of MapReduce processing. MapReduce is responsible for performing the distributed data processing jobs. Typically, dozens of additional Hadoop components are used for big data processing (Dumbill, 2012). Three examples are Hive, Pig, and Oozie.

b) **Hive, Pig, and Oozie**: to run SQL-like queries using Hadoop's MapReduce framework, Hive was created. Hive manages data in database-like structures and translates queries into multi-stage MapReduce jobs. Since Hive is part of the Hadoop framework, it can scale indefinitely as data sizes grow and is also extensible; one can write new user-defined functions (custom processing functions). Pig is used to manage data workflows on Hadoop and contains two components: a high-level language for expressing workflows and a platform to turn these workflows into MapReduce jobs. Pig can perform a series of big data operations: extract-transform-load (ETL), interrogation of raw data, and iterative data processing. Oozie is used to design and manage complex workflows that run on regular intervals and that may be triggered by time and data availability commands.

c) **SpatialHadoop**: several projects and tools have emerged to assist with managing and analyzing spatial big data. SpatialHadoop is an open source MapReduce extension designed specifically to handle huge datasets of spatial data on Apache Hadoop and includes a built-in spatial high-level language, spatial data types, spatial indexes, and spatial operations (GitHub, 2014a). Spatial data types used in MapReduce jobs include point, rectangle, and polygon, while spatial indexes include Grid file, R-tree, and R+-tree with new InputFormats and RecordReaders provided to allow reading and processing spatial indexes efficiently in MapReduce jobs (GitHub, 2014b).

d) **GIS tools for Hadoop**: this open source toolkit is intended for big spatial data analytics and includes three libraries: Esri Geometry API for Java, Spatial Framework for Hadoop, and Geoprocessing Tools (Esri, 2014b). Esri Geometry API for Java, a generic geometry library, can be used to extend the Hadoop core with vector geometry types and operations. Spatial Framework for Hadoop extends Hive and is based on the Esri Geometry API. It is used to enable Hive Query Language users to leverage a set of analytical functions and geometry types in addition to some utilities for JSON used in ArcGIS. Geoprocessing Tools for Hadoop contains a set of ready to use ArcGIS geoprocessing tools. Through these tools, ArcGIS users can move their spatial data and execute a pre-defined workflow inside Hadoop. These were developed primarily to operate on vector data. However, the National Aeronautics and Space Administration (NASA) recently made available a large collection of climate and earth sciences satellite data and has sought new and creative ways to use these data to address initiatives in the President's Climate Action Plan (NASA, 2014). The raster data comprises large amounts imagery of global land surface, vegetation conditions, and climate observations. The spatial big data challenge is to identify new and creative ideas on how to manage, use, visualize, and analyze these datasets.

3.3.2 Application

Big data opportunities exist in different industries (Watson & Marjanovic, 2013), all of which are known to leverage geotechnology. For instance, one recent example in the agriculture domain was the Monsanto Company where a geospatial platform was built on Hadoop and HBase capable of managing over 120 billion polygons and 1.5 trillion data points as a dense grid of data for the entire United States. The integrated farming systems (IFS) combines advanced seed genetics, on-farm agronomic practices, and a big data platform to increase crop yields (Hochmuth & Turcotte, 2013). Walmart applied spatial big data and analytics to predict items needed in its retail stores in the path of Hurricane Frances as it moved from the Caribbean into the Eastern coastal Florida. It used prior purchasing patterns in big data from Hurricane Charlie to predict the store items that would be purchased during Frances' destructive path across the state. Items ranged from emergency products to entertainment items such as "Strawberry pop tarts" (Lee & Kang, 2015).

3.4 Analyzing GIS Data

The decision making process may encompass several stages of analysis given the organizational level (operational, managerial, and strategic) and expected outcomes and goals. In general, these stages of analysis are: descriptive, predictive, and prescriptive (IBM Corporation, 2013). To answer "what has happened?", descriptive analytics uses data to provide trending information on past or current events to provide context for future actions. To answer "what could happen?", predictive analytics provides answers beyond using historical data as the principal basis for decisions and, as such, helps to anticipate likely scenarios rather than reacting to what has already happened. Using descriptive data accumulated over time, predictive analytics uses models for predicting events but does not recommend actions. Prescriptive analysis such as optimization and simulation provide enhanced insight by recommending actions on "what should happen?".

3.4.1 Enabling Technologies

The development of specialized software for spatial data analysis has seen rapid growth and a fairly substantial collection of spatial data analysis software is readily available that ranges from niche programs, customized scripts, and extensions for commercial statistical and GIS packages to a burgeoning open source effort using software environments such as R, Java, and Python (Anselin, Syabri, & Kho, 2006). We now describe some of the specialized software.

1. **GeoDa**: the GeoDa Center for Geospatial Analysis and Computation at Arizona State University develops state-of-the-art methods for geospatial analysis, geovisualization, geosimulation, and spatial process modeling and implements them through open source software tools, applies them to policy-relevant research in the social and environmental sciences, and disseminates them through training and support to a growing worldwide community" (GeoDa Center, 2014). GeoDa is designed to implement techniques for exploratory spatial data analysis (ESDA) on lattice data (points and polygons). The free program provides a user friendly and graphical interface to access techniques of descriptive spatial data analysis, such as spatial autocorrelation statistics and basic spatial regression functionality. It also contains the features of full space-time data support in all views, a cartogram, a refined map movie, parallel coordinate plot, 3D visualization, conditional plots (and maps), and spatial regression.

2. **PySAL**: PySal is an open source cross-platform library of spatial analysis functions written in Python. It is intended to support the development of high-level applications for spatial analysis. As such, it includes libraries for ESDA, spatial dynamic, spatial econometrics, spatial weights, computational geometry, and clustering. Spatial analysts who may be carrying out research projects that require customized scripting or extensive simulation analysis should also find PySAL to be useful (GitHub, 2014c).

3. **R analysis of spatial data and GRASS**: R spatial is an open-source project based on the R project/language. The main libraries include: basic classes for spatial data manipulation, the reading and writing of spatial data, point pattern analysis, geostatistics, cluster maps and areal data analysis, spatial regression, ecological analysis, and many more specialized libraries (Bivand, Pebesma, & Gómez-Rubio, 2013; Bivand, 2014). R is a free software environment for statistical computing and graphics. As such, R provides many standard and innovative statistical analysis methods including many spatial analytic techniques. There are established and trusted methods and new and novel approaches. One can see the latter in R users' ability to freely modify and extend these components to suit their data-management and analytic needs. The Geographic Resources Analysis Support System (GRASS) is a free and open source geographic information system (GIS) software suite used for geospatial data management and analysis, image processing, graphics and maps production, spatial modeling, and visualization (GRASS Development Team, 2014). GRASS, like R, is a collection of separate programs built using shared libraries of core functions that are managed and developed by their respective user communities. GRASS was originally a raster-only GIS platform but recently developed extensions include support for vector-based data.

3.4.2   Applications

In addition to these software packages, a rather comprehensive guide of spatial analysis-related software packages and tools can be found at two sources (de Smith, Goodchild, & Longley, 2014; OSGeo.org, 2014). These various data analytic applications and spatial analytic techniques provide the ability to examine multiple phenomena across many fields, such as economics (Fischer & Getis, 2010), environmental sciences, and health. Several examples follow. GIS in the environmental sciences is used to quantify the distribution of plant and animal species along environmental gradients; that is, species distribution modeling. It is also used for monitoring and assessing compliance with regulations. It helps local, state, and federal governments in balancing the competing demands of residential, commercial, and industrial development with imperatives to minimize environmental degradation (Abrahamsen, Hauge, & Kolbjørnsen, 2012; Fischer & Getis, 2010).

In the health sciences, GIS is used in two broad areas: health (at the individual and community level) and healthcare (related to clinical issues and health service planning and delivery). GIS in health is used to explore and model incidence of disease, detect and analyze disease clusters and patterns, and formulate disease causality hypotheses. GIS in healthcare is used for planning, managing, and delivering health services at the individual level and determining the healthcare needs of the community at large (Fischer & Getis, 2010; Kresse & Danko, 2012).

3.5   Visualizing GIS Data

Data visualization results from collecting and analyzing data. With visualization, one aims to help explain data by leveraging the human visual system to see patterns and relationships (Heer, Bostock, &

Ogievetsky, 2010). Spatial data visualization, also known as geovisualization, is a set of tools and techniques that support exploring, analyzing, and presenting spatial data, which involves studying how humans interact with computers to create graphic illustrations of spatial information and how this process can be made more efficient (Dykes, MacEachren, & Kraak, 2005; Maceachren & Kraak, 1997; de Smith et al., 2014). One definition of geovisualization is that it is a family of techniques to provide visualizations of spatial datasets that extends from static, 2D maps, and cartograms to 3D representations using perspective and shading, solid terrain modeling, and, increasingly, dynamic visualization interfaces such as linked windows, digital globes, fly-throughs, animations, virtual reality, and immersive systems. Geovisualization is the subject of ongoing research by the International Cartographic Association (ICA).

3.5.1   Enabling Technologies

Augmented reality (AR), virtual reality (VR), simulated reality (SR), and geodesign are emerging technologies in the area of spatial data visualization. These technologies are developing separately, but we can expect that there will be some integration and collaboration between them. We can see one example of integration between AR and geodesign in the application of 3D city models in an AR system.

a) **Augmented reality**: augmented reality (AR) is a live view of a physical, real-world environment, the elements of which are augmented (or supplemented) by computer-generated input such as sound, video, graphics, or GPS data in which an application or software modifies (perhaps even diminishing rather than augmenting) a view of reality (Graham, Zook, & Boulton, 2013). Currently, AR is used either with smartphones or AR glasses. A basic example of mobile AR is to place a 3D model on a live camera screen. In another instance, one can use a smartphone to demonstrate the AR EdiBear game in which a bear image moves around freely in a simulated environment while defying physical laws and constraints, such as gravity. AR glasses have the same capabilities as smartphones and include Google Glass, Vuzix, and Epson Moverio. Many software development kits (SDKs) have been released to assist developers in creating AR applications on various platforms such as iOS, Android, Windows, and Blackberry. Wikitude, Metaio, String, IN2AR, and Qualcomm's Vuforia SDKs are some AR SDKs. Location-based AR visualization uses an object's geographic coordinates to determine the object's information on the physical location in the device screen.

b) **Virtual reality:** virtual reality (VR) is a computer-simulated environment that can simulate physical presence in places in the real world or imagined worlds. Some researchers define AR as a special case of VR; others argue that AR is a more general concept and see VR as a special case of AR. The fact is that, in contrast to traditional AR, in VR, the real environment is not completely suppressed; instead, it plays a controlling role. Rather than placing a person into a completely synthetic world, VR attempts to embed synthetic supplements into the real environment (Bimber & Raskar 2005).

   Simulated reality (SR), a special case of VR, confers a wide range of benefits for academia and industry alike that include reduced cost and the ability to simulate dangerous situations and to receive feedback and ongoing assessment. One can use SR in surgery simulation, reconstruction, and combat training. Spatial simulation techniques are playing a key role in the fields of production and logistics, industrial processing, firefighting, and city planning (Fraunhofer-Gesellschaft, 2014).

c) **Geodesign:** geodesign is a set of techniques and enabling technologies for planning built and natural environments as an integrated process. The steps include project conceptualization, analysis, design specification, stakeholder participation and collaboration, design creation, simulation, and evaluation (Geodesign, n.d.). Geodesign can assist individuals in urban planning, architecture, and design by using 3D visualization to see the relationships of projects, assess their feasibility, and plan their implementation. ESRI's CityEngine is an example of Geodesign software that can transform 2D GIS data into 3D city models. Making use of these 3D visualization techniques, designers can view the locations of proposed building blocks, identify shadows and areas of reflected heat, and, thereby, make decisions based on a real visualization.

3.5.2   Applications

Applications using spatial data visualization are abundant. For example, individuals have used data visualization to design and implement a tourism system (Lin, Kao, Lam, & Tsai, 2014), augmented reality in education (Wu, Lee, Chang, & Liang, 2013), and audio stickies, which are visually guided spatial audio

annotations on a mobile augmented reality platform (Langlotz, Regenbrecht, Zollmann, & Schmalstieg, 2013).

In summary, GIS embraces innovative and emerging technologies in many of its aspects. In Section 4, we discuss the role of GIS in IS/research.

4   GIS for IS Research

4.1   Introduction

In this section, we examines GIS as a research area in the context of IS in business schools. Specifically, we 1) introduce IS academics to geographic information systems (GIS), an emerging area of importance in IS research; 2) overview the background of GIS research; and 3) explore the connection of GIS research to IS and analytics.

We address three questions:

1. What are obstacles to encouraging more GIS-related research in the IS field?
2. What are the opportunities and advantages of undertaking GIS-related investigations in the IS field?
3. What are the most promising areas for GIS and locational research?

4.2   IS Research in GIS: Background

The IS field has recognized GIS as part of the IS body of knowledge for nearly two decades, which we can see its inclusion as a topic in the national model curriculum for a four year undergraduate degree in information systems (IS '97) sponsored by the Data Processing Management Association, Association for Computing Machinery, and International Conference on Information Systems (Davis, Gorgone, Couger, Feinstein, & Longenecker, 1997). The AMCIS Conference has regularly included GIS: GIS minitracks were part of nine AMCIS annual conferences throughout 1997-2000, 2006-2007, and 2012-2014. AMCIS held GIS workshops in 2004 and 2013-2015, and ICIS held GIS workshops in 2014. On the other hand, GIS and spatial analysis have only occasionally appeared as a paper in the last five years at the ICIS and HICCS conferences, although five GIS and spatial papers were included in separate sessions in HICCS 2014. The GIS special interest group (SIGGIS), founded in 2011 by Daniel Farkas of Pace University, has sponsored workshops and minitracks and has built network of IS faculty with interests in spatial analysis and GIS. Further, the business geography special interest group of the American Association of Geographers has had regular mini-tracks on business GIS at its annual meeting for the past eight years. The contributed papers are mostly written by authors with geographic training and affiliations, so their perspective has a strong geographic focus.

Several edited and authored scholarly books have been written in the IS field on GIS and spatial analysis topics (Hilton, 2007; Maguire, Kouyoumijan, & Smith, 2008; Mennecke & Strader, 2003; Pick, 2005, 2008; Sugumaran & Degroote, 2011). The books have served to develop and expand the body of knowledge of GIS in IS and business fields and to stimulate research on GIS and spatial analysis.

IS research often receives stimulus from programmatic and curricular interest and emphasis. However, as we discuss in Section 6, studies have shown that GIS is a standard curricular area in only a handful of business and management schools worldwide (out of several thousand) (Ramakrishna, Sarkar, & Vijayaraman, 2010). Likewise, there has been little research on GIS and spatial analysis in the IS community over the past two decades. In fact, only a small number of published papers have appeared in first tier and second tier IS journals, which we examine in Section 4.3.

The research so far contrasts with the geospatial and geo-services industries, which, as we mention in Section 2, is growing rapidly and reaching the overall magnitude of middle-sized industries such as airlines. The growth is stimulated at the consumer level by billions of mobile spatial users. Why does the IS field seem to be largely ignoring GIS? What are some of the causes of this gap? The answers arise from GIS being in the user realm mostly of the government until the last 5-10 years, from the paucity of IS and business school doctoral programs that provide knowledge and research training in the spatial areas, and from industry's competitive secrecy about the technology. On the other hand, public administration schools have stressed GIS to a much larger extent than business schools.

One challenge is that few IS and business school doctoral programs include GIS. Accordingly, either a doctoral student needs to enter doctoral studies already proficient in the area or they need to take strong initiative (and, often, persuade their supervisors) to undertake a geospatial dissertation or receive training after the doctorate through professional or vendor means. Another challenge is that empirical GIS studies in business and industry are often constrained by proprietary barriers and secrecy regarding GIS and spatial strategies, activities, initiatives, markets, and customers. GIS was not well known in business until 2005, when consumer Web mapping became widely available at no cost to consumers through the nearly simultaneous unveiling of Google Maps, Microsoft Virtual Earth (now called Bing Maps Platform), and Yahoo Maps (discontinued in 2015) (Chivers, 2013, Feldman, 2015). Prior to 2005, businesses that used GIS could be especially secretive about it to gain competitive advantage. This practice persists but is gradually opening up and, thus, enabling more opportunity for research. One reason for its opening up might be that GIS is becoming well known to consumers at the grass-roots level, so companies see more marketing advantage in making public some of the secretive GIS applications they are using. On the other hand, a continuing reason for this barrier concerns the particular industry sectors that are the most mature in GIS use (i.e., utilities, defense, military, intelligence, transportation, natural resources, real estate, and retail): most are inherently restricted by confidentiality and secrecy about their products and services.

The usual approach for behavioral and organizational methodology involves surveying, interviewing, or procuring records on business or government subjects that often includes guaranteeing anonymity. To get in the door, it may be necessary to use high-level contacts or provide services that are sought after. Experience in interview studies on GIS indicates that, even with a letter of introduction and offer of anonymity, at best about a quarter of firms will approve significant access to subjects and data.

On the positive side of GIS research, opportunities exist to get in early in IS-based research on GIS and leverage many theories and constructs applicable from the IS field and from cutting-edge developments by industry, such as those we examine in Section 3. One can apply nearly the entire range of IS research methods and approaches to GIS research.

Several factors influence choice of theories and methods. First, prospective empirical studies need to assess the extent of firm secrecy needs and choose methods accordingly. For example, for a highly secretive firm, an anonymized case study may be suitable rather than a broad sample. Second, the research team should carefully assess what it is capable of doing, and, if spatial knowledge gaps exist, it should engage in more training or seek further collaborators to fill in deficits. Third, researchers should seek to maintain sufficient IS core of the study to satisfy IS journals. Since there is a small base of well-accepted GIS conceptual theory in the IS field, researchers fare better with journals by modifying well-known theories towards GIS, or they may go ahead with new theory and concepts but expect mixed response.

If researchers use geospatial and geography concepts and methods, they need to add simple explanations of them to research manuscripts. Induction may need to be used more. Induction reverses the usual deductive approach, which means that empirical findings suggest new conceptual theory rather than the other way around, which typifies new emerging areas of research (Stebbins, 2001).

Due to a limited availability of a broad sample of corporate GIS users (based on survey data), prior empirical studies on GIS in business have often used the case study method, and the themes of those studies have focused on behavioral aspects of GIS, such as GIS for decision support and GIS deployment, rather than technical aspects. It is challenging to obtain such a broad sample. However, once it is available, GIS researchers in the IS field can research managerial, organizational, and strategic aspects of GIS and conduct various quantitative research methods, such as regression using survey data, which has rarely been used in previous GIS research. As for using theory, compared to previous GIS research that has used behavioral theories, future GIS research may use well-known theories of IS research, such as the technology acceptance model (TAM), unified theory of acceptance and use of technology (UTAUT), organization theories, strategic alignment, organizational fit, or competitive advantage. In summary, for GIS research in the IS context, opportunities exist to use well-known IS theories adapted for spatial research, apply quantitative and qualitative research methods, vary units of analysis, and address themes not dealt with previously in GIS research.

4.3 Literature Review on GIS and Location Analysis in Leading IS Journals (1998-2012)

In this section, we review previous research on GIS and location (or spatial) analysis for the past 15 years in the IS field and explore its connection to IS and analytics. To examine the research on GIS and location

(or spatial) analysis done in the IS field, we searched papers published in leading IS journals for the 15 years from 1998 to 2012. The IS journals we selected include *Information Systems Research* (*ISR*), *MIS Quarterly* (*MISQ*), *European Journal of Information Systems* (*EJIS*), *Journal of Management Information Systems* (JMIS), *Decision Support Systems* (*DSS*), *Communications of the ACM* (CACM), and *The Information Society* (*TIS*) [1]. In searching papers on GIS and location analysis, we used "GIS", "location", "spatial", and "geography" as keywords and selected the papers whose abstract included those keywords.

We found few papers on GIS (and location analysis) published in these leading journals; for the period from 1998 to 2012, we found only four papers published: one in *ISR*, one in *JMIS,* and two in *MISQ*. We found none in *EJIS.* On the other hand, *DSS* published thirteen papers during the same period. We found four papers published in *CACM*, and two papers published in *TIS*. Table 1 shows the list of the GIS papers published in the seven leading IS journals. Our search results show a paucity of GIS research in those leading IS journals compared to the research on other contemporary IT topics such as big data and social media. This finding is not surprising since GIS is not a mainstream topic in IS. In fact, quite a few GIS papers have been published in journals from other fields, such as *Journal of Geographical Systems, International Journal of Geographic Information Science*, *Transactions in GIS*, and *GeoInformatica*.

Table 1. List of the GIS Papers Published in Leading IS Journals During 1998-2012

Journal	Authors and year	Paper title
ISR	Dennis & Carte (1998)	Using geographical information systems for decision making: Extending cognitive fit theory to map-based presentations
MISQ	Mennecke, Crossland, & Killingsworth (2000)	Is a map more than a picture? The role of SDSS technology, subject characteristics, and problem complexity on map reading and problem solving
	Walsham & Sahay (1999)	GIS for district-level administration in India: problems and opportunities
EJIS	None published	
JMIS	Biocca, Owen, Tang, & Bohil (2007)	Attention issues in spatial information systems: directing mobile users' visual attention using augmented reality
DSS	Keenan (1998)	Spatial decision support systems for vehicle routing
	Seffino, Medeiros, Rocha, & Yi (1999)	WOODSS—a spatial decision support system based on workflows
	West & Hess (2002)	Metadata as a knowledge management tool: Supporting intelligent agent and end user access to spatial data
	Meeks & Dasgupta (2004)	Geospatial information utility: An estimation of the relevance of geospatial information to users
	Zhu & Chen (2005)	Using 3D interfaces to facilitate the spatial knowledge retrieval: A geo-referenced knowledge repository system
	Johnson (2006)	Spatial decision support for assisted housing mobility counseling
	Scheibe, ,Carstensen, Rakes, & Rees (2006)	Going the last mile: A spatial decision support system for wireless broadband communications
	Huang, Liu, & Chandramouli (2006)	A GIS supported Ant algorithm for linear features covering problems with distance constraints
	Jarupathirun & Zahedi (2007)	Exploring the influence of perceptual factors in the success of Web-based spatial applications

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[1] For *CACM* and *TIS*, we searched papers only in 2005-2012 and 2007-2013, respectively. Since both journals publish a journal issue each month, we limited the time period compared to the other journals.

<p style="text-align:center">**Table 1. List of the GIS Papers Published in Leading IS Journals During 1998-2012**</p>

	Ray (2007)	A Web-based spatial decision support system optimizes routes for oversize/overweight vehicles in Delaware
	Santos et al. (2011)	A Web-based spatial decision support system for vehicle routing using Google Maps
	Coutinho-Rodrigues, Simão, & Antunes (2011)	A GIS-based multicriteria spatial decision support system for planning urban infrastructures
	Kisilevich, Keim, & Rokach, (2013)	A GIS-based decision support system for hotel room rate estimation and temporal price prediction: The hotel brokers' context
CACM	Borriello, Chalmers, LaMarca, & Nixon (2005)	Delivering real-world ubiquitous location systems
	Junglas & Watson (2008)	Location-based services: Evaluating user perceptions of location-tracking and location-awareness services
	Cummings (2011)	Geography is alive and well in virtual teams
	Wicker (2012)	The loss of location privacy in the cellular age
TIS	Engler & Hall (2007)	The Internet, spatial data globalization, and data use: The case of Tibet
	Pick, Nishida, & Zhang (2013)	Determinants of China's technology availability and utilization 2006-2009: A spatial analysis
EJIS	None published	

To better understand what types of GIS research has been conducted for the past 15 years, we reviewed representative research published in leading IS journals by looking at approach, research questions, theory, methodology, and findings.

4.3.1   Representative GIS Research in Leading IS journals

Dennis and Carte's study (1998) is one of the few GIS studies on spatial cognition and behavior. Based on the cognitive fit theory, they examined decision making utility with two different information presentations: map-based presentation (spatial and perceptual) and tabular presentation (analytic). In a laboratory setting, they provided subjects (graduate business students) with two different geographic tasks: a geographic containment task, which is strategic, and a geographic adjacency task, which is tactical. The subjects they made decisions for the tasks by using the two presentation methods. Dennis and Carte found that decision makers using map-based presentation made faster and more accurate decisions when working on the geographic adjacency task, which requires knowledge of adjacent geographic areas (relationships among geographical areas). On the other hand, decision makers using map-based presentation made faster but less accurate decisions when working on the geographic containment task, which does not require knowledge of adjacent geographic areas.

Mennecke et al. (2000) conducted another notable study. By extending Dennis and Carte (1998), they thoroughly examined spatial cognition and behavior. They provided experimental subjects with mapping problems to solve under a dozen possible conditions formulated from 2x2x3 dimensions: manual mapping vs. GIS, students vs. professionals, and three levels of task complexity. By using cognitive fit theory and prior research on map reading and interpretation, Mennecke et al. (2000) examined how decision making was influenced under different conditions. Their findings show that a spatial decision support system increased the efficiency of complex problem solving, that professionals were less efficient than students but had greater accuracy, that professionals using GIS were not more accurate than professionals using manual mapping, and that subjects' willingness to undertake problem solving (i.e., need for cognition) resulted in marginally significant gains in accuracy.

By employing ethnography with an action research segment, Walsham and Sahay (1999) examined the use of GIS for district-level administration in rural district of India, discussed the reasons why GIS

deployment failed, and provided suggestions on how it could be successfully deployed. They found that there were major cultural adjustments during the deployment but insufficient consultation with stakeholders, such as the central government. There was also resistance to "Western" software and to mapping in general, techniques not commonly used in rural India. Their research was based on actor-network theory, which looks at data in terms of actors, actor networks, enrollment in networks, delegates, irreversibility, and black boxes (frozen network elements). Emphasizing that culture needs to be recognized and that full stakeholder evaluations need to be performed ahead of time in a setting such as rural India, they argue that a broader view of networking/partnering may be critical for successfully deploying GIS.

Table 2 summarizes the three studies in terms of approach, research questions, theory, and methodology. Our review of GIS research shows that leading IS journals lack GIS research and that the papers published in these leading journals focused on the topics of GIS for decision support, GIS deployment, techniques used with GIS, and the development of prototype SDSS. There has been no research focusing on managerial issues related to the use of GIS (e.g., how GIS influences business processes or operations).

Table 2. Summary of Example GIS Research

GIS papers	Approach	Theory	Methodology	Research questions
Dennis & Carte (1998)	Laboratory experiment	Cognitive fit theory	Quantitative (ANOVA)	When are (and are not) GIS systems useful?
Walsham & Sahay (1999)	Ethnography, with action research segment	Actor-network theory	Qualitative (interviews)	What influences successful deployment of GIS to aid district-level administration?
Mennecke et al. (2000)	Laboratory experiment	Cognitive fit theory and prior research on map reading and interpretation	Quantitative (ANOVA)	How does map decision making depend on technology (manual mapping vs. GIS), subject characteristics (students vs. professionals), and the three levels of task complexity?

4.3.2 Literature Review on GIS Research in Broader Set of Journals

In addition to the literature review from leading IS journals, we also searched papers published in a broader set of journals from both IS and other related fields for the 1998 to 2015 period. Specifically, we searched the *Communications of the Association for Information Systems* (*CAIS*), *Interfaces*, *Telecommunications Policy*, and *Technological Forecasting and Social Change*.

As in the leading IS journals, we found few papers on GIS. We found 23 papers in total: two in *CAIS*, nine in *Interfaces*, six in *Telecommunications Policy*, and six in *Technological Forecasting and Social Change*. Many of them published in this broader set of journals use GIS as a tool for spatial analysis and data visualization for various research topics, such as routing optimization, location-allocation modeling, Internet, broadband networks, innovation activities and systems, and energy. Exceptions are the two papers published in *CAIS*: One is a GIS tutorial and the other is a paper on developing Web-based SDSS. It is also notable that one researcher published four papers in *Telecommunications Policy* between 2002 and 2012.

In general, our literature review on GIS suggests that there are both challenges and opportunities for publishing papers on GIS in leading IS and related journals. Table 3 shows the list of the GIS papers published in the broader set of journals for 1998-2015.

Table 3. List of the GIS Papers Published in Second-tier Journals during the 1998-2012 Period

Journal	Authors and year	Paper title
CAIS	Pick (2004)	Geographic information systems: A tutorial and introduction
	Sugumaran & Sugumaran (2007)	Web-based spatial decision support systems (WebSDSS): Evolution, architecture, examples and challenges
Interfaces	Taylor & Vasu (1999)	Integrated planning for school and community: the case of Johnston County, North Carolina

Table 3. List of the GIS Papers Published in Second-tier Journals during the 1998-2012 Period

	Weigel & Cao (1999)	Applying GIS and OR techniques to solve Sears technician-dispatching and home-delivery problems
	Erkut, Myroon, & Strangway (2000)	TransAlta redesigns its service-delivery network
	Blakeley, Bozkaya, Cao, Hall, & Knolmajer (2003)	Optimizing periodic maintenance operations for Schindler Elevator Corporation
	Gavinemi, Clark, & Pataki (2005)	Schlumberger optimizes receiver location for automated meter reading
	Dekle, Lavieri, Martin, Emir-Farinas, & Francis (2005)	A Florida county locates disaster recovery centers
	Jang, Lim, Crowe, Raskin, & Perkins (2006)	The Missouri Lottery optimizes its scheduling and routing to improve efficiency and balance
	Bozkaya, Erkut, Haight, & Laporte (2011)	Designing new electoral districts for the city of Edmonton
	Aktas, Ozaydin, Bozakaya, Ulengin, & Onsel (2013)	Optimizing fire station locations for the Istanbul Metropolitan Municipality
Telecomm-unications Policy	Grubesic (2002)	Spatial dimensions of Internet activity
	Gorman & Malecki (2002)	Fixed and fluid: Stability and change in the geography of the Internet
	Grubesic (2008)	The spatial distribution of broadband providers in the United States: 1999-2004
	Grubesic (2010)	Efficiency in broadband service provider provision: A spatial analysis
	Grubesic (2012)	The U.S. national broadband map: Data limitations and implications
	Nishida, Pick, & Sarkar (2014)	Japan's prefectural digital divide: Multivariate and spatial analysis
Technological Forecasting and Social Change	Tang (2006)	Adoption of navigation technologies: Five historical and contemporary cases
	Grübler et al. (2007)	Regional, national, and spatially explicit scenarios of demographic and economic change based on SRES
	Rokityanskiy et al. (2007)	Geographically explicit global modeling of land-use change, carbon sequestration, and biomass supply
	Liu & Sun (2009)	A comparison of the spatial distribution of innovative activities in China and the U.S.
	Binz, Truffer, Li, Shi, & Lu (2012)	Conceptualizing leapfrogging with spatially coupled innovation systems: The case of onsite wastewater treatment in China
	Pick & Nishida (2015)	Digital divides in the world and its regions: A spatial and multivariate analysis of technological utilization

In summary, in this section, we examine the status (and challenges and opportunities) of GIS research in the IS field. Although GIS is not well known in IS research, the increasing use of spatial and locational applications during this decade by business, government, and consumers bodes well for its growing scholarly interest. Several barriers that are beginning to fall include corporate secrecy and limitations on

training and educational emphasis. In this section, we also note that we found few papers published in leading IS journals during 1998-2012. Also, the GIS papers we did find focused more on the design of GIS systems and spatial decision making and less on management, organizational, and strategic aspects. In Section 5, we examine GIS in curricula and teaching in business and management schools with a focus on management information systems curricula.

5   GIS in Business Curricula

5.1   Introduction

Over the years, in response to increasing levels of globalization and a focus on issues such corporate social responsibility, undergraduate and MBA curricula in business and management schools have embraced and incorporated global and ethical content in coursework. In fact, one could argue that providing their students with significant exposure to ethical and global business issues is a "cost of doing business" for business and management schools. In this section, we discuss the role of geography, location, spatial thinking, and spatial analysis enabled by geotechnology in business school curricula. We focus particularly on the IS field and examine instances of GISs' and spatial analysis' infusion in IS coursework. We also discuss opportunities to integrate GIS and spatial analysis in Bachelor of Science in Information Systems (BSIS) and Master of Science in Information Systems (MSIS) model curricula.

5.2   Status of GIS and Spatial Analysis Infusion in Business School Curricula

The extensive benefits businesses have realized from using geospatial technology, which we detail in Section 1, include GISs' availability across enterprise-level platforms, declining costs of hardware and software (King & Arnette, 2011), widespread availability and access to geospatial data (especially through the Internet) (Reames, 2006), and, finally, the migration of GIS software and data into the cloud (Sarkar & Pick, 2014). This raises the question: what is the extent of GISs' and GIS-enabled spatial analysis's infusion in curricula offered by management and business administration schools and colleges? Are business schools educating their graduates, tomorrow's decision makers, about the power of spatial thinking in business? Before we proceed to discuss and examine instances of GIS infusion in business school curricula, we define infusion.

In developing a taxonomy for GIS in education, Kerski (2008) conceptualizes teaching and learning about GIS and contrasts its goals with teaching with GIS. The goals of teaching and learning about GIS are to:

> *become familiar with the theories concerning geographic information science and the acquisition of skills to manage GIS and operate GIS software. Courses emphasize topics such as topology, data structures, database management, map scale and projections, data quality, and generalization.* (Kerski, 2008, p. 541)

Kerski (2008) posited teaching with GIS to be smaller in scope compared to teaching and learning about GIS; teaching with GIS "focuses not on GIS, but on the disciplines that are home to the issues being addressed, using GIS as tools and spatial analysis to understand the Earth" (Kerski, 2008). Our definition of GIS infusion accommodates both teaching with GIS and teaching and learning about GIS. Consistent with Ramakrishna et al. (2010), our definition includes both instances when a course is a separate, standalone offering focusing on GIS and its core concepts and courses in which GIS concepts and applications play a supporting role in reinforcing, exemplifying, or illustrating core principles of a separate business field such as marketing, IS, or operations research.

Over the years, some studies have examined the extent of GISs' and spatial analysis's infusion in curricula of business and management schools. Estaville (2007) conducted an Internet search of the curricula of 140 public and private institutions across the United States and found evidence that only five universities incorporated GIS in their business school coursework. Ramakrishna et al. (2010) further analyzed the curricula of the five business schools with GIS that Estaville (2007) identified and found that three out of the five institutions incorporated GIS in IS curricula as a standalone course on business geography. Each of the other two institutions infused GIS in marketing and supply chain management coursework. Interestingly, two out of the five instances were manifestations of teaching and learning about GIS (Kerski, 2008), while the remaining three infused GIS in courses such as Seminar in end user computing, distribution system design and GIS, and GIS for marketing applications—clearly expositions of teaching with GIS (Kerski, 2008). Li, Wynned, & Babb (2009) comprehensively surveyed 460 AACSB accredited business school curricula and found a very limited (32 out of 460; i.e., 7%) focus on GIS. Li et

al. reasoned that possible explanations for such limited infusion were lack of leadership from in the school or lack of a faculty champion, lack of faculty knowledge and expertise of GIS concepts and tools, lack of resources (textbooks, hardware, software), and lack of knowledge about GIS data sources. Overall, we can reasonably conclude that GISs' and spatial analysis's infusion in business school curricula is staggeringly low. Clearly, business schools are missing an opportunity to educate their students and tomorrow's decision makers about the importance of location and geotechnology in business decision making (King & Arnette, 2011). We now examine specific instances of GIS infusion in business schools reported in the literature.

In one of the earliest instances, Mennecke (1998) describes an instance of a decision support systems (DSS) course in a traditional business school curriculum in which GIS training was introduced as a significant component. Mennecke (1998) reasons that students perceived GIS to be highly relevant because it was presented to them as a useful tool to illustrate DSS concepts. In light of this finding, the author cautions that GIS has the potential to positively impact business education if it is integrated with coursework thoughtfully. The study, however, surprisingly found that students' perception about the impact of GIS on their careers did not improve significantly

In developing a taxonomy for GIS in education, Kerski (2008) conceptualizes teaching and learning about GIS and contrasts its goals with teaching with GIS. The goals of teaching and learning about GIS are to "become familiar with the theories concerning geographic information science and the acquisition of skills to manage GIS and operate GIS software. Courses emphasize topics such as topology, data structures, database management, map scale and projections, data quality, and generalization." (Kerski, 2008). Kerski posits that teaching with GIS is smaller in scope compared to teaching and learning about GIS; teaching with GIS "focuses not on GIS, but on the disciplines that are home to the issues being addressed, using GIS as tools and spatial analysis to understand the Earth" (Kerski, 2008). Our definition of GIS infusion accommodates both teaching with GIS and teaching about GIS during the semester.

Around the mid-2000s, GIS was infused as a standalone first-year course in the MBA program offered by the College of Business and Economics at UCLA (Gadish, 2007), which was the result of an awareness campaign about the GISs' potential in business by a faculty champion. Course content included fundamental GIS principles; location-based services; geographic data and its management; rudimentary spatial analytical functions such as buffers, overlays, and network analysis; and management case studies from various sectors such as telecommunications, utilities, banking, retail, and government. Pre- and post-course surveys indicated that, while a large majority of students were unaware about spatial thinking and GIS before taking the course, almost 98 percent felt that spatial analysis and GIS should be part of an MBA program. More than three-quarters of students agreed that GIS could benefit their professional careers. This finding represents an instance of teaching and learning about GIS and contrasts with the previous two instances discussed that represent teaching with GIS (Kerski, 2008).

Miller, Holmes, and Mangold (2007) also illustrate an instance of teaching with GIS but in the area of marketing. However, in contrast to Mennecke (1998), Smith, Langley, and Mundy (1998), and Gadish, (2007), Miller et al. developed seven GIS modules that were a set of course-specific instructional tools designed for use across the marketing curriculum at Murray State University College of Business. They developed these GIS modules with one eye on course-level learning objectives in key marketing courses such as principles of marketing, consumer behavior, ecommerce, sales management, retail management, and so on to supplement textbook materials for each course. A faculty champion in the marketing department led the effort, and modules were spread over several courses to enable students to develop holistic understanding on how GIS contributes to the various subfields in marketing. This spread also allowed students to gradually develop their GIS skills as they moved through their degree program. An advantage of this approach was that no particular course was limited by the amount of class time, and it also alleviated preparation time required from faculty. The vast majority of students surveyed indicated that the GIS exercises supported them to develop theoretical concepts discussed in the textbook and helped them develop and enhance computer, analytical, and problem-solving skills.

5.2.1   Instances of Infusion in IS Courses

Apart from Mennecke (1998), a handful of other studies contain accounts of GIS infusion in IS curricula or have argued in favor of including GIS in IS coursework. Wu and Kohun (2005) describe two GIS courses (both electives) that were added to the IS curriculum offered by the Department of Computer Information Systems (CIS) at Robert Morris University. The undergraduate elective "Introduction to GIS" covered fundamental principles of GIS, coordinate systems, data structures, map data acquisition, creation of

digital maps, geodatabase, spatial analysis, and includes an applied GIS project. The graduate course "GIS Tutorial and Applications" included digitizing, geocoding and address matching, and spatial data-processing functions such as data query, proximity analysis, and so on. While emphasizing that the primary appeal of a GIS lays in its applications, Wu and Kohun (2005) caution that conceptual understanding of basic GIS architecture is fundamental to intelligently applying a GIS.

Reames (2006) illustrates an instance of developing a special topics course for seniors on geomapping in the Department of Management and Marketing at Angelo State University. The course development was enabled by an internal technology grant and comprised two parts: the first six-week segment focused on hands-on experience of a GIS software in a dedicated IS lab at the end of which students were required to successfully complete three GIS exercises; the second segment focused on applying GIS to three case studies and culminated in an independent project. Its makers designed the course to attract majors from various fields including IS. In comparison to Mennecke (1998), who illustrates an instance of teaching with GIS (Kerski, 2008) as part of an existing DSS core course for IS majors, both Wu and Kohun (2005) and Reames (2006) illustrate instances of teaching and learning about GIS in courses that were electives or special topics. The latter approach of teaching about GIS seems intuitive since the coverage of GIS in an existing core course on a particular IS area will most likely opportunistically use GIS principles and concepts to explain, illustrate, support, and reinforce the fundamentals of the particular core course.

In Table 4, we summarize instances of GIS infusion in business school curricula by field and by type of GIS infusion following Kerski's (2008) taxonomy.

Table 4. GIS infusion in Business Schools and Infusion Paradigm (Adapted and Updated from Ramakrishna et al. 2010)

Business field that infused GIS or B-school program in which GIS content was found	Institution	Course in which GIS was infused	Core or Elective*	Graduate (G) or undergrad (UG) or both	Paradigm of infusion (Kerski, 2008)**	Reference
MIS, CIS	East Carolina University	Decision support systems	C	UG	2	Mennecke (1998)
	Robert Morris University	Introduction to GIS; GIS tutorial and applications	E	UG	1	Wu & Kohun (2006)
	Angelo State University	Geomapping fundamentals	E	UG	1	Reames (2006)
	Ithaca College	GIS for business	NA	Both	1	Boasson (2006)
Marketing & logistics	University of Tennessee	Tools and techniques for logistics analysis	C	G	2	Smith et al. (1998)
Marketing	Murray State University	Principles of marketing, e-commerce, consumer behavior, etc.	C	G & UG	2	Miller et al. (2007)
	Winthorp University	Sales & relationship management	C	UG	2	Bradbard & Fuller (2011)
Marketing, global business	University of Redlands	GIS for business, spatial analysis of global business	C	G	2	Sarkar & Pick (2014)
BS in business	University of Redlands	GIS for business	C	UG	1	Sarkar & Pick (2014)
MBA	University of California at Los Angeles	Managing business processes	C	G	1	Gadish (2007)

Note: * core = C; elective = E
** teaching and learning about GIS = 1; teaching with GIS = 2.

We can see from the literature in this table that IS and marketing are the two business fields that have somewhat integrated GIS, which seems reasonable because several areas in both fields contain an element of location or database concepts that are both key to GIS. We also see that, in these successful instances of infusion, both paradigms of infusion—teaching and learning about GIS and teaching with GIS (Kerski, 2008)—have been equally used. Naturally, when existing coursework has been infused with GIS, teaching with GIS has been the predominant infusion paradigm.

Authors have often reported benefits such as improved student perception about the importance of GIS in business and impact of GIS on their careers, their developing reflective thinking and problem-solving skills, and their developing analytical and higher-order cognitive skills that are often key program-level learning outcomes in business schools. While the existing literature has, perhaps unsurprisingly, unanimously agreed that business school curricula should embrace location and GIS elements, authors have repeatedly emphasized the importance of resources such as technology grants, hardware, software, well-equipped labs, technology training and support, and the presence of a faculty champion as key enablers of GIS infusion.

5.2.2   Alignment of GIS with BSIS and MSIS Curriculum Models

In this section, we examine the latest IS undergraduate (Top et al., 2010) and graduate (Gorgone, Gray, Stohr, Valacich, & Wigand, 2006) curricular guidelines and align concepts of spatial thinking and concepts and tools of spatial analysis that GIS enable with prescribed model curricula. We identify opportunities to infuse undergraduate IS model curricula with GIS and spatial-analysis elements and provide justification for doing so in a few instances. Later in this section, we briefly discuss the fit of GIS with graduate IS model curriculum.

The 2010 IS undergraduate model curriculum revision was motivated by changes in technology and industry practices such as the Web's introduction, the advent of new architectural paradigms, and widespread use of large-scale ERP systems and has been preceded by a period in which interest in studies in IS had noticeably declined (Topi et al. 2010). We can observe that, in the past decade, GIS technology has undergone significant changes including the possibility of migration from desktop to Web-GIS, architectural paradigm shifts such as the introduction of geodatabases, and integration with business intelligence systems.

The latest undergraduate IS model curriculum (Topi et al., 2010) identifies GIS as a sub-topic under information visualization in the first of seven core courses (i.e., foundations of information systems), which is encouraging since the ability to visualize georeferenced data in the form of sophisticated maps is now possible in a few clicks in Web-GIS environments. Information visualization using maps will enable IS undergraduates to identify patterns in geographic data, engage in conversations about issues such as tabular versus map representations, think critically about the data, and ask intelligent questions on why geographic patterns emerge. Information visualization by a GIS often provides the foundation for communication and negotiation (Weigel & Cao, 1999) and facilitates analytical and critical thinking, both of which Topi et al. (2010) has identified as a part of skills and knowledge in the latest IS undergraduate model curriculum.

While the GISs' inclusion in the first core course is encouraging, opportunities to infuse GIS exist in each of the seven undergraduate core courses. For example, a conceptual discussion of the integration of GIS with enterprise systems such as ERP, CRM, and SCM would enrich discourse on business intelligence, a topic in two of the core courses, and expose IS undergraduates to location-based analytics (Garber, 2013) that organizations are increasingly leveraging to make better decisions. GIS can be introduced as an emerging technology, a topic in the enterprise architecture core course, or to enrich discussion about tangible and intangible costs and benefits (Pick, 2008)—topics in the systems analysis and design core course. Table 5 lists topics/sub-topics in core courses prescribed by the IS undergraduate curriculum model that have the potential to be infused by GIS. The list is not meant to be exhaustive, and we intend it to provoke thought among IS academics aspiring to infuse their coursework with GIS.

Opportunities also exist to infuse GIS in IS elective courses at the undergraduate level. One of the electives prescribed in the model curriculum (Tope et al. 2010) is business process management, a course that Gadish (2007) has reported to be infused by GIS. Other prescribed electives that GIS can enrich include data mining and business intelligence, enterprise systems, and social informatics. Table 5 also contains previous reported instances of IS electives that GIS has infused.

At the graduate level, our examination of previously reported instances of GIS infusion in business schools and IS curricula indicates that the model MSIS curriculum's key goals (Gorgone et al., 2006) such as 1) possessing broad business and real world perspective (Boasson, Boasson, & Tastle, 2006; Bradbard & Fuller, 2011), 2) developing analytical and critical thinking skills (Miller et al., 2007; Bradbard & Fuller, 2011; Sinton, 2012), and 3) enhancing specific skills related to a career (Gadish, 2007) are all positively impacted by GIS infusion. Potential for GIS infusion exists in several prescribed graduate-level

IS core courses such as fundamentals of IS, emerging technologies and issues, and project and change Management.

We conclude this section by discussing strategies for creating GIS courses (either infused or standalone) in the framework of undergraduate and graduate model IS curricula. From Table 5, we can see that one can successfully infuse GIS into courses by employing either of Kerski's (2008) paradigms: learning about GIS or teaching with GIS. In the table, with one exception, business school faculty designed and delivered GIS courses for business students. Sheperd (2009) refers to this approach as a "homegrown" strategy of incorporating GIS coursework in business schools. In contrast to the homegrown strategy, another alternative is Sheperd's "service" strategy in which geography departments recruit business students into their mainstream GIS courses and/or design and deliver GIS courses designed for business students. For instance, "service" strategy is seen in the business geography track in the Department of Geography at the University of North Texas, a track that includes coursework on Intermediate geographic information systems, which fulfills an elective requirement for an IS undergraduate.

Table 5. Topics in IS Undergraduate Core Courses (Tope et al. 2010) that GIS can Infuse

Course: IS 2010.1 Foundations of Information Systems
Characteristics of IS professionals, IS career paths, quality of information, IS infrastructure, business intelligence, information visualization (GIS already prescribed by Topi et al., 2010), enterprise-wide IS, etc.
Course: IS 2010.2 Data and Information Management
Database approach, types of database management systems, use of a database in an enterprise context, data quality management, business intelligence, etc.
Course: IS 2010.3 Enterprise Architecture
Role of open source software, software as a service, enterprise data models, emerging technologies, etc.
Course: IS 2010.4 IT Infrastructure
User interfaces, Organizing storage on organizational networks, cloud computing, etc.
Course: IS 2010.5 IS Project Management
Project management lifecycle, project scheduling management, project-quality management, project execution, control, and closure, etc.
Course: IS 2010.6 SYSTEMS Analysis and Design
Project specification, analysis of project feasibility, data-collection methods, user interface design, ethical considerations in requirements specification, etc.

5.2.3 GIS Employment Opportunities for IS Graduates

Suggested career tracks for IS undergraduates include business analyst, database administrator, database analyst, e-Business manager, and so on (Topi et al. 2010); while, for graduates, recommended career options include doctoral studies, a career in computer forensics, consulting, mobile computing, data warehousing, or IS management. Several of these career tracks such as business analyst, e-commerce manager, or careers in mobile computing need to require understanding and appreciation of the importance of location and a GIS's database aspects (e.g., a career as a database administrator). Aside from students' perceiving GIS to positively impact their careers in relatively small-sample studies (Gadish, 2007), limited evidence (Oxera, 2013) exists about the actual impact of geo-education on business school graduates, which presents a promising research opportunity. However, one might argue that, by virtue of exposure to GIS, the fact that IS graduates' critical thinking, spatial thinking, problem solving, and higher-order cognitive skills are improved would provide them with competitive advantage in the employment marketplace.

In summary, we recognize that GISs' and spatial analysis's infusion in business school curricula. Based on examining a handful of instances of successful infusion reported in the literature, we see that GIS infusion in business schools may happen at both graduate and undergraduate levels and predominantly in the business fields of IS and marketing. Instances of teaching and learning about GIS and teaching with GIS are equally uncommon. While the latest IS undergraduate model curriculum has opened the door for GIS infusion, significant opportunities to geospatially infuse IS curricula at both graduate and undergraduate levels exist.

6   Ethical Aspects of GIS

6.1   Introduction

Geographic information (GI) is as ubiquitous as it is important and valuable. As we show in earlier sections, from providing insight about the exact location of a store, customer, or target to understanding proximity to customers, competitors, and complementary businesses and to defining sales territories, GI can assist organizations in differentiating themselves from their peers. It is, therefore, unsurprising that GI and spatial analysis embedded in a GIS often lie at the heart of ethical issues in using and developing GIS. Examples of ethical issues involving geospatial data and GIS usage include retailers' soliciting private customer information to increase sales by refining targeted marketing; organizations' using GIS for mapping and identifying neighborhoods that are home to religious minorities with particular socio-economic attributes, which may be susceptible to ideologically based violent extremism (DiBiase, Goranson, Harvey, & Wright, 2009); organizations' sharing information for profit with business partners or governmental agencies to mine information and derive intelligence (Blakemore & Longhorn, 2004); and impropriety in GIS software's use for personal and professional gain (Barnes, 2010). Researchers have developed ideal case studies for examining GIS ethical and social issues (DiBiase et al., 2009; Onsrud, 2009).

In this section, we overview ethical issues in using GIS, developing ethics codes for GIS, and implementing geographic information technologies ethically. As surveillance, digital privacy, and ethics of location-based tracking (Wang & Loui, 2009) increasingly become part of public discourse and as ethics in business and society are increasingly becoming part of business education, IS academics and professionals need to be informed about these issues.

6.2   Ethical Issues in Using GIS and GIS Code of Ethics

Researchers identified the need to protect personal privacy in using GIS (Onsrud, Johnson, & Lopez 1994) and identifying ethical issues in using and developing GIS (Onsrud, 1995) nearly two decades ago. Onsrud et al. (1994) point out that the capability to store, display, and analyze personal geographic information and the impact of combining GI databases with non-geographic datasets can be immense but, at the same time, raise strong privacy concerns. The authors also express concern that the typical citizen is neither aware of the level of detailed spatial information collected about them nor about the extent to which such information is shared between different stakeholders. Onsrud et al. (1994) also note that enacting overreaching legislation can stifle GISs' long-term development and use by both industry and government and recommend that the GIS industry create an atmosphere of self-regulation that is less likely to restrict beneficial uses of GIS and can also adapt with changing times.

Craig (1993), Onsrud (1995), and others have suggested developing a GIS code of ethics. While commenting that four major issues of privacy, accuracy, property (ownership and pricing) and accessibility need to be addressed by information sciences, Craig (1993) investigated the ethics codes of 48 professional organizations in planning, social sciences, public affairs, natural sciences, and so on and determines that standard ethics codes had remarkably similarity in areas such as obligation to society in general, obligation to funders and employers, obligation to colleagues and the profession, and, finally, obligation to human subjects. Unlike other code of conduct-development practices that involve consulting peer groups from in a field but generally exclude the public, with regard to GIS, Onsrud (1995) recommends a more inclusive approach, one that involves obtaining opinions from members of the public on the appropriateness of conduct in situations that may engender spatial ethical decision making.

While various organizations operating in the geospatial arena have formulated ethical codes of conduct in using GIS (for an overview, see Blakemore & Longhorn, 2004), the Urban and Regional Information Systems Association (URISA), a leading organization of GIS professionals published a GIS code for ethics in 2003. The code comprises four primary categories: 1) obligations to society, 2) obligations to employers and funders, 3) obligations to colleagues and the profession, and 4) obligations to individuals in society (Craig, 1993). Key obligations of GIS professionals include doing the best work possible, speaking out about issues, honoring privacy, and respecting individuals.

6.3   Ethically Implementing GIS

While several organizations have developed GIS codes of ethics, including URISA, the GIS Certification Institute, and Geospatial Information and Technology Association, how to best ethically implement GIS is

still evolving. One primary reason includes the acceleration in globalization of geospatial information resources and related services. The globalization of geographic information and volunteered geo-data that social networks now generate are significant challenges towards protecting personal privacy, protecting property rights in spatial data products and services, and securing geographic information from misuse (Onsrud, 2009). Onsrud argues that laws such as copyright and intellectual property and the use of technology such as digital rights management tools to prevent non-authorized users from using one's information products are two possible deterrents of breaching privacy and misusing GIS. However, Onsrud also cautions that globalization has made understanding rules that govern propriety in using GI and GIS exceedingly complex. Accordingly, he recommends that an approach based on core ethical values that are much more universal and, therefore, not prone to change over time or location is more appropriate and pragmatic for ethical implementing GIS. Onsrud (p. 28) concludes that "implementers of GIS, geospatial technology code writers, and builders of geographic databases and spatial data infrastructure need to be responsible, prudent, and comprehensive in incorporating basic moral values into the geospatial infrastructure we help create.".

In conclusion, in this section, we acknowledge that geographic information, its consumption, distribution, and usage are the focus of robust conversations on digital surveillance and privacy in numerous spheres such as the government, academia, industry, and individuals. As geotechnology evolves, volunteered and non-volunteered geographic information are propagated at the speed of light, and big data analytical principles are applied to make sense of all the data that are produced. Awareness about ethically using GI and GIS is essential for students and academics in business schools and IS programs.

7 Conclusion

This tutorial updates a previous tutorial on geographic information systems (Pick, 2004) with significant additions. Around the time the prior tutorial was published, geotechnology came to the forefront and was identified as a high-growth, high-demand, and economically vital sector by the U.S. Department of Labor. Adopting and using GIS has since been catalyzed by increasing levels of availability of geographic information, greater levels of user-friendliness of GIS software solutions, GISs' migration into the cloud, and GISs' increasing integration with other enterprise and analytics software and technologies. Location-based technologies are now not just in the purview of governments and corporations but also at the fingertips of the common user.

While principles of GIS have largely remained the same, this tutorial has adds significantly to Pick (2004) by covering new areas of GIS methodologies such as spatial statistics, space-time modeling and trend analysis, and 3D modeling. In particular, in Section 3, we discuss the connection of GIS with emerging technologies such as mobile smartphones and other smart devices, unmanned aerial vehicles, and enabling technologies such as Apache Hadoop, which is associated with big data, augmented reality, and virtual reality. The early tutorial discusses prior research on GIS in the IS field principally because, at that time, research questions that involved GIS had largely been answered in fields such as geography or geographic information science. However, as we discuss here, IS researchers have gradually incorporated GIS to answer research questions related to spatial decision-support systems, the adoption and diffusion of information and communications technologies and innovation, the design of interfaces, the impact of location technologies, and other interesting research problems.

This tutorial introduces GISs' infusion into business and management curricula, especially IS programs. We examine examples of such infusion, paradigms of infusion, facilitators and innovators of curricular infusion of GIS, and opportunities to integrate GIS in both graduate and undergraduate model curricula in IS. As location information becomes pervasive and location-based technologies and GIS become ubiquitous, ethical issues about sharing and dissemination of geographic information become critical. Understanding the impact on privacy of individuals and the role of organizations to ethically leverage geotechnology for the benefit of society have become essential. As such, our discussing ethics of GIS is another novel addition.

It is generally well accepted that we now live in the age of big data and analytics. Location information is crucial to understanding flows, movements, patterns, trends of people, other natural phenomena, and physical objects; and describing and analyzing behaviors and attitudes in environments that are increasingly dynamic and prone to uncertainty. Accordingly, we anticipate GISs' role to become critical in the years ahead. In this tutorial, we overview GIS from multiple perspectives with a focus on the IS field.

Acknowledgments

References

Abrahamsen, P., Hauge, R., & Kolbjørnsen, O. (2012). *Geostatistics Oslo 2012*. Heidelberg, Germany: Springer.

Anselin, L., Syabri, I., & Kho, Y. (2006). GeoDa: An introduction to spatial data analysis. *Geographical Analysis*, *38*(1), 5-22.

Atkas, E., Ozaydin, O., Bozkaya, B., Ulengin, F., & Onsel, S. (2013). Optimizing fire station locations for the Intanbul Metropolitan Municipality. *Interfaces*, 43(3), 240-255.

Baca, G. (2012). *An analysis of US Army unmanned ground vehicle strategy.* Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA568455

Barnes, T. (2010). Case study: Sharing alpha software. Retrieved from http://gisprofessionalethics.org

Bernard, L., Mäs, S., Müller, M., Henzen, C., & Brauner, J. (2013). Scientific geodata infrastructures: Challenges, approaches and directions. *International Journal of Digital Earth*, 7(7), 613-633.

Bertram, V. (2008) Unmanned surface vehicles—a survey. *Skibsteknisk Selskab.* Retrieved from http://www.manualdev.com/pdf/unmanned-surface-vehicles-a-survey-skibsteknisk-78245.pdf

Bimber, O., & Raskar, R. (2005). *Spatial augmented reality: Merging real and virtual worlds.* Wellesley, MA: A.K. Peters.

Binz, C., Truffer, B. Li, L., Shi, Y., & Lu, Y. (2012) Conceptualizing leapfrogging with spatially coupled innovation systems: The case of onsite wastewater treatment in China. *Technological Forecasting and Social Change*, (79)1, 155-171.

Biocca, F., Owen, C., Tang, A., & Bohil, C. (2007). Attention issues in spatial information systems: Directing mobile users' visual attention using augmented reality. *Journal of Management Information Systems* (23)4, 163-184.

Bivand, R., Pebesma, E., & Gómez-Rubio, V. (2013). *Applied spatial data analysis with R* (2nd ed., Vol. 10). New York, NY: Springer.

Blakeley, F., Bozkara, B., Cao, B., Hall, W., & Knolmajer, J. (2003). Optimizing periodic maintenance operations for Schindler Elevator Corporation. *Interfaces*, *33*(1), 67-79.

Blakemore, M., & Longhorn, R. (2004). Ethics and GIS: The practitioner's dilemma. In *Proceedings of the AGI Conference, Workshop on GIS Ethics*.

Boasson, E., V. Boasson, & Tastle, W. (2006). A new tool in IS management: Geographic information systems. *Information Systems Education Journal*, 4, 3-9.

Bone, E., & Bolkcom, C. (2003). Unmanned aerial vehicles: Background and issues for congress. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA467807

Borriello, G., Chalmers, M., Lamarca, A., & Nixon, P. (2005). Delivering real-world ubiquitous location systems. *Communications of the ACM*, (48)3, 36-41.

Boston Consulting Group. (2012) *Geospatial services: A $1.6 trillion growth engine for the U.S. economy*. Boston, MA: Boston Consulting Group.

Bozkaya, B., Erkut, E., Haight, D., & Laporte, G. (2011). Designing new electoral districts for the city of Edmonton, *Interfaces*, (41)6, 534-547.

Bradbard, D., & B. Fuller (2011). Introducing geographic information systems in the business school curriculum with Business Analyst Desktop. In *Proceedings of the Annual Meeting of the Decision Sciences Institute*. Houston, TX: Decision Sciences Institute.

Bureau of Labor Statistics. (2012). *Occupational outlook handbook 2012-2013*. Washington, DC: Bureau of Labor Statistics.

Caccia, M., Bibuli, M., Bono, R., & Bruzzone, G. (2008). Basic navigation, guidance and control of an unmanned surface vehicle. *Autonomous Robots*, *25*(4), 349-365.

Carpenter, J., & Snell, J. (2013). *Future trends in geospatial information management: The five to ten year vision.* Retrieved from http://ggim.un.org/docs/Future-trends.pdf

Chang, R. M., Kauffman, R. J., & Kwon. Y. (2014). Understanding the paradigm shift to computational social science in the presence of big data. *Decision Support Systems*, 63, 67-80.

Chivers, T. (2013). The story of Google Maps. *The Telegraph*. Retrieved from http://www.telegraph.co.uk/technology/google/10090014/The-story-of-Google-Maps.html

Chun, Y., & Griffith, D. A. (2013). *Spatial statistics and geostatistics*. Los Angeles, CA: Sage.

Cisco Systems. (2014). *Cisco visual networking index: Global mobile data traffic forecast update, 2013-2018*. Retrieved from http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.pdf

Committee on Earth Observation Satellites Working Group on Information Systems and Services and the U.S. Geological Survey Community for Data Integration Data Management Best Practices. (2012). *Data life cycle models and concepts CEOS version 1.2*. Retrieved from http://wgiss.ceos.org/dsig/whitepapers/Data%20Lifecycle%20Models%20and%20Concepts%20v12.docx

Coutinho-Rodrigues, J., Simão, A., & Antunes, C. H. (2011). A GIS-based multicriteria spatial decision support system for planning urban infrastructures. *Decision Support Systems*, *51*(3), 720-726.

Craig, W. (1993). A GIS code of ethics: What we can learn from other organizations? In *Proceedings of the Urban and Regional Information Systems Association Annual Conference*. Des Plaines, IL: URISA.

Bivand, R. (2014). CRAN task view: Analysis of spatial data. Retrieved from http://cran.r-project.org/web/views/Spatial.html

Cummings, J. (2011). Geography is alive and well in virtual teams. *Communications of the ACM*, 54(8), 24-26.

Data.gov. (2009). Retrieved from http://www.data.gov

Davis, G. B., Gorgone, J. T. Couger, J. D., Feinstein, D. L., & Longenecker, H. E., Jr. (1997). *S 97 model curriculum and guidelines for undergraduate degree programs in information systems.* New York: NY: Association for Computing Machinery.

DeGarmo, M., & Nelson, G. M. (2004). Prospective unmanned aerial vehicle operations in the future national airspace system. In *AIAA 4th Aviation Technology, Integration and Operations Forum* (pp. 20-23). Retrieved from http://arc.aiaa.org/doi/pdf/10.2514/6.2004-6243

Dekle, J., Lavieri, M. S., Martin, E., Emir-Farinas, H., & Francis, R. L. (2005). A Florida county locates disaster recovery centers. *Interfaces*, *35*(2), 133-139.

Dennis, A. R., & Carte, T. A. (1998). Using geographical information systems for decision making: Extending cognitive fit theory to map-based presentations. *Information Systems Research,* 9(2), 194-203.

deSmith, M., Longley, P., & Goodchild, M. (2014). Geospatial analysis—a comprehensive guide. Retrieved from http://www.spatialanalysisonline.com/software.html

DiBiase, D., Goranson, C., Harvey, F., & Wright, D. (2009). The GIS professional ethics project: Practical ethics education for GIS pros. In *Proceedings of the 24th International Cartography Conference*. Bern, Switzerland: International Cartographic Association.

Dramowicz, E. (2005). Retail trade area analysis using the Huff Model. *Directions Magazine.* Retrieved from http://www.directionsmag.com/entry/retail-trade-area-analysis-using-the-huff-model/123411

Dykes, J., MacEachren, A. M., & Kraak, M.-J. (2005). *Exploring geovisualization*. Amsterdam, Netherlands: Elsevier.

Engler, N. J., & Hall, G. B. (2007). The Internet, spatial data globalization, and data use: The case of Tibet. *The Information Society*, 23(5), 345-359.

Erkut, E., Myroon, T. I., & Strangway, K. (2000). TransAlta redesigns its service-delivery network. *Interfaces*, *30*(2), 54-69.

Esri. (2014a). *Esri living atlas of the world*. Retrieved from http://doc.arcgis.com/en/living-atlas

Estaville, L. E. (2007). GIS and colleges of business: A curricular exploration. *Journal of Real Estate Literature*, *15*(3), 443-448.

Faundeen, J. L., Burley, T. E., Carlino, J. A., Govoni, D. L., Henkel, H. S., Holl, S. L., & Zolly, L. (2013). *The United States geological survey science data lifecycle model: U.S. geological survey open-File report 2013-1265*. Retrieved from http://dx.doi.org/10.3133/ofr20131265

Feldman, S. (2015). A history of Web mapping. *Slideshare*. Retrieved from http://www.slideshare.net/stevenfeldman/history-of-web-mapping

Federal Geographic Data Committee. (2014). *Framework introduction and guide*. Washington, DC.

Fischer, M., & Getis, A. (Eds.). (2010). *Handbook of applied spatial analysis: Software tools, methods and applications*. Heidelberg, Germany: Springer-Verlag.

Francica, J. R. (2008). Location-based services: Practices and products. In S. Shekhar & H. Xiong (Eds.), *Encyclopedia of GIS* (pp. 623-627). Heidelberg, Germany: Springer.

Fraunhofer-Gesellschaft. (2014). Simulated reality. Retrieved from http://www.fraunhofer.de/en/research-topics/information-communication/simulated-reality.html

Gadish, D. (2007). Incorporating geographic information systems into an MBA program. *Journal of Education and Human Development*, *1*(2), 1-8.

Gage, D. W. (1995). *UGV history 101: A brief history of Unmanned Ground Vehicle (UGV) development efforts*. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA422845

Gapminder. (2014). GapMinder, for a fact-based world view. Stockholm, Sweden: GapMinder Foundation.

Garber, L. (2013). Analytics goes on location with new approaches. *Computer*, *46*(4), 14-17.

Gavirneni, S., Clark, L., & Pataki, G. (2004). Schlumberger optimizes receiver location for automated meter reading. *Interfaces*, *34*(3), 208-214.

GeoDa Center. (2014) *About us*. Retrieved from http://geodacenter.asu.edu/about

Geodesign. (n.d.). In *Wikipedia*. Retrieved from http://en.wikipedia.org/w/index.php?title=Geodesign&oldid=610044082

Esri. (2014b). *GIS Tools for Hadoop*. Retrieved from http://esri.github.io/gis-tools-for-hadoop/

GitHub. (2014a). *SpatialHadoop*. Retrieved from http://spatialhadoop.cs.umn.edu/

GitHub. (2014b). *SpatialHadoop on GitHub*. Retrieved from https://github.com/aseldawy/spatialhadoop2

GitHub. (2014c). Pysal/pysal. Retrieved from https://github.com/pysal/pysal

Google. (2014). ATAP Project Tango. *Retrieved from* https://www.google.com/atap/projecttango/#project

Gorgone, J. T., Gray, P., Stohr, E. A., Valacich, J. S., & Wigand, R. T. (2006). MSIS 2006: Model curriculum and guidelines for graduate degree programs in Information Systems. *Communications of the Association for Information Systems, 17*, 1-56.

Gorman, S. P., & Malecki, E. J. (2002). Fixed and fluid: Stability and change in the geography of the Internet. *Telecommunications Policy*, *26*(7-8), 389-413.

Graham, M., Zook, M., & Boulton, A. (2013). Augmented reality in urban places: Contested content and the duplicity of code. *Transactions of the Institute of British Geographers*, *38*(3), 464-479.

GRASS Development Team. (2014). *GRASS GIS*. Retrieved from http://grass.osgeo.org/

Grewal, M. S., Weill, L. R., & Andrews, A. P. (2007). *Global positioning systems, inertial navigation, and integration* (2nd ed.). New York: John Wiley & Sons.

Grubesic, T. H. (2002). Spatial dimensions of Internet activity. *Telecommunications Policy*, *26*(7-8), 363-387.

Grubesic, T. H. (2008). The spatial distribution of broadband providers in the United States: 1999-2004. *Telecommunications Policy*, *32*(3-4), 212-233.

Grubesic, T. H. (2010). Efficiency in broadband service provision: A spatial analysis. *Telecommunications Policy*, *34*(3), 117-131.

Grubesic, T. H. (2012). The U.S. national broadband map: Data limitations and implications. *Telecommunications Policy*, *36*(2), 113-126.

Grübler, A., O'Neill, B., Riahi, K., Chirkov, V., Goujon, A., Kolp, P., Prommer, I., Scherbov, S., & Slentoe, E. (2007). Regional, national, and spatially explicit scenarios of demographic and economic change based on SRES. *Technological Forecasting and Social Change*, *74*(7), 980-1029.

Guo, Y., Qingyun, Y. L., Zhang, W., & Xu, L. (2008). Application of augmented reality GIS in architecture. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *37*, 331-336.

Harington, T., & Gross, D. (2012). Dashboards turn data into information. *Transmission and Distribution World*, *64*(5), 30.

Heer, J., Bostock, M., & Ogievetsky, V. (2010). A tour through the visualization zoo. *Communications of the ACM*, *53*(6), 59-67.

Heipke, C. (2010). Crowdsourcing geospatial data. *ISPRS Journal of Photogrammetry and Remote Sensing*, *65*(6), 550-557.

Herwitz, S. R., Johnson, L. F., Dunagan, S. E., Higgins, R. G., Sullivan, D. V., Zheng, J., & Brass, J. A. (2004). Imaging from an unmanned aerial vehicle: Agricultural surveillance and decision support. *Computers and Electronics in Agriculture*, *44*(1), 49-61.

Hirschheim, R., & Sabherwal, R. (2001). Detours in the path toward strategic information systems alignment. *California Management Review*, *44*(1), 87-108.

Hilton, B. (Ed.). (2007). *Emerging spatial information systems and applications.* Hershey, PA: IGI Global Publishing.

Hochmuth, E., & Turcotte, E. (2013). *Geospatial processing on Hadoop* (presentation). *Retrieved from* http://cdn.oreillystatic.com/en/assets/1/event/100/Working%20with%20Geospatial%20Data%20Using%20Hadoop%20and%20HBase%20and%20How%20Monsanto%20Used%20It%20to%20Help%20Farmers%20Increase%20Their%20Yield%20Presentation.pdf

Hodgson, M. E., Battersby, S. E., Davis, B. A., Liu, S., & Sulewski, L. (2014). Geospatial data collection/use in disaster response: A United States nationwide survey of state agencies. In M. Buchroithner, N. Prechtel, & D. Burghardt (Eds.), *Cartography from pole to pole* (pp. 407-419). Heidelberg, Germany: Springer.

Hofmann-Wellenhof, B., Lichtenegger, H., & Collins, J. (1993). *Global positioning system. Theory and practice.* Heidelberg, Germany: Springer.

Huang, B. Liu, N., & Chandramouli, M. (2006). A GIS supported Ant algorithm for the linear feature covering problem with distance constraints. *Decision Support Systems*, *42*(2), 1063-1075.

Huff, D. L. (1963). A probabilistic analysis of shopping center trade areas. *Land Economics*, *39*(1), 81-87.

Humphrey, D. (2014). UAV and GIS: An emerging dynamic duo. *ArcUser*, Retrieved from http://www.esri.com/~/media/Files/Pdfs/news/arcuser/0314/arcuser-spring-2014.pdf

IBM Corporation. (2014). *What is big data?* Retrieved from http://www-01.ibm.com/software/data/bigdata/what-is-big-data.html

IBM Corporation. (2013) *Descriptive, predictive, prescriptive: Transforming asset and facilities management with analytics.* Retrieved from http://public.dhe.ibm.com/common/ssi/ecm/en/tiw14162usen/TIW14162USEN.pdf

International Telecommunication Union. (2012). *Measuring the information society* (executive summary). Retrieved from https://www.itu.int/dms_pub/itu-d/opb/ind/D-IND-ICTOI-2012-SUM-PDF-E.pdf

Jang, W., Lim, H. H., Crowe, T. J., Raskin, G., & Perkins, T. E. (2006). The Missouri lottery optimizes its scheduling and routing to improve efficiency and balance. *Interfaces*, *36*(4), 302-313

Jarupathirun, S., & Zahedi, F. (2005). GIS as spatial decision support systems. In J. B. Pick (Ed.), *Geographic information systems in business* (pp. 150-173). Hershey, PA: Idea Group Publishing.

Jarupathirun, S., & Zahedi, F. (2007). Exploring the influence of perceptual factors in the success of Web-based spatial DSS. *Decision Support Systems*, *43*(3), 933-951.

Johnson, M. P. (2005). Spatial decision support for assisted housing mobility counseling. *Decision Support Systems*, *41*(1), 296-312.

Junglas, I. A., & Watson, R. T. (2008). Location-based services. *Communications of the ACM*, *51*(3), 65-69.

Keenan, P. B. (1998). Spatial decision support systems for vehicle routing. *Decision Support Systems*, *22*(1), 65-71.

Kerski, J. J. (2008). Geographic information systems in education. In J. P. Wilson & A. S. Fotheringham (Eds.), *The handbook of geographic information science.* Malden, MA: Wiley-Blackwell.

King, M., & Arnette, A. (2011). Integrating geographic information systems in business school curriculum: An initial example. *Decision Sciences Journal of Innovative Education*, *9*(3), 325-347.

Kisilevich, S., Keim, D., & Rokach, L. (2013). A GIS-based decision support system for hotel room rate estimation and temporal price prediction: The hotel brokers' context. *Decision Support Systems*, *54*(2), 1119-1133.

Kresse, W., & Danko, D. (Eds.) (2012). *Springer handbook of geographic information.* Heidelberg, Germany: Springer.

Langlotz, T., Regenbrecht, H., Zollmann, S., & Schmalstieg, D. (2013). Audio stickies: Visually-guided spatial audio annotations on a mobile augmented reality platform. In *Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration* (pp. 545-554). New York, NY: Association for Computing Machinery.

Laudon, K., & Laudon, J. (2014). *Management information systems: Managing the digital firm* (13th ed.). Upper Saddle River, NJ: Pearson Education.

Lee, J.-G, & Kang. M. (2015). Geospatial big data: Challenges and opportunities. *Big Data Research, 2*, 74-81.

Li, L., Goodchild, M. F., & Xu, B. (2013). Spatial, temporal, and socioeconomic patterns in the use of Twitter and Flickr. *Cartography and Geographic Information Science*, *40*(2), 61-77.

Li, Y., Wynned, A. J., & Babb, J. (2009). Preparing tomorrow's global decision-makers: A case for geographic information systems in business curriculum. In *Proceedings of the 40th Annual Meeting of the Decision Sciences Institute* (pp. 3741-3746). Houston, TX: Decision Sciences Institute.

Lin, P.-J., Kao, C.-C., Lam, K.-H., & Tsai, I.-C. (2014). Design and Implementation of a tourism system using mobile augmented reality and GIS technologies. In J. Juang, C.-Y. Chen, & C.-F. Yang (Eds.), *Proceedings of the 2nd International Conference on Intelligent Technologies and Engineering Systems* (pp. 1093-1099). Heidelberg, Germany: Springer International Publishing.

Liu, F., & Sun, Y. (2009). A comparison of the spatial distribution of innovative activities in China and the U.S. *Technological Forecasting and Social Change*, *76*(6), 797-805.

Lloyd, C. D. (2010). *Spatial data analysis.* New York, NY: Oxford University Press.

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2011). *Geographic information systems and science* (3rd ed.). New York: John Wiley and Sons.

Maceachren, A. M., & Kraak, M.-J. (1997). Exploratory cartographic visualization: Advancing the agenda. *Computers & Geosciences*, *23*(4), 335-343.

Maguire, D., Kouyoumijan, V., & Smith, R. (2008). *The business benefits of GIS: An ROI approach*. Redlands, CA: Esri Press.

Manley, J. E. (2008). Unmanned surface vehicles, 15 years of development. In *OCEANS 2008* (pp. 1-4), New York, NY: IEEE. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5152052

Manoochehri, M. (2013). *Data just right: Introduction to large-scale data & analytics* (1st ed.). Boston, MA: Addison-Wesley Professional.

Meeks, W. L., & Dasgupta, S. (2004). Geospatial information utility: An estimation of the relevance of geospatial information to users. *Decision Support Systems, 38*(1), 47-63.

Mennecke, B. (1998). Teaching spatial analysis in business: The case of geographic information systems in a decision support systems course. In *Proceedings of the 13th Annual Conference of the International Academy of Management Annual Conference* (pp. 181-189).

Mennecke, B. E., & Strader, T. (Eds.) (2003). *Mobile commerce: Technology, theory and applications*. Hershey, PA: IRM Press.

Mennecke, B., Crossland, M., & Killingsworth, B. (2000). Is a map more than a picture? The role of SDSS technology, subject characteristics, and problem complexity on map reading and problem solving. *MISQ, 24*(4), 601-629.

Miller, F. L., Holmes, T. L., & Mangold, W. G. (2007). Integrating geographic information systems (GIS) into the marketing curriculum. *Marketing Education Review,* 17(3), 49-63.

Mitchell, A. (1999). *The Esri guide to GIS analysis. Volume 1: Geographic patterns and relationships*. Redlands, CA: Esri Press.

Mitchell, A. (2005) *The Esri guide to GIS analysis. Volume 2: Spatial measurements and statistics*. Redlands, CA: Esri Press.

Montoya, L. (2003). Geo-data acquisition through mobile GIS and digital video: An urban disaster management perspective. *Environmental Modelling and Software*, *18*(10), 869-876.

NASA. (2014). *OpenNEX challenge.* Retrieved from https://nex.nasa.gov/nex/static/htdocs/site/extra/opennex/

Nishida, T., Pick, J. B., & Sarkar, A. (2014). Japan's prefectural digital divide: Multivariate and spatial analysis. *Telecommunications Policy*, *38*(11), 992-1010.

O'Sullivan, D., & Unwin, D. (2010). *Geographic information analysis*. New York: John Wiley and Sons.

Onsrud, H. (1995). Identifying unethical conduct in the use of GIS. *Cartography and Geographic Information Systems*, *22*(1), 90-97.

Onsrud, H. (2009). Implementing geographic information technologies ethically. *In essays on geography and* GIS (Volume 2*, pp. 15-28). Redlands, CA: Esri Press.

Onsrud, H., Johnson, J., & Lopez, X. (1994). Protecting privacy in using geographical information systems. *Photogrammametric Engineering and Remote Sensing*, *60*(9), 1083-1095.

Open Geospatial Consortium. (2014). Retrieved from http://www.opengeospatial.org/

Open Government Initiative. (2009). Retrieved from http://www.whitehouse.gov/open

OSGeo.org. (2014). Retrieved from http://www.osgeo.org/

Oxera. (2013). *What is the economic impact of Geo services?* Retrieved from http://www.oxera.com/Latest-Thinking/Publications/Reports/2013/What-is-the-economic-impact-of-Geo-services.aspx.

Papp, R. (2001). Introduction to strategic alignment. In Rapp, R. (Ed.), *Strategic information technology: Opportunities for competitive alignment* (pp. 1-24). Hershey, PA: IGI Publishing.

Patterson, T., McClean, S., Morrow, P., & Parr, G. (2011). Utilizing geographic information system data for unmanned aerial vehicle position estimation. In Proceedings of the Canadian Conference on Computer and Robot Vision (pp. 8-15).

Pick, J. B. (2004). Geographic information systems: A tutorial and introduction. *Communications of the Association for Information Systems*, *16*, 307-333.

Pick, J. B. (Ed.) (2005). *Geographic information systems for business.* Hershey, PA: IGI Global Publishing.

Pick, J. B. (2008). *Geo-business: GIS in the digital organization.* New York: John Wiley and Sons.

Pick, J. B., Nishida, T., & Zhang, X. (2013). Determinants of China's technology availability and utilization 2006-2009: A spatial analysis. *The Information Society*, *29*(1), 26-48.

Pick, J. B, & Nishida, T. (2015). Digital divides in the world and its regions: A spatial and multivariate analysis of technological utilization. *Technological Forecasting and Social Change*, *9*, 1-17.

Pick, J., & Sarkar, A. (2015). *The global digital divides: Explaining change*. Heidelberg, Germany: Springer.

Power, D. J., & Sharda, R. (2007). Model-driven spatial decision support systems: Concepts and research directions. *Decision Support Systems*, *43*(3), 1044-1061.

Ramakrishna, H., Sarkar, A., & Vijayaraman, B. (2010). Infusion of GIS and spatial analysis in business school curricula: A status report. *Journal of Informatics Education Research*, 213-233

Ray, J. J. (2007). A Web-based spatial decision support system optimizes routes for oversize/overweight vehicles in Delaware. *Decision Support Systems*, *43*(4), 1171-1185.

Reames, S. (2006). Business geographic information systems—a course in business geomapping. *Information Systems Education Journal, 4*(52), 3-15.

Rokityanskiy, D. Benítez, P. C., Kraxner, F., McCallum, I., Obersteiner, M., Rametsteiner, E., & Yamagata, Y. (2007). Geographically explicit global modeling of land-use change, carbon sequestration, and biomass supply. *Technological Forecasting and Social Change*, *74*(7), 1057-1082.

Santos, L., Coutinho-Rodrigues, J., & Antunes, C. H. (2011). A Web spatial decision support system for vehicle routing using Google Maps. *Decision Support Systems*, *51*(1), 1-9.

Sarkar, A., & Pick, J. (2014). A model and case analysis of geographical information systems curricula in management schools. In *Proceedings of Americas Conference on Information Systems*. Atlanta, GA: Association for Information Systems.

Schall, G., Mendez, E., Kruijff, E., Veas, E., Junghanns, S., Reitinger, B., & Schmalstieg, D. (2009). Handheld augmented reality for underground infrastructure visualization. *Personal and Ubiquitous Computing*, *13*(4), 281-291.

Scheibe, K. P. Carstensen, L. W., Jr., Rakes, T. R., & Rees, L. P. (2006). Going the last mile: A spatial decision support system for wireless broadband communications. *Decision Support Systems*, *42*(2), 557-570.

Data.gov. (2014). *Data catalog*. Retrieved from http://catalog.data.gov/dataset

Seffino, L. A., Medeiros, C. B., Rocha, J., & Yi, B. (1999). WOODSS—a spatial decision support system based on workflows. *Decision Support Systems*, *27*(1-2), 105-123.

Sheperd, I. (2009). From geography department to business school: Strategies for transplanting GIS courses between disciplines. *Journal of Geography in Higher Education*, *33*(1), S28-S45.

Sinton, D. (2012). Making the case for GIS&T in higher education. In D. Unwin, , K. Foote, N. Tate, & D. DiBiase (Eds.) *Teaching geographic information science and technology in higher education*. Malden, MA: John Wiley & Sons.

Smith, C. D., Langley, C. J., & Mundy, R. (1998).Removing the barriers between education and practice: Tools and techniques for logistics management. *Journal of Business Logistics, 19*(2), 173-195.

De Smith, M. J., Goodchild, M. F., & Longley, P. A. (2006) *Geospatial analysis*. Leicester, England: Troubador Publishing.

Stebbins, R. A. (2001). *Exploratory research in the social sciences*. Thousand Oaks, CA: Sage.

Sugumaran, R., & Degroote, J. (2011). *Spatial decision support systems: Principles and practices.* Boca Raton, FL: CRC Press.

Sugumaran, V., & Sugumaran, R. (2007). Web-based spatial decision support systems (WebSDSS): Evolution, architecture, examples and challenges. *Communications of the Association for Information Systems*, *19*, 844-875.

Tang, H. K. (2006). Adoption of navigation technologies: Five historical and contemporary cases. *Technological Forecasting and Social Change*, *73*(7), 845-859.

Taylor, R. G., & Vasu, M. (1999). Integrated planning for school and community: The case of Johnston County, North Carolina. *Interfaces*, *28*(1), 57-87.

Tomlinson, R. (2011). *Thinking about GIS: Geographic information system planning for managers* (4th ed.). Redlands, CA: Esri Press.

Topi, H., Valacich, J. S., Wright, R. T., Kaiser, K., Nunamaker, J. F., Sipior, J. C., & de Vreede, G.-J. (2010). IS 2010: Curriculum guidelines for undergraduate degree programs in Information Systems. *Communication of the Association for Information Systems*, *26*, 359-428.

Tsou, M.-H., & Sun, C.-H. (2006). Mobile GIServices applied to disaster management. In J. Drummond, R. Billen, D. Forrest, & E. Joao (Eds.), *Dynamic and mobile GIS: Investigating changes in space and time* (pp. 213-236). London: Taylor & Francis.

Tsou, M. H., & Leitner, M. (2013). Visualization of social media: Seeing a mirage or a message? *Cartography and Geographic Information Science*, *40*(2), 55-60.

U.S. Bureau of the Census. (2012). *TIGER/Line Shapefiles*. Washington, DC.

U.S. Geologic Survey. (2013). *Science data life cycle model for the USGS: Model development workspace.* Washington, DC. Retrieved from https://my.usgs.gov/confluence/display/cdi/Science+Data+Life+Cycle+Model+for+the+USGS%3A+Model+Development+Workspace

U.S. Geologic Survey. (2015). *U.S. Geologic Survey Center for LIDAR Information Coordination and Knowledge (CLICK)*. Washington, DC. Retrieved from USGS website: http://lidar.cr.usgs.gov/index.php

Walsham, G., & Sahay, S. (1999). GIS for district-level administration in India: Problems and opportunities. *MIS Quarterly*, *23*(1), 39-66.

Wang, J., & Loui, M. (2009). Privacy and ethical issues in location-based tracking systems. In *Proceedings of the 2009 IEEE International Symposium on Technology and Society* (pp. 1-4). Washington, DC: IEEE Computer Society.

Watson, H., & Marjanovic, O. (2013). Big data: The fourth data management generation. *Business Intelligence Journal*, *18*(3), 4-8.

Weigel, D., & Cao, B. (1999). Applying GIS and OR techniques to solve Sears technician-dispatching and home-delivery problems. *Interfaces*, *29*(1), 112-130.

The Apache Software Foundation. (2014). *Welcome to Apache^TM Hadoop®!* Retrieved from http://hadoop.apache.org/

West, L. A., Jr., & Hess, T. J. (2002). Metadata as a knowledge management tool: Supporting intelligent agent and end user access to spatial data. *Decision Support Systems*, *32*(3), 247-264.

Dumbill, E. (2012). *What is Apache Hadoop?* Retrieved from http://radar.oreilly.com/2012/02/what-is-apache-hadoop.html

National Ocean Service. (2014). *What is LIDAR?* Retrieved from http://oceanservice.noaa.gov/facts/lidar.html

Wicker, S. (2012). The loss of location privacy in the cellular age. *Communications of the ACM*, *55*(8), 60-68.

Wu, P., & Kohun, F. (2005). Designing geographic information system courses in the IS curriculum. *Proceedings of ISECON, 22*, SS.2564.

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers and Education*, *62*, 41-49.

Yang, C., Raskin, R., Goodchild, M., & Gahegan, M. (2010). Geospatial cyberinfrastructure: Past, present and future. *Computers, Environment and Urban Systems*, *34*(4), 264-277.

Zhu, B., & Chen, H. (2005). Using 3D interfaces to facilitate the spatial knowledge retrieval: A geo-referenced knowledge repository system. *Decision Support Systems*, *40*(2), 167-182.

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