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The Value of Using GIS and Geospatial Data to Support Organizational Decision Making

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*"If a man does not know to what port he is steering, no wind is favorable."
...Seneca, 4 B.C. – 65 A.D.*

*"I am told there are people who do not care for maps, and I find it hard to believe."
...Robert Louis Stevenson, 1850 – 1894*

ABSTRACT

For several years GIS has been expanding beyond its niche of analyzing earth science data for earth science purposes. As GIS continues to migrate into business applications and support operational decision-making, GIS will become a standard part of the portfolio of information systems organizations rely on to support and guide operations. There are several ways in which GIS can support a transformation in organizational decision-making. One of these is to inculcate a geospatial 'mindset' among managers, analysts, and decision makers so that alternative sources of data are considered and alternative decision making processes are employed.

CHAPTER ORGANIZATION

This chapter presents a data-centric view of the ways that GIS and geospatial data support organizational decision-making. As such, the chapter is organized to cover the following topics:

SECTION	TOPICS
Introduction	<ul style="list-style-type: none"> • Non-traditional uses of GIS • GISs are descriptive and can be prescriptive • Having geospatial and spatiotemporal mindsets are important • Three themes to carry away
Background	<ul style="list-style-type: none"> • GIS fit the general systems model • Three relevant geosciences functions • Spatial and spatiotemporal data and information
Issues in Decision-making	<ul style="list-style-type: none"> • Decision models fit general systems models • Decision inputs can include geospatial data • Understanding errors in modeling organizations
GIS Support to Decision-making	<ul style="list-style-type: none"> • Age of the spatial economy • Integrating business, geospatial, and remotely sensed data • Incorporating geospatial and spatiotemporal contexts • Data aspects of GIS in decision-making
Geospatial Data Issues to Improve Decision-making	<ul style="list-style-type: none"> • Drilling into geospatial data types and uses • Considering evaluation paradigms for geospatial data in GIS
Evaluating the Value of Geospatial information in GIS	<ul style="list-style-type: none"> • Considering the value of information • The status quo for evaluating geospatial data • An alternative: Geospatial Information Utility
Looking into the Future	<ul style="list-style-type: none"> • Advances in remote sensing add opportunities
Summary	<ul style="list-style-type: none"> • Recapping the three themes

INTRODUCTION

This chapter explores themes that are based on some non-traditional ways geographic information systems (GIS) are able to support businesses through transforming organizational decision-making at operational, tactical, and strategic levels. The starting point is the recognition that GIS and the geospatial sciences are mostly gaining prominence and popularity by providing answers to analysts, researchers, practitioners and decision makers for those problems—of different types and levels of complexity—that have a recognized spatial or spatiotemporal component. This, in fact, is what most organizations come to GIS for: to find descriptive and prescriptive answers to space and time problems. Within the geospatial sciences, and considering the use of GIS, descriptive answers are provided through analysis of collected sampling data. An entire field of statistical analysis called geostatistics (Isaaks and Srivastava 1989) exists to guide and improve the quality of statistical analysis of spatially oriented data. Just as other fields combine expert domain knowledge and inferential statistical analyses to make probabilistic predictions about future operating environments or activities, GIS is also used in prescriptive ways to support decision-making. For managers in different industries and in firms of different sizes, using GIS to provide both descriptive and prescriptive answers means being able to adopt a spatiotemporal “mindset” that automatically presumes business data have space and time components that can be mined and analyzed to improve decision-making.

We consider the distinction between spatial and geospatial (or geographic) data important: spatial roughly means “place” or “space” (e.g., answers where, how far, and how long or wide kinds of questions) whereas geospatial, which is properly a subset of spatial, means “place or space tied to a geographic reference.” We also consider the distinction between spatial (or geospatial, depending on the context or frame of reference) and spatiotemporal to be important because of the exclusion or inclusion of a temporal frame of reference, which includes place or space changes over time.

A geospatial mindset means having a pre-disposition towards considering the analysis of business problems from a spatial or spatiotemporal perspective. Thus both the spatiotemporal and geospatial mindsets are important and worth mentioning separately. For example, a manager uses her spatiotemporal mindset to examine her continental transportation and logistics operations as occurring in “4-D” (e.g., latitude, longitude, elevation, and time) or her intra-factory materials movement as occurring in 4-D (e.g., length, width, height, and time) by including consideration of the space/place relationships that change over time. Hence, space-time or spatiotemporal issues matter. Another manager seeks to optimize the expansion of a cellular telephone transmission network through the mini-max decision of how few new cell phone towers should be built (i.e., fewer towers, lower cost) versus how many are needed (i.e., more towers, better signal strength)—the mini-max decision is about minimizing cost while maximizing signal coverage to users. The use of a GIS—which requires geospatial and other cost and performance data—allows managers to perform better analyses for these kind of problems.

To extend and employ the geospatial and spatiotemporal mindsets, the biblical proverb about the difference between giving a person a fish to feed them for a day, or teaching them to fish so they can feed themselves for all days is useful. The real question the business community should be asking of GIS is not “what is the (spatial) answer to my current problem?” But rather, “in what ways should I be thinking about my current sources of business data within a spatial context?” And, “what other sources and types of data support a spatiotemporal ‘mindset’ useful in improving the accuracy and speed of my organizational decision-making?” This is a key opportunity for GIS to support business in innovative ways. Three themes running through this chapter are:

- ❑ GIS can improve organizational decision making through the awareness that all business decisions include space and time components. The benefit is that thinking spatiotemporally provides additional analytical approaches and methods.
- ❑ GIS use both business data and remotely sensed data. An awareness of the power of the different forms and sources of remotely sensed data and the ways their integration can transform organizational notions about how and where to collect business data helps improve both GIS-based and non-GIS based decision making.
- ❑ Accessing many different data sources and types imply challenges with using these data; these challenges include determining the quality of the data ingested, manipulated and outputted; and equally as importantly, determining the utility and

relevance of the ingested and outputted data and information as they pertain to the result of the final decision or action.

Another definition is useful: From Lillesand and Kiefer (2000, p. 1), “Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation.” The terms remotely sensed data (noun) and remote sensing (verb) are different forms of the same concept: to collect data on objects of interest from afar. Far and close are immaterial, e.g., imaging is big in the medical world, where the distances are pretty close compared to the altitude of a satellite orbiting hundreds of miles in space. Our thesis includes remote sensing (or remotely sensed data) as fact and as metaphor.

In the geospatial sciences, normally an actual sensor (e.g., electro-optical, radar, laser, radiometer) is employed to passively or actively perform the remote sensing. In both the geosciences and business operations, the distinction between passive and active data collection is important. Passive sensors rely on emitted radiance or other phenomena from the object of interest to perform the data collection. Active sensors emit electromagnetic energy to excite or illuminate the object of interest so that the sensor detects reflected energy from the object of interest. Both have their advantages and disadvantages. In our chapter, this has a normative meaning—remote sensing taken at its face—and a metaphorical meaning that means managers and decision makers should consider the act of remote sensing as a guide to finding alternative means for collecting

and processing the data and information they need to make competitive business decisions at all levels of the operating spectrum.

Considering our central theme of opening business managers' minds to alternative forms of data, alternative sources of data, and alternative concepts for tying data, sources, and decision models together, other means might be considered as the vehicles that perform remote sensing. For example, agent-based queries on a firm's operating network retrieve local sales updates from distributed databases and then autonomously feed those changes to a central decision support system for analysis; this could be considered as remote sensing in a non-traditional context.

BACKGROUND

Any discussion of GIS should begin with recognition of that GIS represents a holistic system of the systems with several complex yet easy to use components, such that:

$$\text{GIS} = f\{ \text{Hardware, Software, Data, Connectivity, Procedures, Operators} \}$$

Where *Hardware* represents all systems hardware; *Software* represents operating software and other applications and tools; *Data* are primary and supporting data received from many sources, ingested into, manipulated by, and outputted from GIS systems; *Connectivity* represents system inter-networked connectivity linking GIS to remote data sources and other supporting applications; *Procedures* are the automated and manual processes, methods, and other algorithms necessary to use the GIS system; and *Operators* are the operators, analysts, researchers and others who use GIS hardware, software, data,

connectivity, and procedures in order to support spatial analyses and other organizational decision making. To further ground this view of the value of GIS to organizational decision-making and performance, it is also important to know that GIS operate as any other system according to a general system model incorporating inputs, processes, outputs, and feedback as shown in Figure 1.

Figure 1 goes here

In its niche, GIS evolved by analyzing earth science data primarily for earth science reasons. Much of this data is collected from remote sensing devices and specialists' fieldwork. Bossler (2002) and others point out the three main components, functions, or fields in the geospatial sciences: remote sensing, global positioning systems (GPS) and GIS, which functionally translate into: *collecting data* (i.e., remote sensing), *locating objects* (i.e., through the use of global positioning system or other survey or locational technique), and *analyzing data* and information (i.e., through the use of GIS). Many sub-fields and applications exist to develop and hone these functions. The "sub-fields" are the decomposition of these three main functions or fields. For example, collecting data can be decomposed into passive versus active sensors; or sensors based on placement relative to the surface of the earth, e.g., space-, air-, surface-, or sub-surface-based sensors; or by their phenomenologies, e.g., imagery-, acoustic-, magnetic-, radio-electronic signal-, olfactory-, thermal-, seismic-based sensors. Therefore, there are many different ways to decompose each of collect, locate, and analyze functions and each of these decompositions constitutes the "sub-fields" to us. The point is relevant because

each of these fields and sub-fields are developed and advanced relatively independently of the others. Each independent evolution includes hardware capabilities, software applications, data structures and forms, means for data transmission and sharing, operator training, and process improvements. All of these fields and sub-fields will continue to grow at a rapid rate as each uncovers faster, more versatile, and more accurate tools and ways to collect, locate, analyze and present GIS input and output data. This growth in capability, performance and versatility will be in part driven by external demands placed by communities of users as GIS penetrates into mainstream business operations.

Spatiotemporal information is comprised of spatial and temporal information. Spatial information is a component of organizational information that links to a place, without respect to any specific geographic reference orientation (Longley, Goodchild et al. 2001). As mentioned, spatial information addresses 'where' and 'how far' kinds of questions. For example, sales figures for a region, inventory at distributed locations, machinery laid out on a shop floor, and even the swirls and whorls on a fingerprint are all spatial information. Geospatial information is a subset of spatial information, which includes an absolute or relative geographic or relative geographic basis, called geo-referencing. We will mostly use the term geospatial data as the term of preference in the latter part of the chapter. References to spatial data (versus geospatial data) are made to form the context for the focus on geospatial data. Detailing the issues and potential applications for non-geographic spatial data (e.g., particularly in the case of the geospatial information utility) is beyond the scope of our interest and work for now. Also, geospatial data occur in GIS far more frequently. There are, however, classes of systems such as automated computer-

aided drawing (CAD) and computer-aided manufacturing (CAM) that specialize in the use, analysis and output of non-geographic spatial data and information. One caveat: GISs predominantly use geospatial data, but also use other forms of data, CAD/CAM applications predominantly use non-geographic spatial data, but some can also use geospatial data.

Planned locations for new cell phone towers and the real-time dynamic location information of en-route FedEx delivery trucks are examples of geospatial information. Temporal information is another component of organizational information, which is linked to particular events or places, which can also be specific as occurring at a specific time. Temporal information addresses 'when', 'how often' questions, including start and stop times, or alternatively, duration intervals, and irrespective of the type of system (mechanical, electronic, or organizational), networks' latency for node-to-node processing and delay times. Temporal information is particularly useful in longitudinal analyses; that is, making assessments of changes in events or places over time, and in forecasting future changes in events or places over time. Just-in-time techniques widely-used in manufacturing today aim to deliver raw materials to factories or finished goods inventory to distributors at tightly specified intervals. In the previously mentioned case of the FedEx truck on delivery, it is important to consider not only where the truck is located, but also when it is located there. These are examples of using temporal information. By convention, the term spatiotemporal information includes information having a spatial orientation, a temporal orientation, or both. Considering the value of dynamic and static data, both spatial and temporal data can be static or dynamic.

Cognitively speaking, spatial and temporal reasoning are common forms of reasoning; so much so they are not commonly thought of in any determined way. However, the value of reasoning and problem solving in spatiotemporal terms is gaining attention. Organizations like the National Center for Geographic Information and Analysis (NCGIA) are pursuing spatiotemporal reasoning and analysis (Frank, Campari et al. 1992).

There is nothing inherently transformational about spatiotemporal information per se. The types of information provided as examples above are already being collected and analyzed in organizations. Today, however, decision timelines, like other operational aspects of organizational life, are becoming highly compressed. Advances in remote sensing and information systems provide the means to collect, analyze, exploit and disseminate questions, decisions, actions, and their results with ever-greater fidelity and robustness with ever-shorter collection, analysis, and dissemination timelines (Johnson, Watts et al. 2001). This is how a spatiotemporal mindset will be transformational: using information collected from a broader range of sources in more innovative ways to solve complex analytical and decision problems—the “faster, better, cheaper” paradigm.

DECISION MAKING

Once thinking is focused in terms of a systems process model, or better yet, in systems-of-systems terms, it is natural to consider the extension of the general systems model to the art and science of decision-making. To do this, it is necessary to consider the nature of decision inputs, decision processes, and decision outputs. One current focus in

decision sciences is on developing systematic methods to improve decision-making, because "...interest in decision making is as old as human history" (Hoch and Kunreuther 2001, pg. 8). The recognition that up to 80% of an organization's data are spatial (Bossler 2002) is forcing, in part, this transformation to further systematize decision making. Christakos, et al., (2002), describe how spatiotemporal information associates events with their spatial and temporal ordering, and that by using these data in new decision models, managers are able to achieve improved fidelity and quality in their decision-making. The future of this field is to encourage a mindset of spatial thinking in managers of all disciplines (DeMers 2000). Broadly speaking, consistent with the general systems model Figure 2 depicts how systematized decision-making is comprised of (decision) inputs, (decision) processes, and (decision) outputs. Also essential are feedback loops to evaluate decision inputs and processes. Decision analysis is a related science, which is also being systematized (Clemen and Reilly 2001).

Figure 2 goes here

Decision inputs include the decision requirements (e.g., what needs to be decided and other parameters, primary and other supporting data and metrics, and the degree of uncertainty or risk that is present or can be tolerated in the decision. Decision processes include the phases of the decision (e.g., generating and evaluation options), roles of actors involved in the decision, and decision support tools or systems. Specifically included are the internal systems, subsystems and processes found within the organization (labeled as "subsystems" on the figure above); and the applications, models

and other domain specific algorithms affecting decision processes that determine how decision inputs are manipulated and otherwise analyzed in order to arrive at decision outputs. Finally, decision outputs include the decision in a form that can be communicated clearly to those who must act on it and may include a statement of the level of confidence associated with the decision result. A critical area is the impact errors have on analyzing organizational systems' behavior (i.e., with their associated operating activities), and how they are accounted for or dealt with within decision-making paradigms. Figure 3 depicts key issues that must be considered in determining, accounting for, and ultimately eliminating errors found within organizational systems as a result of operating activities and managerial decision-making. It should be the goal of analysts, researchers, managers, and decision makers to be able to account for random errors and to eliminate bias errors. This model is particularly useful in considering the 'nouns and verbs' that go into an assessment of what makes an organizational system work. It represents a broad systems view of how errors are induced into analyses of businesses' operational activities and processes. The reason this view of errors is relevant to considering how GIS support decision-making in business is that the analytical structure resembles the analytical process in GIS analyses. Later in the chapter we will focus on errors within a more narrow data quality perspective, with respect to the geospatial data ingested into GIS to support decision-making.

Figure 3 goes here

GIS SUPPORT TO DECISION MAKING

Fujita, Krugman, and Venables (1999) call this the age of the spatial economy and describe “economic geography”, which considers where and why economic activity occurs. Business leaders must accommodate themselves to the distributed, geographic nature of their industries and, significantly, also to the growing use of spatial, geographic, and temporal information within decision-making paradigms. The increased use of these data is forcing new decision-making methods and tools. GIS, as an aid to decision making, provides crucial support to decision makers in many fields. However, the effective use of GIS requires high quality, accurate information as inputs. And, effectively used GISs output high quality, accurate, relevant, and “actionable” information to decision makers. Later, we will address how to value the spatiotemporal information used in GIS and how to value the output of GIS to decision makers within a spatiotemporal reasoning mindset, for as Albert Einstein’s contemporary, Hermann Minkowski, lectured in 1905: “Henceforth space by itself and time by itself, are doomed to fade away to mere shadows, and only a kind of union between the two will preserve an independent reality” (Raper 2000).

Incorporating the geospatial sciences into organizational decision making complements and improves the quality of decisions (Malczewski 1999). Further, new decision constructs supported by GIS are also supporting participatory group decision-making (Jankowski and Nyerges 2001): generating creative options, identifying and quantifying multiple evaluation criteria, developing the causal linkage between options and

evaluation criteria, and analyzing the uncertainty associated with the options-evaluations criteria. GIS and spatiotemporal data can help with all.

Readers should consider the lessons found in the history of information systems (IS) and management information systems (MIS). From the early, very limited beginnings of automated data processing on punch cards to vastly complex and responsive IS and MIS today, the inputs, processes, outputs, and uses of IS and MIS have evolved; sometimes incrementally and predictably, and sometimes dramatically and innovatively. GIS as a subclass of management information systems is gaining mainstream use and acceptance. As with the evolution of other forms of MIS, new and innovative uses and applications can spawn competitive advantage for managers and decision makers who grasp their potential significance and who are willing to experiment with the traditional and non-traditional use of these systems to solve many different types of problems.

The value of GIS, to our data-centric view, is:

- To allow decision makers to analyze and correlate their organization's operating activities in spatial and spatiotemporal terms, in ways probably not employed before.
- To inculcate in managers and decision makers the mindset that spatial, geospatial, and spatiotemporal factors are important. Specifically:
 - To guide decision makers to consider alternative forms of data.

- To guide decision makers to consider alternative sources of data, where this means considering traditional remotely sensed data.
- To guide decision makers to consider using geoscience remote sensing as a metaphor for innovations in business data collection and processing.
- To guide decision makers to reevaluate their decision-making processes to incorporate GIS provided alternatives.

As GIS breaks into the organizational mainstream, geospatial and spatiotemporal analyses allow managers and decision makers to incorporate additional data types and sources. Specifically, formally traditional “business data”, which all along had space and time components, but which often went un-analyzed (or at the very best, under-analyzed in not-so-sophisticated ways considering today’s computational tools and processing power), can also now be incorporated into GIS analyses for improved organizational decision-making. Thinking back on when business data was not thought of in robust spatiotemporal terms, it is not hard to imagine the manager of Sears Catalog division from 100 years ago trying to collect sales data for goods shipped across a growing country. What decisions did that long-ago manager face? What could he influence to improve Sears’ profitability through managing the goods sold for shipment across the country? More importantly, what could he have done differently if he had the analytical tools of GIS to help more precisely analyze his (textual) sales data within a place and

time construct overlain on a map of production sites, distribution sites and networks, transportation nodes and links, and customers sorted by demand preferences and purchasing patterns?

Of long-time interest in GIS analyses are incorporation of remotely sensed data, which include environmental, intelligence, scientific, and other data from space-, air-, surface-, and subsurface-borne sensors. Beyond the use of remotely sensed data, in increasing complexity and utility are the collection and use of various types of structured and unstructured and unstructured organizational data, which are analyzed in GIS within spatial and spatiotemporal contexts, or are correlated, with the available remotely sensed data in industry- and organization-unique ways. While many types of organizations need these data for operational purposes, managers and decision makers know that after the geospatial function “locate it,” a decision must be made to act on “it”.

Considering the breadth of topics in the use of GIS in business today, including the sentence, “GIS has been built up based on a combination of theories and concepts from IS and geography,” we consider that many technical GIS readers will be interested in the ‘manipulate it’ and ‘act on it’ functions most fundamental to GIS users, developers, and data providers. However, it is not just environmental data directly resulting from remote sensing—and remote sensing can take on many non-traditional forms—but also the spatiotemporal associations being addressed within business data that are important for business leaders and managers. Therefore, a new imperative in the field centers on the issue of the value of spatiotemporal data and information ingested into and outputted

from GIS, specifically as they pertain to improving organizational decision-making. One focus considers both the state of today's GIS analysis technologies and also the technology and process advances that will shape tomorrow's convergence of GIS users and organizational decision makers.

Figure 4 shows how data inputs are moved into the system towards data uses, passing through several filters that consider data form and type, data resolution and data accuracy.

Figure 4 goes here

Both GIS and other business data are provided in several forms and types. For GIS, these data are typically raster, vector, elevation, spectral, textual, or structured (i.e., numerical data in tables, etc.) types. Business data can also take many forms; however, the most common seem to be the forms found in typical office productivity software suites: e.g., structured data found in databases and spreadsheet programs and non-structured data found in textual documents and presentation graphics. These data are often of interest to GIS analysts and can be integrated into GIS-supported decision-making.

Figure 5 goes here

As mentioned, data comes in many forms: vector, raster, gridded elevation, textual, and spectral are most common. Form is important because, as with application file types that most managers are comfortable with (e.g., using spreadsheet files, database files, word processing files, etc.), only allowed file types operate within specific applications. Data accuracy refers to getting things right where “right” means correct in many different dimensions, as with resolution. Data accuracy most often refers to content correctness and locational correctness. Accuracy can be: content, horizontal, vertical, spectral, radiometric, and temporal. Another consideration is data resolution, which refers to the ability to discretely discriminate between objects in the area of view. As mentioned this can be thought of as how well something can be seen. It is important to note that there are many different types of resolution: spatial, spectral, radiometric, and temporal to name the most common.

Figure 6 goes here

Data sources are varied (Decker 2001). One way to classify data ingested into GIS and used for organizations’ operational activities is to consider the remotely or environmentally sensed data, which are often purchased from commercial geospatial data collection vendors (Althausen 2002) or are found in government, public, and other databases. Next are firm-specific operational data collected internally and finally industry-specific data procured from industry analysts and associations. Many of the data type or form and data accuracy issues are inimical to traditional business data, though we have considered these primarily on geospatial data terms. Figures 5 and 6 link the

decision process model with some of the data issues encountered within “decision processes”. Managers and analysts must always ask themselves, what data do I have already available? What data do I need to perform a certain analysis? And, what other sources of data exist so that I can augment what I have to satisfy what I need? In Figure 6, the inclusion of geospatial data in the decision process increases the sophistication of what can be accomplished, however, it also increases the complexity of issues, such as also being forced to consider data resolution.

DATA ISSUES FOR IMPROVED DECISION MAKING

Thinking specifically about GIS-oriented data types, raster data are organized arrays of data structured into regular cells such as pixels making up a satellite image or orthophoto (Decker 2001). Rasters are used to classify some set of one or more “real world” areas of features found within the area encompassed by the pixel boundaries. As each cell represents a unit of surface area (Ormsby, Napoleon et al. 2001), this requires that each cell or pixel assume the measured or estimated value of the most dominant soil, terrain, or vegetation feature found within it. The benefit of raster data is that the use of regions of pixels can easily be formed to represent regions of common characterization (e.g., soil or vegetation type) or activity (e.g., changes in land cover type, such as through construction of buildings, roads, etc., or in dynamic activities such fires, floods, etc.) Pixels and grid arrays come in many different sizes, known as resolution. If the pixel size is small (e.g., representing inches by inches of ground surface), this is not a problem; however, in the case of French SPOT imagery of 10-meter resolution or early Landsat

imagery of 30-meter resolution, pixels equal cells of 10 x 10 meters or 30 x 30 meters in size, respectively, which represent simplification of larger amounts of earth surface or surface-based activity that must nominally be represented as a single constant value within this relatively large space. Thus, depending on the ground sample distance, which translates to pixel size, a possible disadvantage of raster data is that of representing too coarse a degree of 'mapping' from the real world to the represented world. Another disadvantage is that the pixel is what the pixel is; what information one gets from viewing the raster pixel (or more realistically, the grouping of several raster pixels clustered together) is interpretive. That is, how well the GIS or other system codes the pixel and how well the analyst understands the coding of the pixel determine the limit of information that can be gleaned from the pixel. Common uses of rasters include map background displays upon which other data are overlaid. A principal benefit of rasters is to create various theme-based data layers, which can be stacked upon one another to integrate together different pieces of information. For example, raster displays often provide photo- or map-based backgrounds that analysts can easily identify with while more easily manipulated data such as vector data are overlaid to aid the analysis.

Vector data are mathematical representations of geographic objects, or other business-content objects having some geospatial meaning. Vector data are normally thought of as points, lines, and polygons. These data can be maintained in relational data tables and through the tools and applications commonly found in GIS can be used to create stand-alone vector displays or overlaid upon raster-based displays. Couclelis (1992) in Burrough and McDonnell (1998) said, "Objects in vector GIS may be counted, moved

about, stacked, rotated, colored, labeled, stuck together, viewed from different angles, shaded, inflated, shrunk, stored and retrieved, and in general, handled like a variety of everyday objects that bear no particular relationship to geography.” Vector data, as objects, can be stored in databases with various attributes, properties, and behaviors. For example, a stream (or a line segment in vector terms), drawn on a map display as a blue line, could be clicked to reveal an information table of stream attributes such as stream width, depth, bottom type, bank slope, bank height, current speed, average temperature, etc., which delivers far more information than could be displayed with a series of blue pixels or the photographed image of the stream in a raster display. An example of a vector object in a business context might be a wireless telephone company’s grid of points depicting each cell phone transmitter tower, such that each point that represented a single cell phone tower could be linked to an attribute table with technical information about the tower and its current status in the operation of the wireless telephone network. Ingested into an application linked to the GIS that models network performance, the phone company could model different hypothetical locations for the towers to increase network “up” time and signal strength to users who depend on a certain quality of service when selecting their wireless phone service provider.

Other GIS data include elevation data, which is normally represented as “z” values representing height or elevation in an x, y grid that locates these points on the surface of the earth, where “x” and “y” could be longitude and latitude, or other referencing scheme. Elevation models have been used extensively to add relief or 3-dimensionality to normal 2-dimensional map displays. This is often accomplished by “draping” raster or vector

layers over the top of wire-frame grid of x, y, and z points so that photos and maps are seen in their dimensional relief. This allows whole new classes of analyses and uses to emerge, including anything from airline pilot training simulations to the highly technical computer gaming and simulation industry. It is important to note that there is a big difference in computational processing power required and application complexity found between viewing a static 3-D image on a screen or using an application such as an interactive computer game or pilot's flight simulator that must render many rapidly changing versions of the view per minute. The essential concept is the integration of raster, vector, and elevation data for complex presentation to the viewer. Examples of textual data that may be used within GISs and benefit business applications include street addresses of a firm's customer, vendors, other suppliers, or competitors. Examples of numerical data ingested into GISs are values for things that have no intrinsic shape such as elevation, rainfall, temperature, slope, wind or current speed values, which relate to earth 'things' or business data such as sales volumes, which can be tied to business operations in a geographical place or region.

Figure 7 goes here

Earlier we discussed errors in analyses, with respect to organizational systems. The use of GIS and business data in decision-making necessitates a concern for data quality and errors induced into analyses from the source data. Evaluation paradigms become vital. Figure 7 considers two different evaluation paradigms for considering the data used in GIS analyses: data quality, which focuses on data accuracy and resolution, and

information utility, which extends data quality issues within a user's relevance context that also considers the source and form of the data as well as its intended use. We make a distinct difference between performing accuracy assessments or developing error matrices, and calculating the utility of the information content to the user.

An important point not yet addressed here are some of the uses these analyses and the supporting geospatial data. Rare is the field that cannot or does not benefit from GIS; shown here is partial list of fields using GIS technologies and output innovatively:

- Land management
- Telecommunications
- Agriculture
- Military operations
- Intelligence
- Transportation
- Law enforcement
- Recreation
- Marketing
- Operations
- Sales & retail
- Logistics

The focus of Figure 7 is the scope of the data quality paradigm and the broader scope of the information utility paradigm. See (Congalton and Green 1999; Congalton and Plourde 2002) for excellent treatment of accuracy issues and data quality. See (Meeks and Dasgupta 2003) for a detailed treatment of geospatial information utility.

EVALUATING THE VALUE OF GEOSPATIAL INFORMATION IN GIS

“Information is the substance from which managerial decisions are made,” (Forrester 1961, pg. 427), which drives the need for valuing information in organizations.

Information value is comprised of quantitative and qualitative aspects. Quantifying the value of information allows comparisons between the outcomes of organizational systems' performance or of decisions made with or without the "n-th" piece of information. Semantically describing information allows managers and researchers to understand the complex and integrated ways information contributes to competitive value or otherwise improves performance. Reichwald (1993), in Wigand et al. (1997), identifies three levels of information exchange: syntactic, semantic, and pragmatic. Information transmission occurs at the syntactic level. The semantic level adds meaning to the symbols transmitted. The pragmatic level adds sender's intention and receiver's use to the meaning and transmission of information. The ways in which businesses, organizations, and consumers interact and value information are being transformed. As business managers interact with GIS analysts and other geospatial professionals the full range of meaning to be derived from data and information of all types must be considered.

Lawrence (1999) provides a useful treatment of quantitative issues surrounding information value today. As managers are often concerned with resource allocation and financial performance, a current measure of the value of information is to calculate the dollar cost or benefit of using information within a decision-making context. This is called the value of the informed decision. Decision trees and expected value calculations are the staple of the value of the informed decision. Lawrence offers several models, primarily focused on treating value as a utility function. These useful methods are focused on decision-making outcomes. However, two common aphorisms are relevant:

‘the whole is greater than the sum of the parts’ and one familiar to engineers and social scientists: ‘tell me how you will measure me and I will tell you how I will perform.’ The information value literature mostly addresses the measurement of components of information. However, there is a dearth of literature addressing how to holistically value the contribution of information to the organization. Though Lawrence and others address utility, it is important to note that considering the ‘whole’ speaks to integrating diverse and complex types of information.

Modern decision-making, that is, analyze, decide, act, and evaluate occurs in very compressed cycle times. Perhaps a new information valuation schema should consider a jigsaw puzzle metaphor. The need for and the use of information is rarely so binary that one piece of information crosses the threshold for a managerial “eureka!” Effective decision-making relies on the collection and analysis of many disparate pieces of information. Some (like a puzzle’s edge and corner pieces) are easy to find and fit into context. The place (or ‘role’) of other puzzle pieces is not so readily apparent. Though the puzzle is not complete until all pieces are in place, by the time the puzzle is 80-90% complete, it becomes pretty clear what the final image will look like. Similarly, in organizations, not all ‘puzzle pieces’ are equal. It is precisely the unequal-ness that makes valuing information important: to be able to compare acquisition costs (sometimes known and often times unknown) against the presumed a priori benefits of collecting and using the targeted pieces of information to make decisions.

As the acquisition and use of information are costly, the optimal use of information involves economic tradeoffs. Therefore, valuing information is attracting research and

thought. However, till now, little attention has been paid to integrated information valuation within the geospatial information domain, which is increasingly coming to the attention of decision makers seeking to improve decision models by considering spatiotemporal factors. In earlier work (2003), we proposed a metric called Geospatial Information Utility (GeoIU) to allow decision makers to assess the degree of utility incurred for accessed geospatial data sets when making decisions that incorporate those geospatial data and information. The GeoIU metric uses multi-attribute utility theory to assess, score, and weight metadata queries run against geospatial data and information discovered in distributed sources. When using spatial and temporal information to improve decision making, attention must be paid to uncertainty and sensitivity issues (Crosetto and Tarantola 2001). Attention must also be paid to spatial and temporal scales relevant to the decision being supported (Pereira 2002) and to the quality and utility of available data, with respect to the intended use(s) of the data (Obermeier 2001). This last issue defines the core problem GeoIU addresses: that decision makers collect and use geospatial data of varying spatial and temporal scales in order to improve decision making, but that more attention needs to be paid to finding appropriate methods for assessing the utility of the geospatial data being used (Bruin, Bregt et al. 2001). Figure 8 restates the general systems model in terms of GIS processes.

Figure 8 goes here

It is often useful to broadly classify GIS and geospatial data users into two broad categories: (1) public-sector users and (2) private-sector and business users. Public-

sector users are primarily interested in public domain uses of geospatial and spatiotemporal data: for example, military planners may require highly accurate, very current digital data sets for planning flight routes for cruise missiles. Flight route planning requires digital elevation models to support terrain contour matching algorithms within the missiles' guidance modules. To optimally employ so-called "smart weapons" such as these, planners and targeteers must have access to current, high quality digital data sets with minimal horizontal and vertical accuracy errors. In order to reduce operational risk in the development of missile flight routes based on new digital geospatial data sets, the 'pedigree' or quality of the supporting data must be assessed (Johnson, Watts et al. 2001). Many other public sector uses of GIS and geospatial data abound: fuel modeling to predict and prevent wildfires, cadastral records and land tax planning, information visualization of municipal government services via web-based GIS applications, and many more. Each of these uses of geospatial data has different requirements for data accuracy, currency, and form; some applications have stringent requirements and others less so.

Business users are primarily interested in commercial or business intelligence analyses of geospatial data and information. These users may also have varying needs for highly accurate and current data sets: for example, wireless telephone service planners may employ GIS technologies and data analyses in order to determine optimal site locations of a new array of digital wireless telephone signal towers. Their analyses might focus on making maximum use of both send and receive signal strengths vis-à-vis local terrain limitations (e.g., received signal strength is a function of transmitted power, number and

locations of transmitter towers, radio frequency line-of-sight obstacles, etc.) in order to minimize the number of towers needed while providing a guaranteed quality of service for their wireless telephone subscribers; using fewer, well placed towers may mean lower operating costs and higher operating margins. Similar to the missile flight route problem, a wireless telephone tower location analysis based on geospatial data of poor or uncertain quality is subject to errors, which may roll through the calculations, quite possibly resulting in improperly located towers, reduced systems performance, higher installation and operations and maintenance costs, and unhappy customers.

As successful and useful analyses depend on many factors, including data quality and data accuracy in many forms, it is important the growing field of GIS users has adequate mechanisms to evaluate the relevance of their data to their analyses. As shown in Figure 9, GeoIU tools can be used as a “filter” between data sources and analytical engines and processes to give analysts and decision-makers insight into the uncertainty they face.

Figure 9 goes here

Aircraft- or satellite-based multi-spectral imaging (MSI) sensors have improved our understanding of the earth’s surface and human activities on it (Lillesand and Kiefer 2000). Depending on the resolution of the image, electro-optical (EO) (i.e., photographic) imagery of a stand of trees on a plot of land may or may not permit general classification of tree type. This question, and these sources of spatial information, may be pertinent to several types of decision makers. For example, local tax assessors may

care about land use classification for tax purposes (Montgomery and Schuch 1993), forest rangers may care about tree, vegetation, and soil types and moisture contents to perform predictive fire-fuel modeling (Burrough and McDonnell 1998), a paper company may care about assessing the density and maturity of certain tree types for determining the readiness of the harvest of a particular tract. The predominant tree types within a given image pixel would dictate how that pixel would be coded or classified. With the advent of early MSI sensors, such as NASA's LANDSAT-series, capable of imaging in seven spectral bands and displaying results on false-color images using three user-selected bands, greater understanding of the earth's surface became possible. From EO's one visible band to MSI's seven spectral bands, forest rangers using GIS and MSI data are able to interpret soil moisture or hardness, as well as more complete and accurate classification of the trees mentioned above. Newer hyper-spectral imagery (HIS) sensors sense the earth in 200+ bands, providing finer (i.e. narrower) resolution represented by narrower 'slices' of the electromagnetic spectrum. This dramatic increase in spectral resolution is being accompanied with increases in spatial resolution (i.e., how clearly things can be seen) and accuracy (i.e., how correctly things can be located).

LOOKING INTO THE FUTURE

Sensing as a means of generating source data to feed business and organizational information processors: humans are thought to sense in five or more dimensions: sight, hearing, taste, smell, touch. In phenomenology-based sensing, we can think of sight as supported by the many forms of imagery: electro-optical (EO) visual images, radar

images, motion video, moving target indicator (MTI), light detection and ranging (LIDAR/LADAR), etc. Similarly, hearing can be thought of as acoustic sensing and electronic or signals intercepts sensing; smell is represented as olfactory biological and chemical remote sensing; and touch is represented by seismic sensing and thermal sensing in many forms. The human sense taste seems to have no analog in the remote sensing world; however, there are other technical sensing phenomenologies that have no direct human analog either, such as magnetic measurement and signatures.

Not only are emerging and continually evolving technologies improved and exploited to expand data collection capabilities, but these order of magnitude increases in capabilities can be and are being translated into the data processing realm as well. For example, a highly integrated multi-disciplinary approach (called Multi-Intelligence, or “Multi-INT”) is being refined within a military/national security/national intelligence context. This Multi-INT approach represents a highly focused degree of integration of the different collection ‘senses’ (remember this represents as many as 15 different forms of sensing versus the five that a human uses). The point is that order of magnitude increases in information richness (i.e., number, quality, and completeness of feature or entity attributes) and information accuracy (i.e., including spatial location accuracy and content accuracy), collected and analyzed dynamically over time are possible.

What was once the domain of GIS specialists is now falling into the realm of business managers who want to develop new decision-making constructs to improve their organization’s strategic and tactical tempo of activities and performance within their

respective industries. It is not necessarily the sources of spatiotemporal data (e.g., remotely sensed satellite imagery) that are critical—though they are becoming more and more useful in all sectors—but it is the uses of these data that are important and bear watching. This leads us to the conclusion that GIS is able to support business and improve managerial decision making on several levels.

At the first level, GIS answers space and time questions. At the next level, GIS allows analysts, managers and decision makers to think differently about what constitutes useful data in evolving decision-making models. This includes admitting that heretofore-unused data sources (including remote sensing sources) may improve decision-making. At this same level of complexity GIS allows analysts, managers, and decision makers to think differently in their current decision making processes and to adjust these processes to accommodate the new reality of GIS. The evolving field of information visualization supports and is supported by advances in GIS. Incorporating GIS in decision-making forces managers and others to decide what they want to see and how they want to see it. Finally, at the most sophisticated level of GIS integration, using GIS permits managers to inculcate within their organizations a spatially- and temporally-oriented mindset. Analysts, managers, and decision makers who have developed a spatiotemporal mindset look at their problems, processes, input data and output needs completely differently. And this may be the greatest benefit GIS provides business managers: the help them to see their problems and solutions differently so that they may solve their problems more effectively.

SUMMARY

This chapter encourages managers and decision makers in non-earth sciences organizations to consider using GIS to improve decision-making. We feel there are several innovative ways GIS can help make these improvements. As identified in Introduction with the “Three themes to carry away”, we believe:

- GIS can improve organizational decision making through the awareness that all business decisions include space and time components. The benefit is that thinking spatiotemporally provides additional analytical approaches and methods.

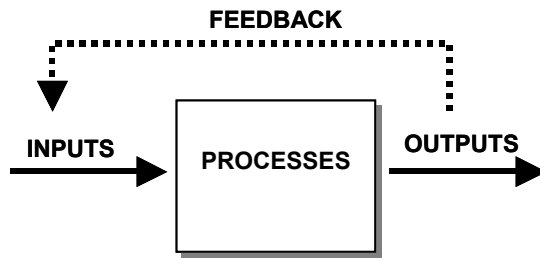
- GIS use both business data and remotely sensed data. An awareness of the power of the different forms and sources of remotely sensed data and the ways their integration can transform organizational notions about how and where to collect business data helps improve both GIS-based and non-GIS based decision making.

- Accessing many different data sources and types imply challenges with using these data; these challenges include determining the quality of the data ingested, manipulated and outputted; and equally as importantly, determining the utility and relevance of the ingested and outputted data and information as they pertain to the result of the final decision or action.

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FIGURES

Figure 1. A General Systems Model

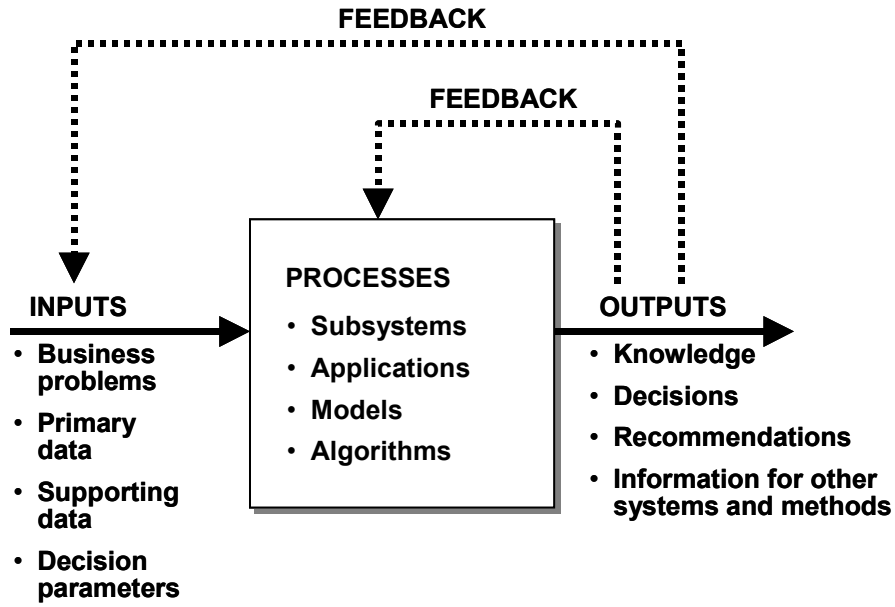


Figure 2. The General Systems Model Applied to Decision Making

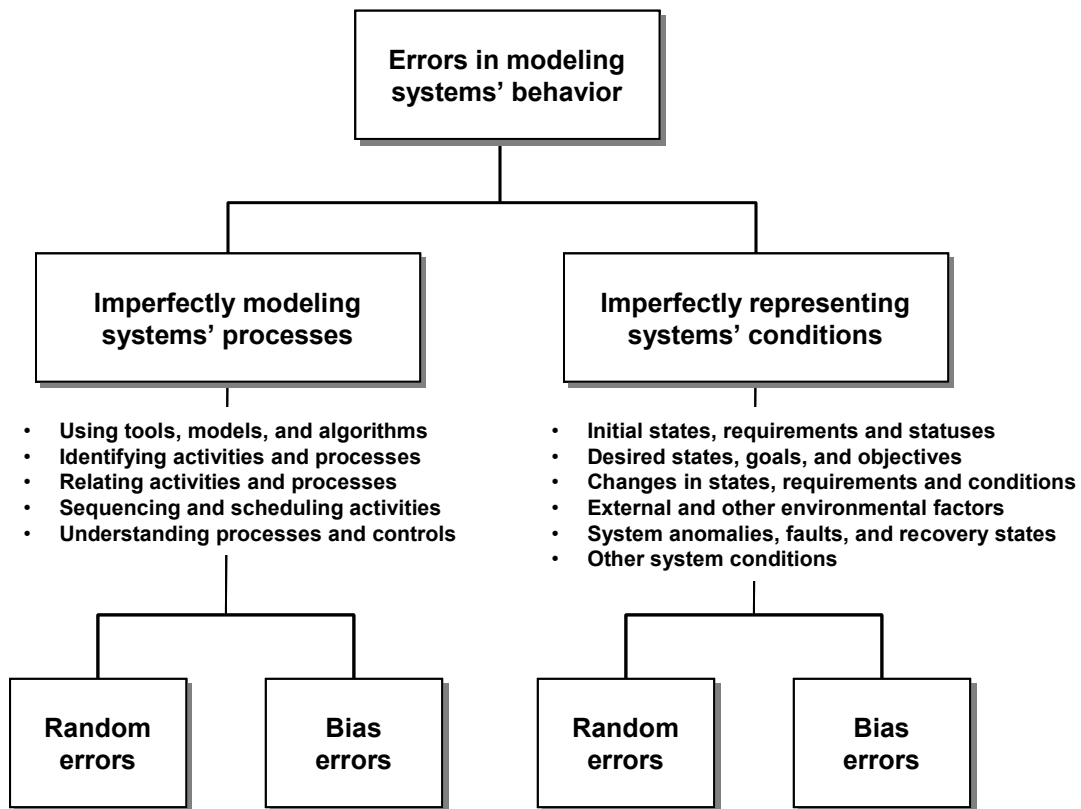


Figure 3. Understanding Sources of Errors in Organizational Systems

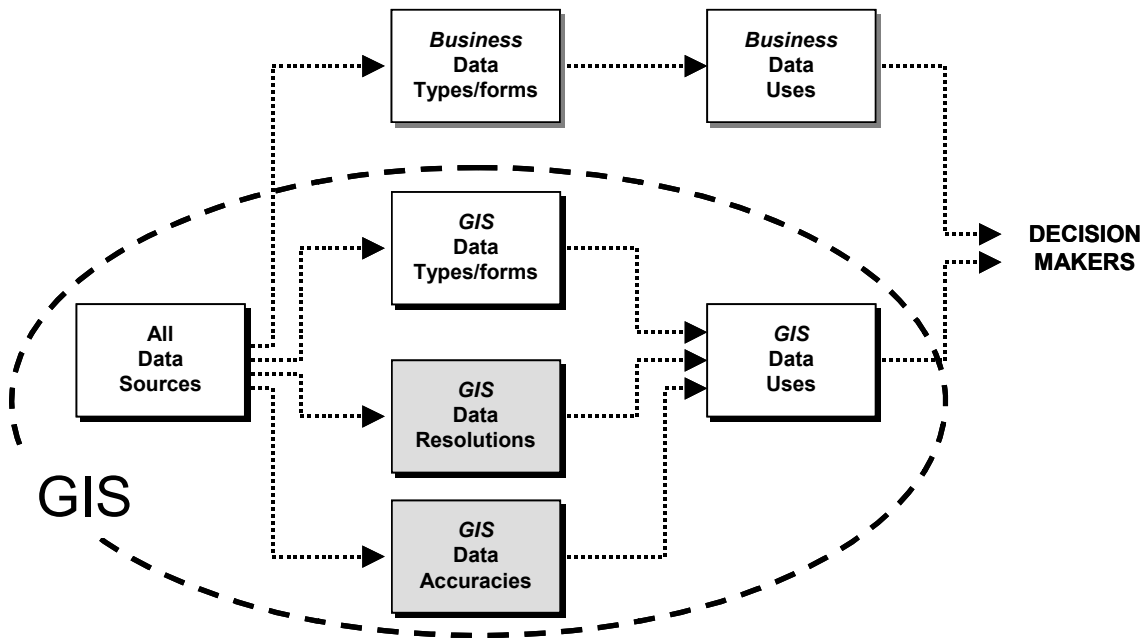


Figure 4. Considering Different Aspects of Geospatial Data in GIS

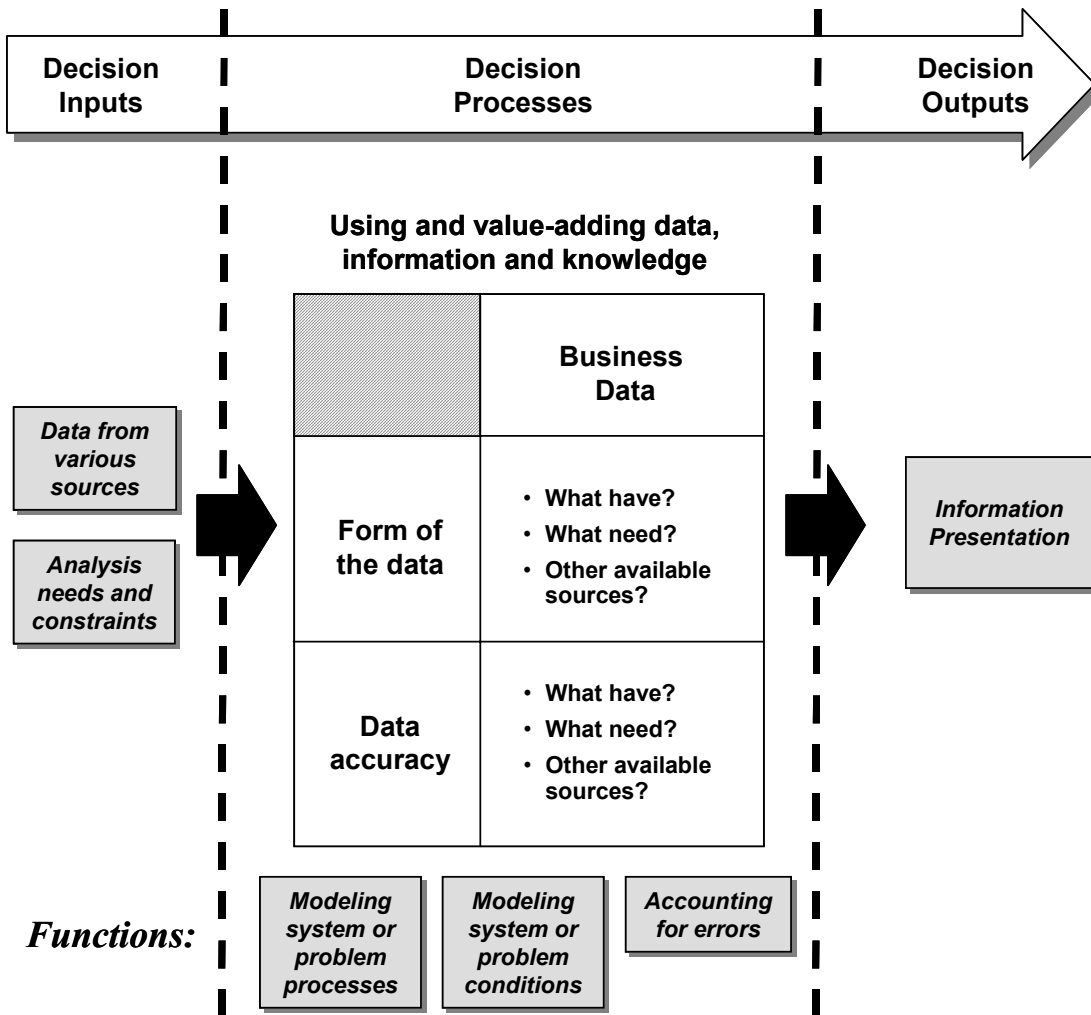


Figure 5. Considering Data Issues in Business Analyses

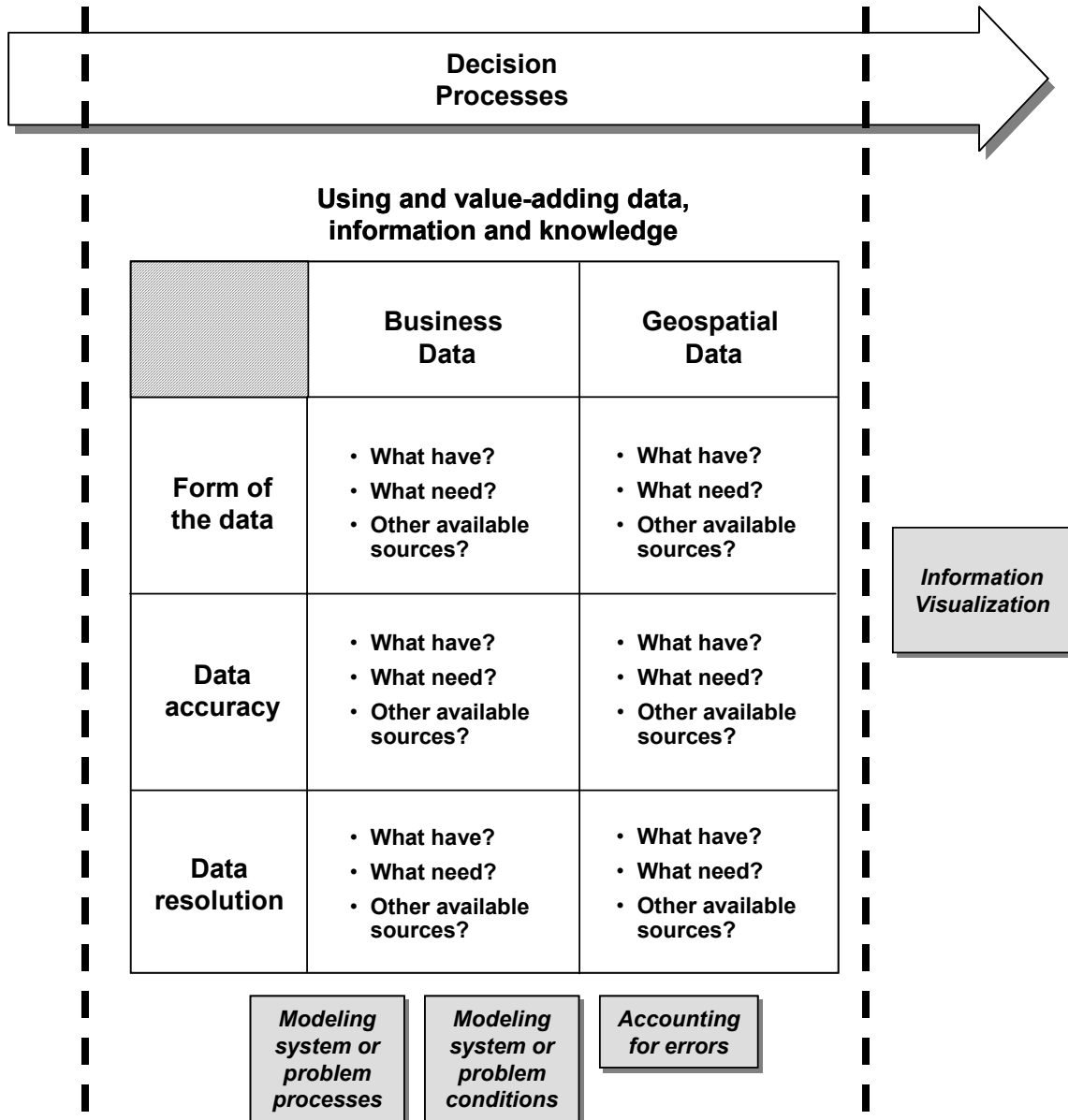


Figure 6. Combining Geospatial and Business Data

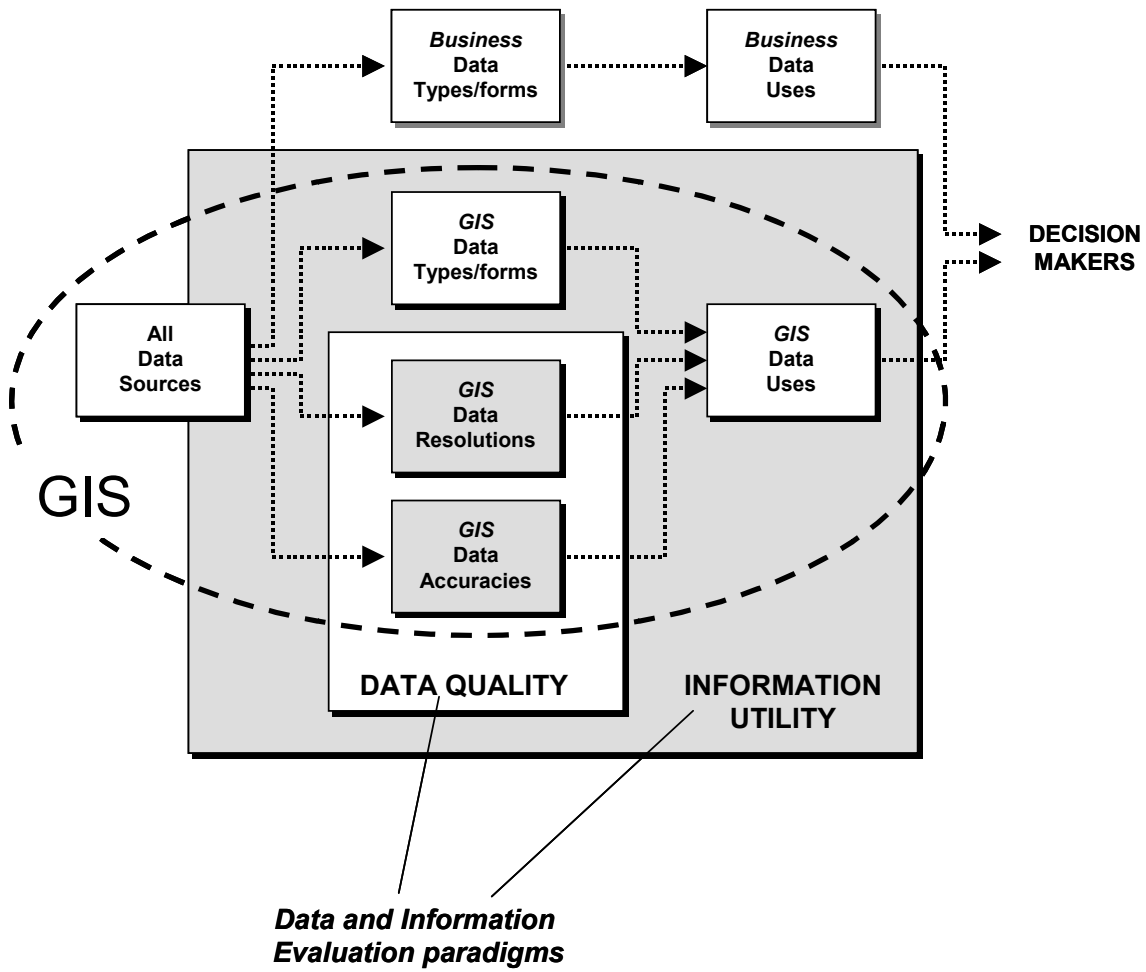


Figure 7. Considering Evaluation Paradigms for Geospatial Data in GIS

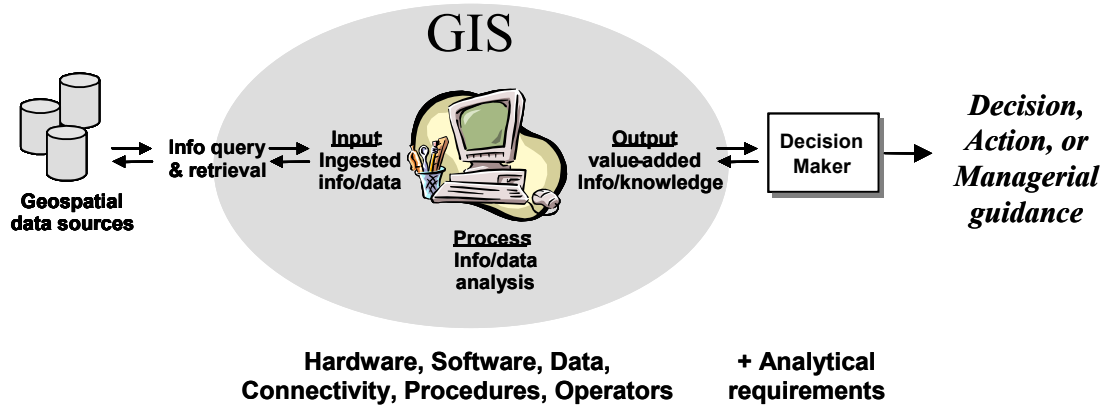


Figure 8. A Simplified Model of GIS as a System Supporting Decision Making

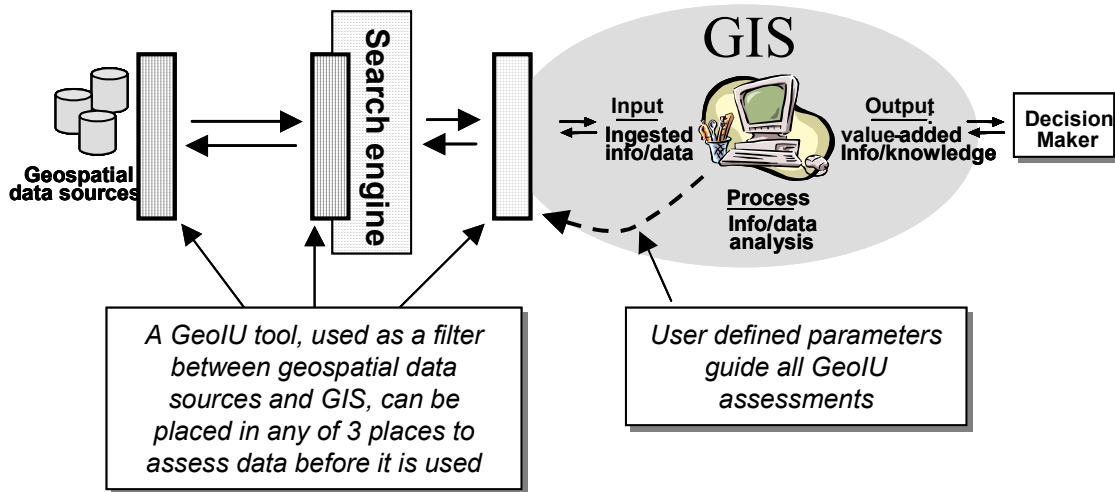


Figure 9. Assisting the GIS Process with Utility Assessments from GeoIU