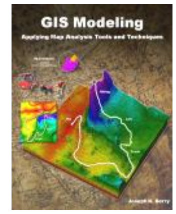
Beyond Mapping IV



GIS Modeling book

Topic 5 – Structuring GIS Modeling Approaches (Further Reading)

Explore the Softer Side of GIS — *describes a Manual GIS (circa 1950) and the relationship between social science conceptual* *(January 2008)*

Use Spatial Sensitivity Analysis to Assess Model Response — *develops an approach for assessing the sensitivity of GIS models* *(August 2009)*

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Explore the Softer Side of GIS

(GeoWorld, January 2008)

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While computer-based procedures supporting Desktop Mapping seem revolutionary, the idea of linking descriptive information (What) with maps (Where) has been around for quite awhile. For example, consider the manual GIS that my father used in the 1950s outlined in figure 1.

The heart of the system was a specially designed index card that had a series of numbered holes around its edge with a comment area in the middle. In a way it was like a 3x5 inch recipe card, just a little larger and more room for entering information. For my father, a consulting forester, that meant recording timber stand information, such as area, dominant tree type, height, density, soil type and the like, for the forest parcels he examined in the field (What). Aerial photos were used to delineate the forest parcels on a corresponding map tacked to a nearby wall (Where).

What went on between the index card and the map was revolutionary for the time. The information in the center was coded and transferred to the edge by punching out (notching) the appropriate numbered holes. For example, hole #11 would be notched to identify a Douglas fir timber stand. Another card would be notched at hole #12 to indicate a different parcel containing ponderosa pine. The trick was to establish a mutually exclusive classification scheme that corresponded to the numbered holes for all of the possible inventory descriptors and then notch each card to reflect the information for a particular parcel.

Cards for hundreds of timber stands were indiscriminately placed in a tray. Passing a long needle through an appropriate hole and then lifting and shaking the stack caused all of the parcels with a particular characteristic to fallout— an analogous result to a simple SQL query to a digital database. Realigning the subset of cards and passing the needle through another hole then shaking would execute a sequenced query—such as Douglas fir (#11) AND Cohasset soil (#28).

The resultant card set identified the parcels satisfying a specific query (What). The parcel ID# on each card corresponded to a map parcel on the wall. A thin paper sheet was placed over the base map and the boundaries for the parcels traced and color-filled (Where)—a "database-entry geo-query." A "map-entry geo-query," such as identifying all parcels abutting a stream was achieved by viewing the map, is achieved by noting the parcel ID#'s on the map and searching with the needle to subset the abutting parcels to get their characteristics.

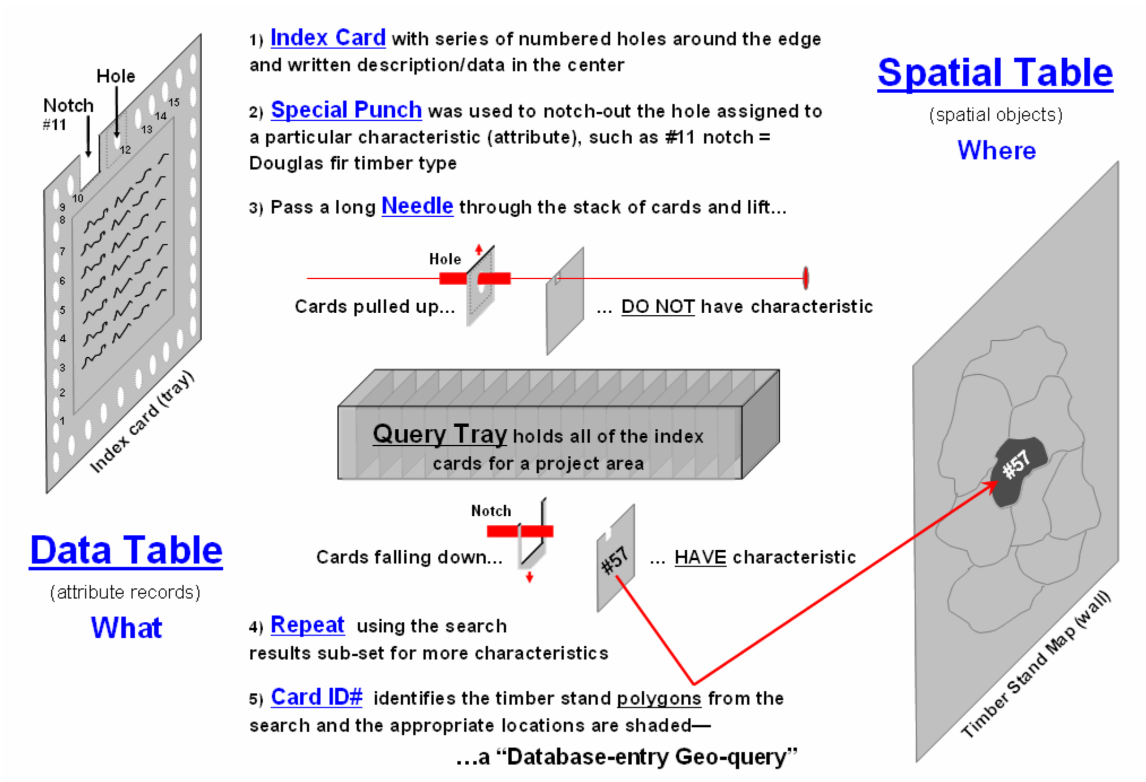

Figure 1. Outline of the processing flow of a manual GIS, circa 1950.

The old days wore out a lot of shoe leather running between the index card tray and the map tacked to the wall. Today, it's just electrons scurrying about in a computer at gigahertz speed. However, the bottom line is that the geo-query/mapping approach hasn't changed substantially—linking "What is Where" for a set of pre-defined parcels and their stored descriptors. But the future of GIS holds entirely new spatial analysis capabilities way outside our paper map legacy.

Figure 2 graphically relates the softer (human dimensions) and harder (technology) sides of GIS. The matrix is the result of musing over some things lodged in my psyche years ago when I was a grad student (see Author's Note 1). Last month's column (December 2007) described the Philosopher's Levels of **Understanding** (first column) that moves thinking from descriptive *Data*, to relevant *Information*, to *Knowledge* of interrelationships and finally to prescriptive *Wisdom* that forms the basis for effective decision-making. The dotted horizontal line in the progression identifies the leap from visualization and visceral interpretation in GeoExploration of Data and Information to the map analysis ingrained in GeoScience for gaining Knowledge and Wisdom for problem solving.

	Human Dimensions' Framework		Technology's Expression	
	Philosopher's Levels of **Understanding**	*Cognitive Levels of* **Judgment**	**Map Types**	**Spatial Processing**
Prescription ← *Increasing Abstraction* — Description	**Data** – all facts	**Facts** – Earth circumference is 24,900 mi – Britney Spears was born 12/2/1981 – Britney Spears is 26 years old – the temperature is 32° F :	**Base** – measured features, conditions and characteristics (fact)	**Collect** – direct acquisition of primary information (e.g. elevation)
	Information – facts within a context	**Relevant Facts** – the temperature is 32° F	**Derived** – inferred conditions and characteristics (implied fact)	**Calculate** – uses algorithms to derive secondary information (e.g., slope)
	Knowledge – interrelationships among relevant facts	**Perception** – it sure is cold (Floridian) – it's not cold (Alaskan)	**Interpreted** – adjusted to reflect expertise and presumption (judgment)	**Calibrate/Weight** – translates information into relative scales (preference & importance)
	Wisdom – actionable knowledge	**Opinions/Values** – I hate this weather (Floridian) – I love this weather (Alaskan)	**Modeled** – potential solution within model logic and expression (conjoined judgment)	**Simulate** – "what if" investigation of alternative scenarios (multiple perspectives)

Figure 2. Conceptual framework for moving maps from Description to Prescription application.

The second column extends the gradient of Understanding to the stark reality of **Judgment** that complicates most decision-making applications of GIS. The basic descriptive level for *Facts* is analogous to that of Data and includes things that we know, such as the circumference of the earth, Brittney Spears' birth date, her age and today's temperature. *Relevant Facts* correspond to Information encompassing only those facts that pertain to a particular concern, such as today's temperature of 32^{o}F.

It is at the next two levels that the Understanding and Judgment frameworks diverge and translate into radically different GIS modeling environments. Knowledge implies certainty of relationships and forms the basis of science—discovery of scientific truths. The concept of *Perception*, however, is a bit mushier as it involves beliefs and preferences based on experience, socialization and culture—development of perspective. For example, a Floridian might feel that 32^{o} is really cold, while an Alaskan feels it certainly is not cold, in fact rather mild. Neither of the interpretations is wrong and both diametrically opposing perceptions are valid.

The highest level of *Opinion/Values* implies actionable beliefs that reflect preferences, not universal truths. For example, the Floridian might hate the 32^{o} weather, whereas the Alaskan loves it. This stark dichotomy of beliefs presents a real problem for many GIS technologists as the bulk of their education and experience was on the techy side of campus, where mapping is defined as precise placement of physical features (description of facts). But the other side of campus is used to dealing with opposing "truths" in judgment and sees maps as more fluid, cognitive drawings (prescription of relationships).

The columns on the right attempt to relate the dimensions of Understanding and Judgment to **Map Types** and **Spatial Processing** used in prescriptive mapping. The descriptive levels are well known to GIS'ers—*Base* maps from field *collected* data (e.g., elevation) and *Derived* maps *calculated* by analytical tools (e.g., slope from elevation).

Interpreted maps, on the other hand, *calibrate* Base/Derived map layers in terms of their perceived impact on a spatial solution. For example, gentle slopes might be preferred for powerline routing (assigned a value of 1) with increasing steepness less preferred (assign values 2 through 9) and very steep slopes prohibitive (assign 0). A similar preference scale might be calibrated for a preference to avoid locations of high Visual Exposure, in or near Sensitive Areas, far from Roads or having high Housing Density. In turn, the model criteria are *weighted* in terms of their relative importance to the overall solution, such as a homeowner's perception that Housing Density and Visual Exposure preference ratings are ten times more important than Sensitive Areas and Road Proximity ratings (see Author's Note 2).

Interpreted maps provide a foothold for tracking divergent assumptions and interpretations surrounding a spatially dependent decision. *Modeled* maps put it all together by *simulating* an array of opinions and values held by different stakeholder groups involved with a particular issue, such as homeowners, power companies and environmentalists concerns about routing a new powerline.

The *Understanding* progression assumes common truths/agreement at each step (more a natural science paradigm), whereas the *Judgment* progression allows differences in opinion/beliefs (more a social science paradigm). GIS modeling needs to recognize and embrace both perspectives for effective spatial solutions tuned to different applications. From the softer side perspective, GIS isn't so much a map, as it is the change in a series of maps reflecting valid but differing sets of perceptions, opinions and values. Where these maps agree and disagree becomes the fodder for enlightened discussion, and eventually an effective decision. Judgment-based GIS modeling tends to fly in the face of traditional mapping— maps that change with opinion sound outrageous and are radically different from our paper map legacy and the manual GIS of old. It suggests a fundamental change in our paradigm of maps, their use and conjoined impact— are you ready?

Author's Notes: *1) Ross Whaley, Professor Emeritus at SUNY-Syracuse (and member of my doctoral committee) in a plenary presentation at the New York State GIS Conference outlined the cognitive levels of judgment, described how they impact natural resource decision-making and commented on spatial information's role in the mix. His remarks rekindled a flurry of thoughts from social science courses and late night discussions that continue to haunt my overly technical emersion in GIS technology. Figure 2 ties together some of these "softer science" musings on the critical challenges face GIS as it crosses the chasm from descriptive to prescriptive applications—thank you to Jim Smith, Perry Brown, Al Dyer, Evan Vlachos and the cauldron of thinking at Colorado State University in the 1970s. 2) Related discussion on the softer side of GIS is in Topics 7 and 8 in the* Map Analysis *book (Berry, 2007;*

*GeoTec Media, **www.geoplace.com/books/MapAnalysis**) and Topics 19 and 23 in the online Beyond Mapping III compilation (**www.innovativegis.com/basis/MapAnalysis**).*

Use Spatial Sensitivity Analysis to Assess Model Response

(GeoWorld, August 2009)

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Sensitivity analysis …sounds like 60's thing involving a lava lamp and a group séance shrouded in a semi-conscious fog attempting to make one more sensitive to others. Spatial sensitivity analysis is kind of like that, but less Kumbaya and more quantitative investigation into the sensitivity of a model to changes in map variable inputs.

The Wikipedia defines *Sensitivity Analysis* as "the study of how the variation (uncertainty) in the output of a mathematical model can be apportioned to different sources of variation in the input of a model." In more general terms, it investigates the effect of changes in the inputs of a model to the induced changes in the results.

In its simplest form, sensitivity analysis is applied to a static equation to determine the effect of input factors, termed scalar parameters, by executing the equation repeatedly for different parameter combinations that are randomly sampled from the range of possible values. The result is a series of model outputs that can be summarized to 1) identify factors that most strongly contribute to output variability and 2) identify minimally contributing factors.

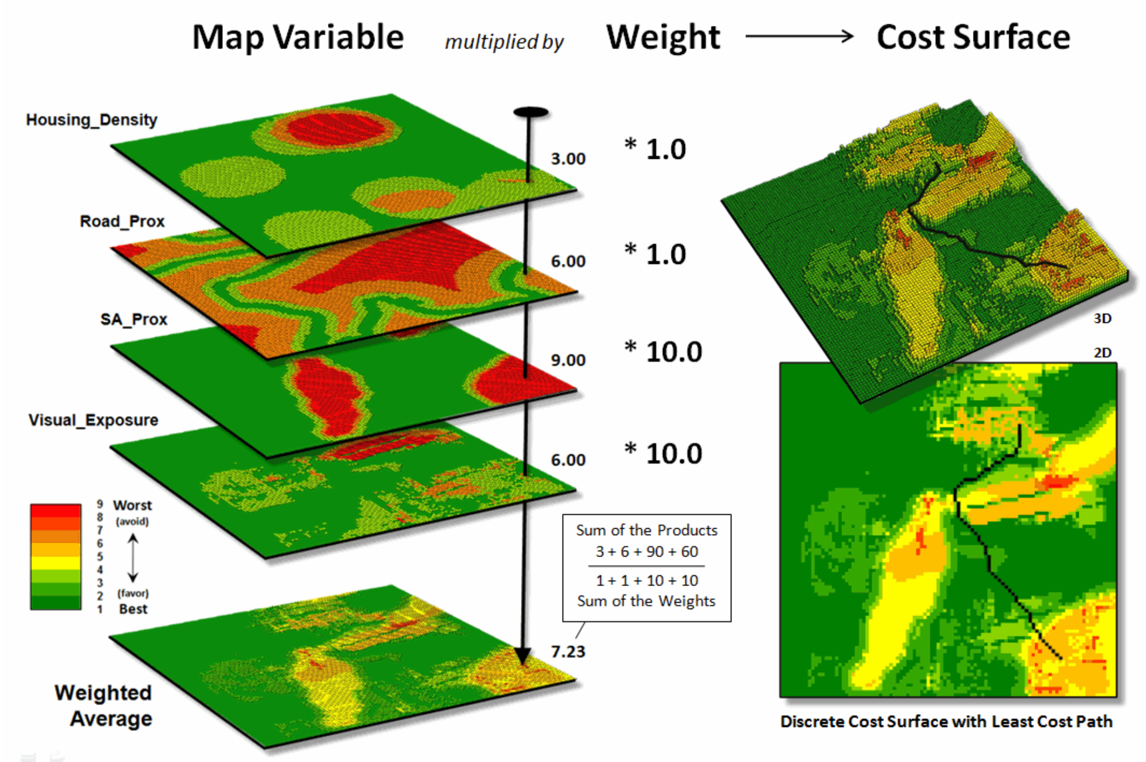

Figure 1. Derivation of a cost surface for routing involves a weighted average of a set of spatial considerations (map variables).

As one might suspect, spatial sensitivity analysis is a lot more complicated as the geographic arrangement of values within and among the set of map variables comes into play. The unique spatial patterns and resulting coincidence of map layers can dramatically influence their relative importance— a spatially dynamic situation that is radically different from a static equation. Hence a less robust but commonly used approach systematically changes each factor one-at-a-time to see what effect this has on the output. While this approach fails to fully investigate the interaction among the driving variables it provides a practical assessment of the relative influence of each of the map layers comprising a spatial model.

The left side of figure 1 depicts a stack of input layers (map variables) that was discussed in the previous discussions on routing and optimal paths. The routing model seeks to avoid areas of 1) high housing density, 2) far from roads, 3) within/near sensitive environmental areas and 4) high visual exposure to houses. The stack of grid-based maps are calibrated to a common “suitability scale” of 1= best through 9= worst situation for routing an electric transmission line.

In turn, a “weighted average” of the calibrated map layers is used to derive a *Discrete Cost Surface* containing an overall relative suitability value at each grid location (right side of figure 1). Note that the weighting in the example strongly favors avoiding locations within/near sensitive environmental areas and/or high visual exposure to houses (times 10) with much less concern for locations of high housing density and/or far from roads (times 1).

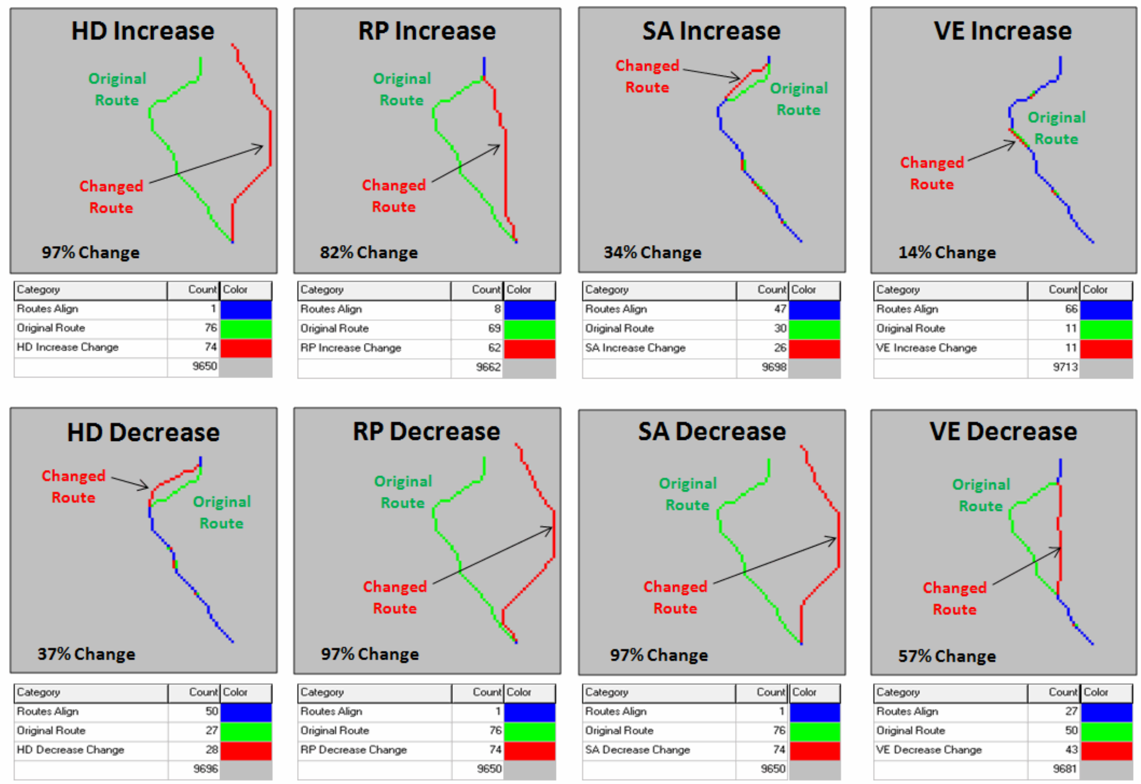

Figure 2. Graphical comparison of induced changes in route alignment (sensitivity analysis).

The routing algorithm then determines the path that minimizes the total discrete cost connecting a starting and end location. But how would the optimal path change if the relative importance weights were changed? Would the route realign dramatically? Would the total costs significantly increase or decrease? That's where spatial sensitivity analysis comes in.

The first step is to determine a standard unit to use in inducing change into the model. In the example, the average of the weights of the base model was used—1+1+10+10= 22/4= 5.5. This change value is added to one of the weights while holding the other weights constant to generate a model simulation of increased importance of that map variable.

For example, in deriving the sensitivity for an increase in concern for avoiding high housing density, the new weight set becomes HD= 1.0 + 5.5= 6.5, RP= 1.0, SA= 10.0 and VE= 10.0. The top-left inset in figure 2 shows a radical change in route alignment (97% of the route changed) by the increased importance of avoiding areas of high housing density. A similar dramatic change in routing occurred when the concern for avoiding locations far from roads was systematically increased ($RP_{increase}$= 82% change). However, similar increases in importance for avoiding sensitive areas and visual exposure resulted in only slight routing changes from the original alignment ($SA_{increase}$= 34% and $VE_{increase}$=14%).

The lower set of graphics in figure 2 show the induced changes in routing when the relative importance of each map variable is decreased. Note the significant realignment from the base route for the road proximity and sensitive area considerations ($RP_{decrease}$= 97% and $SA_{decrease}$=97%); less dramatic for the visual exposure consideration ($VE_{decrease}$= 57%); and marginal impact for the housing density consideration ($HD_{decrease}$= 37%). An important enhancement to this summary technique beyond the scope of this discussion calculates the average distance between the original and realigned routes (see author's note) and combines this statistic with the percent deflection for a standardized index of spatial sensitivity.

Map Variable	Original Weight Set	Increased Weight Set	Alignment Change *(percent)*	Total Cost Change *(percent)*
Housing Density	**1.0**	***6.5*** , 1.0, 10.0, 10.0	(74/76 * 100)= **97%**	(197/165 * 100)= **119%**
Road Proximity	**1.0**	1.0, ***6.5*** , 10.0, 10.0	(62/76 * 100)= **82%**	(200/165 * 100)= **121%**
Sensitive Area Proximity	**10.0**	1.0, 1.0, ***15.5*** , 10.0	(26/76 * 100)= **34%**	(168/165 * 100)= **102%**
Visual Exposure	**10.0**	1.0, 1.0, 10.0, ***15.5***	(11/76 * 100)= **14%**	(166/165 * 100)= **101%**
Average Weight	***5.5***		*Original route length= 76*	*Original route cost= 165*

Map Variable	Original Weight Set	Decreased Weight Set *(standardized*)*	Alignment Change *(percent)*	Total Cost Change *(percent)*
Housing Density	**1.0**	***1.0*** , 6.5, 15.5, 15.5	(60/76 * 100)= **37%**	(169/165 * 100)= **102%**
Road Proximity	**1.0**	6.5, ***1.0*** , 15.5, 15.5	(62/76 * 100)= **97%**	(182/165 * 100)= **110%**
Sensitive Area Proximity	**10.0**	1.0, 1.0, ***4.5*** , 10.0	(26/76 * 100)= **97%**	(197/165 * 100)= **119%**
Visual Exposure	**10.0**	1.0, 1.0, 10.0, ***4.5***	(11/76 * 100)= **57%**	(188/165 * 100)= **114%**
Average Weight	***5.5***		*Original route length= 76*	*Original route cost= 165*

**To avoid negative/zero weight, a constant shift (5.5) was added to HD (-4.5) and RP (-4.5) calculations to adjust to 1.0 as lowest weight value*

Figure 3. Tabular Summary of Sensitivity Analysis Calculations.

Figure 3 is a tabular summary of the sensitivity analysis calculations for the techy-types among us. For the rest of us after the "so what" big picture, it is important to understand the sensitivity of any spatial model used for decision-making—to do otherwise is to simply accept a mapped result as a "pig-in-a-poke" without insight into its validity nor an awareness of how changes in assumptions and conditions might affect the result.

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Author's Note: *For a discussion of "proximal alignment" analysis used in the enhanced spatial sensitivity index, see the online book Map Analysis, Topic 10, Analyzing Map Similarity and Zoning (www.innovativegis.com/basis/MapAnalysis/).*

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