

GIS and
Multicriteria Decision
Analysis

REDLANDS INSTITUTE

Glossary

Additivity: variables (criteria) have the property of additivity if they have no mutual effect or interaction on each other.

Algorithm: a set of rules for solving a problem.

Analytic hierarchy process (AHP): an approach to multiattribute decision making based on the concept of pairwise comparisons.

Attribute: (1) a measurable quantity or quality associated with an object (point, line, polygon, raster) in a GIS; (2) information source available to the decision maker for formulating and achieving his or her objectives.

Bayesian theory: an extension of classical probability theory; formal procedure for revising currently held (prior) probabilities in the light of additional information; it is used primarily for the evaluation of the relationship between empirical evidence and one's beliefs about a problem under consideration.

Binary map: an attribute map that contains only two possible values of the attribute: presence (1) or absence (0).

Binary variable: a variable that takes on a value of 0 or 1.

Boolean operations: a logical combinatorial system based on Boolean algebra; the operations include AND, OR, XOR (exclusive OR), IMP (implication), EQV (equivalence), and NOT; the most commonly used operations in geographic analysis are AND (intersection) and OR (union).

Buffer: a zone of specified distance around an object (point, line, or area).

Cartesian coordinates: a two-dimensional coordinate system in which x measures horizontal distance and y measures vertical distances.

Cartographic modeling: a procedure combining individual GIS operations to build complex models for spatial analysis.

Cell: (1) the basic element of spatial information in a grid (raster) data set; (2) a single value in a database (or spreadsheet) defined by intersecting a row or record with a field or column.

Choice: a phase of decision making in which choice among alternatives is made.

Compensatory decision rule: a multicriteria decision making that allows trade-offs between criteria.

Compromise programming: a multiobjective decision-making method based on the displaced ideal concept; it assumes that choice among alternatives depends on the point of reference that is used (e.g., ideal point) and attempts to minimize the "distance" between alternatives and the reference point.

Concordance methods: a class of multiattribute decision methods based on a pairwise comparison of alternatives; the basic elements of the concordance methods are the concordance and discordance measures; a wide variety of formulas are available to calculate the overall score for each alternative on the basis of the two measures; the simplest approach is to calculate the overall score for each alternative as the sum of the concordance indices.

Concordance set: the set of all criteria for which an alternative is not worse than the competing alternative.

Conjunctive screening: a noncompensatory screening method that selects the alternatives that meet the specified cutoff values on all evaluation criteria.

Connectivity: a topological property of lines and nodes being linked or attached to each other, typically pertaining to infrastructure networks such as utility and transportation systems.

Constraint: a restriction that rules out certain combinations of decision variables as feasible solutions; the constraints are used to eliminate from consideration points, lines, polygons, and/or rasters that are characterized by certain attributes and/or certain values of attributes.

Constraint map: a map layer in the GIS database representing the set of feasible alternatives.

Correlation: a method for establishing the strength of the statistical relationship between a dependent variable and one or more independent variables.

Coupling: a measure of the degree to which functions in one software package can be controlled directly from another.

Criterion: the standard of judgment or rules on the basis of which the alternative decisions are ranked according to their desirability; a generic term including both the concepts of attribute and objective.

Criterion map: a map layer in the GIS database representing the spatial distribution of an attribute that measures the degree to which its associated objective is achieved; criterion maps are categorized into deterministic, probabilistic, and fuzzy.

Database: a collection of interrelated sets of data that is stored in a computer information system to serve one or more applications.

Database management system (DBMS): a collection of computer programs that allow for organizing and using data stored in a database.

Data envelopment analysis (DEA): a methodology for analyzing the relative efficiency of several decision-making units or alternatives; the hypothesis underlining DEA is that multiple, incommensurate inputs in a given spatial

unit (decision alternatives) generate multiple, incommensurate outputs in that unit; the unit's efficiency is measured as a ratio of a weighted sum of the outputs to a weighted sum of the inputs; the units under consideration are evaluated according to the efficiency measures.

Data interchange: the process of converting existing digital data into the data structure and file format used internally by a GIS.

Data map layer: a logical set of thematic data described and stored in a GIS database.

Data sharing: the use of data already generated by a third party such as federal and state agencies.

Decision: a choice among alternatives.

Decision alternatives: a set of courses of action among which the decision maker must choose; an alternative is specified completely by defining the values of associated decision variables.

Decision analysis: a set of systematic procedures for analyzing complex decision problems; the basic strategy is to divide the decision problem into small, understandable parts, analyze each part, and integrate the parts in a logical manner to produce a meaningful solution.

Decision making: the process of defining a problem and its environment, identifying alternatives, evaluating alternatives, selecting an alternative, and implementing the decision.

Decision matrix: a convenient framework in which to present the elements of decision making; the matrix contains the decision outcomes for a set of alternatives and a set of evaluation criteria.

Decision outcome space: a set of decision consequences associated with decision alternatives.

Decision rule: the procedure that orders the decision space via a one-to-one or one-to-many relationship of outcomes to decision alternatives; it dictates how best to rank alternatives or to decide which alternative is preferred to another.

Decision space: a set of decision variables associated with decision alternatives.

Decision support system (DSS): an interactive computer-based system that can help decision makers utilize data and models to solve unstructured or semistructured problems.

Decision variable: a variable under direct control of the decision maker; measures the performance of alternative decisions; depending on the problem situation the decision variables may be deterministic, random, or linguistic; a set of decision variables defines the decision space.

Design: a phase of decision making that involves designing possible solutions to a decision problem.

Deterministic model: a model constructed for a condition of assumed certainty; the models assume that there is only one possible result (which is known) for each alternative course or action.

- Dialog generation and management system (DGMS):** a collection of computer programs that allow for organizing and using a dialogue system.
- Dialog system:** the hardware and software that create and implement a user interface for a DSS.
- Digitizing:** the process of encoding hard-copy documents on a tablet to capture line work in digital form.
- Disconcordance set:** the set of all criteria for which an alternative is worse than the competing alternative.
- Disjunctive screening:** a noncompensatory screening method that selects alternatives that satisfy specified cutoff values on at least one evaluation criterion.
- Dominance:** if an alternative *A* is at least as desirable as alternative *B* on all criteria and more desirable on at least one criterion, alternative *B* is dominated by *A*; by identifying the set of dominated alternatives, the set of all feasible alternatives can be subdivided into dominated and nondominated alternatives; the nondominated alternatives are also referred to as *efficient* or *noninferior*.
- DSS development tools:** software components (such as editors, code libraries, specific objects, visual interfaces) that facilitate the development of a specific DSS [e.g., Arc Macro Language (AML)–ARC/INFO].
- DSS generator:** a computer software package that provides tools and capabilities that assist a developer in quickly building a specific DSS; a GIS can be considered as a spatial decision support system generator.
- Elimination by aspects:** a noncompensatory screening method that proceeds by comparing alternatives on one attribute (aspect) at a time; alternatives that fail to meet a specified standard are eliminated from further consideration.
- Entity:** a geographical feature that exists and is distinguishable in the real world (e.g., a building, land parcel, street, tree, river, etc.)
- Error:** the deviation of data from some value considered “true.”
- Error propagation analysis:** a set of procedures concerned with the way known errors (uncertainties) in a set of input data affect the error in the final output (criterion outcomes); unlike sensitivity analyses, it requires a priori knowledge of the error associated with the input data.
- Feasible solution:** a solution (alternative) that satisfies all the constraints.
- Flat file:** a simple collection of records (representing entities) for which there are identical categories of data (attributes) associated with each record; also referred to as is a spreadsheet or rectangular database.
- Function:** in addition to meaning in a general sense the purpose of a thing, function in mathematics refers to a relationship implying that a change in one variable depends on a change in another; it can be expressed as $y = f(x)$; *y* is a function of or depends on *x*.
- Fuzzy set:** a collection of elements or objects without a well-defined boundary.
- Geocoding:** a process wherein a digital map feature is assigned locational attribute (geographical coordinates) to serve as unique ID.
- Geographical data:** any data that have been collected for a specific location.
- Geographical information:** georeferenced data that have been processed into a form that is meaningful to the recipient and is of a real or perceived value in the decision-making process.
- Geographical information system (GIS):** a computer system containing a set of procedures that facilitate the data input, data storage, data manipulation and analysis, and data output for both geographical and attribute data.
- Geographical position system (GPS):** hardware and software designed to communicate with satellites to determine ground location.
- Goal:** an a priori value or level of aspiration.
- Goal programming:** a form of linear programming–based approach to multiobjective decision making; each objective is defined as a goal with a specified attainment (aspiration) level, modeled as a constraint; the objective function is an expression that minimizes deviation from goals.
- Graphic user interface (GUI):** a graphical method of controlling how a user communicates with a computer to perform various tasks that are displayed on the computer screen in the form of menus, dialogue boxes, buttons, edit boxes, picklists, toggles, radio buttons, command input, and viewing screens.
- Heuristics:** principles that contribute to the reduction of search activity in a problem-solving process.
- Ideal point:** represents a hypothetical alternative (decision outcome) that consists of the most desirable weighted standardized levels of each criterion across the alternatives under consideration.
- Ideal point method:** a multiattribute decision method that orders a set of alternatives on the basis of their separation from the ideal point.
- Image processing:** a computer-based technique used to interpret and manipulate raster data.
- Intelligence:** the first stage of decision making which involves identifying a decision problem.
- Interactive programming methods:** a class of multiobjective decision methods that implicitly assume the existence of a utility/value function that is optimized by means of a formal mechanism involving an interactive exchange of information between a substantive model of the decision situation (computer-based system) and the decision maker.
- Interoperability:** seamless accessing and sharing of multiple data structures across multiple hardware platforms, operating systems, and application software.
- Interpolation:** a procedure for estimating the values of an attribute in locations where those values are unknown, based on known values of nearby “control” points.
- Lexicographic screening:** a noncompensatory method that considers one attribute (map layer) at a time, beginning with the most important.
- Line:** a one-dimensional object on a map representing a linear entity that has a beginning point and an ending point.

Line-in-polygon: a spatial query that determines which polygon boundary encompasses a specified line.

Linear programming: a mathematical model with a linear objective function and a set of linear constraints and nonnegative variables.

Linearity: an assumption that the desirability of an additional unit of an attribute is constant for any level of that attribute.

Linguistic variable: a variable that takes on words or sentences in a natural language; the values of linguistic variables are then assigned with appropriate fuzzy sets.

Loose coupling: a strategy for designing an SDSS that facilitates the integration of GIS and MCDM techniques using a file exchange mechanism.

Map algebra: an extension of conventional algebra to operations on maps [e.g., output map $= f(\text{input map } 1, \text{input map } 2, \dots, \text{input map } n)$].

Matrix: a structure of numbers arrayed in rows and columns.

Measurement: the process of assigning symbols to the attributes of objects, events, or states.

Measurement functions: GIS functions enabling calculations of distance, area, and volume.

Membership function: a function that represents any element x of X partially belonging to a subset A of X , or the grade of membership of x in A .

Metadata: data about the data in an information system.

Model base: a collection of preprogrammed quantitative models (e.g., geostatistical, simulation, optimization) organized as a single unit.

Model-based management system (DBMS): a collection of computer programs that allow for organizing and using a model stored in a model base.

Modifiable area unit problem: states that changing the shape (the zoning problem) or size (the aggregation problem) of the units on which the data are mapped can change the resulting models generated from the data.

Multicriteria decision analysis: a set of procedures for analysis of complex decision problems involving noncommensurable, conflicting criteria on the basis of which alternative decisions are evaluated.

Multicriteria-spatial DSS (MC-SDSS): a spatial decision support system that integrates GIS capabilities and multicriteria decision analysis.

Neighborhood functions: GIS analytical functions that involves ascribing values to a location according to the characteristics of the surrounding area; the value assigned to each location on the output layer is a function of independent values in the neighborhood of that location on the input layer; examples of the neighborhood functions include search and surface operations, and interpolation.

Network: a system of lines linking a given set of points.

Noncompensatory decision rule: a multicriteria decision making procedure that does not permit trade-offs between criteria; poor performance on one evaluation criterion is not compensated by good performance on other criteria.

Objective (or feature): an entity represented by a point/symbol, line, and area on a map (in a GIS database); each object is described by locational data and attribute data, the former recording the location of the object and the latter describing its characteristics (attributes).

Objective: a statement about the desired state of the system under consideration; it indicates the directions of improvement of one or more attributes; objectives are functionally related to or derived from a set of attributes.

Objective function: the mathematical relationship representing the attributes on which decisions are made.

Object-oriented database (OODB): a database defined by a series of predefined objects and their properties and behavioral characteristics.

Optimal solution: a feasible solution that minimizes or maximizes the value of the objective function.

Optimization: a normative approach for identifying the best solution for a given decision problem.

Order weight: assigned to the rank-order position of attribute values for a given alternative; applying order weights has the effect of weighting attributes based on their rank from minimum to maximum value for each alternative.

Order weighted average (OWA): a multiattribute fuzzy method that assigns to each alternative a weighted sum with ordered attributes; in addition to criterion weights, order weights are used; the method provides continuous fuzzy aggregation operations between the fuzzy intersection and union, with a weighted average combination falling midway in between.

Overlay: GIS procedures for generating a new layer (output layer) as a function of two or more input layers; the attribute value assigned to every location on the output layer is a function of the independent values associated with that location on the input layers.

Parameter: a constant value over the range of decision alternatives.

Point: a zero-dimensional object on a map representing a single x, y (optionally, z) location on the earth surface.

Point-in-polygon: a spatial query that determines which polygon boundary encompasses a specified point.

Polygon: a two-dimensional object on a map representing shapes of an entity.

Precision: the ability to repeat a measurement over and over again coming close to the same answer for each one.

Preferential independence: an assumption that the trade-off of pairs of criteria is independent of a fixed value for any other criterion at hand.

Probability: a subset of events that could occur out of a total population of events, conventionally expressed as a proportion of 1.

Probability map: a map of data that are standardized according to a particular statistical distribution.

Query: a logical search specification finding spatial features with linked records that contain matching locational attributes and/or descriptive attributes.

Ranking: arranging in order according to some criterion.

Raster structure: a form data structure for representing objects on a map that is composed of small, internally uniform cells (pixels) arranged in a grid.

(Re)classification: GIS operations that transform the attribute data associated with a single map layer; they involve the grouping of objects into classes according to the new values assigned to the objects of the input data according to certain locational and nonlocational attribute values.

Relational database: a type of logical database structure that treats data as if they were stored in two-dimensional tables; it can relate any piece of information stored in one table to any piece in another as long as the two tables share a common data element.

Remote sensing: a process of gathering data about the surface of the Earth and the environment from a distance, usually by aircraft or space sensors.

Risk: the possibility of a range of possible outcomes resulting from a decision or course of action.

Scale: a level of representation of reality; the relationship between distance on a map image and the corresponding distance in reality, commonly expressed as a fraction.

Scanning: a process of converting an analog source document into digital raster form either by using a flat-bed scanner or a drum scanner.

Semistructured decision: a decision in which some aspects of a problem are structured and others are unstructured.

Sensitivity analysis: a procedure for identifying the effects of introduced small changes in the inputs (geographical data and the decision maker's preference) on the outputs (ranking of alternatives); unlike error propagation analysis, it imposes perturbations or variations on the inputs.

Set: a definable collection of things (elements or numbers).

Simple additive weighting (SAW): a multiattribute procedure based on the concept of a weighted average; it calculates a total score for each alternative by multiplying the importance weight assigned to each attribute by the scaled attribute value and summing the products over all attributes; the alternative with the highest overall score is best; the procedure can be performed using GIS supporting overlay operations.

Solver: an application program for solving optimization problems (e.g., What's Best! is a solver that can be used within the spreadsheet environment).

Simulation: a methodology for performing experiments using a model of the real-world system.

Spatial data transfer standard (SDTS): a standard for transferring data between multiple geographical data management systems.

Spatial decision support system (SDSS): an interactive, computer-based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semistructured spatial decision problem.

Spatial expert system (SES): a computer-based system that employs reasoning methodologies in a particular spatial problem domain in order to transfer expertise and render advice or recommendations, much like a human expert.

Spatial multicriteria decision making: a process involving a set of geographically defined alternatives (events), from which a choice of one or more alternatives is made (their ordering performed) with respect to a given set of evaluation criteria.

Spatial query: a GIS function that makes it possible to find, display, and/or isolate attributes records linked to map objects located within a defined area of interest: window, circle, polygon, or trace.

Specific DSS: a system devoted to the analysis of a particular set of problems (e.g., MC-SDSS for environmental problems, marketing, transportation).

Standardization: a procedure for obtaining comparable scales.

State of nature (or environment): uncontrollable factor in a decision situation [e.g., a state of the economy (e.g., recession, inflation) or a weather condition (e.g., rain, drought, frost)].

Structured decision: a type of decision that is repetitive and routine; decision situations for which solution techniques are already available (also referred to as a routine or programmed decision).

Technique for generating efficient solutions: a method for identifying a set of efficient (nondominated) solutions by transforming the multicriteria decision problem into a single-criterion form to generate one efficient solution, and then, by parametric variation of the single-criterion problem, the complete set or a subset of efficient solutions is generated.

Tight coupling: a strategy for designing SDSSs that is based on a single data or model manager and a common user interface.

Topology: rules defining the relationships between spatial features, including such properties as continuity, nearness, and inside versus outside.

Trade-off: a marginal rate of substitution; the amount of one attribute the decision maker is willing to give up to gain a specified amount of some other attribute.

Transitivity: a preference structure holding the following property: If alternative *A* is preferred to *B*, and *B* to *C*, then *A* is preferred to *C*.

Uncertainty: the possibility of more than one outcome resulting from a particular course of action when the chance or probability of one particular outcome is unknown; a state of nature characterized by the absence of any information related to a desired outcome.

Unstructured decision: one in which the decision maker must provide judgment evaluation, and insight because the decision problem is novel, nonroutine and has no agreed-upon procedure for solving it.

User interface: the component of a computerized support system that allow communication between the system and its user.

Utility: a preference measure for a decision outcome.

Utility function: encodes a decision maker's attitude toward risk, taking in mathematical form by relating the decision maker's satisfaction with the outcome (or "utility" associated with the outcome) to the monetary value of the outcome itself.

Utility function methods: involve two elements: (1) the single-attribute utility function is used to transform the attribute levels into an interval-utility scale, and (2) the trade-off analysis for defining the weights (scaling constants) is employed to determine the relative importance of the attributes; for an additive model, the overall utility or value for each alternative is a weighted average of the single-attribute utilities.

Utility independence: an assumption that the utility of an alternative on a criterion is independent of the outcomes on other criteria.

Variable: a measurable factor that bears on the problem of interest.

Vector: a graphical data structure for storing spatial data involving assigning coordinates for each object.

Weight: a value assigned to an evaluation criterion that indicates its importance relative to the other criteria under consideration; the weights imply the trade-offs among criteria with respect to certain transformed measures.

What-if analysis: a procedure for exploring the effects of alternative assumptions about the input data (geographical data, the decision maker's preference) on the model's outputs.

Appendix: GIS and Decision Analysis Software Sources

Following is a list of GIS and Decision Analysis software products that support many of the spatial decision analysis techniques and methods that have been discussed in this book.

GIS software

ARC/INFO, ArcView and Extensions, MapObjects, Spatial Database Engine (SDE)

Environmental Systems Research Institute Inc.
380 New York Street
Redlands, CA 92372, USA
<http://www.esri.com>

GisPlus, Maptitude, TransCAD
Caliper Corporation
1172 Beacon Street, Newton, MA 02161, USA
<http://www.caliper.com>

GRASS
GRASS Research Group
Center for Applied Geographic and Spatial Research
Baylor University, P.O. Box 97351
Waco, Texas 76798-7351, USA
<http://www.baylor.edu/~grass/>

To Beata and Nina

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