Introduction to Spatial Complexity and MCDA

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Course Content

- Spatial complexity
- Spatial Decision Support Systems
- Multi-criteria Decision Analysis (MCDA) integration in GIS
- GIS-MCDA methods

Spatial Complexity

- Multidimensional problem
- Influenced by several criteria
  - With different importance
- Different decision-makers
  - with often conflictual preferences

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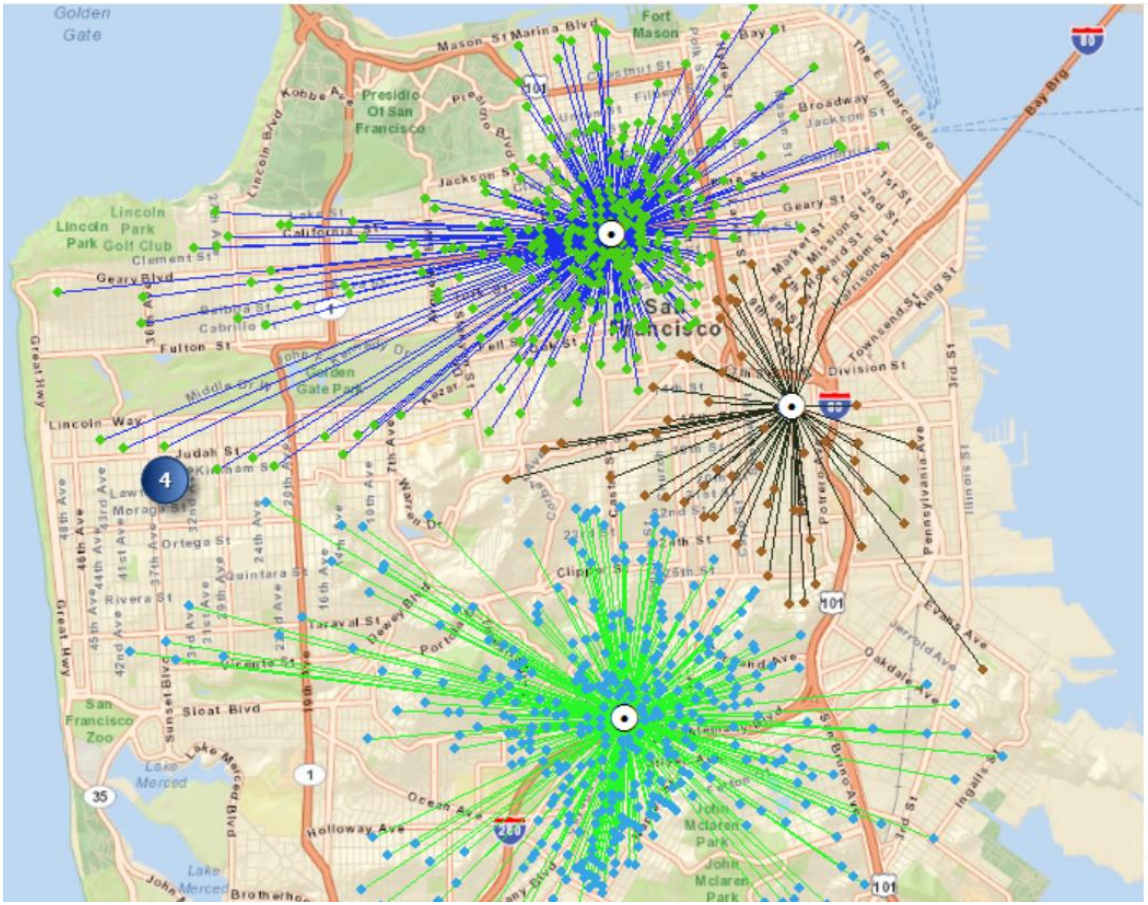
Location-Allocation



Source: https://desktop.arcgis.com/ru/arcmap/latest/extensions/business-analyst/location-allocation.htm

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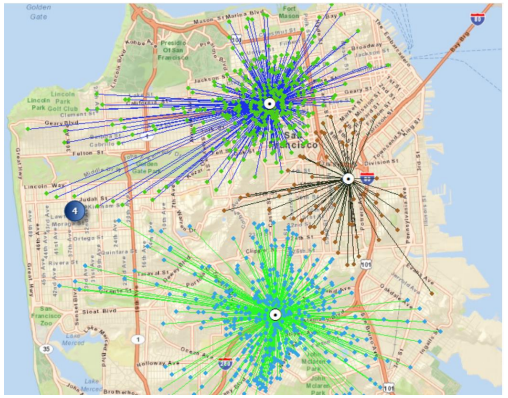
Location-Allocation

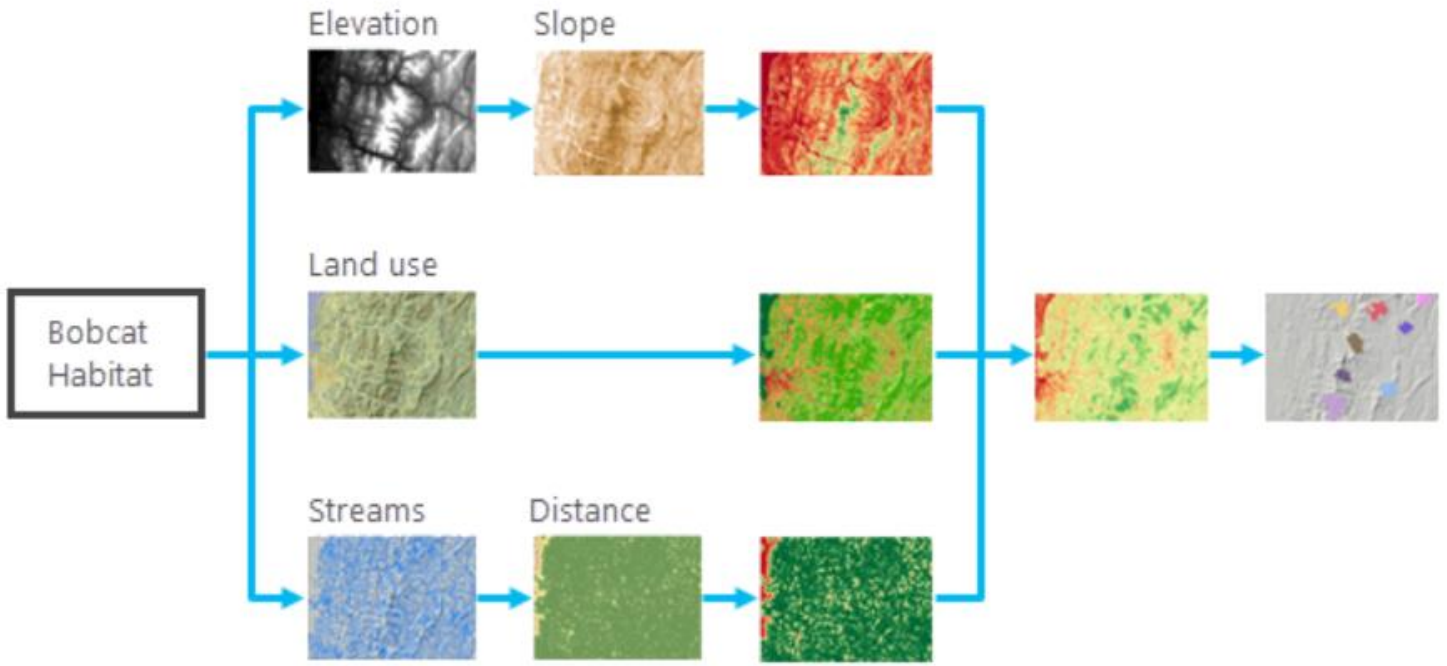


- **Facilities**
  - provide goods and/or services
- **Demand points**
  - Consume goods and/or services

- Goal of location-allocation: locate the facilities in a way that supplies the demand points most efficiently

- Twofold problem: simultaneously **locates** facilities and **allocates** demand points to the facilities

Landuse suitability



Source: https://pro.arcgis.com/en/pro-app/2.8/help/analysis/spatial-analyst/suitability-modeler/the-general-suitability-modeling-workflow.htm

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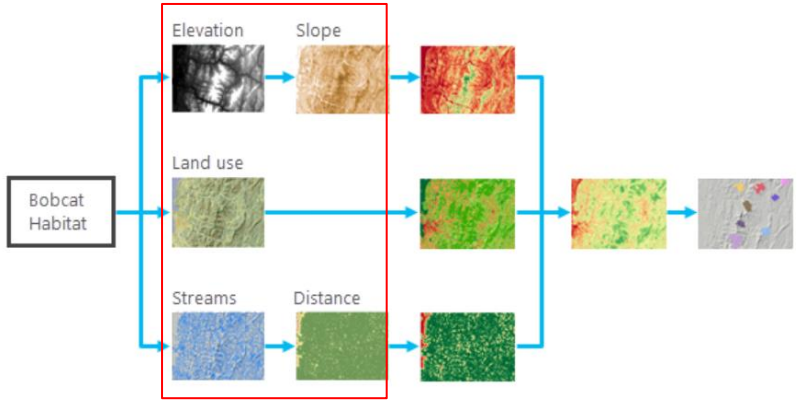
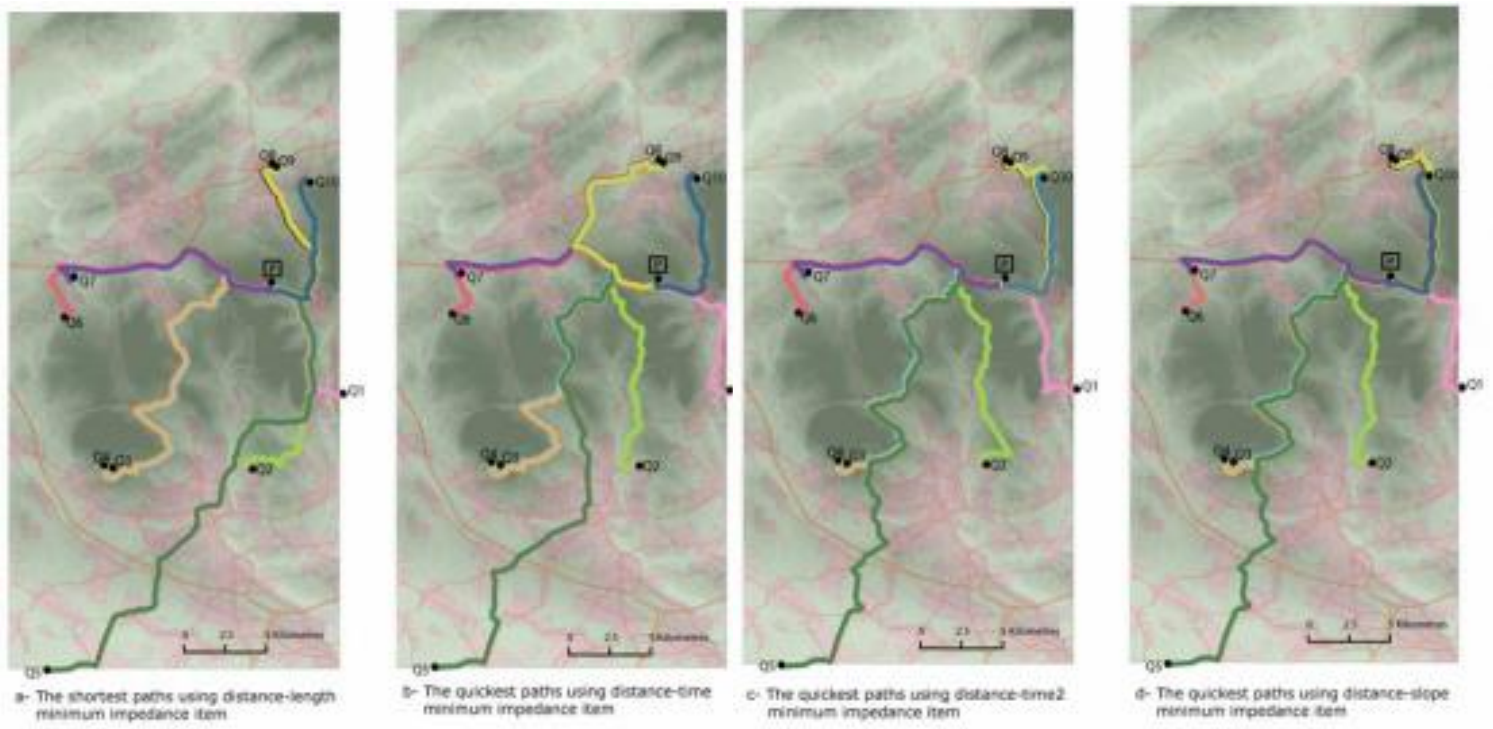
Suitability Modelling

- Identifies the best locations to site something or preserve an area
  - For example: housing development, a school, or a corporate headquarters
- Multiple criteria
- In the case of bobcat habitat:
  - Slope
  - Landuse types
  - Distance from streams
- Weight criteria relative to one another and combine them to create a suitability map



Network optimal location



Source: Sylvie, D. (2007). Gis-based accessibility analysis for network optimal location model. Cybergeo, Systems, Modelisation Geostatistiques, Article, 407.

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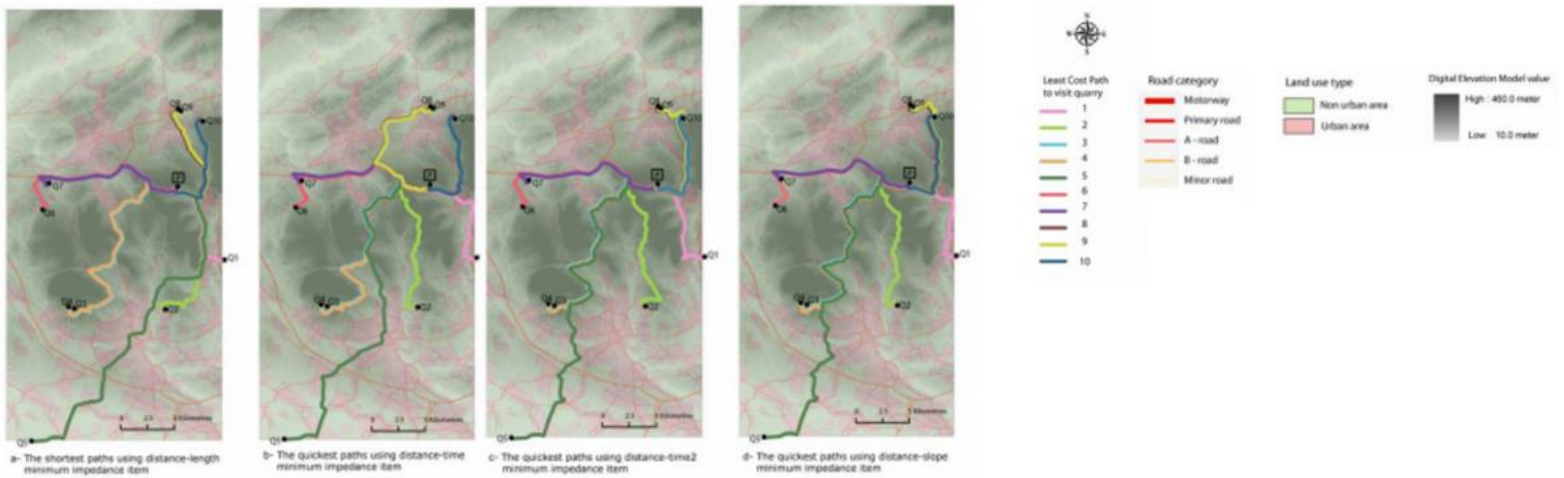
Network optimal location

GIS-based accessibility analysis for network optimal location model

Defined route systems:

Route-system	Distance measures	Measure take into account:
Route-length	Distance-length	Metric distance
Route-time	Distance-time	Time of transport depending on type of road
Route-time2	Distance-time2	Time of transport depending on urban/non urban areas
Route-slope	Distance-slope	As distance-time2, with weighting of gradient slope



a- The shortest paths using distance-length minimum impedance item

b- The quickest paths using distance-time minimum impedance item

c- The quickest paths using distance-time2 minimum impedance item

d- The quickest paths using distance-slope minimum impedance item

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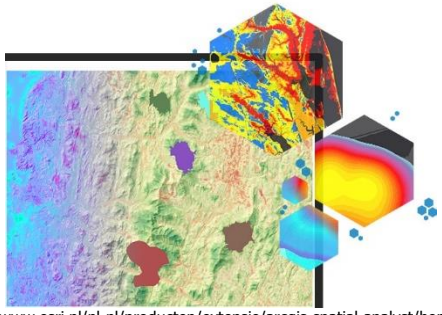
Multi-criteria Decision Analysis (MCDA) integration in GIS

Confluence of the two research areas:

- Spatial Analysis
- Spatial Decision Support Systems

Spatial Analysis



Source: https://www.esri.nl/nl-nl/producten/extensie/arcgis-spatial-analyst/home

- "Set of techniques and models that are explicitly concerned with spatial patterns and processes"

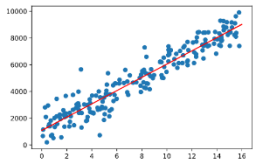
- "A distinctive feature of spatial analysis is that its results dependent on the locations of objects (events) and their attributes"

- "The results would be different under rearrangements of the spatial distribution of attributes or reconfiguration of the spatial structure"

Spatial Analysis

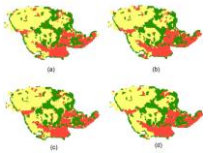
From the perspective of decision analysis, we can classify spatial modeling approaches into two categories:

- statistical modeling



- mathematical modeling
  - Simulation

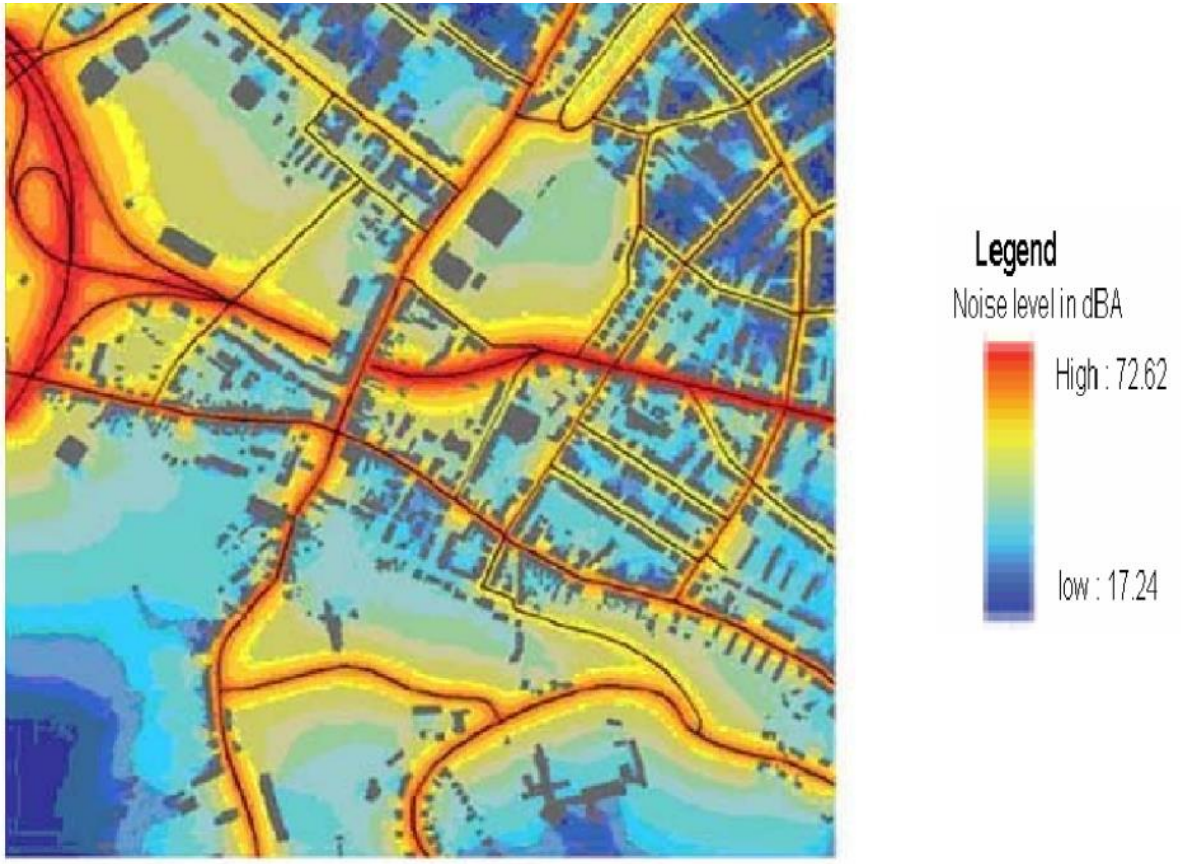
  - optimization



Spatial Simulation

- System components are mathematically defined
- Components are related to each other in a series of functional relationships
- Result: a mathematical description of a decision process
  - model is solved repeatedly, using different parameters and different decision variables every time
  - As these values are changed, a range of solutions are obtained for the problem and the 'best' solution can be chosen from that range.

Noise simulation



Source: Kurakula, V., Skidmore, A., Kluijver, H., Stoter, J., Dabrowska Zielinska, K., & Kuffer, M. (2007, March). A GIS based approach for 3D noise modelling using 3D city models. Enschede, The Netherlands: ITC.

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Spatial Optimization

- "seek to find the best (optimal) solution to well defined spatial decision or management problems"

- decision/management alternatives (or decision variables) have a geographic (spatial) meaning

Spatial Optimization

Common to all optimization models:

- quantity (quantities) to be minimized or maximized
  - quantity is often termed the **objective or criterion function**
- set of constraints imposed on the decision variables
  - define the set of feasible solutions
- solution to an optimization problem determines the values of decision variables subject to a set of constraints

Spatial Optimization

minimize or maximize f(x), subject to: $x \in X$

f(x): a criterion (objective) function

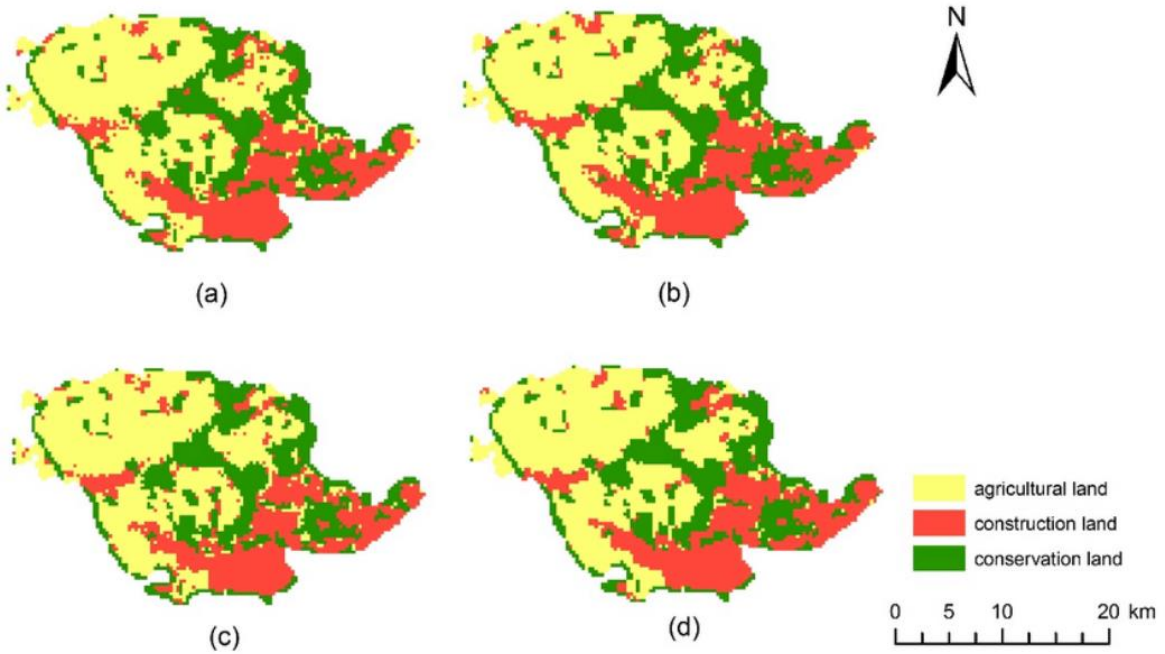
x: a set of decision variables

X: a set of feasible alternatives

If the problem involves a single criterion function: **single-criterion** (objective) model

If more than one criterion function is to be optimized simultaneously: **multicriteria** (multiobjective) model

solutions from spatial optimization results



a) agriculture-oriented solution, (b) construction-oriented solution, (c) conservation-oriented solution, and (d) solution maximizing spatial compactness.

Song, M., Chen, D., Woodstock, K., Zhang, Z., & Wu, Y. (2019). An RP-MCE-SOP framework for China's county-level "Three-Space" and "Three-Line" planning—An integration of rational planning, Multi-Criteria evaluation, and spatial optimization. Sustainability, 11(11), 2997.

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Simulation versus Optimization

- Simulation modeling starts with the actions and studies the effects on the overall system objectives by testing different policies under various external conditions

- Optimization procedures start with a definition of the system objectives

and specify the actions that will satisfy those objectives at the optimum level

  - Once the optimum conditions are established, the vicinity of the optimal points is analyzed to determine the effect of variations in the system

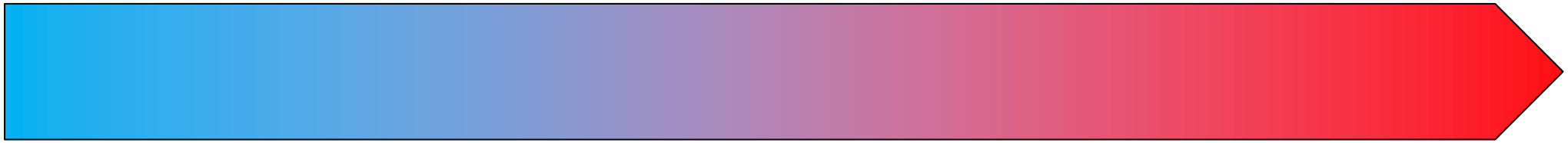
Spatial Decision Support Systems

- One of the central elements of GIScience
- The need to expand GIS capabilities for tackling complex spatial decision problems
- Improve the performance of decision makers, managers, and citizens when they confront spatial decision problems.

Spatial Decision Support Systems

- "A Spatial Decision Support System (SDSS) can be defined as an interactive, computer- based system designed to support a user or group of users in achieving higher **effectiveness** in **decision making** while solving a **semi-structured spatial decision problem**"

Semi-Structured Decisions



Structured decisions

Semi-Structured decisions

- location-allocation problems
- site search and selection problems
- land use suitability evaluation
- transportation problems
- plan/policy evaluation

Unstructured decisions

The structured part of the semi-structured problem may be amenable to automated solution by the use of a computer, while the unstructured aspects are tackled by decision makers

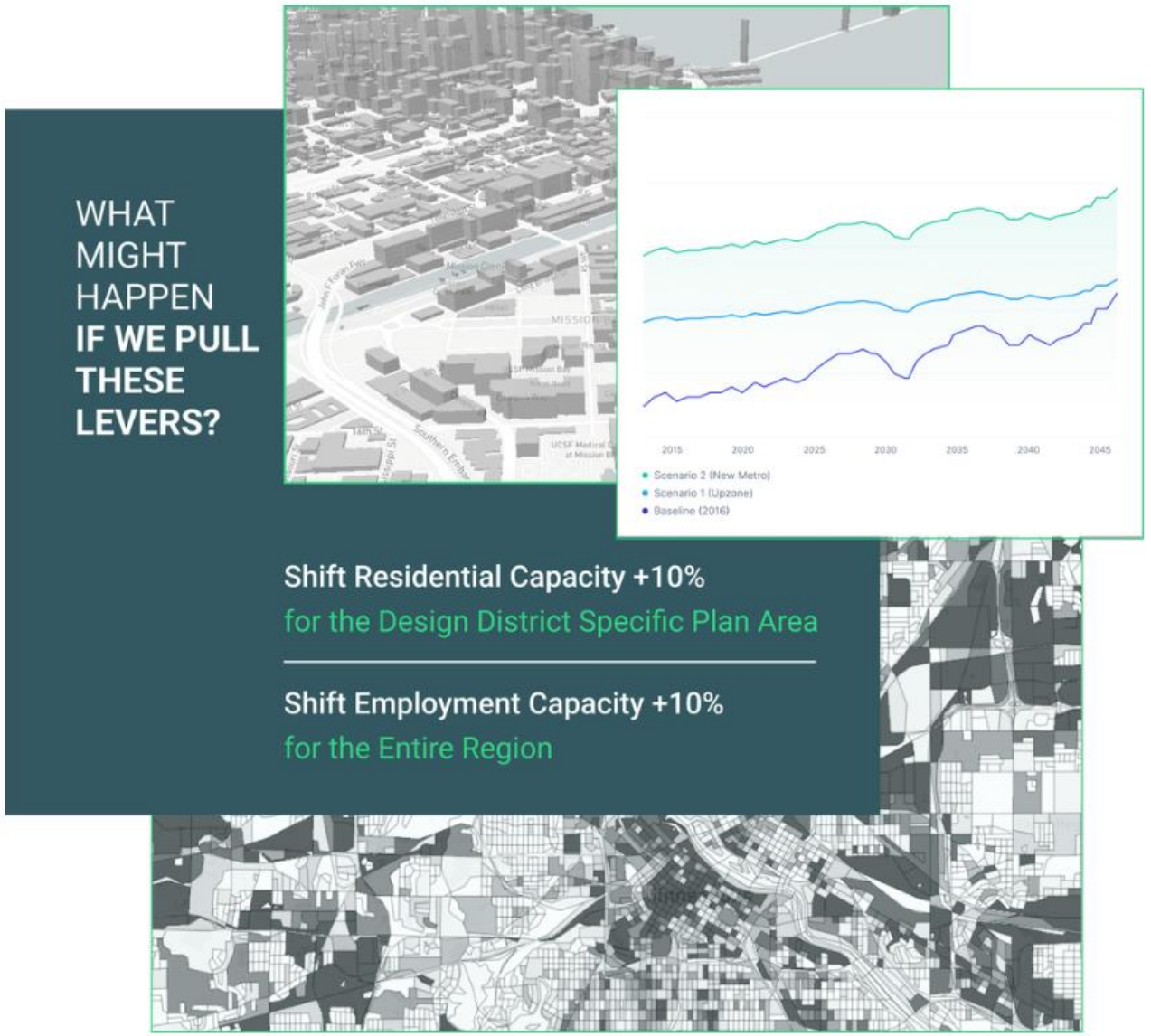
Spatial Decision Support System

- The primary aim of SDSS is to improve the effectiveness of decision making by incorporating decision makers' knowledge and experience into computer-based procedures.
- Central to the concept of SDSS is the interaction of the user(s) with a computer-based system
- The ability of a GIS to handle preferences, judgments, arguments, and opinions involved in the planning process is very important
- One way of achieving this is to incorporate MCDA techniques into the GIS-based procedures

SDSS Examples

SDSS for Urban Planning

UrbanSim



"Support planning and analysis of urban development, incorporating the interactions between land use, transportation, the economy, and the environment."

Source: https://www.urbansim.com/scenario-modeling

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Infrastructure and Mobility

UrbanFootprint

Source: https://urbanfootprint.com/solutions/infrastructure-mobility/

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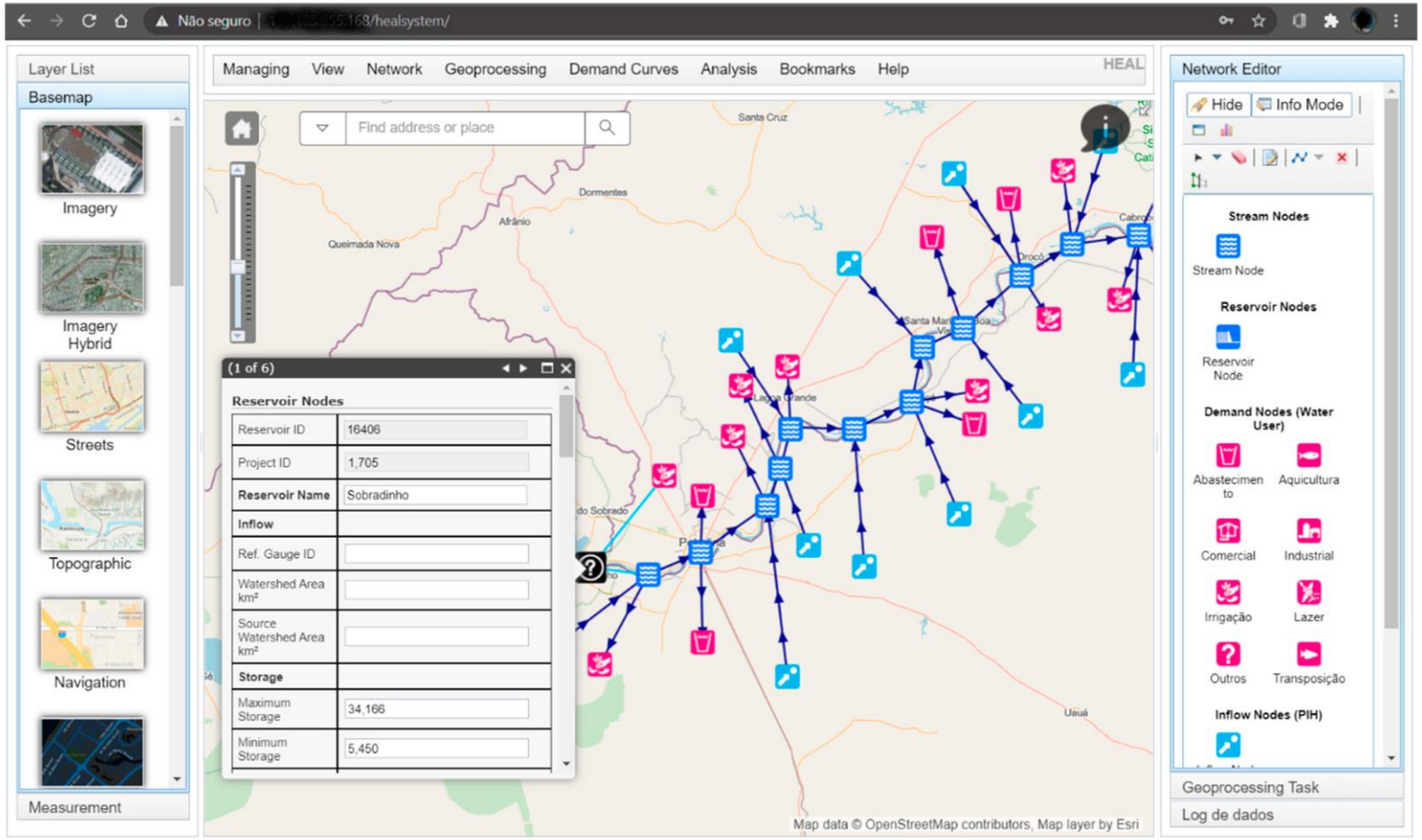
SDSS for (Inter-)Basin Management of Water Resources

Identification and analysis of an optimal economic allocation of water resources in the sub-middle basin of the São Francisco River in Brazil



Source: Souza da Silva, G.N.; Alcoforado de Moraes, M.M.G. Decision Support for the (Inter-)Basin Management of Water Resources Using Integrated Hydro-Economic Modeling. Hydrology 2021, 8, 42. https://doi.org/10.3390/hydrology8010042

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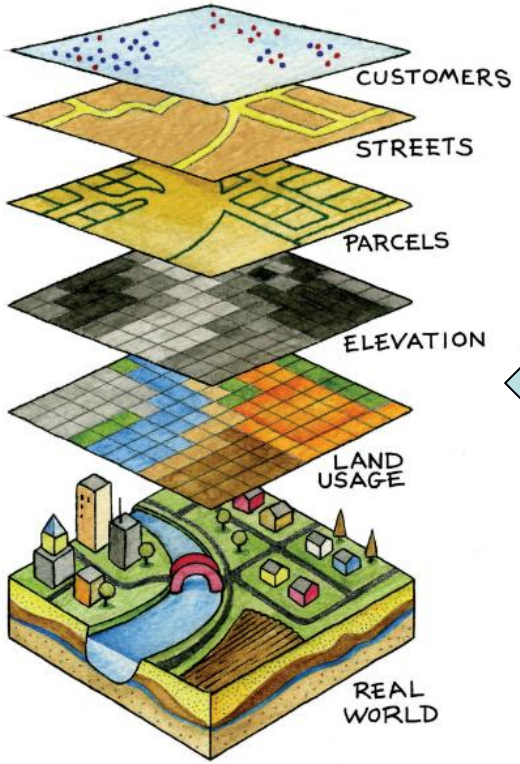
Multi-criteria Spatial Decision Support Systems

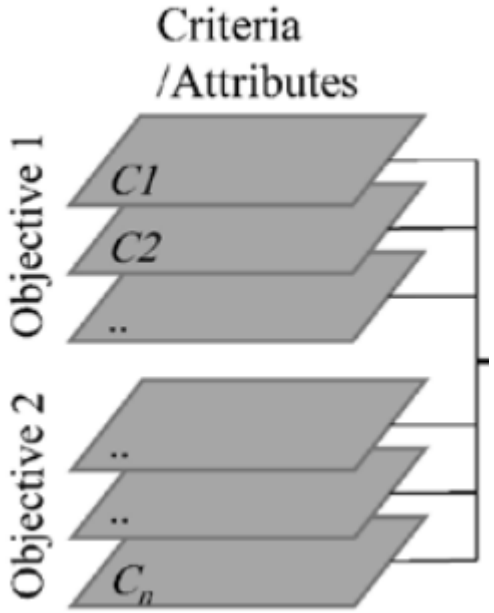
- A class of SDSS that is based on the concept of integrating GIS and MCDA
- At the most fundamental level, GIS-based MCDA (GIS-MCDA) is a procedure that transforms and combines geographic data (input maps) and the decision maker's (expert or agent) preferences into a decision (output) map.

Synergy Between GIS and MCDA

- storage, processing, manipulation & analysis and management of geospatial data
- integrate data from diverse sources



GIS



MCDA

- Management of conflicting preferences with respect to evaluation criteria

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Spatial MCDA

Three GIS-MCDA methods:

- Conventional MCDA for spatial decision making
- Spatially explicit MCDA
- spatial multiobjective (multicriteria) optimization

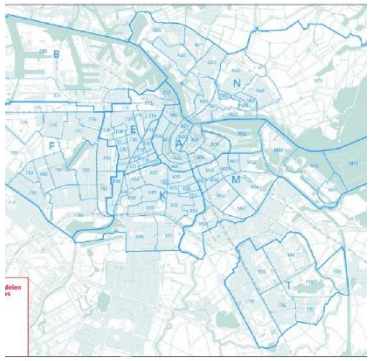
Conventional MCDA

- Common methods in GIS-MCDA
- Mainly aspatial
  - extensions of existing MCDA methods to analyze spatial decision problems
  - Spatial heterogeneity and spatial dependency are not considered
  - spatial variability is involved only implicitly by defining evaluation criteria based on the concept of spatial relations such as proximity, adjacency, and contiguity

Spatially Explicit MCDA

- "A model is said to be spatially explicit when it differentiates behaviors and predictions according to spatial location"

Spatially Explicit MCDA



- MCDA model is considered as spatially explicit if:
  - its decision outcomes (rankings or orderings of decision alternatives) are not invariant under relocation of the feasible alternatives
  - decision alternatives in a spatially explicit MCDA model be geographically defined
    - Such alternatives consist of, at least, two elements: action (what to do?) and location (where to do it?)
  - it contains spatial concepts such as location, distance, contiguity, connectivity, adjacency, or direction

Spatial Multiobjective Optimization

- Specifically designed for modeling spatial systems and solving spatial problems such as:
  - site search problems
  - location allocation
  - transportation problem
  - vehicle routing