ArcGIS Spatial Analyst – Suitability Modeling

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Suitability modeling

• Where to site a new housing development?
• Which sites are better for deer habitat?
• Where is economic growth most likely to occur?
• Where is the population at the greatest risk if a chemical spill were to happen?

Reality

GIS layers

Suitability for store

Model criteria:
- Zoned commercial
- Near target population
- Away from competition
What we know

• The best locations can be determined from the features at each location

• You can identify the features that define the best locations

• You can quantify the relative preference of the features relative to one another

• You know what is not important to the phenomenon

• The attributes and numbers associated with the data vary in type and meaning
The presentation outline

• Background

• How to create a suitability model and the associated issues

• Demonstration

• Looking into the values and weights a little deeper

• Demonstration

• Fuzzy logic
Manipulation of raster data - Background

- Locational perspective of the world
- Define a portion of the landscape’s attributes
- Worm’s eye view
- To return a value for each cell you must know
  - What is your value
  - What function to apply
  - What cell locations to include in the calculations
    - Within a grid
    - Between grids
Discrete and continuous phenomena

- **Discrete phenomena**
  - Landuse
  - Ownership
  - Political boundaries

- **Continuous phenomena**
  - Elevation
  - Distance
  - Density
  - Suitability
The presentation outline

- Background
- How to create a suitability model and the associated issues
  - Demonstration
  - Looking into the values and weights a little deeper
  - Demonstration
- Fuzzy logic
General suitability modeling methodology

- There is a fairly standard methodology to follow:

  1. Build a team
  2. Define the goal
  3. Define the measures
  4. Create and run model
  5. Present the results
  6. Choose an alternative

Document everything!
Define the goal

- Define the problem
  - “Locate a ski resort”
- Establish the over arching goal of the problem
  - Make money
- This is a team activity
  - Stakeholders, decision makers
- Identify issues
  - Legal constraints
- Obtain GIS data
  - DEM, roads, land use, and houses
Define the measures for success

- How will you know if the model is successful?
- Criteria should relate back to the overall goals of the model
- May need to generalize measures
  - On average near the water
- Determine how to quantify
  - “Drive time to the city”
Break model into sub-models

• Helps clarify relationships, simplifies problems
ModelBuilder

- ArcGIS graphical model building capabilities
Types of suitability models - Binary

- Use for simple problems - query
- Classify layers as good (1) or bad (0) and combine:

  \[ \text{BestSite} = \text{Terrain} \& \text{Access} \& \text{Cost} \]

- Advantages: Easy
- Disadvantages:
  - No “next-best” sites
  - All layers have same importance
  - All good values have same importance
Types of suitability models - Weighted

- Use for more complex problems

- Classify layers into suitability 1–9
  - Weight and add together:
    \[
    \text{BestSite} = (\text{Terrain} \times 0.5) + (\text{Access} \times 0.3) + (\text{Cost} \times 0.2)
    \]

- Advantages:
  - All values have relative importance
  - All layers have relative importance
  - Suitability values on common scale

- Disadvantages:
  - Preference assessment is more difficult
General suitability modeling methodology

- There is a fairly standard methodology:
  - Build a team
  - Define the goal
  - Define the measures
  - Create and run model
  - Present the results
  - Choose an alternative

*Document everything!*
The suitability modeling model steps

- **Determine significant** layers for each sub model from the phenomenon’s perspective
- **Reclassify** the values of each layer onto a relative scale
- **Weight** the importance of each layer and each sub model
- **Add** the layers and sub models together
- **Analyze** the results and make a decision
Determining significant layers

- The phenomena you are modeling must be understood

- What influences the phenomena must be identified

- How the significant layers influence the phenomena must be determined

- Irrelevant information must be eliminated

- Simplify the model
  - Complex enough to capture the essence and address the question
Reclassify – Place various criteria on common scale

• Base data may not be useful for measuring all criteria
  - Need to measure access, not road location

• May be easy:
  - ArcGIS Spatial Analyst tools
  - Distance to roads

• May be harder:
  - Require another model
  - Travel time to roads
Why reclassify? – Values vary

Ratio:

Interval:
Why reclassify - Values vary

Ordinal:

Nominal:

<table>
<thead>
<tr>
<th>Name</th>
<th>Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amos Andy</td>
<td>555-2543</td>
</tr>
<tr>
<td>Andrews Fred</td>
<td>555-6769</td>
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<tr>
<td>Aprills James</td>
<td>555-9063</td>
</tr>
<tr>
<td>Aster Susan</td>
<td>555-7754</td>
</tr>
<tr>
<td>Atwater Henry</td>
<td>555-2156</td>
</tr>
</tbody>
</table>
Reclassify - Define a scale of suitability

• Define a scale for suitability
  - Many possible; typically 1 to 9 (worst to best)
  - Reclassify layer values into relative suitability
  - Use the same scale for all layers in the model

<table>
<thead>
<tr>
<th>Accessibility sub model</th>
<th>Development sub model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Travel time suitability</strong></td>
<td><strong>Soil grading suitability</strong></td>
</tr>
<tr>
<td>Best</td>
<td>Best</td>
</tr>
<tr>
<td>9 – 0 minutes to off ramp</td>
<td>9 – Recent alluvium; easy</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>5 – 15 minutes to off ramp</td>
<td>5 – Landslide; moderate</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1 – 45 minutes to off ramp</td>
<td>1 – Exposed bedrock; hard</td>
</tr>
<tr>
<td>Worst</td>
<td>Worst</td>
</tr>
</tbody>
</table>

Distance to roads

Suitability for Ski Resort

Within and between layers
The Reclassify tool

- May use to convert measures into suitability
The suitability modeling model steps

- **Determine significant** layers for each sub model from the phenomenon’s perspective
- **Reclassify** the values of each layer onto a relative scale
- **Weight** the importance of each layer and each sub model
- **Add** the layers and sub models together
- **Analyze** the results and make a decision
Weight and add the layers

- Certain criteria may be more significant than others and must be weighted appropriately before combining
  - Terrain and access may be more significant to the ski area than cost
- Use Weighted Overlay, Weighted Sum tool, or Map Algebra

\[
\text{SkiSite} = (\text{Terrain} \times 0.5) + (\text{Access} \times 0.3) + (\text{Cost} \times 0.2)
\]
The Weighted Overlay tool

- Weights and combines multiple inputs
  - Individual criteria (layers)
  - Sub models
Present results/Choose an alternative

• Model returns a suitability “surface”
  - Ranks the relative importance of each site to one another relative to the phenomenon

• Create candidate sites
  - Select cells with highest scores
  - Define regions with unique IDS
  - Eliminate regions that are too small

• Choose between the candidates
Validation

- Ground truth
- User experience
- Alter values and weights
- Perform sensitivity analysis
Limitations of a suitability model

• Results in a surface indicating which sites are more preferred by the phenomenon than others

• Does not give absolute values (can the animal live there or not; ordinal not interval values)

• Heavily dependent on the reclass and weight values
The presentation outline

• Background

• How to create a suitability model and the associated issues

• **Demonstration**

• Looking into the values and weights a little deeper

• Demonstration

• Fuzzy logic
Demo 1: Suitability Model

Reclass
Weight
Add
The story is not over

- How the reclass and weights have been assigned has not been critically examined
- Do the reclassification values accurately capture the phenomenon?
- The reclassification by expert opinion – are there other approaches?
- Continuous criterion were reclassified by equal interval
- Assumes more of the good features the better
- What happens when there are many criteria?
Multicriteria decision making

- GIS and Multicriteria Decision Analysis (J. Malczewski)
- Operation Research (linear programming)
- Decision support
- We are not trying to identify the best method
  - Problem you are addressing
  - Available data
  - Understanding of the phenomenon
- Provide you with alternative approaches
- To make you think about the values and weights
The model creation framework

• The one presented is:
  - Determine significant layers
  - Reclassify
  - Weight
  - Add
  - Analyze

• The decision support world:
  - Problem definition
  - Evaluation criteria (Significant layers and reclass)
  - Alternatives
  - Criterion weights (Weight)
  - Decision Rules (Add)
  - Sensitivity analysis
  - Recommendation
Problem definition

- Most important and most time consuming

- It is glossed over

- Measurable

- The gap between desired and existing states

- Break down into sub models
  - Helps clarify relationships, simplifies problem
Evaluation criteria

(Determine significant layers and Reclass)

• Objectives and criteria
  - Build on slopes less than 2 percent

• Many times take on the form:
  - Minimize cost; Maximize the visual quality

• The more the better; the less the better

• Proxy criteria
  - Reduce the lung disease – amount of carbon dioxide

• How to determine influence of the attributes
  - Literature, studies, Survey opinions
  - Conflicts?
Evaluation criteria methods

(Determine significant layers and Reclass)

- Direct scaling (as you have seen)

- Linear transformation
  - Divide each value by the maximum value
  - Scale 0 – 1 (relative order of magnitude maintained)
  - Apply to each layer (to all types of data?)

- Value/utility functions

- Others:
  - Fuzzy sets
Evaluation criteria: Value/Utility functions

(Determine significant layers and Reclass)

• Reclassify with equations – ratio data
  
  - Mathematical relationship between data and suitability

- Graph showing suitability vs. distance to water with the equation:

  \[ \text{WaterSuit} = 9 + (-0.0018 \times \text{WaterDist}) \]

- Graph with y-intercept set where \([\text{WaterDist}] = 5000\)
- Solve for line slope: -0.0018

Implement with model or Map Algebra:
Evaluation criteria: Value/utility functions

(Determine significant layers and Reclass)

- Not a linear decay in preference
- The intervals for the attribute are not equal
- Or the preference scaling is not equal

![Distance vs Suitability Graph](dist_vs_suitability.png)
The framework

• The one presented is:
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Decision alternatives and constraints

• Constraints
  - Reduces the number of alternatives
  - Feasible and non feasible alternatives

• Types of Constraints
  - Non compensatory
    - No trade offs - in or out (legal, cost, biological)
  - Compensatory
    - Examines the trade offs between attributes
      - Pumping water – (height versus distance relative a cost)

• Decision Space
  - Dominated and non-dominated alternatives
The framework

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Criterion weighting - (Weight)

• Ranking Method
  - Rank order of decision maker (1 most, 2, second…)

• Rating Method
  - Decision maker estimates weights on a predetermined scale
  - Point allocation approach (similar to demonstration)
  - Ratio estimation procedure (Easton)
    - Arbitrarily assign the most important, other assigned proportionately lower weights

• Pairwise

• Trade-off analysis
Criterion weighting: Pairwise - (Weight)

- Analytical hierarchy process (AHP) (Saaty)
- Three steps
  - Generate comparison matrix
  - Compute criterion weights
    - Sum columns; divide by column sum; average rows
    - Estimate consistency ratio (math formulas)
- Pairwise comparison
  - Rate1: Equal importance – 9: Extreme importance

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Terrain</th>
<th>Access</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Terrain</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Access</td>
<td>1/3</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Cost</td>
<td>1/6</td>
<td>1/8</td>
<td>1</td>
</tr>
</tbody>
</table>

::: ArcGIS Spatial Analyst - Suitability Modeling
Criterion weighting: Trade-off – *(Weight)*

- Direct assessment of trade-offs the decision maker is willing to make (Hobbs and others)
- Compares two alternatives with respect to two criteria defining preference or if indifferent
- Compare other combinations

<table>
<thead>
<tr>
<th>Site 1</th>
<th>Site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>Aspect</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
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<td>8</td>
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</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
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The framework

• The one presented is:
  - Determine significant layers
  - Reclassify
  - Weight
  - Add
  - Analyze

• The decision support world:
  - Problem definition
  - Evaluation criteria
  - Alternatives
  - Criterion weights
  - **Decision Rules**
  - Sensitivity analysis
  - Recommendation

(Significant layers and reclass) (Weight) (Add)
Decision rules - (Add)

- Simple Additive Weighting (SAW) method
- Value/utility functions (Keeney and Raiffa)
- Group value/utility functions
- Ideal point method
- Others:
  - Concordance method
  - Probabilistic additive weighting
  - Goal programming
  - Interactive programming
  - Compromise programming
  - Data Envelopment Analysis
Decision rules: SAW - *(Add)*

- What we did earlier
- Assumptions:
  - Linearity
  - Additive
  - No interaction between attributes
- Ad hoc
- Lose individual attribute relationships
- All methods make some trade offs
Decision rules: Group Value - *(Add)*

- Method for combining the preferences of different interest groups

- **General steps:**
  - Group/individual create a suitability map
  - Individuals provide weights of influence of the other groups
  - Use linear algebra to solve for the weights for each individual’s output
  - Combine the outputs

- Better for value/utility functions
Decision rules: Ideal Point - (Add)

- Alternatives are based on separation from the ideal point
- General steps
  - Create weighted suitability surface for each attribute
  - Determine the maximum value
  - Determine the minimum value
  - Calculate the relative closeness to the ideal point

\[ C_{i+} = \frac{s_{j-}}{s_{i+} + s_{i-}} \]

- Rank alternatives
- Good when the attributes have dependencies
The framework

• The one presented is:
  - Determine significant layers
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  - Weight
  - Add
  - Analyze

• The decision support world:
  - Problem definition
  - Evaluation criteria (Significant layers and reclass)
  - Alternatives
  - Criterion weights (Weight)
  - Decision Rules (Add)
  - Sensitivity analysis
  - Recommendation
Sensitivity analysis (and error analysis)

- Systematically change one parameter slightly
- See how it affects the output
- Error
  - Input data
  - Parameters
  - Address by calculations or through simulations
The framework

• The one presented is:
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  - Weight
  - Add
  - Analyze

• The decision support world:
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  - Criterion weights (Weight)
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  - Sensitivity analysis
  - Recommendation
Outline

• Background

• How to create a suitability model and the associated issues

• Demonstration

• Looking into the values and weights a little deeper

• Demonstration

• Fuzzy logic
Demo 2: Non-linear Suitability Model

Use functions for reclassification
Reclassify
Raster Calculator
Suitability model steps – Fuzzy analysis

- **Determine significant** layers for each sub model from the phenomenon’s perspective

- **Reclassify** the values of each layer onto a relative scale

- **Weight** the importance of each layer and each sub model

- **Add** the layers and sub models together

- **Analyze** the results and make a decision
Fuzzy overlay – The problem

- Inaccuracies in geometry
- Inaccuracies in classification process
Fuzzy overlay - **Reclass**

- Predetermined functions are applied to continuous data
- 0 to 1 scale of possibility belonging to the specified set
- **Membership functions**
  - FuzzyGaussian – normally distributed midpoint
  - FuzzyLarge – membership likely for large numbers
  - FuzzyLinear – increase/decrease linearly
  - FuzzyMSLarge – very large values likely
  - FuzzyMSSmall – very small values likely
  - FuzzyNear – narrow around a midpoint
  - FuzzySmall – membership likely for small numbers
Fuzzy overlay - **Reclass**
Fuzzy overlay - (Add)

• Meaning of the reclass values - possibilities therefore no weighting

• Analysis based on set theory

• Fuzzy analysis
  - And - minimum value
  - Or – maximum value
  - Product – values can be small
  - Sum – not the algebraic sum
  - Gamma – sum and product
Demo 3: Fuzzy Analysis

Fuzzification

Fuzzy Overlay
Summary

• Problems with:
  - If cells need to be contiguous
  - Locating one alternative influences the location of another

• Can be done in the vector world

• Multiple ways to derive values and weights

• Multiple ways to combine the criteria

• Your values and weights depend on:
  - the goal
  - the data
  - the understanding of the phenomenon

• The values and weights can dramatically change the results

Carefully think about the values and weights you use
Spatial Analyst - Technical Sessions

• **An Introduction - Rm 03**  
  Tuesday, July 9, 8:30AM – 9:45AM  
  Wednesday, July 10, 1:30PM – 2:45PM

• **Suitability Modeling - Rm 03**  
  Tuesday, July 9, 10:15 AM – 11:30PM  
  Wednesday, July 10, 3:15PM – 4:30PM

• **Python – Raster Analysis - Rm 03**  
  Tuesday, July 9, 3:15PM – 4:30PM  
  Thursday, July 11, 8:30AM – 9:45PM

• **Creating Surfaces – Rm 03**  
  Wednesday, July 10, 8:30AM – 9:45PM
Spatial Analyst Technical Sessions (short)

• Creating Watersheds and Stream Networks – Rm 31C
  Thursday, July 11, 10:15AM – 11:45AM

• Regression Analysis Using Raster Data – Hall G Rm 2
  Wednesday, July 10, 10:30AM – 11:00AM
Demo Theater Presentations – Exhibit Hall B

- **Modeling Rooftop Solar Energy Potential**
  Tuesday, July 9, 5:30PM – 6:00PM

- **Surface Interpolation in ArcGIS**
  Wednesday, July 10, 4:30PM – 5:30PM

- **Getting Started with Map Algebra**
  Tuesday, July 9, 10:00AM – 11:00AM

- **Agent-Based Modeling**
  Wednesday, July 10, 1:00PM – 2:00PM

- **Image Classification with Spatial Analyst**
  Tuesday, July 9, 3:00PM – 3:30PM
Thank you...

Please fill out the session evaluation

First Offering ID: 1179
Second Offering ID: 1300

Online – www.esri.com/ucsessionssurveys
Paper – pick up and put in drop box