Retrospective GIS-Based Multi-Criteria Decision Analysis

A Case Study of California Waste Transfer Station Siting Decisions

John Cirucci
GEOG 596A Capstone Proposal
Penn State MGIS
December 2014

Advisors: Justine Blanford/Doug Miller
Overview

- Background on MCDA theory
- Applications for GIS-based MCDA
- Objectives of Retrospective GIS-based MCDA
- Case study selection and characterization
- Retro-GIS-MCDA methodology
- Expected outcomes
- Capstone project timeline
“MCDA” describes the collection of formal approaches to take explicit account of multiple criteria, especially for complex and high impact decisions.

Many decisions are spatial...
Many GIS analyses provide spatial decision support...
GIS-based MCDA discipline is an expanding niche field.
General MCDA Process

1. Problem Identification
2. Problem Structuring
3. Model Building
4. Information Synthesis
5. Action Plan

DECISION RULES
- Criteria preferences
- Aggregation method

Criteria
Alternatives
Uncertainties
Stakeholders
Environmental factors & constraints

Belton & Stewart (2002)
Categories of Decision Rules for MCDA Models

Value Measurement

- Linear logic
- Many aggregation options
- Software tools readily adapted
- Raster overlay techniques applicable

Outcomes do not always accurately represent true stakeholders’ valuation

Reference Point

- Heuristic approach - how people make difficult decisions
- Boolean overlay applicable
- Good for initial screening
- May result in >1 alternative or no alternatives. Not always appropriate for rigorous MCDA

Outranking

- Elicits stakeholder valuation
- Highly interactive
- Ambiguity made explicit
- Labor and computation intensive
Example: Land Suitability for Agave Bioenergy Feedstock
Value Measurement with Analytical Hierarchy Process (AHP) and final Reference Point

- Hybrid Value Measurement and Reference Point
- Fuzzy membership criteria valuation
- Aggregation with the AHP
- Criteria Sensitivity

Example: Housing Development Siting in Vaud, Switzerland
Outranking Method with Closeness Relationship and Zone Classification

- Homogeneous “zones” to create discrete number of alternatives
- Vector data structure
- “Favorable”/“Unfavorable”/“Uncertain” Suitability Index

Criteria
- Landscape impact
- Air pollution
- Noise
- Accessibility
- Local climate
- Landslide risk
- Distance to facilities
- Viewpoint quality

Partial Literature Survey – Cirucci (2014)

<table>
<thead>
<tr>
<th>Lead Author</th>
<th>Year</th>
<th>Article Type</th>
<th>Case Study Topic</th>
<th>Decision Problem</th>
<th>Application Domain</th>
<th>Method Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerts</td>
<td>2003</td>
<td>method/case study</td>
<td>restoration of open mining area</td>
<td>land suitability</td>
<td>forestry</td>
<td>Reference Point (ILP)</td>
</tr>
<tr>
<td>Chang</td>
<td>2008</td>
<td>method/case study</td>
<td>landfill siting</td>
<td>site selection</td>
<td>waste management</td>
<td>Ref Pt / Value Msrmt (AHP)</td>
</tr>
<tr>
<td>Craig</td>
<td>1999</td>
<td>method/case study</td>
<td>malaria transmission</td>
<td>climate suitability</td>
<td>MISC - disease</td>
<td>Value Measurement</td>
</tr>
<tr>
<td>Dewi</td>
<td>2010</td>
<td>review</td>
<td>sustainable waste management</td>
<td>site selection</td>
<td>waste management</td>
<td>--</td>
</tr>
<tr>
<td>Eastman</td>
<td>1999</td>
<td>method/case study</td>
<td>industrial allocation in Kenya</td>
<td>land suitability</td>
<td>regional planning</td>
<td>Value Measurement</td>
</tr>
<tr>
<td>Evans</td>
<td>2004</td>
<td>method/case study</td>
<td>nuclear waste siting</td>
<td>site selection</td>
<td>waste management</td>
<td>Value Measurement</td>
</tr>
<tr>
<td>Feizizadeh</td>
<td>2014</td>
<td>method/case study</td>
<td>landslide susceptibility</td>
<td>land suitability</td>
<td>natural hazards</td>
<td>Value Measurement (AHP)</td>
</tr>
<tr>
<td>Feizizadeh</td>
<td>2014</td>
<td>method/case study</td>
<td>landslide susceptibility</td>
<td>land suitability</td>
<td>natural hazards</td>
<td>Value Measurement (AHP)</td>
</tr>
<tr>
<td>Greene</td>
<td>2011</td>
<td>review</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Hanashima</td>
<td>2002</td>
<td>method/case study</td>
<td>DEM analysis</td>
<td>land suitability</td>
<td>MISC - generic</td>
<td>Value Measurement</td>
</tr>
<tr>
<td>Hansen</td>
<td>2005</td>
<td>case study</td>
<td>wind farm siting</td>
<td>site selection</td>
<td>MISC - energy</td>
<td>Value Measurement</td>
</tr>
<tr>
<td>Hill</td>
<td>2005</td>
<td>method/case study</td>
<td>water catchment suitability</td>
<td>land suitability</td>
<td>hydrology</td>
<td>Value Measurement (AHP)</td>
</tr>
<tr>
<td>Jankowski</td>
<td>1995</td>
<td>review</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Jankowski</td>
<td>2001</td>
<td>method/case study</td>
<td>site selection for habitat restoration</td>
<td>site selection</td>
<td>environment</td>
<td>NEW - collaborative decision</td>
</tr>
<tr>
<td>Jiang (Eastman)</td>
<td>2000</td>
<td>method/case study</td>
<td>industrial allocation in Kenya</td>
<td>land suitability</td>
<td>regional planning</td>
<td>Value Measurement (AHP)</td>
</tr>
<tr>
<td>Joerin</td>
<td>2001</td>
<td>method/case study</td>
<td>housing siting</td>
<td>land suitability</td>
<td>urban planning</td>
<td>Outranking</td>
</tr>
<tr>
<td>Joerin</td>
<td>1998</td>
<td>method/case study</td>
<td>housing siting</td>
<td>land suitability</td>
<td>urban planning</td>
<td>Outranking</td>
</tr>
<tr>
<td>Karnatak</td>
<td>2005</td>
<td>method</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Value Measurement (AHP)</td>
</tr>
<tr>
<td>Kordi</td>
<td>2011</td>
<td>method/case study</td>
<td>dam siting</td>
<td>site selection</td>
<td>hydrology</td>
<td>Value Measurement (AHP)</td>
</tr>
<tr>
<td>Lewis</td>
<td>2014</td>
<td>case study</td>
<td>biofeedstock crop land suitability</td>
<td>land suitability</td>
<td>agriculture</td>
<td>Value Measurement (AHP)</td>
</tr>
<tr>
<td>Ma</td>
<td>2005</td>
<td>case study</td>
<td>anaerobic digester energy</td>
<td>land suitability</td>
<td>energy manufacture</td>
<td>Value Measurement</td>
</tr>
<tr>
<td>Malczewski</td>
<td>2006</td>
<td>review</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Malczewski</td>
<td>2004</td>
<td>review</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Simao</td>
<td>2009</td>
<td>case study</td>
<td>wind farm siting</td>
<td>site selection</td>
<td>MISC - energy</td>
<td>Value Measurement</td>
</tr>
<tr>
<td>Soltani</td>
<td>2014</td>
<td>review</td>
<td>municipal solid waste management</td>
<td>site selection</td>
<td>waste management</td>
<td>--</td>
</tr>
<tr>
<td>Wanderer</td>
<td>2014</td>
<td>case study</td>
<td>solar power plant impact</td>
<td>impact assessment</td>
<td>environment</td>
<td>Value Measurement (AHP)</td>
</tr>
<tr>
<td>Weber</td>
<td>2011</td>
<td>method/case study</td>
<td>business location</td>
<td>site selection</td>
<td>urban planning</td>
<td>Value Measurement (AHP)</td>
</tr>
<tr>
<td>Wood</td>
<td>2007</td>
<td>case study</td>
<td>marine conservation</td>
<td>land suitability</td>
<td>environment</td>
<td>Value Measurement</td>
</tr>
<tr>
<td>Yemshanov</td>
<td>2013</td>
<td>method/case study</td>
<td>invasive species risk</td>
<td>Misc - risk management</td>
<td>environment</td>
<td>NEW - MA frontier</td>
</tr>
</tbody>
</table>
## GIS-Based MCDA Article Survey (2006)

<table>
<thead>
<tr>
<th>APPLICATION DOMAIN</th>
<th>DECISION PROBLEM</th>
<th>Environment</th>
<th>Urban Planning</th>
<th>Forestry</th>
<th>Transportation</th>
<th>Hydrology</th>
<th>Waste Management</th>
<th>Agriculture</th>
<th>Natural Hazard</th>
<th>Recreation</th>
<th>Real Estate</th>
<th>Geology</th>
<th>Manufacturing</th>
<th>Cartography</th>
<th>Miscellaneous</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Land Suitability</td>
<td>19</td>
<td>4</td>
<td>12</td>
<td>3</td>
<td>4</td>
<td>11</td>
<td>8</td>
<td>9</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>8</td>
<td>17%</td>
</tr>
<tr>
<td></td>
<td>Scenario Evaluatn</td>
<td>8</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>11</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>Site Selection</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Resource Allocation</td>
<td>10</td>
<td>10</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>8</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Transport Routing</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Impact Assessmt</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Location- Allocation</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>Miscellaneous</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>17%</td>
<td>12%</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
<td>8%</td>
<td>8%</td>
<td>5%</td>
<td>4%</td>
<td>2%</td>
<td>3%</td>
<td>2%</td>
<td>8%</td>
<td>17%</td>
<td>100%</td>
</tr>
</tbody>
</table>

319 GIS-MCDA peer-reviewed articles

Malczewski (2006)
Retrospective GIS-Based MCDA

Hypothesis:
Given a large enough population set of similar historical spatial decisions, inverse problem approach can be applied to determine subjective valuation of criteria by stakeholders.
Capstone: Retrospective GIS-Based MCDA

Geospatial statistical analysis will be integrated with Multiple Criteria Decision Analysis methodology to retrospectively examine a prior site decision case study which entailed multiple stakeholders with conflicting motivations and data uncertainty.

**Approach:**
Actual decision results for a selected decision domain case will be contrasted with predictive results using regression and stochastic analysis of criteria weighting and uncertainty without explicit information about stakeholders’ valuation.

**Objectives:**
1) Create probabilistic model for prediction of future related decision outcomes
2) Provide insights in decision-maker strategies
3) Develop and demonstrate a new methodology applicable to other GIS decision domains
# Retro-GIS-MCDA Case Study Decision Domains Selection

<table>
<thead>
<tr>
<th>Subject</th>
<th>Data Availability</th>
<th>Size of Decision Set</th>
<th>Decision Set Consistency</th>
<th>Sources</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>power plant - NG</td>
<td>++</td>
<td>++</td>
<td>OK</td>
<td>EIA, EPA (eGrid), DOE</td>
<td>Not strong NIMBY</td>
</tr>
<tr>
<td>power plant - biomass</td>
<td>++</td>
<td>+</td>
<td>highly variable</td>
<td>EIA, EPA (eGrid), DOE</td>
<td>Often co-located w existing facility</td>
</tr>
<tr>
<td>power plant - WTE</td>
<td>++</td>
<td>-</td>
<td>temporal</td>
<td>EIA, EPA (eGrid), DOE, ERC</td>
<td>86 over 30 years</td>
</tr>
<tr>
<td>waste transfer stations</td>
<td>+</td>
<td>++</td>
<td>OK</td>
<td>EPA, state data</td>
<td>Very large decision set</td>
</tr>
<tr>
<td>pipeline</td>
<td>+</td>
<td>++</td>
<td>highly variable</td>
<td>NPMS</td>
<td>many factors over full length</td>
</tr>
<tr>
<td>landfill</td>
<td>++</td>
<td>++</td>
<td>OK</td>
<td>EPA, state data</td>
<td>Real estate intensive</td>
</tr>
<tr>
<td>distribution centers</td>
<td>-</td>
<td>++</td>
<td>OK</td>
<td>proprietary</td>
<td>requires specific supply chain insight</td>
</tr>
<tr>
<td>data centers</td>
<td>-</td>
<td>++</td>
<td>OK</td>
<td>proprietary</td>
<td>power reliability dominates</td>
</tr>
<tr>
<td>retail stores</td>
<td>(+)</td>
<td>++</td>
<td>local effects</td>
<td>proprietary</td>
<td>requires specific business insight</td>
</tr>
<tr>
<td>medical clinics</td>
<td>+</td>
<td>++</td>
<td>local effects</td>
<td>study region</td>
<td>Most information public domain</td>
</tr>
<tr>
<td>manufacturing</td>
<td>-</td>
<td></td>
<td>highly variable</td>
<td>proprietary</td>
<td>requires specific supply chain insight</td>
</tr>
</tbody>
</table>
Waste Transfer Station Siting Decision – Problem Structuring

Potential Criteria

- Location of final disposal facility
- Location and capacity of existing local WTSs
- Location of source – residential population, commercial
- Transportation infrastructure – roadway, rail, barge
- Proximate population (noise, odor, traffic)
- Demographics – income, age, household size, ethnicity
- Population density and growth rate
- Land Use / Zoning
- Protected areas: wetlands, flood plains, endangered species habitats, airports
- Political boundaries
- WTS characteristics - waste types, capacity, acreage, technology
- Owner/Operator type – public or private

Stakeholders

- Community and neighborhood groups
- Industry and business representatives
- Environmental organizations
- Local and state elected officials
- Public works officials
- Academic institutions
Waste Transfer Stations – Dataset Selection

State – California
Department of Resources Recycling and Recovery

Solid Waste Information System (SWIS) database
- 3210 solid waste facilities
  - 703 active waste transfer stations
  - 365 mixed municipal waste transfer stations

SWIS data:
- Location – coordinates and address
- Owner and operator information
- Waste types and capacity
- Acreage
- Operational status
- Permit status and links
Example: Orange County / Anaheim / CVT Regional WTS
Methodology for Retrospective GIS-MCDA

**Preliminary data preparation**
- Review and compilation of data sources:
  - SWIS database
  - Permit data
  - Census data
  - Land use data

**Review several site locations**
- Detailed breakdown of 4-5 WTS decisions
  - Map details
  - Access public record
  - Individual geospatial statistical analyses

**Complete data preparation**
- Revise and complement data sources (may need automation)
  - Establish homogeneous WTS site subsets
  - Rapport with stakeholders

**Develop model structures**
- Develop 1) problem structure assumptions
  - 2) reverse decision characterization

**Perform regression analysis**
- Apply and test deterministic and stochastic analytical methods to establish criteria parameters
  - Set up Value Measurement and Reference Point decision rule models
  - For data subsets

**Evaluate model effectiveness**
- Evaluate criteria parameter uncertainties and model goodness of fit
  - Compare regression between WTS site subsets

**Assess methodology**
- Outcomes
- Usefulness
- Applicability
- Further development
Expected Outcomes

1) Characterization of California waste transfer station site decisions
   - Probabilistic model
   - Stakeholder criteria valuation parameters

2) Assessment of the Retro-GIS-MCDA methodology:
   - Additional stakeholder strategy insights
   - Predictive effectiveness
   - Deficiencies and development needs

3) Assessment of method amenability
   - Other application domains
   - Other GIS decision problems

4) Recommendations
   - Future work requirements
   - Practical applications

5) Publication in refereed journal in addition to conference presentation(s)
Capstone Project Timeline

December
- Target journal selection and presentation venues
- Abstract preparation and submission

January
- Conference presentation

February
- Journal paper first draft

March
- Journal paper final draft
- Final report completion

April
- Journal paper submission

May
- Final report completion

> May
- Final report completion
References


Acknowledgements

Tom Seager, Associate Professor
Valentina Prado, PhD candidate
School of Sustainable Engineering and the Built Environment
Arizona State University

Dr. Douglas Miller

Dr. Justine Blanford