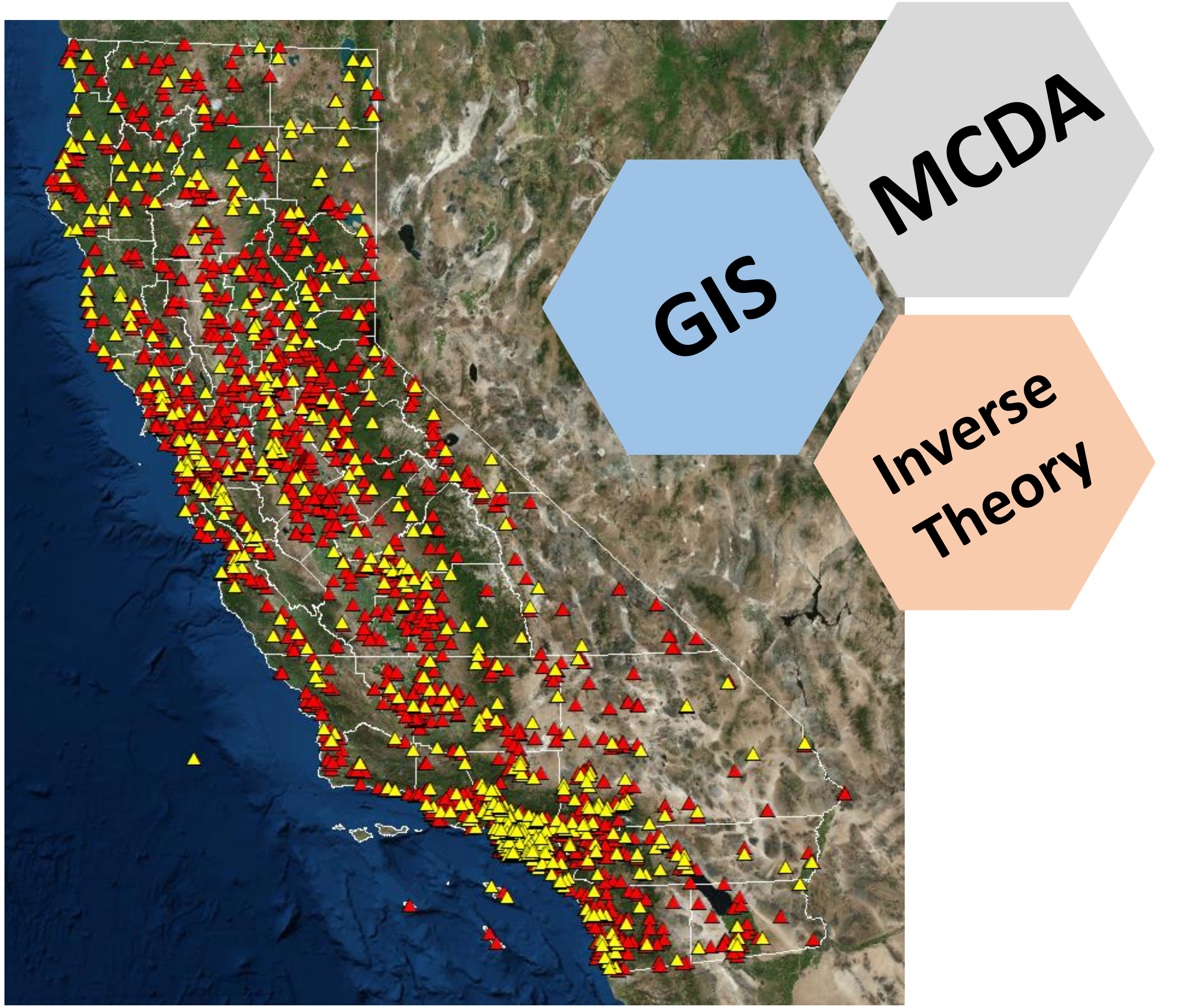
Retrospective GIS-Based Multi-Criteria Decision Analysis

A Case Study of California Waste Transfer Station Siting Decisions



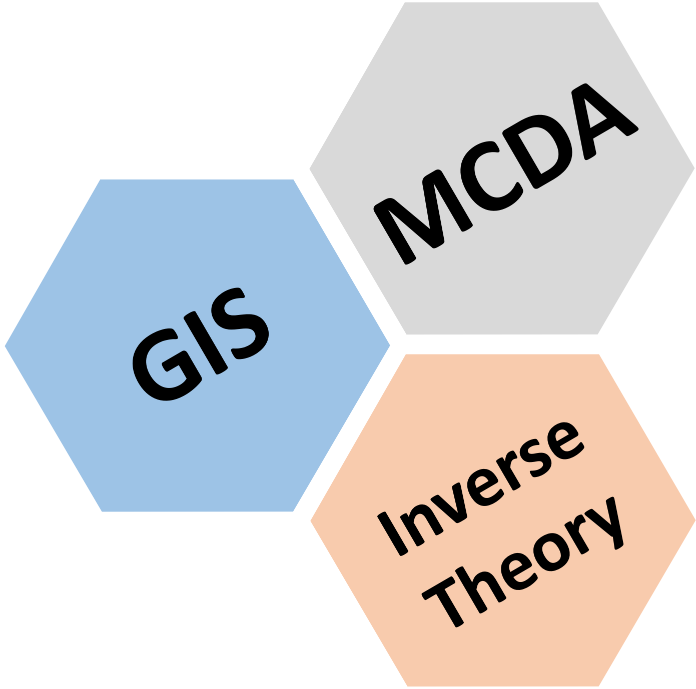
John Cirucci
GEOG 596A Capstone Proposal
Penn State MGIS
December 2014

Advisors: Justine Blanford/Doug Miller

PENNSTATE
World Campus

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



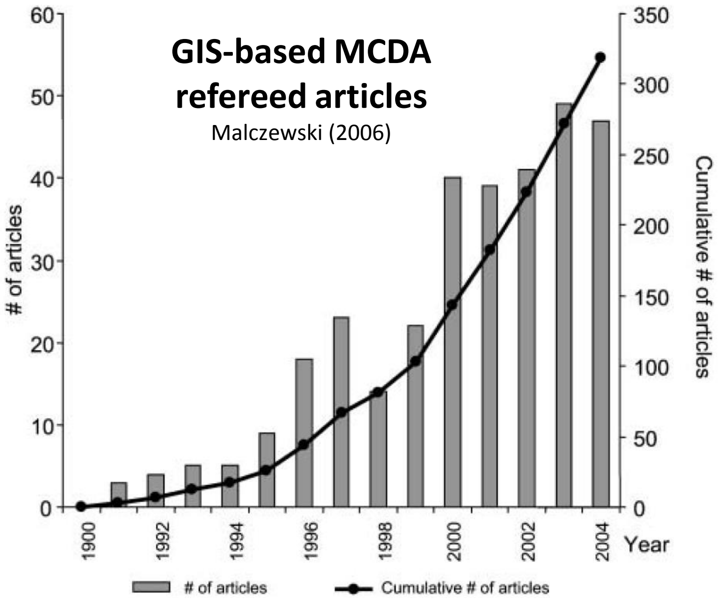
Multi-Criteria Decision Analysis (MCDA)

Photo Credit: Diane Diederich/Getty Images

Photo Credit: Michael Blann/Digital Vision/Getty Images

Most decisions entail consideration of multiple criteria

- process is simple
- criteria are implicit
- decider is an individual



"**MCDA**" describes the collection of **formal** approaches to take **explicit** account of multiple criteria, especially for **complex** and **high impact** decisions.

Belton & Stewart (2002)

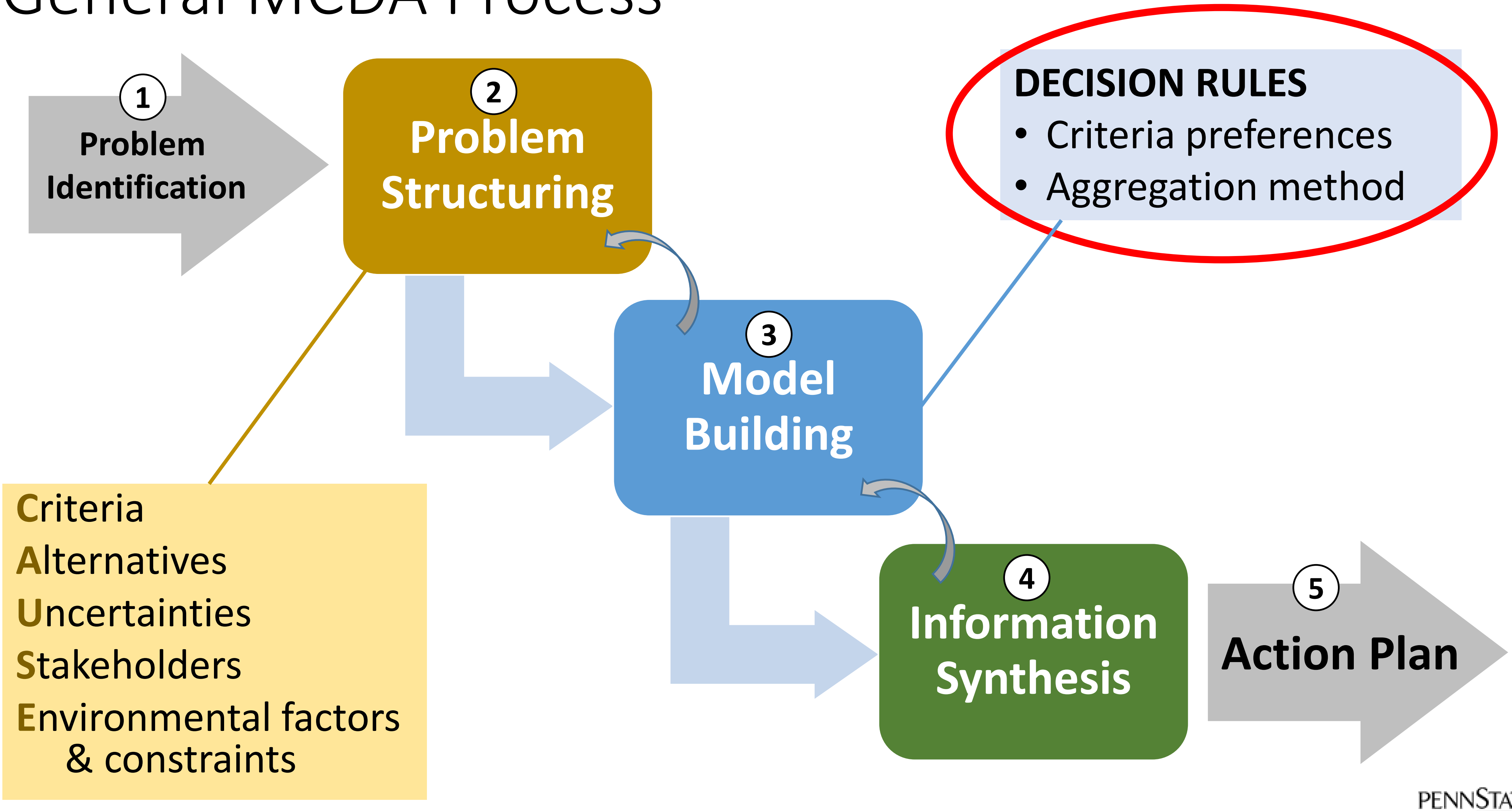
Many decisions are spatial…

Many GIS analyses provide spatial decision support…

GIS-based MCDA discipline is an expanding niche field

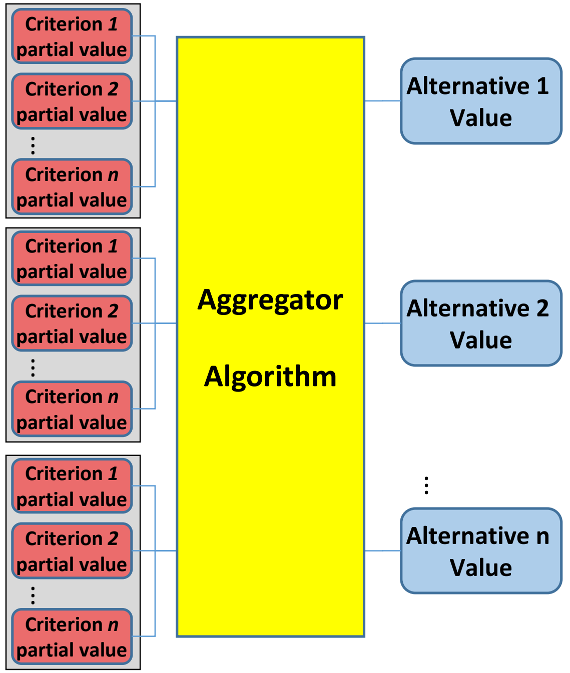
PENNSTATE

General MCDA Process



Categories of Decision Rules for MCDA Models

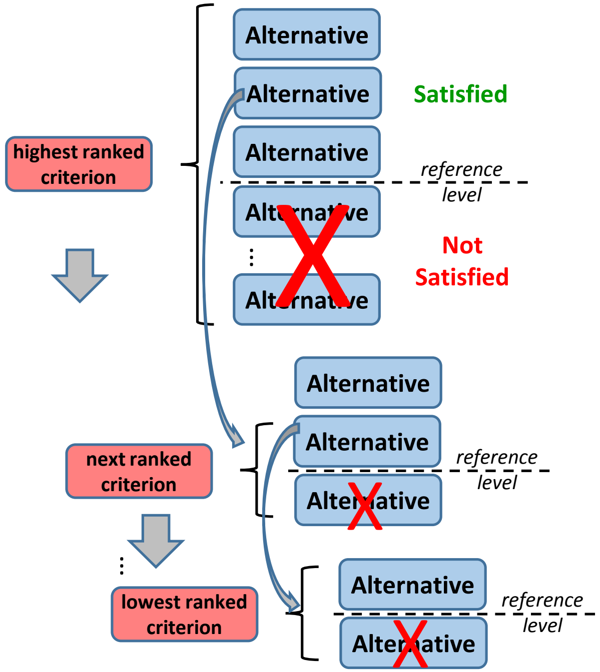
Value Measurement



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

Outcomes do not always accurately represent true stakeholders' valuation

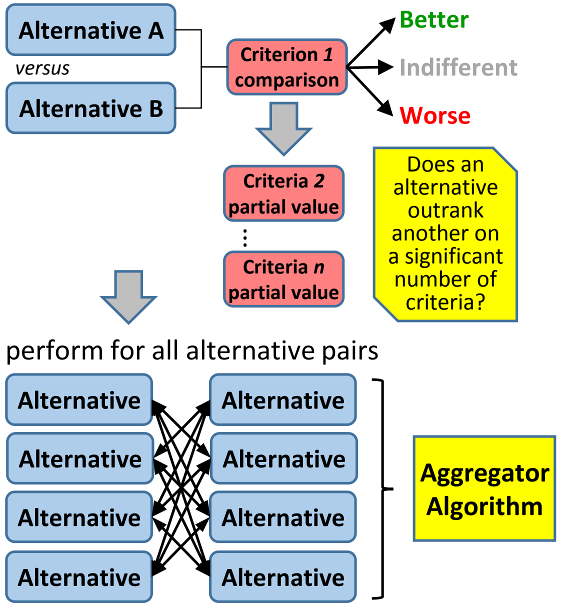
Reference Point



- 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

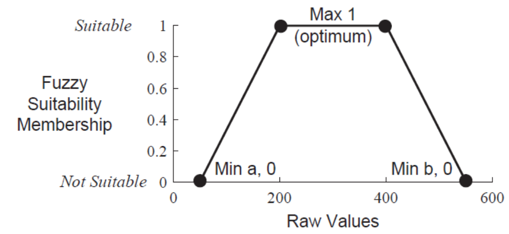


- Elicits stakeholder valuation
- Highly interactive
- Ambiguity made explicit
- Labor and computation intensive

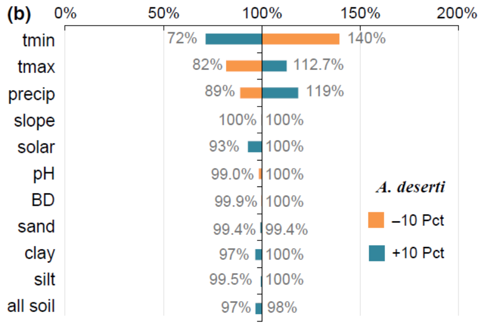
Example: Land Suitability for Agave Bioenergy Feedstock

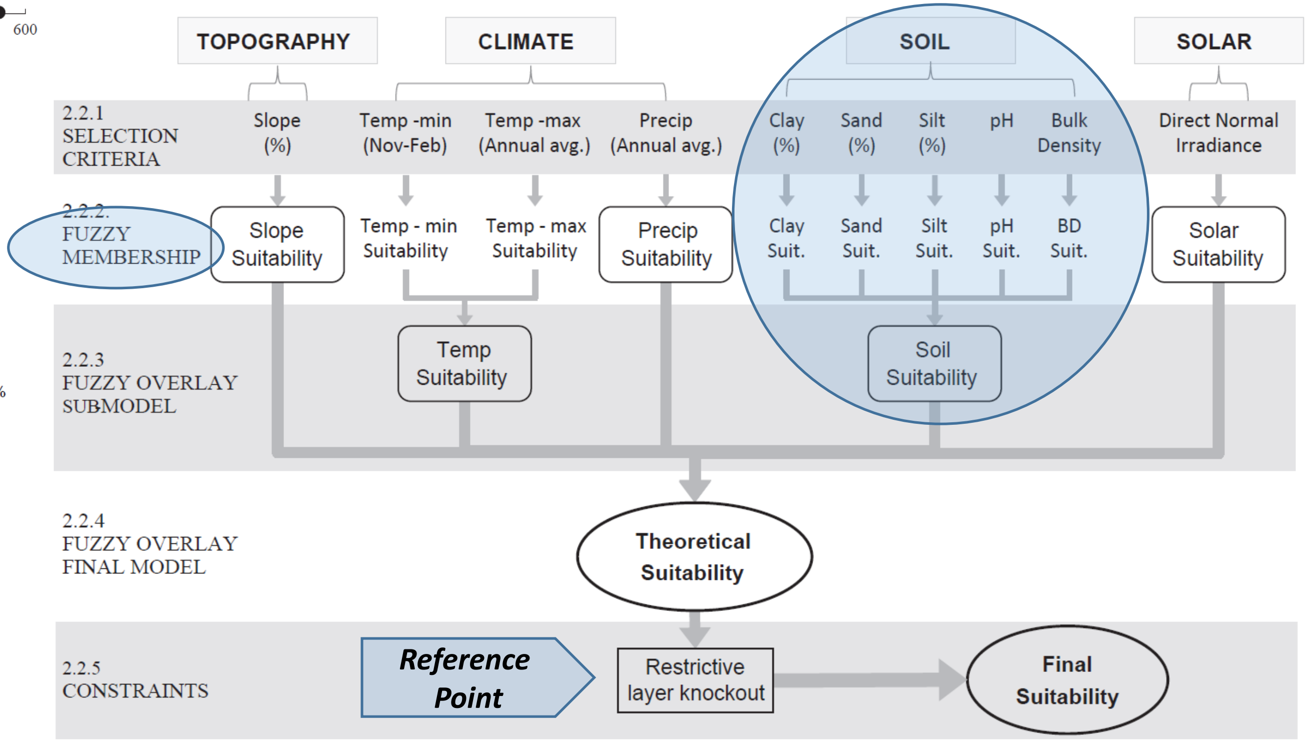
Value Measurement with Analytical Hierarchy Process (AHP) and final Reference Point

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

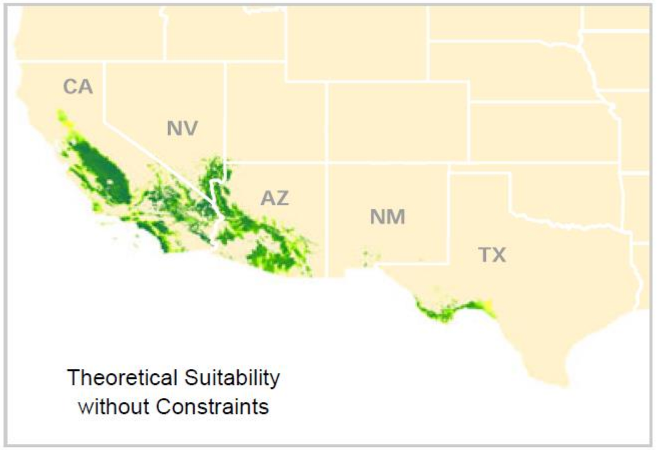


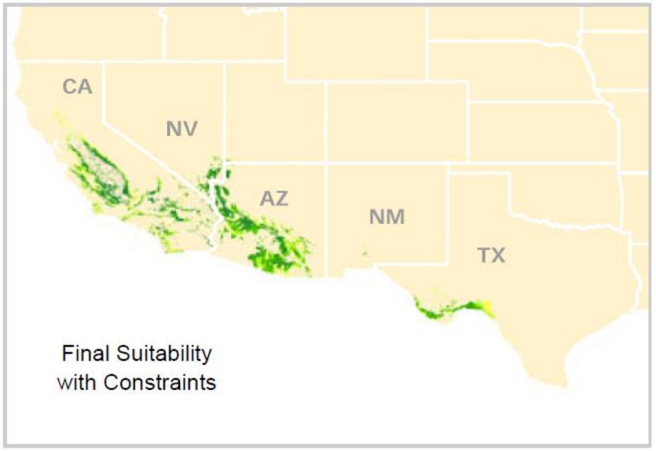
Criteria Sensitivity





Agave deserti

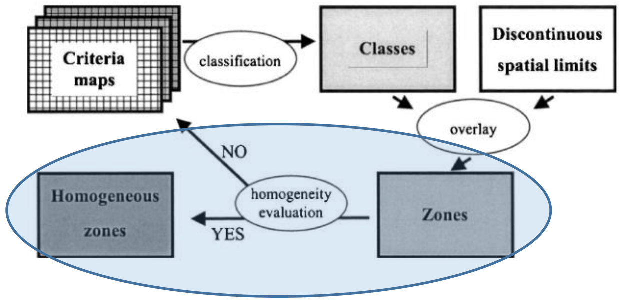




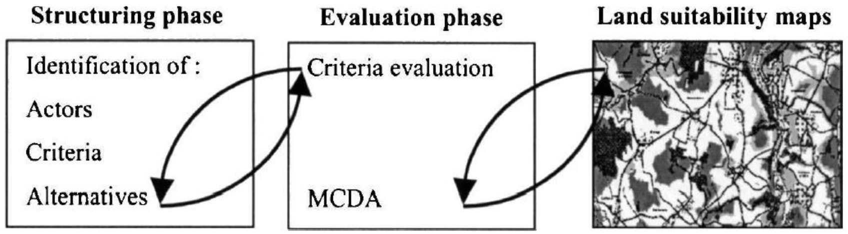
Lewis et al (2014). Fuzzy GIS-based multi-criteria evaluation for US Agave production as a bioenergy feedstock . GCB Bioenergy

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

$A: [N_{a,1}, N_{a,2}, \ldots, N_{a,n}]$
$B: [N_{b,1}; N_{b,2}; \ldots, N_{b,n}]$

A: element A
B: element B
$N_{j,i}$: score of element j for the criterion i.

$$r(A,B) = C(A,B) \cdot \prod_{i \in I} \frac{1 - d_i(A,B)}{1 - C(A,B)}$$

$r(A, B)$: Degree of credibility of closeness relationship between A and B. $r(A, B) \in [0; 1]$.

$$I = \{i: d_i(A,B) > C(A,B)\}$$

$C(A, B)$: Global concordance. $C(A, B) \in [0; 1]$
$d(A, B)$: discordance index on criteria i.
$d_i(A, B) \in [0; 1]$

$$C(A,B) = \frac{\sum_{i=1}^{n} w_i \cdot c_i(A,B)}{\sum_{i=1}^{n} w_i}$$

w_i: weights on criteria i. $w_i \in [0; 1]$
$c_i(A, B)$: concordance index on criteria i.
$c_i(A, B) \in [0; 1]$

$$c_i(A,B) = \begin{cases} 1 & \text{if } Xi < q_i \\ \frac{p_i - X_i}{p_i - q_i} & \text{if } Xi \in [q_i; p_i] \\ 0 & \text{if } Xi > p_i \end{cases}$$

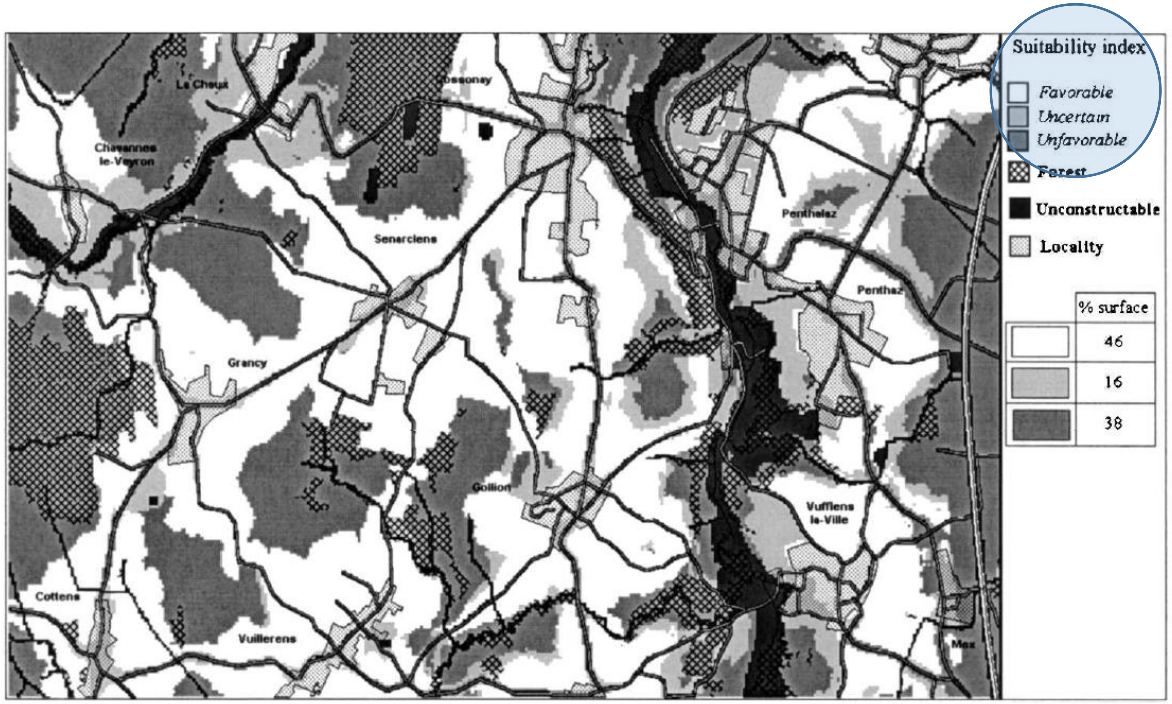
$c_i(A, B)$: concordance index, $c_i(A, B) \in [0; 1]$
q_i: indifference on criterion i. q_i: in criteria units
p_i: strict difference on criterion i. p_i: in criteria units
X_i: Absolute difference between A and B on criterion i.

$$X_i = |N_{A,i} - N_{B,i}|$$

$N_{A,i}$: score of A on criterion i.
$N_{B,i}$: score of B on criterion i.

$$d_i(A,B) = \begin{cases} 0 & \text{if } Xi < p_i \\ \frac{p_i - X_i}{p_i - v_i} & \text{if } Xi \in [p_i; v_i] \\ 1 & \text{if } Xi > v_i \end{cases}$$

$d_i(A, B)$: discordance index on criterion i.
$d_i(A, B) \in [0; 1]$
p_i: strict difference on criterion i. p_i: in criteria units
v_i: veto on criterion i. v_i: in criteria units.



Joerin et al (2001). Using GIS and outranking multicriteria analysis for land-use suitability assessment. Int J GIS

Partial Literature Survey – Cirucci (2014)

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

GIS-Based MCDA Article Survey (2006)

APPLICATION DOMAIN	DECISION PROBLEM: Land Suitability	Scenario Evaluatn	Site Selection	Resource Allocation	Transport Routing	Impact Assessmt	Location-Allocation	Miscel-laneous	TOTAL
Environment	19	8	3	10	0	5	0	10	**17%**
Urban Planning	4	8	5	10	1	0	3	6	**12%**
Forestry	12	2	8	3	3	0	0	2	**9%**
Transportation	3	2	0	0	13	2	0	9	**9%**
Hydrology	4	11	4	2	0	1	0	6	**9%**
Waste Management	11	2	5	0	7	0	1	0	**8%**
Agriculture	8	3	4	7	0	2	0	2	**8%**
Natural Hazard	9	4	0	0	1	0	0	1	**5%**
Recreation	3	2	6	0	0	0	0	3	**4%**
Real Estate	4	3	2	1	0	0	0	2	**4%**
Geology	3	0	0	0	0	1	0	5	**3%**
Manufacturing	3	0	4	0	0	0	0	0	**2%**
Cartography	0	0	0	0	0	0	0	5	**2%**
Miscellaneous	8	4	5	2	0	0	3	4	**8%**
TOTAL	**29%**	**15%**	**14%**	**11%**	**8%**	**3%**	**2%**	**17%**	**100%**

319 GIS-MCDA peer-reviewed articles

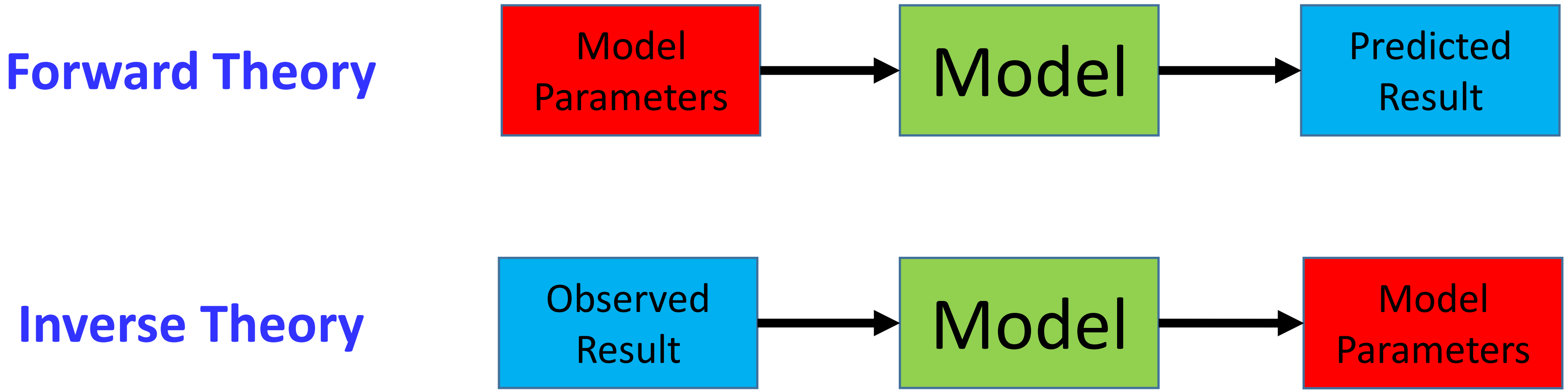
Malczewski (2006)

PENNSTATE

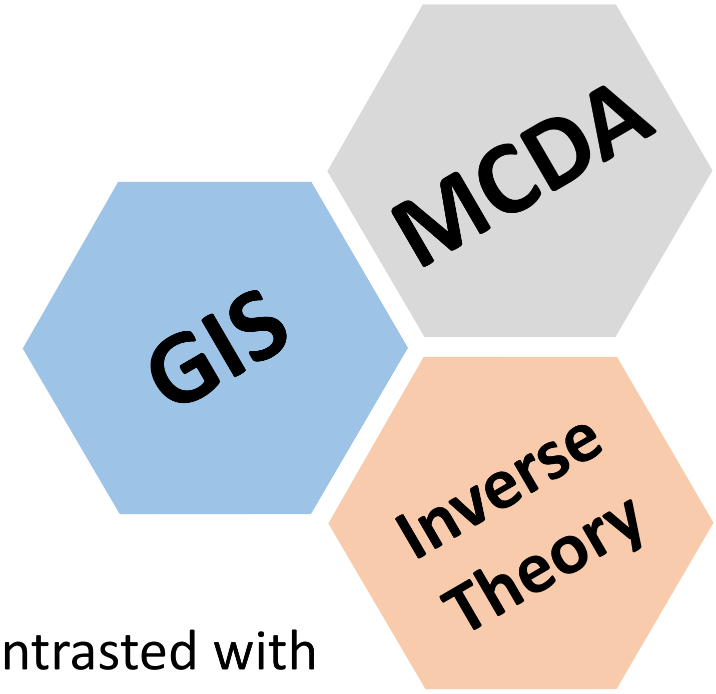
Retrospective GIS-Based MCDA

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.

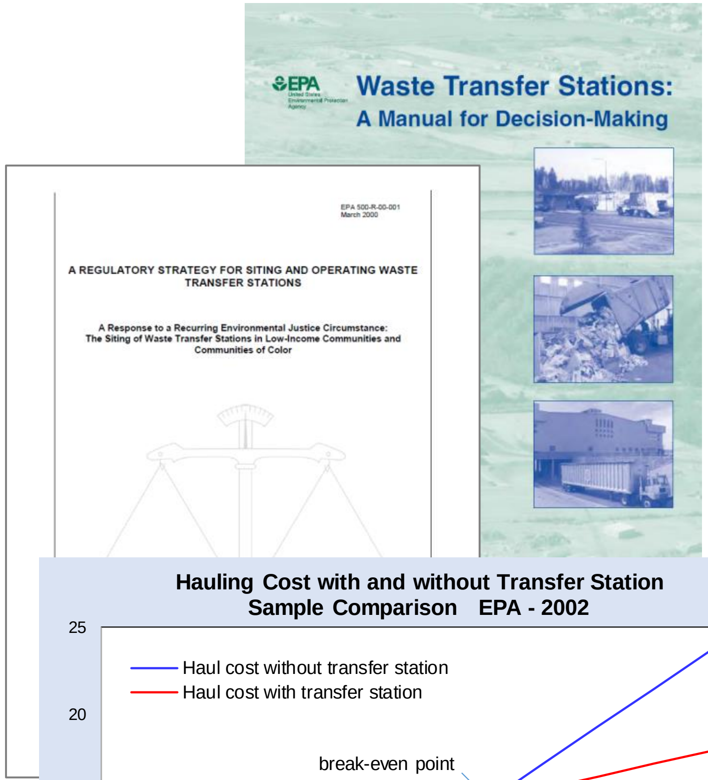
Objectives:

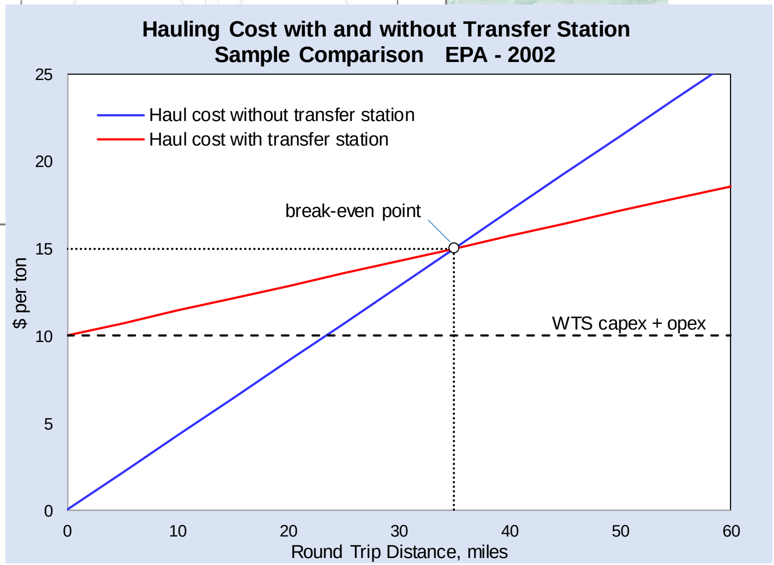
1) Create probabilistic model for prediction of future related decision outcomes
2) Provide insights in decision-maker strategies
3) Develop and demonstrate a new methodology applicable to other GIS decision domains

Retro-GIS-MCDA Case Study Decision Domains Selection

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

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

PENNSTATE

Waste Transfer Stations – Dataset Selection

State – California

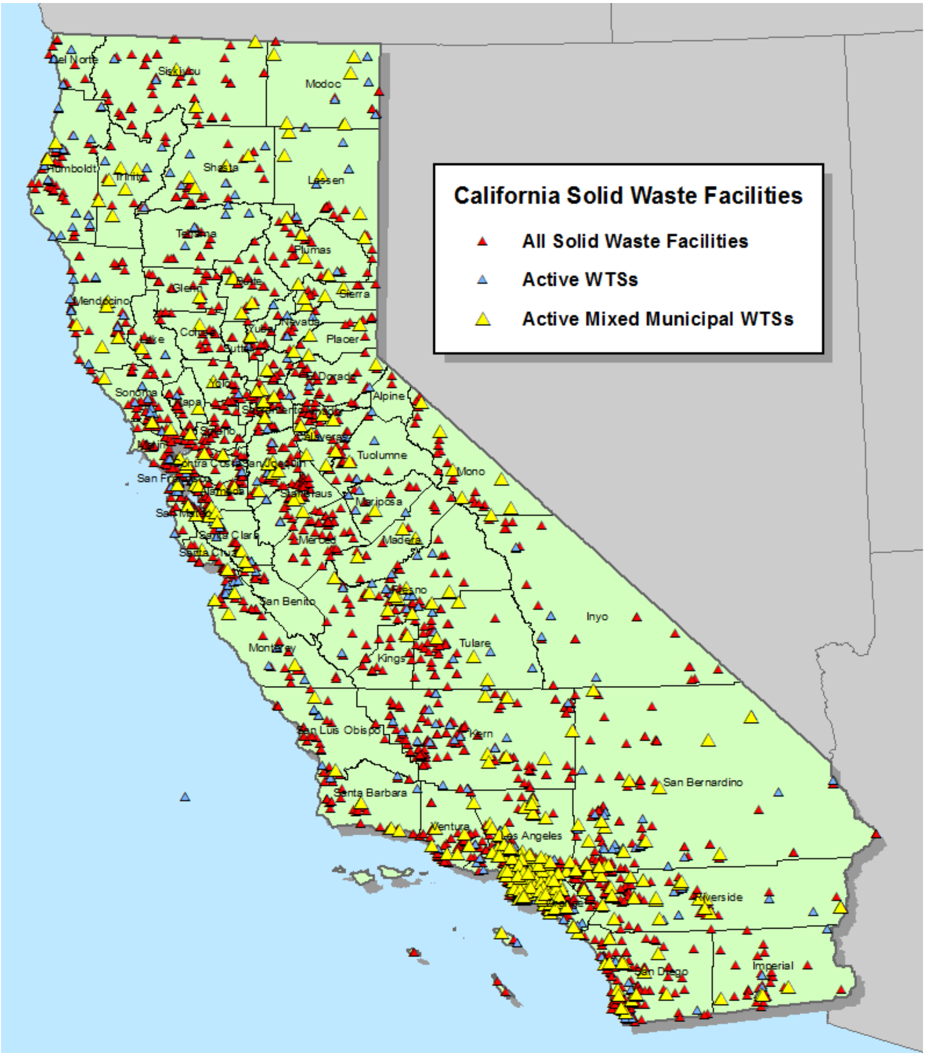
Department of Resources Recycling and Recovery

Solid Waste Information System (SWIS) database

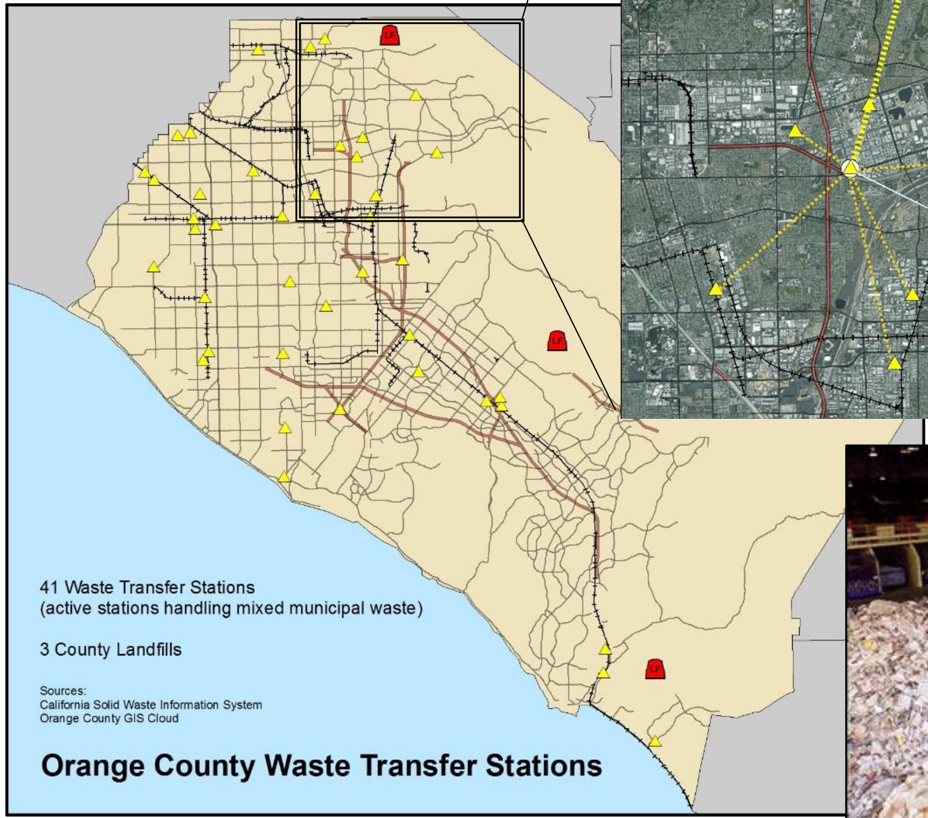
- 3210 solid waste facilities
  - 703 active waste transfer stations
    - 365 mixed municipal waste transfer stations

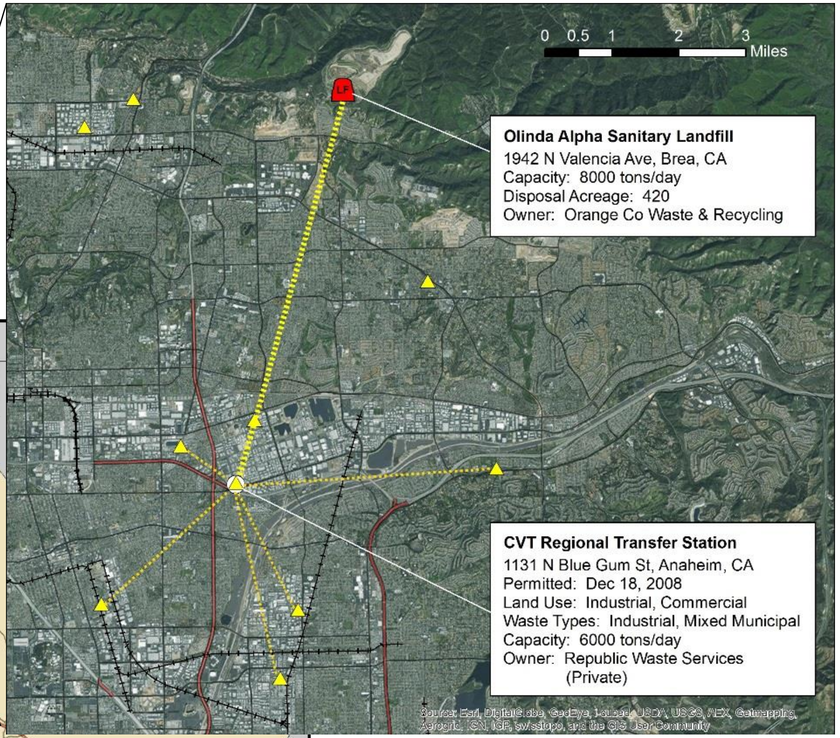
SWIS data:

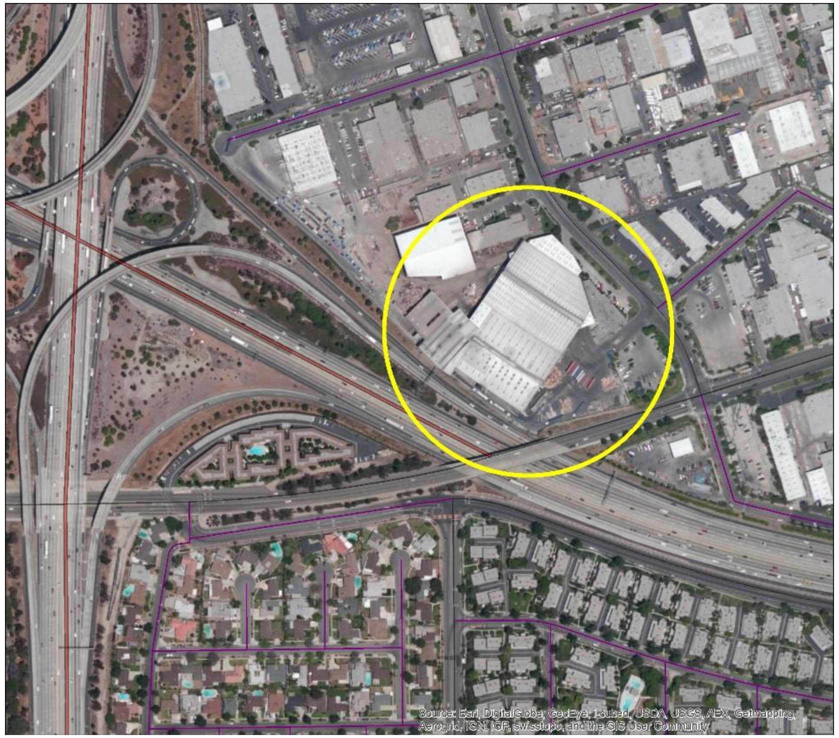
- Location – coordinates and address
- Owner and operator information
- Waste types and capacity
- Acreage
- Operational status
- Permit status and links



Example: Orange County / Anaheim / CVT Regional WTS

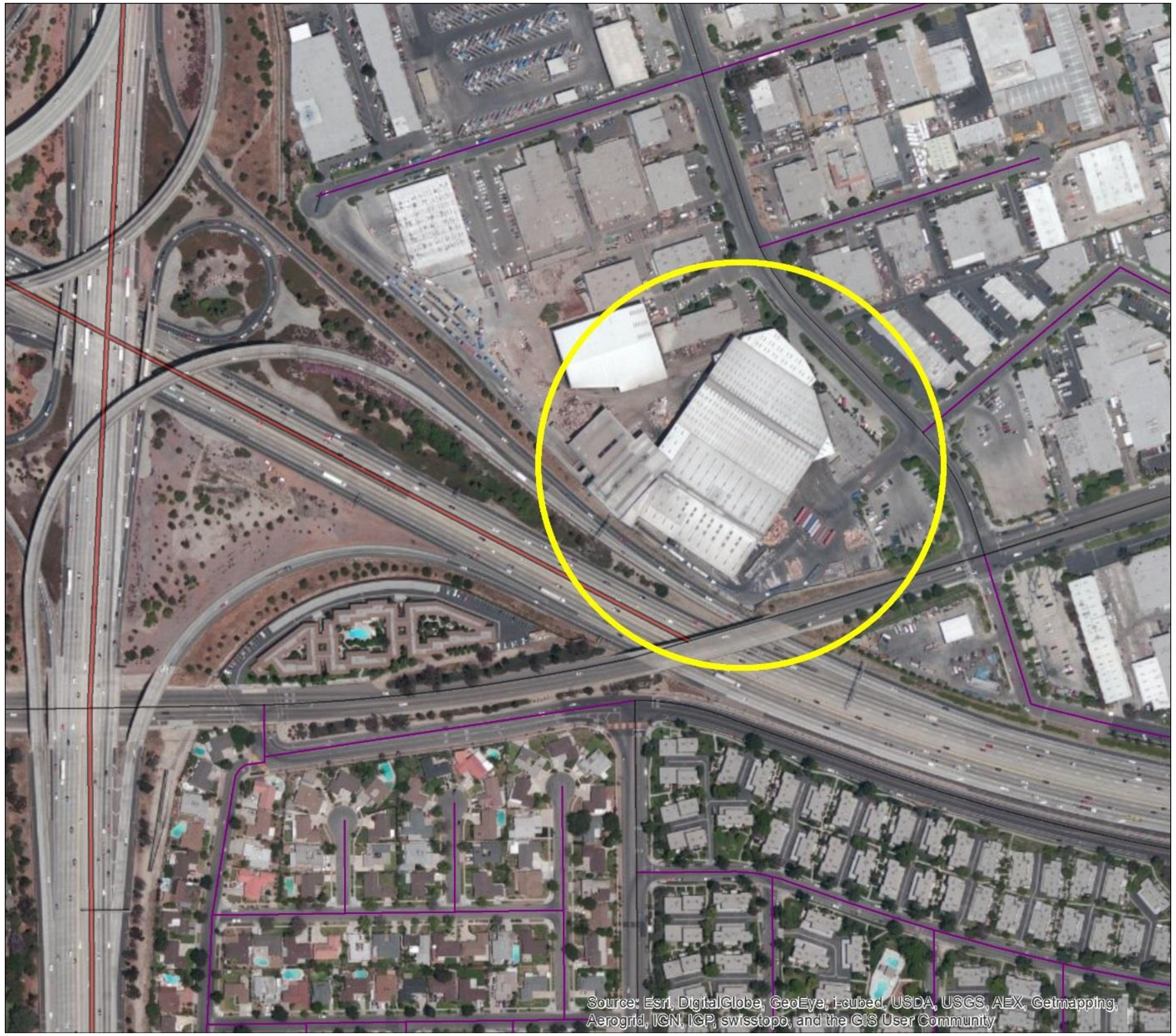






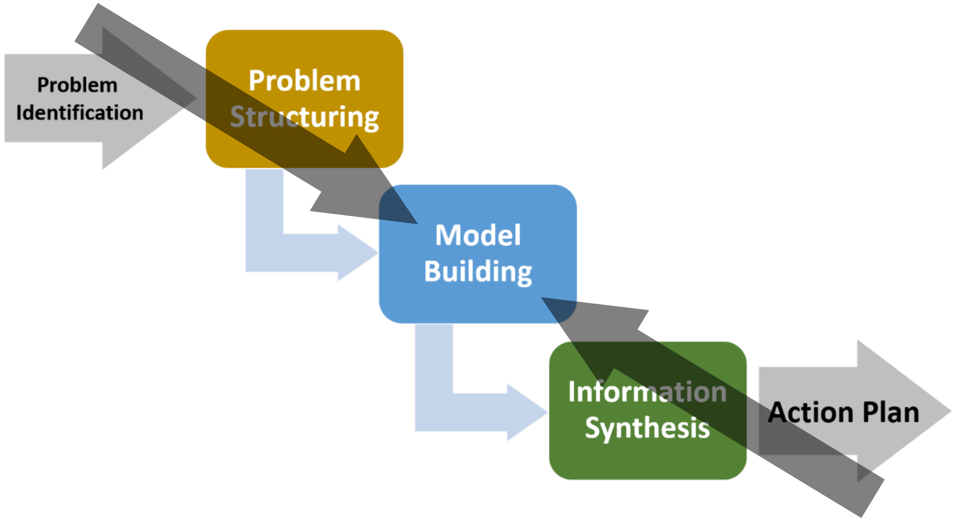
PENNSTATE

CVT Regional WTS, Anaheim, Orange County



Caltrans WTS, Mountain Pass, San Bernardino County

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

Set up Value Measurement and Reference Point decision rule models

Perform regression analysis

Apply and test deterministic and stochastic analytical methods to establish criteria parameters (partial values, reference points) 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

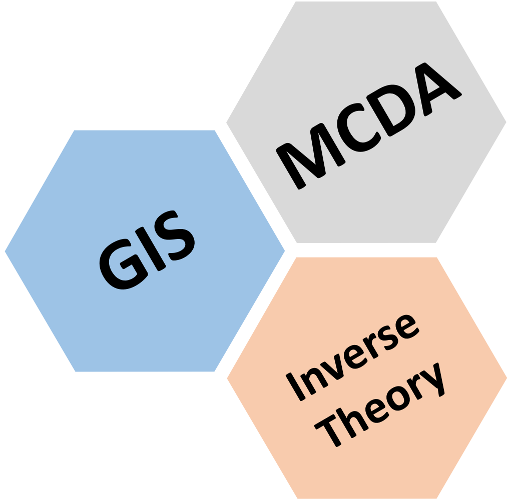
1) Characterization of California waste transfer station site decisions
   - ❖ Probabilistic model
   - ❖ Stakeholder criteria valuation parameters

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

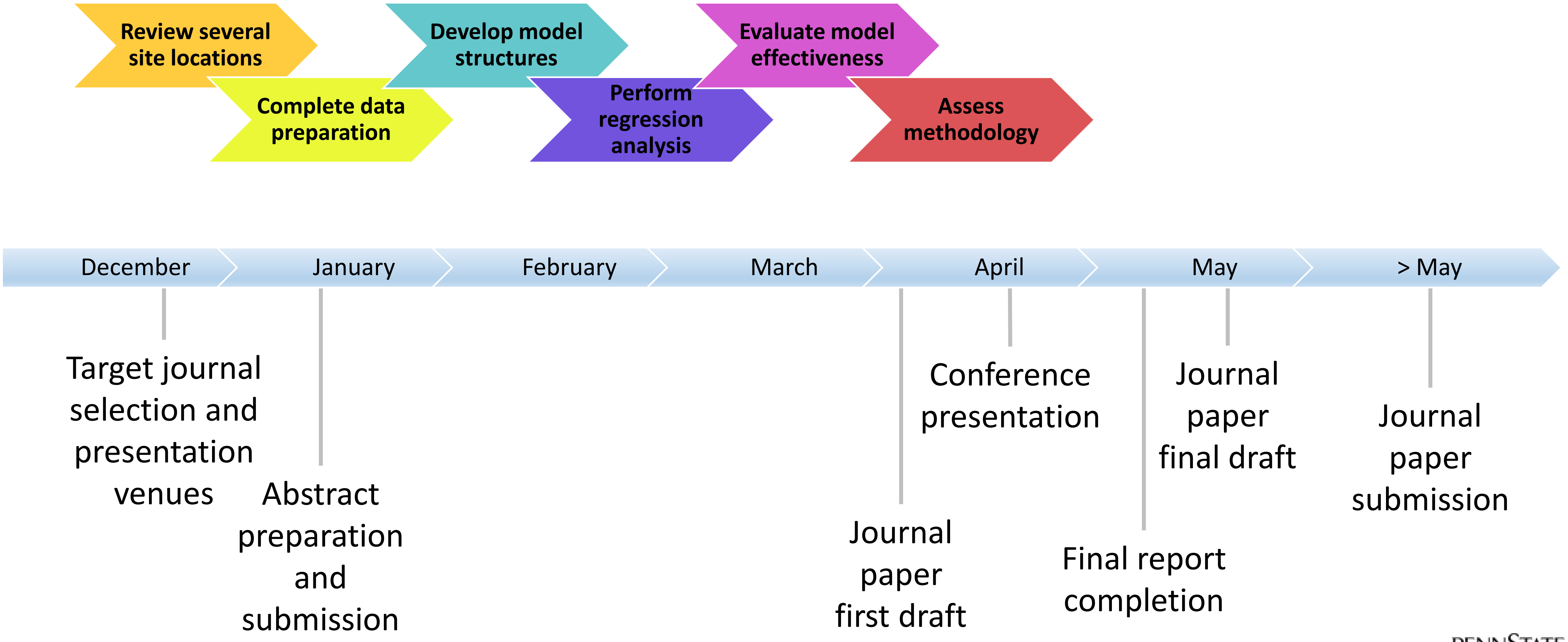
3) Assessment of method amenability
   - ❖ Other application domains
   - ❖ Other GIS decision problems

4) Recommendations
   - ❖ Future work requirements
   - ❖ Practical applications

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



Capstone Project Timeline



References

Aerts, J., Eisinger, E., Heuvelink, G., Stewart, T. (2003). Using Linear Integer Programming for Multi-Site Land-Use Allocation. Geographical Analysis, 35 (2)

Belton, V., & Stewart, J. (2002). MULTIPLE CRITERIA DECISION ANALYSIS An Integrated Approach. Boston: Kluwer Academic Publishers.

Chang, N., Parvathinathan, G., & Breeden, J. B (2008). Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. Journal of Environmental Management, 87(1), 139-153. doi:10.1016/j.jenvman.2007.01.011

Craig, M. H., Snow, R. W., & Le Sueur, D. (1999). A climate-based distribution model of malaria transmission in sub-Saharan Africa. Parasitology today, 15(3), 105-111.

Dewi, O. C., Koerner, I., & Harjoko, T. Y. (2010). A Review on Decision Support Models for Regional Sustainable Waste Management. Proceedings of the International Solid Waste Association World Congress 2010.

Drews, L. V (2012). Multi-Criteria GIS Analysis for Siting of Small Wind Power Plants - A Case Study from Berlin. Master degree thesis, LUMA-GIS Thesis nr 17. Advisor: Per Schubert. Lund University. Lund, Sweden.

Eastman, J (1999). Multi-criteria evaluation and GIS. Geographical Information Systems, (1), 493-502.

Ehrgott, M., Figueira, J. R., Greco, S. (2010). Trends in Multiple Criteria Decision Analysis. Springer, [Chapter 13, “Multiple Criteria Decision Analysis and Geographic Information Systems.” Malczewski, J. 369-395.]

Environmental Protection Agency. (2002) Waste Transfer Stations: A Manual for Decision-Making. EPA 530-R-02-002.

Environmental Protection Agency. (2000) A Regulatory Strategy for Siting and Operating Waste Transfer Stations. EPA 500-R-00-001.

Evans, A. J., Kingston, R., & Carver, S (2004). Democratic input into the nuclear waste disposal problem: The influence of geographical data on decision making examined through a Web-based GIS. Journal Of Geographical Systems, 6(2).

Feizizadeh, B., Jankowski, P., & Blaschke, T (2014). A GIS based spatially-explicit sensitivity and uncertainty analysis approach for multi-criteria decision analysis. Computers & Geosciences.

Feizizadeh, B., Roodposhti, M., & Jankowski, P (2014). A GIS-based extended fuzzy multi-criteria evaluation for landslide susceptibility mapping. Computers & Geosciences

Greene, R., Devillers, R., Luther, J. E., & Eddy, B. G. (2011). GIS-Based Multiple-Criteria Decision Analysis. Geography Compass, 5(6), 412-432.

Hanashima, Y., & Yamazaki, K. (2002). The iterative method in multi-criteria decision analysis: A case study of fuzzy GIS. In Proceedings of the10th International Conference on GeoComputation, Sydney, Australia.

Hansen, H. S. (2005, January). GIS-based multi-criteria analysis of wind farm development. In ScanGIS 2005: Scandinavian Research Conference on Geographical Information Science (pp. 75-87).

Hill, J., Braaten, R., Veitch, S., Lees, B., Sharma, S. (2005). Multi-criteria decision analysis in spatial decision support: the ASSESS analytical hierarch process and the role of quantitative methods and spatially explicit analysis. Environmental Modelling & Software, 20, 955-976.

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. *International journal of geographical information systems*, *9*(3), 251-273.

Jankowski, P., & Nyerges, T (2001). GIS-supported collaborative decision making: results of an experiment. Annals Of The Association Of American Geographers, 91(1), 48-70.

Jiang, H., & Eastman, J (2000). Application of fuzzy measures in multi-criteria evaluation in GIS. International Journal Of Geographical.

Joerin, F., Golay, F., & Musy, A (1998). GIS and multicriteria analysis for land management. COST C4 Final Conference Jukkasjärvi.

Joerin, F., Thériault, M., & Musy, A (2001). Using GIS and outranking multicriteria analysis for land-use suitability assessment. International Journal Of Geographical Information Science, 15(2), 153-174. doi:10.1080/13658810051030487

Jones, J. M. (2010). Use of multi-criteria decision analysis with fuzzy measures in historical GIS. Master's Theses. Paper 3840. Advisors: M. K. Davis, G. Pereira, K Richardson. San Jose State University.

Karnatak, H. C., Saran, S., Bhatia, K., & Roy, P. S (2007). Multicriteria Spatial Decision Analysis in Web GIS Environment. Geoinformatica, 11(4), 407-429. doi:10.1007/s10707-006-0014-8

Kordi, M., & Brandt, S. A. (2012). Effects of increasing fuzziness on analytic hierarchy process for spatial multicriteria decision analysis. Computers, Environment and Urban Systems, 36(1), 43-53.

Kosko, B. (1990). Fuzziness vs. Probability. International Journal of General Systems, 17, 211-240.

Lewis, S. M., Gross, S., Visel, A., Kelly, M., & Morrow, W. (2014). Fuzzy GIS-based multi-criteria evaluation for US Agave production as a bioenergy feedstock . GCB Bioenergy.

Ma, J., Scott, N. R., DeGloria, S. D., & Lembo, A. J (2005). Siting analysis of farm-based centralized anaerobic digester systems for distributed generation using GIS. Biomass And Bioenergy, 28(6), 591-600.

Malczewski, J. (1999). GIS and MULTICRITERIA DECISION ANALYSIS. New York: John Wiley & Sons, Inc.

Malczewski, J (2004). GIS-based land-use suitability analysis: a critical overview. Progress in Planning, 62(1), 3-65. doi:10.1016/j.progress.2003.09.002

Malczewski, J (2006). GIS-based multicriteria decision analysis: a survey of the literature. International Journal of Geographical Information Science, 20(7), 703-726.

Saaty, T. L. (1990). How to make a decision: the analytic hierarchy process. European journal of operational research, 48(1), 9-26.

Simão, A., Densham, P. J., & Haklay, M. ((2009). Web-based GIS for collaborative planning and public participation: An application to the strategic planning of wind farm sites. Journal Of Environmental Management, 90(6), 2027-2040.

Soltani, A. Hewage, K., Reza, B., Sadiq, R. (2014). Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management: A review. Waste Management.

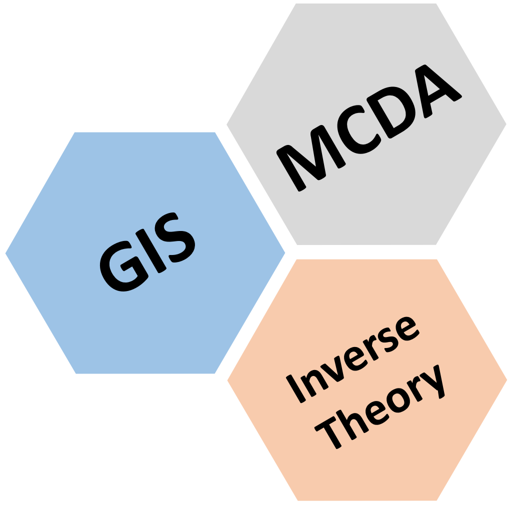
Wanderer, T., & Herle, S (2014). Creating a spatial multi-criteria decision support system for energy related integrated environmental impact assessment. Environmental Impact Assessment Review.

Weber, P., & Chapman, D (2011). Location Intelligence: An Innovative Approach to Business Location Decision-making. Transactions In GIS, 15(3), 309-328.

Wood, L. J., & Dragicevic, S (2007). GIS-Based Multicriteria Evaluation and Fuzzy Sets to Identify Priority Sites for Marine Protection. Biodiversity And Conservation, 16(9), 2539-2558.

Yemshanov, D., Koch, F., Ben-Haim, Y., Downing, M., Sapio, F., Siltanen, M. (2013). A New Multicriteria Risk Mapping Approach Based on a Multiattribute Frontier Concept. Risk Analysis. 33 (9)

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

PENNSTATE