MCDA Consulting LLC

Prioritizing Stormwater Project Alternatives
Using Multiple Criteria Decision Analysis

12th ANNUAL OHIO STORMWATER CONFERENCE
Sharonville Convention Center
May 10, 2019

Gina Beim, P.E., M. ASCE
Gina.Beim@MCDAconsulting.com

1

MCDA Consulting LLC

Learning Objectives

- Recognize common pitfalls in complex decision making and prioritization problems.
- Assign weights to decision making objectives in a manner that accurately reflects the decision maker's preferences and is theoretically valid.
- Create a hierarchy of goals, objectives and measures relevant for selecting watershed restoration, green infrastructure and BMP projects.
- Cite examples of projects in which multi criteria decision making approaches were used for selecting watershed restoration, green infrastructure and BMP projects.

2

MCDA Consulting LLC

Outline

- Motivation
- Background on MCDA / Modeling the decision choice
- Simple example
- Case Studies
- Summary
- Questions

3

MCDA Consulting LLC

Motivation

Choosing among several alternatives for
- Watershed Restoration
- Green Infrastructure Projects
- Best Management Practices

Multiple, conflicting objectives
- Cost
- Effectiveness
- Operational Complexity
- Socio-economic Impact
- Public Perception

Decision making is complex.

Multi Criteria Decision Analysis (MCDA) makes the decision process manageable and transparent.

4

MCDA Consulting LLC

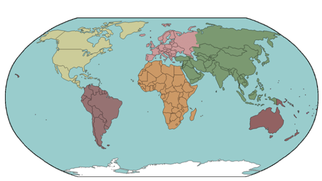
Motivation

8 Case studies
- 6 countries
- Average of 7 measures

as many as 26
- Average of 17 alternatives

as many as 70

USA, CANADA, CHINA, AUSTRALIA, IRAN, SAUDI ARABIA



5

MCDA Consulting LLC

Background on MCDA / Modeling the decision Choice

6

MCDA Consulting LLC

What is MCDA

A field of Operations Research

A collection of mathematical methods that help evaluate alternatives and prioritize/select them based on the Decision Maker's values and preferences.

A framework for addressing complex decision making problems involving multiple, conflicting criteria/goals/objectives

11/11/2019 © MCDA Consulting LLC 7

7

MCDA Consulting LLC

Why not select using B/C analysis?

Some things cannot be monetized

The distribution of benefits among different stakeholders is not captured by a single net benefits measure

Trade-offs are not explicit

11/11/2019 © MCDA Consulting LLC 8

8

MCDA Consulting LLC

Why not just make a spreadsheet?

Different measurement scale for each criterion

Difficult to correctly assign weights for each criterion

Complexity of preferences is not captured

Green Infrastructure Project Choice

	Project 1	Project 2	Project 3
Cost			
Public acceptance			
Effectiveness			

11/11/2019 © MCDA Consulting LLC 9

9

MCDA Consulting LLC

MCDA Background

Between WWII and 1970: Operations research, optimization, single objective function

1970s: first multi criteria decision aid methods

Ralph Keeney and Howard Raiffa wrote "Decisions with Multiple Objectives" in 1975

11/11/2019 © MCDA Consulting LLC 10

10

MCDA Consulting LLC

Multi Criteria Decision Analysis

Helps stakeholders

- Consider all relevant alternatives
- Articulate what is important
- Define criteria (goals) that are comprehensive but not overlapping
- Make trade-offs fairly explicit
- Account for uncertainty
- Examine results (sensitivity analysis)
- Document the decision process

11/11/2019 © MCDA Consulting LLC 11

11

MCDA Consulting LLC

Multi Criteria Decision Analysis

Does not

- Decide for the decision maker
- Analyze everything in terms of $$
- Pre judge/ pre select an alternative

11/11/2019 © MCDA Consulting LLC 12

12

MCDA Consulting LLC

MCDA approaches

Outranking (alternatives ranked on each criterion)
AHP (pairwise comparisons of alternatives)
Multi Attribute Utility/Value Theory
- Captures preferences in detail with Utility/Value Functions
- Alternatives ranked based on overall utility

11/11/2019 © MCDA Consulting LLC 13

13

MCDA Consulting LLC

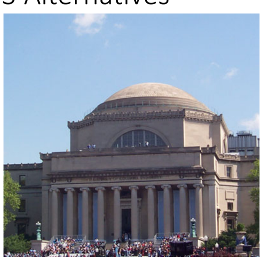
Simple example: Choose college

11/11/2019 © MCDA Consulting LLC 14

14

MCDA Consulting LLC

3 Alternatives



Columbia

MIT

Stanford

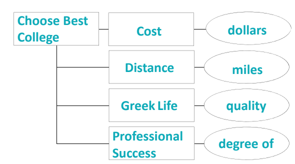
© MCDA Consulting LLC

15

MCDA Consulting LLC

4 Criteria, Measures
comprehensive, non redundant

Cost (dollars)
Distance from home (Miles? Travel time?)
Future professional success (qualitative, probabilistic? Stats?)



Hierarchy of Goals, Sub-goals, measures

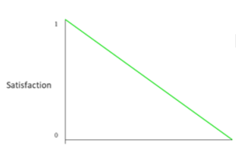
11/11/2019 © MCDA Consulting LLC 16

16

MCDA Consulting LLC

Value Functions: Satisfaction as a function of each measure

Ask the Decision Maker questions to help build the functions



Linear, continuous

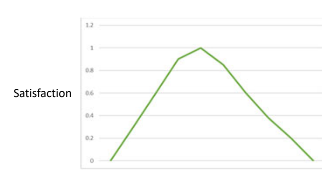
11/11/2019 © MCDA Consulting LLC 17

17

MCDA Consulting LLC

Value Functions: Satisfaction as a function of each measure

Non linear, continuous



11/11/2019 © MCDA Consulting LLC 18

18

MCDA Consulting LLC

Value Functions: Satisfaction as a function of each measure

Professional Success, Greek Life

Non continuous function, histogram

19

MCDA Consulting LLC

Weights

Should truly represent trade-offs that decision maker is willing to make

Depend on scale / range (e.g. cost)

Hard to assign directly (cognitive biases)

Mathematically valid

Graphic tools and trade off questions are one way to assess (there are others)

20

MCDA Consulting LLC

Assessing weights through trade-off questions

2 hypothetical colleges **A** and **B**

A is as good as possible on Greek Life and as bad as possible on Distance.
B is as good as possible on Distance and as bad as possible on Greek Life.

They are equal on the other measures.

Would you prefer **A** or **B**? (Suppose you say **B**)

How much would **A** need to improve on the measure "Distance" for you to be indifferent between these 2 hypothetical colleges?

21

MCDA Consulting LLC

MCDA process

Units of measurements for cost, distance, Greek life and professional success

Scores of Columbia, MIT and Stanford on cost, distance, Greek life and professional success (s_{ij})

Family's value functions for cost, distance, Greek life and Professional success (u (s))

Weights of cost, distance, Greek life and professional success (w_i)

The collection of weights and value functions is called a "preference set".

The total score of each college is a weighted sum

$$s_j = \sum_{i=1}^{I} w_i u(s_{ij})$$

22

MCDA Consulting LLC

College choice: sensitivity analysis

Based on what you told us, Stanford is looking the best.
Does it make sense?

What if you placed less emphasis on distance, for example – would results change?
What if you got the assessment for Greek Life at Columbia wrong – would results change?

In other words, is the result robust?

How many preference sets? Parent 1, Parent 2, child? Parents, child? The family?
Are results consistent throughout preference sets?

23

MCDA Consulting LLC

Case Studies

24

MCDA Consulting LLC

Small Urban Watershed, Montreal

- Best BMP combination for residential watershed in the suburbs of Greater Montreal
- 4 higher level criteria: **water quantity control** (sub criteria: peak flow and runoff volume reduction; delay to reach outfall peak flow); **water quality control** (sub criteria: Total Suspended Solids; Total Phosphorous; Total Nitrogen); **cost** and **social performance** (sub criteria: aesthetic and landscape benefits, acceptability, perceived quality of life improvement and contributions to sustainable development).
- 12 alternative combinations of green roofs, rain gardens, rain barrels and pervious pavement.
- 3 groups of stakeholders/preference sets: land developers and planners, engineers, citizens.
- Rain gardens and combination of rain gardens with pervious pavement ranked at the top for all preference sets.

Carvallo Aceves, M. and Fuamba, M.: *Methodology for Selecting Best Management Practices Integrating Multiple Stakeholders and Criteria*. Part 2: Case Study. Water (2016), 8, 56. MDPI.

25

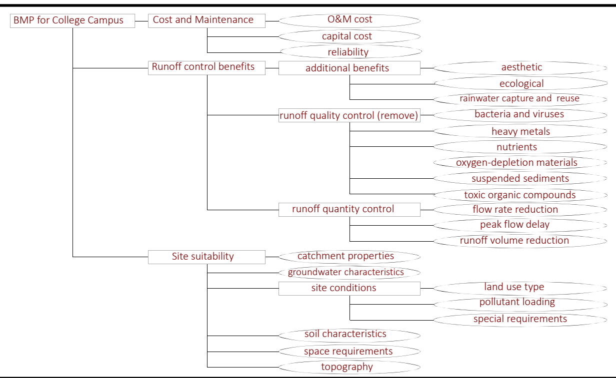
MCDA Consulting LLC

College Campus, China

- Select BMPs for a college campus in Foshan City, China
- 3 higher level criteria, 12 sub-criteria, 26 measures
- 12 BMP alternatives: Infiltration trench; Infiltration basin; Dry detention pond; Wet detention pond; Vegetated filter strip; Grassed swale; Constructed wetlands; Sand filter; Green roof; Rain barrel; Porous pavement; Bioretention cells
- Top rated BMPs: bioretention cell, wet pond and green roofs.
- Lowest rated BMPs: porous pavements, infiltration trenches, and rain barrels.
- A plan for installation throughout campus was designed.

- Jia, H. et al: Development of a multi-criteria index ranking system for urban runoff best management practices (BMPs) selection. Environ Monit Assess (2013) 185:7915–7933, Springer Science+Business Media Dordrecht.

26



27

MCDA Consulting LLC

Rural Watershed, Michigan

- Select best combination of BMPs for Honeyoey Creek-Pine Creek watershed, a USEPA Area of Concern.
- 3 criteria: stream health scores, farmers' social preferences and BMP installation costs.
- 8 combinations of BMPs: no management, no-tillage, native grass, cover crop, residue management and forest.
- MCDA to select approach for each of 185 sub basins.
- MCDA to select optimal combination of sub basin approaches.
- Multiple stakeholders / various preferences sets.
- Group process to select final plan.

Sabbaghian, R. J. et al: *Application of risk-based multiple criteria decision analysis for selection of the best agricultural scenario for effective watershed management.* Journal of Environmental Management 168 (2016) pp. 260 – 272, Elsevier.

28

MCDA Consulting LLC

Industrial Site, Australia

- Identify optimum strategies to improve the quality of runoff from the Brooklyn Industrial Precinct in Melbourne, Australia.
- 3 higher level criteria: Environmental, Economic and Social (TRIPLE BOTTOM LINE)
- 11 lower level criteria: Total Runoff, Volume Reduction, Sediment Removal, Nutrient Removal, Heavy Metal Removal, Peak Flow Reduction, Habitat Creation, Potable Water Savings, Equivalent Annual Cost, Capital Cost, Operation And Maintenance Cost, Improvement of Livability.
- 10 potential combinations of sedimentation basin areas and bioretention areas
- Optimum solution: combination of 5300 ft^2 vegetated swale and 38000 ft^2 bioretention area.
- Sensitivity analysis on weights, recognizing their subjectivity. Solution robust.

- Jayasooriya, V. M. et al. *Multi Criteria Decision Making in Selecting Stormwater Management Green Infrastructure for Industrial areas Part 1: Stakeholder Preference Elicitation* Water Resources Management (2019) 33:627–639. *Part 2: A Case Study with TOPSIS* Water Resources Management (2018) 32:4297–4312. Springer.

29

MCDA Consulting LLC

Summary

30

MCDA Consulting LLC

MCDA Methods have been used around the world to select stormwater projects.

We reviewed some of these case studies.

The professionals who chose this approaches recognized that it was superior to B/C analysis or a simple spreadsheet, because they

- **did not monetize all criteria;**
- **made trade-offs clear;**
- **incorporated stakeholders/decision maker's values;**
- **documented decision process.**

In a simple example, we have

- **identified goals and scales to measure each goal;**
- **organized the decision problem in a hierarchy;**
- **modeled preferences with Value Functions;**
- **revealed decision maker's preferences through trade-off questions.**

31

MCDA Consulting LLC

Questions

32

MCDA Consulting LLC

Case Studies (1)

- Sabbaghian, Reza Javidi; Zarghami, Mahdi; Nejadhashemi, A. Pouyan; Sharifi, Mohammad Bagher; Herman, Matthew R. and Daneshvar, Fariborz: *Application of risk-based multiple criteria decision analysis for selection of the best agricultural scenario for effective watershed management.* Journal of Environmental Management 168 (2016) pp. 260 – 272, Elsevier.
  - Select best alternative (scenario) for Honeyoey Creek-Pine Creek watershed in Michigan
  - 3 criteria: stream health scores, farmers' social preferences and BMP installation costs
  - 8 scenarios (combinations of BMPs such as no management or base management, no-till , native grass, cover crop, residue management and forest. 185 sub basins. Rank scenarios for each, then combine for watershed
- Carvallo Aceves, M. and Fuamba, M.: *Methodology for Selecting Best Management Practices Integrating Multiple Stakeholders and Criteria*. Part 2: Case Study. Water (2016), 8, 56. MDPI.
  - Select best combination of BMPs for urbanized watershed in the suburbs of the Greater Montreal Area
  - 4 higher level criteria technical performance: water quantity control, water quality control, economic cost, and social performance.
  - 4 BMPs, combined for a total of 12 alternatives
- Jia, Haifeng; Yao, Hairong; Tang, Ying; Yu, Shaw L.; Zhen, Jenny X. and Lu, Yuwen: *Development of a multi-criteria index ranking system for urban runoff best management practices (BMPs) selection.* Environ Monit Assess (2013) 185:7915–7933, Springer Science+Business Media Dordrecht.
  - Screening tool for selecting BMPs for a site in Foshan City, China
  - 3 higher level criteria: site suitability, runoff control performance, and cost considerations, 12 sub-criteria, 26 measures
  - 12 structurual BMPs
- Di Matteo, Michael; Maier Holger R. and Dandy Graeme C.: *Many-objective portfolio optimization approach for stormwater management project selection encouraging decision maker buy-in.* Environmental Modelling and Software 111 (2019) 340–355. Elsevier
  - Stormwater management alternatives for major coastal city in Australia
  - 4 high level criteria: economic cost, water quality improvement, stormwater harvesting capacity, and combined urban vegetation and amenity improvement70 potential BMPs

33

MCDA Consulting LLC

Case Studies (2)

- Martin, C.; Ruperd Y. and Legret M.: *Urban stormwater drainage management: The development of a multicriteria decision aid approach for best management practices.* European Journal of Operational Research 181 (2007) 338–349. Elsevier
  - Not a case study – France. Methodology proposal
  - 8 criteria: Pollution retention; Probability of system failure; O&M needs and frequency; Impact on groundwater quality; Amenity level; Contribution to urban sustainable development policies; Capital costs; Maintenance costs;
  - 3 different sets of weights (local government, regional planning; homeowners association);
  - 8 BMPs.
- Chow, J.-f.; Savić, D.; FortuneD.; Kapelan, Z. and Mebrate, N.: *Using a systematic, multi-criteria decision support framework to evaluate sustainable drainage designs.* Proceedings, 12th International Conference on Computing and Control for the Water Industry (2013)
  - Not a case study – UK. Methodology proposal
  - 4 high level criteria: stormwater quantity, water quality improvement, energy efficiency, environmental aspects; 8 measures. B/C analysis
- Thompson, Michael; Haselbach, Liv; and Poor, Cara: *A stormwater treatment strategy for port pavement runoff*. Transportation Research Board 93rd Annual Meeting Compendium of Papers (2014), TRB, Washington DC. (no full text)
  - Multi-criteria decision support tool for selecting treatment options for stormwater runoff from a ferry terminal

34