Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

Contents of this Presentation

- Introduction and background
- Integration of Transportation Investments
- Trade-off analysis
- Uncertainty
- Summing up …
Part 1.
Introduction and Background

Root of the Problem

- Typical highway manager at state/county/city oversees several different facility types:
  - Pavements
  - Bridges and Culverts
  - Road-side Appurtenances
  - Road-way Appurtenances, etc.
Often need to evaluate investment options and make decisions involving several facilities of same/different types on the basis of multiple performance objectives.

Possible trade-offs among performance measures Possible trade-offs among modes.
Root of the Problem

- Often need to evaluate investment options and make decisions
  - involving several facilities of same/different types
  - on the basis of multiple performance objectives

Part 2.
Integration of Transportation Investments

Integrating the Various Program Areas

Integrating the Various Performance Measures/Objectives
Integration of Transportation Investments

Integrating the Various Program Areas

Integrating the Various Performance Measures/Objectives

Pavement Preservation
Bridge Preservation
Roadside Improvement
Etc.

SAFETY  MOBILITY  ECON DEV.  ETC
Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

Integrating the Various Performance Measures/Objectives

**Question:**
Consider packing stuff in your bag this morning
What factors did you consider?

<table>
<thead>
<tr>
<th>Item weight</th>
<th>Item volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usefulness to my person</td>
<td>Usefulness to the day’s business</td>
</tr>
</tbody>
</table>

The Knapsack problem - conceptual illustration
“Project” selection - conceptual illustration

<table>
<thead>
<tr>
<th>Decision Variables</th>
<th>$X_1$</th>
<th>$X_2$</th>
<th>$X_3$</th>
<th>$X_4$</th>
<th>$X_5$</th>
<th>$X_6$</th>
<th>$X_7$</th>
<th>$X_8$</th>
<th>$X_9$</th>
<th>$X_{10}$</th>
<th>$X_{11}$</th>
<th>$X_{12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEMS</td>
<td>📚</td>
<td>📦</td>
<td>📗</td>
<td>📚</td>
<td>📗</td>
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<tr>
<td>Reward</td>
<td>$r_1$</td>
<td>$r_2$</td>
<td>$r_3$</td>
<td>$r_4$</td>
<td>$r_5$</td>
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<td>$r_9$</td>
<td>$r_{10}$</td>
<td>$r_{11}$</td>
<td>$r_{12}$</td>
</tr>
<tr>
<td>Cost</td>
<td>$c_1$</td>
<td>$c_2$</td>
<td>$c_3$</td>
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"Reward", usefulness, benefit, or utility, could be:
- Your degree of satisfaction

"Cost", disbenefit, or disutility, could be:
- The volume of the item (b’cos the knapsack space is limited)

Here, each item is a “project”
Each different alternative constitutes a “portfolio”
Possible portfolios are:

Selection based on following performance measures:
- Overall usefulness to you
- Overall usefulness to business
- Overall weight of all items
- Overall space taken by all items

\{ benefits \}
\{ costs \}
Generally, for the Knapsack problems...

<table>
<thead>
<tr>
<th>Item OR Project</th>
<th>Item 1</th>
<th>Item 2</th>
<th>Item 3</th>
<th>...</th>
<th>Item N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reward</td>
<td>$r_1$</td>
<td>$r_2$</td>
<td>$r_3$</td>
<td>...</td>
<td>$r_N$</td>
</tr>
<tr>
<td>Cost</td>
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Let $X_i$ represent the decision variables, $i = 1, 2, ..., N$.

Total Cost = $\sum_{i=1}^{N} X_i c_i$

Total Reward = $\sum_{i=1}^{N} X_i r_i$

Average Cost = $\frac{1}{N} \sum_{i=1}^{N} X_i c_i$

Average Reward = $\frac{1}{N} \sum_{i=1}^{N} X_i r_i$

Possible Objectives:
- Maximize total benefits
- Minimize total cost
- Maximize benefit cost ratio
- Maximize Net Present Value
- Etc.
Generally, for the Knapsack problems, ...

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</tbody>
</table>

**Possible “Cost” constraints**

- Total “cost” of all items must be less or equal to some maximum threshold, $c^*$
  \[
  \sum_{i=1}^{N} X_i c_i \leq C^* 
  \]

- Average “cost” of all items must not exceed some maximum threshold, $c^{**}$
  \[
  \frac{1}{N} \sum_{i=1}^{N} X_i c_i \leq c^{**} 
  \]

- Cost of any individual item must not exceed some maximum threshold, $c^{***}$
  \[
  c_i \leq c^{***} 
  \]

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Generally, for the Knapsack problems ...

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<tbody>
<tr>
<td>Item or Entity</td>
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</tr>
</tbody>
</table>

**Possible “benefit” constraints**

- Total “benefit” of all items must not be less than some minimum threshold, $b^*$
  \[
  \sum_{i=1}^{N} X_i b_i \geq B^* 
  \]

- Average “benefit” from all items must not be less than some minimum threshold, $b^{**}$
  \[
  \frac{1}{N} \sum_{i=1}^{N} X_i b_i \geq b^{**} 
  \]

- “Benefit” from any individual item must not be less than some minimum threshold, $b^{***}$
  \[
  b_i \geq b^{***} 
  \]
What are the possible trade-offs?

<table>
<thead>
<tr>
<th>Decision Variables</th>
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<th>( X_3 )</th>
<th>( \ldots )</th>
<th>( X_N )</th>
</tr>
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<tbody>
<tr>
<td>Item or Entity</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Entity 1</td>
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<td></td>
</tr>
<tr>
<td>Entity 2</td>
<td></td>
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<tr>
<td>Entity 3</td>
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<td></td>
</tr>
<tr>
<td>Entity ( N )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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By implementing a project instead of another,

- what do I benefit?
- what do I lose?

In terms of the various performance measures (cost, safety, durability, mobility, etc.?)

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Applying the Knapsack Concept to Highway Facilities Management

*Optimizing Discrete Investment Decisions for a Network of Systems for purposes of preservation*
Selecting projects from a vast pool of projects – what kind of projects?

- Reconstruction
- Rehabilitation
- Minor Maintenance
- Major maintenance

Selecting projects from a vast pool of projects – which factors influence your selection of projects?

- Initial Cost
- Life-cycle cost
- Economy
- Safety
- Added durability of the Facility
- Congestion Mitigation
- Environment
What about Uncertainty?

- For each project, impacts shown below are not fixed (certain) but have a range of values (uncertainty)

<table>
<thead>
<tr>
<th>Initial Cost</th>
<th>Life-cycle cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy</td>
<td>Safety</td>
</tr>
<tr>
<td>Added durability of the Facility</td>
<td>Congestion Mitigation</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
</tr>
</tbody>
</table>

Summing Up . . .

- Evaluation and Decision making based on multiple objectives has potential to:
  - Enable analysis of trade-offs among performance measures
  - Enable analysis of trade-offs among facility types
  - Include more stakeholders (users, community, etc.) in decision-making process
  - Enable more direct inclusion of stakeholder concerns
  - Reduce biased/subjective/parochial decision-making
Questions?