Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

Integrated Solutions for Transportation: Perspectives and Practices

NEXTRANS @ JTRP Road School
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Samuel Labi
Purdue University  School of Civil Engineering

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

Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

Root of the Problem

- Often need to evaluate investment options and make decisions
  - involving several facilities of same/different types
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Part 2.
Integration of Transportation Investments

Integrating the Various Program Areas

Integrating the Various Performance Measures/Objectives
Integration of Transportation Investments

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>Usefulness to my person</th>
<th>Item weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item volume</td>
<td></td>
</tr>
</tbody>
</table>

Usefulness to the day’s business

**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>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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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</tr>
<tr>
<td>Cost</td>
<td>$c_1$</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>
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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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**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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**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?

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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
- Minor Maintenance
- Major Maintenance
- Initial Cost
- Added durability of the Facility
- Life-cycle cost
- Safety
- Economy
- Environment
- Congestion Mitigation
**What about Uncertainty?**
- For each project, impacts shown below are not fixed (certain) but have a range of values (uncertainty)

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<td>Added durability of the Facility</td>
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**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?