Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

Integrated Solutions for Transportation: Perspectives and Practices

NEXTRANS @ JTRP Road School
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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.
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

<table>
<thead>
<tr>
<th>Cost ($) of the action</th>
<th>Added facility durability</th>
<th>Impact on Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact on Environment</td>
<td>Impact on Mobility/Accessibility</td>
<td>Etc.</td>
</tr>
</tbody>
</table>
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
Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

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
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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>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><strong>ITEMS</strong></td>
<td>![Image 168x601 to 187x619]</td>
<td>![Image 229x592 to 264x624]</td>
<td>![Image 267x606 to 283x621]</td>
<td>![Image 305x601 to 328x615]</td>
<td>![Image 286x603 to 303x621]</td>
<td>![Image 398x594 to 411x618]</td>
<td>![Image 330x589 to 364x619]</td>
<td>![Image 438x593 to 460x618]</td>
<td>![Image 468x594 to 480x618]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reward</strong></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>
<td><strong>Cost</strong></td>
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<td>$c_5$</td>
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</table>

“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)

Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

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

  ![Image 164x199 to 201x244] ![Image 327x217 to 354x241] ![Image 237x191 to 270x244] 

- 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
  
  \[
  \{ \text{benefits} \}
  \]
  \[
  \{ \text{costs} \}
  \]
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>( X_1 )</th>
<th>( X_2 )</th>
<th>( X_3 )</th>
<th>( \cdots )</th>
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\[
\text{Total Cost} = \sum_{i=1}^{N} X_i c_i
\]

\[
\text{Total Reward} = \sum_{i=1}^{N} X_i r_i
\]

\[
\text{Average Cost} = \frac{1}{N} \sum_{i=1}^{N} X_i c_i
\]

\[
\text{Average Reward} = \frac{1}{N} \sum_{i=1}^{N} X_i r_i
\]

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, $c^{***}$
  \[ c_i \leq c^{***} \]

Generally, for the Knapsack problems ...

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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

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

Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments
What about Uncertainty?

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

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

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?