

# Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments



*Integrated Solutions for Transportation: Perspectives and Practices*

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# 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.



## Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

### Root of the Problem

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- 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

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  - 
  - on the basis of multiple performance objectives

**Cost (\$)** of the action

Added facility **durability**

Impact on **Safety**

Impact on the **Environment**

Impact on **Mobility/Accessibility**

Etc.

## Root of the Problem

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  - on the basis of multiple performance objectives

## Part 2.

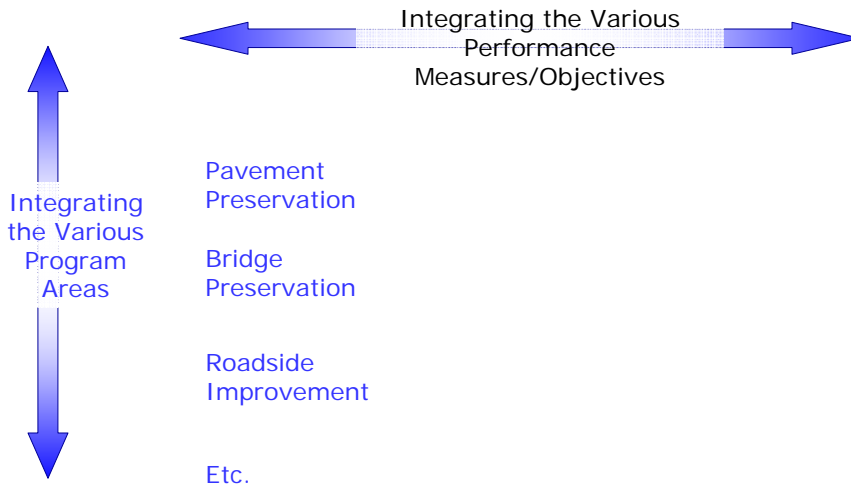
### Integration of Transportation Investments

Integrating the Various Program Areas

Integrating the Various Performance Measures/Objectives

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### Integration of Transportation Investments



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### Integration of Transportation Investments



## 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?

Usefulness to my person

Item weight

Usefulness to the day's business













Item volume

### The Knapsack problem - conceptual illustration



## Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

### "Project" selection - conceptual illustration

Decision Variables	$X_1$	$X_2$	$X_3$	$X_4$	$X_5$	$X_6$	$X_7$	$X_8$	$X_9$	$X_{10}$	$X_{11}$	$X_{12}$
ITEMS												
Reward	$r_1$	$r_2$	$r_3$	$r_4$	$r_5$	$r_6$	$r_7$	$r_8$	$r_9$	$r_{10}$	$r_{11}$	$r_{12}$
Cost	$c_1$	$c_2$	$c_3$	$c_4$	$c_5$	$c_6$	$c_7$	$c_8$	$c_9$	$c_{10}$	$c_{11}$	$c_{12}$



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

"Reward", usefulness, benefit, or utility, could be:  
 - Your degree of satisfaction







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- ❑ 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 ...

<b>Decision Variables</b>	$X_1$	$X_2$	$X_3$	...		$X_N$
<b>Item OR Project</b>				...		
	Item 1	Item 2	Item 3			Item N
<b>Reward</b>	$r_1$	$r_2$	$r_3$	...		$r_N$
<b>Cost</b>	$c_1$	$c_2$	$c_3$	...		$c_N$





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

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

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

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

## Generally, for the Knapsack problems, ...





<b>Decision Variables</b>	$X_1$	$X_2$	$X_3$	...		$X_N$
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<b>Reward</b>	$r_1$	$r_2$	$r_3$	...		$r_N$
<b>Cost</b>	$c_1$	$c_2$	$c_3$	...		$c_N$

### Possible Objectives

- Maximize total benefits
- Minimize total cost
- Maximize benefit cost ratio
- Maximize Net Present Value
- Etc.



## Generally, for the Knapsack problems, ...

<b>Decision Variables</b>	$X_1$	$X_2$	$X_3$	...		$X_N$
<b>Item or Project</b>	 Item 1	 Item 2	 Item 3	...		 Item N
<b>Reward</b>	$r_1$	$r_2$	$r_3$	...		$r_N$
<b>Cost</b>	$c_1$	$c_2$	$c_3$	...		$c_N$

### 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 ...

<b>Decision Variables</b>	$X_1$	$X_2$	$X_3$	...		$X_N$
<b>Item or Entity</b>	 Entity 1	 Entity 2	 Entity 3	...		 Entity N
<b>Reward</b>	$r_1$	$r_2$	$r_3$	...		$r_N$
<b>Cost</b>	$c_1$	$c_2$	$c_3$	...		$c_N$

### 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?

<b>Decision Variables</b>	$X_1$	$X_2$	$X_3$	...		$X_N$
<b>Item or Entity</b>	 Entity 1	 Entity 2	 Entity 3	...		 Entity N
<b>Reward</b>	$r_1$	$r_2$	$r_3$	...		$r_N$
<b>Cost</b>	$c_1$	$c_2$	$c_3$	...		$c_N$

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.?)*

### Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

## Applying the Knapsack Concept to Highway Facilities Management

*Optimizing Discrete Investment Decisions  
for a Network of Systems  
for purposes of preservation*

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- Selecting projects from a vast pool of projects -  
what kind of projects?



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- 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

## Uncertainty-Based Tradeoff Analysis for Integrated Transportation Investments

### Summing Up . . .

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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?*