DESIGN AND IMPLEMENTATION OF A FLEXIBLE TRANSPORTATION SYSTEM

Second Annual Transportation Student Research Symposium
Northeastern University
February 10, 2006

Joshua McConnell
Major Points

• Flexibility is one way to address uncertainty in complex systems
  – Need to ensure benefits of flexibility are inline with costs
• Flexibility over the entire system life-cycle must be addressed
• System should be architected with the following considerations in mind:
  – Physical system flexibility
  – Execution Implementation
  – Addressing downside and upside uncertainty
  – Information gathering to promote institutional learning
  – Enabling additional policy choices
• Choice of system architecture, institutional architecture, and technology is critical in accomplishing these objectives
Agenda

• Transportation and complex systems
• Uncertainty
• Flexibility and Real options
• ITS and ITS as a real option
• Case studies
  – Case I: Infrastructure vs ITS as a real option
  – Case II: Congestion pricing architecture
Transportation Systems and Common Challenges

Factors considered here:
Technical: congestion
Uncertainty: demand / congestion
Economic: costs and benefits
Implementation: political resistance
Complex Systems

Nested Complexity

- Many subsystems
- Unknown relationships
- Time scales
- Non-linear effects
- Large system
- Difficult to quantify and reach agreement
- **Difficult to predict future behavior**
Types of Uncertainty in Transportation Systems: Some Examples

Many types of uncertainty exist in transportation systems, making decisions concerning future status difficult.

- **Technical**: demand/congestion, mode share, technology availability/development
- **Economic**: costs and benefits, economic activity, funding availability
- **Political**: political support or resistance, political objectives and priorities
- **External**: security
Strategies for Addressing Uncertainty

Luckily, some strategies exist!

- **Reduce or control uncertainty**
  - Increase information and knowledge of system
  - Reduce system complexity
  - Manage demand

- **Increase robustness**
  - Increased capacity / less sensitivity to uncertainty

- **Design in flexibility**
  - Ability to alter system configuration, based on future circumstances
Overview of Flexibility

• What is flexibility?
  – Ability to change the future configuration of a system, i.e. postpone final configuration of system until a future date when additional information is available

• Why flexibility?
  – Flexibility adds value to the system, allowing the system to adapt to future circumstances

• Flexibility is not for free!
  – In general flexible system has higher up front costs than non-flexible system
  – General costs include:
    • Purchase price: Money to buy flexibility
    • Exercise price: Money to use or activate flexibility in operations
    • Transaction costs: Increased complexity in design and management
Real Options: Tool for Providing Flexibility

- Real options – similar to financial options, but applied to “real” asset design and management
- Gives option owner the right, but not the obligation to take some action now or at future date at a predetermined price
- Can be crafted to take advantage of “good times” (calls) and/or limit exposure in “bad times” (puts)
- Real options deal with the “unknowns” – recognized sources of uncertainty
Valuing ITS

Total value of ITS = inherent ITS value + value of flexibility in ITS

• Inherent ITS value
  – Technical – ability to manage and coordinate operation
  – Economic – typically substantially lower capital costs than traditional infrastructure
  – Travelers – increases traveler level of service
Value from using ITS in Flexible Manner

• ITS as a real option sub-set of real options
• Provide flexibility to transportation system, some examples….
  – Delay infrastructure construction
  – Provide means to gather new information
  – Provide ability to expand or contract system based on future needs and events
  – Can be structured to create non-traditional opportunities
  – Functionality can be introduced in phases or as modules
Case I: Build vs ITS Option: Purpose

- Illustrate quantitative benefits of flexibility – deal with downside uncertainty
- Fully evaluating benefits from ITS
Alternatives: No Flexibility

Current State

Possible Future States

- What to do? Infrastructure highest NPV, ITS highest B/C
- NPV and B/C only show Expected Value – significant probability of loss if no future congestion \(\rightarrow\) 40%
## Analysis of Alternatives

<table>
<thead>
<tr>
<th></th>
<th>EX NPV</th>
<th>Benefit to Cost Ratio</th>
<th>EX Benefits</th>
<th>EX Costs</th>
<th>Prob.</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trad. Infra.</strong></td>
<td>$6M</td>
<td>1.25</td>
<td>$30M</td>
<td>$24M</td>
<td>High cong = .6</td>
<td>High cong = $50 M</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low cong = .4</td>
<td>Low cong = $0 M</td>
</tr>
<tr>
<td><strong>ITS</strong></td>
<td>$0.5</td>
<td>1.33</td>
<td>$2M</td>
<td>$1.5M</td>
<td>High cong = .6</td>
<td>High cong = $3.3 M</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low cong = .4</td>
<td>Low cong = $0 M</td>
</tr>
<tr>
<td><strong>Status Quo</strong></td>
<td>-$10M</td>
<td>n/a</td>
<td>-$10M</td>
<td>0</td>
<td>High cong = .6</td>
<td>High cong = -$17 M</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low cong = .4</td>
<td>Low cong = $0 M</td>
</tr>
</tbody>
</table>
Re-valuing ITS to Account for Flexibility

Current situation, t<0

- ITS has lower costs, reducing capital at risk at t=0.
- Decision for larger investment postponed when additional information or funding is available

Implement alternative, t=0

Exercise option, t>0

ITS option to Delay infrastructure
Re-valuing ITS to Account for Flexibility

- New expected NPV of ITS = $13M, value of ITS + infra = $2.7M
- Flexibility = $13M - $2.7M = $10.3M
  - $10.3M flexibility value > $5M cost, so flexibility economically feasible
  - Value from ITS: EX inherent value = $2M, Value of flexibility = $10.3M

EX NPV = $6 M
B/C = 1.25

EX NPV = $13 M
B/C = 1.3

EX NPV = -$10 M
B/C = NA
New Decision Tree
(perfect information assumed)

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>ITS Option</th>
<th>Status Quo</th>
</tr>
</thead>
<tbody>
<tr>
<td>high p = .6</td>
<td>$50M - $24M</td>
<td>high p = .6</td>
</tr>
<tr>
<td>low p = .4</td>
<td>$0M - $24M</td>
<td>low p = .4</td>
</tr>
</tbody>
</table>

Extra $5M construction cost for delay, work around existing ITS

$10.3M flexibility value > $5M cost, so flexibility economically feasible

Value from ITS: EX inherent value = $2M, Value of flexibility = $10.3M

- New expected NPV of ITS = $13M, value of ITS + infra = $2.7M
- Flexibility = $13M - $2.7M = $10.3M
Case II: Congestion Pricing: Purpose

- Impact of system architecture on:
  - Up and downside uncertainty
  - Implementation
  - Non-transportation benefits
Case II: Congestion Pricing: ITS Decision Tree

Current State: Heavy Congestion

- Full Congestion Pricing System
- Managed lanes (i.e. HOT) Possibly Leading to Congestion Pricing
- No Additional Capabilities, maintain HOT lanes

Switch operation to alternative managed lane type (i.e. BRT or freight)

- Full Congestion Pricing System
- Switch
- Maintain

Flexibility Created in System

Architecture – expand from network of HOT lanes to congestion pricing system

Operation – switch operation of managed lanes; i.e. from HOT to BRT or freight lanes
Case II: Congestion Pricing: Alternative ITS as a Real Option Architectures

Which technology and architecture to choose?
Case II: Congestion Pricing: Some Issues to Consider

• **System efficiency and effectiveness**
  – Is infrastructure and operations adequate to handle needed levels of traffic?
  – Is system cost effective?

• **Flexibility technical issues**
  – What does flexible system architecture look like?
  – Is flexibility useful?

• **Flexibility non-technical issues**
  – Can flexibility be used in system? i.e. if flexibility requires system change will stakeholders resist changes in system? If so, what can be done to overcome this resistance?
Case II: Congestion Pricing: Stakeholder Resistance

Stakeholders resistant to ITS as a real option

Stakeholders supportive to ITS as a real option

= No exercise of ITS options

How to make this transition?

= Exercise of ITS options…?
Case II: Congestion Pricing: Creating a Winning Stakeholder Coalition through Technology Choices

Can technology and architecture be designed to appeal to broader stakeholder coalition?

One way is through dual use technologies

**Camera Based Architecture**
Can appeal to security minded stakeholders, al la Chicago

**Smartcard Based Architecture**
Can appeal to private industry, with dual use as banking cards, parking cards, health information, etc.
Tying it all Together

• Flexibility is one way to address uncertainty in complex systems
  – Need to ensure benefits of flexibility are inline with costs
• Flexibility over the entire system life-cycle must be addressed
• System should be architected with the following considerations in mind:
  – Physical system flexibility
  – Execution Implementation
  – Addressing downside and upside uncertainty
  – Information gathering to promote institutional learning
  – Enabling additional policy choices
• Choice of system architecture, institutional architecture, and technology is critical in accomplishing these objectives