DESIGN AND IMPLEMENTATION OF A FLEXIBLE TRANSPORTATION SYSTEM USING A LIFE-CYCLE FLEXIBILITY FRAMEWORK

Malaysia Group Meeting
October 8, 2004

Joshua McConnell
Outline

• Complex systems and uncertainty
• Flexibility and real options
• Areas of flexibility research
  – Life-cycle flexibility framework
  – ITS as a real option and infrastructure/operation integration
  – Quantification with real options
• Case studies
Transportation Systems and Common Challenges

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

Nested Complexity, a la CLIOS

- Many subsystems
- Unknown relationships
- Difficult to predict future behavior & uncertainty of environment
- Time scales
- Non-linear effects
- Large system
- Difficult to quantify and reach agreement
### Complex System Problems vs. Solutions

<table>
<thead>
<tr>
<th>Complex System Problems</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficult to predict behavior</td>
<td>More information, new types of information, more time to gather information</td>
</tr>
<tr>
<td>Need to address many different subsystems – technical and institutional</td>
<td>Architecture that satisfy technical needs and enable institutions</td>
</tr>
<tr>
<td>Solutions to fix current and future problems</td>
<td>Deal with uncertainty with flexible systems</td>
</tr>
<tr>
<td>Changes to system expensive: economic, political capital, social impacts, time, etc.</td>
<td>Evaluate flexibility benefits and costs, limit downside risks, enable upside opportunities</td>
</tr>
</tbody>
</table>
Uncertainty

- Uncertainty appears in different areas
  - Technical, management, economic, political, etc.
- Steps to address these uncertainties common
  - Factor of safety, management reserves, spreading project work, etc.
- Another way to classify:

<table>
<thead>
<tr>
<th>Status of Knowledge</th>
<th>Identification of Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Known knowns</td>
</tr>
<tr>
<td></td>
<td><em>(Traditional factor of safety)</em></td>
</tr>
<tr>
<td>Unknown knowns</td>
<td><em>(Additional research / study / experience)</em></td>
</tr>
<tr>
<td>Known unknowns</td>
<td><em>(Traditional scope of real options)</em></td>
</tr>
<tr>
<td>Unknown unknowns</td>
<td><em>(Unexpected/ unknowable events)</em></td>
</tr>
</tbody>
</table>
General Strategies for Addressing Uncertainty

• **Reduce Uncertainty**
  – Increased information, reduced complexity, etc.

• **Increase System Robustness**
  – Scenario planning, factor of safety, etc.

• **Increase System Flexibility/Adaptability**
  – Real options, modularity, etc.
Outline

• Complex systems and uncertainty
• **Flexibility and real options**
• Areas of flexibility research
  – Life-cycle flexibility framework
  – ITS as a real option and infrastructure/operation integration
  – Quantification with real options
• Case studies
What does flexibility and Real Options get you?

Flexibility

- Investing in flexibility today gives organization ability to chose alternative actions at some time in the future
- Making alternatives available useful for dealing with uncertainty

Real Options

- Flexible systems have higher initial costs than non-flexible systems. Real options is tool for valuing flexibility, allowing comparison of flexible and non-flexible solutions.
- Real option analysis results can be incorporated into traditional BCA.
  - Benefits = Traditional benefits + value of option (flexibility)
  - Costs = Traditional costs + cost of option
Challenges of designing flexible systems

• However, several challenges exist…
  – Accessing value of flexibility not always straightforward
  – Lack of managerial ability to exercise flexibility
  – Multiple sources of uncertainty in a system
  – Difficulty in assessing when to exercise flexibility
  – Need to look at both known and unknown unknowns
  – Institutional environment not conducive for explicitly addressing uncertainty or designing & exercising flexible systems

• Current real options theory does not address many of these issues – relatively new field

• Need to address these challenges in a holistic manner – belief that properly designed flexible solutions can address several of these challenges simultaneously
What we need

Identified Needs

• New framework for thinking about flexibility in a holistic manner

• New transportation system architectures that provide flexibility

• Continued work on Real Options theory

Concepts

• Life-cycle Flexibility Framework

• Integrate infrastructure and operations planning & use of ITS technologies to create flexibility

• Increased consideration of how Real Options are used
Outline

• Complex systems and uncertainty
• Flexibility and real options
• Areas of flexibility research
  – Life-cycle flexibility framework
  – ITS as a real option and infrastructure/operation integration
  – Quantification with real options
• Case studies
ITS as a Real Option (I)

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 (*buy, sell, delay, switch,* etc.)
  - now or at future date (*at or before option maturity*)
  - at a predetermined price (*exercise or strike price*)

- Can be crafted to take advantage of “good times” (*calls*) and/or limit exposure in “bad times” (*puts*)

- Real options add value when future is uncertain and increase in value as volatility increases
ITS as a Real Option (II): Classification and Examples

**Infrastructure or Operation Based Options**
- Delay traditional infrastructure investment (ITS instead of infrastr.)
- Provide future ITS capability (fiber optics)
- Expand or contract services easier than with traditional infrastr. (experiment with new services, gather new information)

**Integrated Infrastructure and Operations Options**
- Create new, non-traditional opportunities (smart card use for parking, ATM, retail)
- Functionality introduced in phases over time or location (cameras for red light enforcement, toll collection, demand management)
- Switch between functions (cameras for roadway status or security)

Integrating Infrastructure and Operations does more than improve efficiency, Also creates new opportunities in flexibility.
Quantitative Valuation with Real Options (I)

- Real options mathematics based on financial option mathematics
- Option value based on uncertainty associated with underlying asset and underlying asset’s current value
  - For financial stock options, underlying asset is stock and uncertainty is around future stock price
- Key assumptions for real options:
  - Underlying asset priced in market
  - Uncertainty, and hence underlying asset value, is determined by Brownian motion (random motion around drift trend)
  - Option holders can not influence asset value
  - Option holders can exercise options
  - Cost of exercising options is negligible compared to price of option
- These assumptions may not be true. If not, it will impact how real options are created and valued.
Quantitative Valuation with Real Options (II)

Uncertainty and asset value determined by Brownian motion and option holder unable to influence price

- Stakeholder actions affect underlying asset, changes option value
- Option architecture will drive option value
- Example: option to expand ETC system → congestion pricing system
  - Arch. 1 (“down”): toll road concessionaires tasked with integration and implementing congestion pricing system
  - Arch. 2 (“up”): additional capabilities implemented w/ cong. pricing system: more customers using system better for banks, retailers, etc.
Quantitative Valuation with Real Options (III)

Option holders can exercise option and exercise cost is negligible

• In previous example, if government is option holder, toll operators resist option to expand to congestion pricing system
  – Exercise of fiscal option built in – imagine brokerage NOT wanting to allow option owner to exercise option!
  – Even if option built into concession agreement at $t = 0$, toll operators can still work to change concession agreement, underlying asset value or uncertainty (traffic demand), metric triggering implementation, data, etc.

• Exercise cost to overcome resistance from stakeholders and exercise option may be large or in undesirable form
  – Cost of option = capital required for HW/SW integration + additional operating expenses above isolated ETC system
  – Unlike financial option, exercise costs may not be agreed to a priori or small part of overall transaction (brokerage fees)
  – Exercise costs may not be monetary – may require spending political capital, sustaining negative publicity, etc.
Framework: Life-Cycle Flexibility (I)

Life-Cycle Flexibility = “Expanded Objective Function”
- Technical, Enterprise, Institutional Architectures, technologies & policy
- Assessment and implementation
- Enterprise readiness

Mitigate / Exploit uncertainty in physical system
Deploy, maintain, upgrade, retire, etc.
Congestion, safety, costs, schedule, etc.

Life-cycle flexibility activities in addition to existing design, management and policy processes
# Framework: Life-Cycle Flexibility (II)

<table>
<thead>
<tr>
<th>Life-cycle Flexibility Activities</th>
<th>Design Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise Readiness</td>
<td>Pre-design phase, policy making</td>
</tr>
<tr>
<td>Technical, Enterprise &amp; Institutional Architecting and Evaluation</td>
<td>Design &amp; policy making activities</td>
</tr>
<tr>
<td>Architecture Implementation</td>
<td>Project Implemented</td>
</tr>
<tr>
<td>Flexibility Assessment</td>
<td></td>
</tr>
<tr>
<td>Flexibility Implementation</td>
<td></td>
</tr>
<tr>
<td>Environmental Assessment</td>
<td>Determining needs for project continuation or new project</td>
</tr>
</tbody>
</table>
The picture so far…

- Uncertainty poses challenge in complex systems
- Flexibility is way to deal with uncertainty
- Real Options analysis way to think about designing flexibility into system and quantitatively evaluating flexibility
- ITS as a real option through integrating infrastructure and operation planning can create real options
- Challenges associated with Real Options analysis include stakeholder actions that change option value or make exercising flexibility difficult or costly
- These challenges must be addressed in option architecture and stakeholder involvement
- Life-cycle flexibility is methodology for systematically addressing these challenges
Outline

• Complex systems and uncertainty
• Flexibility and real options
• Areas of flexibility research
  – Life-cycle flexibility framework
  – ITS as a real option and infrastructure/operation integration
  – Quantification with real options
• Case studies
Case I: Flexibility in Technical System

Enterprise Readiness
- Technical, Enterprise & Institutional Architecting and Evaluation
- Architecture Implementation
- Flexibility Assessment
- Flexibility Implementation
- Environmental Assessment

Current State
- EX NPV = $6M
- B/C = 1.25

Possible Future States
- EX NPV = $0.5M
- B/C = 1.33
- EX NPV = -$2M
- B/C = NA
Case I: Evaluation of Flexibility

EX NPV = $6M  
B/C = 1.25

EX NPV = -$2M  
B/C = NA

EX NPV = $7M  
B/C = 1.52

Economic Value Flexibility = $7M – $(6+0.5)M = $0.5M

ITS Cost = $1.5M > $0.5M benefit → Flexibility appears to be not economically feasible in this case, however....
Case I: Re-structuring and Re-evaluating Option

Modeling ITS as compound option that Increases information on congestion changes value of ITS as a real option

- New expected NPV of ITS option = $13.5M
- Economic value flexibility = $13.5M− $(6+0.5)M = $7M
- ITS cost = $1.5M < $7M, ∴ flexibility economically feasible
Case I: Build vs ITS Option: Analysis of Value of Flexibility

Discount Rate

Value of Flexibility

Perfect Information

Increasing Construction Costs

Low Additional Information
Case I: ITS Implementation

ITS as a Real Option

- Technically feasible
- Economically attractive under *some* conditions for different stakeholders
- Creates quantifiable flexibility in physical system through:
  - additional decision making opportunities
  - discounted future costs
  - additional information gathering

But can it REALLY be implemented?

One potential problem in implementing the system architecture and later, the flexibility… New distribution of benefits away from infrastructure construction firms causes resistance to ITS as a real option and “Stiglarian” regulatory capture

A question for life-cycle flexibility is how to get around these types of implementation problems and still create flexible system?
Case II: Flexibility in Technical System

<table>
<thead>
<tr>
<th>Enterprise Readiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical, Enterprise &amp; Institutional Architecting and Evaluation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Architecture Implementation</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Flexibility Assessment</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Environmental Assessment</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Flexibility Implementation</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Baseline Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera</td>
</tr>
<tr>
<td>ENPV</td>
</tr>
<tr>
<td>Costs</td>
</tr>
<tr>
<td>B/C</td>
</tr>
</tbody>
</table>

T = 0: Heavy Traffic

Expand ITS capabilities

Full Congestion Pricing

ITS as a Real Option Possibly Leading to Congestion Pricing

No Additional Capabilities

Expand ITS capabilities
Case II: Architecture & Technology Choice

Choosing architectures & technologies:

- Evaluate flexibility value (ROA, decision tree)
- Evaluate implementability and assessment value

Basic Architecture of Option:
HOT lanes expandable into congestion pricing system
Case II: Implementation and Assessment

ITS as a real option can enable:
- Modular expansion of ITS to full congestion pricing system
- Non-transportation for upside potential & implementation
- New ITS org. or processes for “unknown unknowns”
Case II: Evaluation and Implementability

- Economic Analysis of Flexibility

<table>
<thead>
<tr>
<th></th>
<th>Baseline Flexibility</th>
<th>Upside Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Camera</td>
<td>Smart Card</td>
</tr>
<tr>
<td>ENPV</td>
<td>$30M</td>
<td>$45M</td>
</tr>
<tr>
<td>Costs</td>
<td>$15M</td>
<td>$30M</td>
</tr>
<tr>
<td>B/C</td>
<td>3</td>
<td>2.5</td>
</tr>
</tbody>
</table>

- Implementability
  - Camera based system architecture
    - Few stakeholders naturally in favor of this, entrench interests against
    - Few upside opportunities
  - Smart Card based system architecture
    - New stakeholder coalition with upside options to expand Smart Card use into parking garages, retail stores, information sharing, banking, etc. creates natural coalition in favor of architecture and flexibility implementation
    - New stakeholder coalition can create political pressure for full, and mandatory, congestion pricing system

- Final Evaluation
  - Make final decision of flexibility based on more than quantitative results
Tying it all Together

- Flexibility is one way to address uncertainty in complex systems
  - Need to ensure benefits of flexibility are inline with costs, driving a need for the measurement/valuation of flexibility, identification of how to create value and its implementability
- Flexibility over the entire system life-cycle must be addressed
- System architecture should have the following considerations explicitly included – “expanded objective function”:
  - Physical system flexibility
  - System and flexibility Implementation
  - Addressing downside and upside uncertainty
  - Information gathering to promote institutional learning
  - Enabling additional policy choices
- Choice of system architecture, institutional architecture, technology and stakeholders is critical in accomplishing these objectives and will affect value of flexibility
Selected References

Backup Slides
Uncertainty

• Uncertainty appears in different areas
  – Technical, management, economic, political, etc.
• Many common ways to address uncertainty:
  – Factor of safety, management reserves, spreading project work, etc.

**Problem**: These approaches are “silied” and result in “pushing” uncertainty to other areas

**Research objective**: Use *flexibility* to address uncertainty holistically and find system, enterprise and institutional architectures that resolve multiple uncertainties at acceptable costs
## Life-Cycle Flexibility Activities (I)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organizational Readiness for Flexibility</strong></td>
<td>• Support for addressing uncertainty in owner organizations</td>
</tr>
<tr>
<td></td>
<td>• Ability to architect flexible systems in design organization</td>
</tr>
<tr>
<td></td>
<td>• Incentivize addressing uncertainty in institutions</td>
</tr>
<tr>
<td><strong>System, Enterprise and Institutional Architecture</strong></td>
<td>• Address uncertainty in an integrated manner using technology, management, organization and policy tools</td>
</tr>
<tr>
<td></td>
<td>• Flexibility &amp; support can be at system, enterprise and institutional levels</td>
</tr>
<tr>
<td></td>
<td>• System architecture can enable implementation (architectural and flexibility)</td>
</tr>
</tbody>
</table>
## Life-Cycle Flexibility (II)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture Implementation</td>
<td>• System, Enterprise and Institutional architecture to support implementation of system at T=0 (system deployment)</td>
</tr>
<tr>
<td>Flexibility Assessment</td>
<td>• Assess environment to determine when to implement flexibility</td>
</tr>
</tbody>
</table>
| Flexibility Implementation         | • Create environment capable of implementing flexibility at T>0  
  • Feasibility of implementing system flexibility                                |
| Environmental Assessment            | • Assess and evaluate changing environment for “unknown unknowns” to allow for flexibility at institutional level                         |
### Case II: Congestion Pricing: Key Aspects (I)

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Platform / Modular – allows phased development and implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Dual use, expandable</td>
</tr>
<tr>
<td>Uncertainty Management - Downside</td>
<td>Limits investment exposure for full system until future congestion status better known</td>
</tr>
<tr>
<td>Uncertainty Management – Upside</td>
<td>Expands architecture into full congestion pricing system, expands technology usage into non-transportation usages, can create value</td>
</tr>
<tr>
<td>Revenue</td>
<td>Adds non-traditional revenue stream from non-transportation uses</td>
</tr>
</tbody>
</table>
**Case II: Congestion Pricing: Key Aspects (II)**

<table>
<thead>
<tr>
<th>Economic</th>
<th>Flexibility created through full investment delay, information gathering and expansion opportunities; valued through real options or decision tree analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Political Support and Implementation</td>
<td>Architecture creates implementation opportunities - architecture chosen to include new stakeholders w/ interest in seeing system implemented and expanded – “portfolio of stakeholders”; new coalition to overcome resistance from entrenched interests</td>
</tr>
<tr>
<td>Organizational Structure and Incentives</td>
<td>ITS functions split between traditional DOT organization and knowledge organization for unknown unknowns</td>
</tr>
</tbody>
</table>
Potential Benefits...

• **Life Cycle Flexibility Benefits**
  – Explicitly considers implementation issues early in process
  – Architecture & technology selected partly to address implementation

• **ITS as a Real Option Benefits**
  – Used to phase in larger ITS capabilities or delay infrastructure
  – Used to collect information on system operations and can be coupled with organization to scan environment
  – Create innovative opportunities in non-transportation applications, with benefits of new revenue streams and increased stakeholder support
...and Challenges

- **Life Cycle Flexibility Challenges**
  - New mind set for individuals and operating procedures for organizations
  - Validating and demonstrating that life-cycle flexibility framework creates a better transportation system

- **ITS as a Real Option Challenges**
  - Properly valuing flexibility
  - Incremental approach may overlook opportunities for bold action
  - Potential to create open conflict with embedded interests and difficult to entice new, non-transportation stakeholders
  - Potential conflict with government philosophy on revenue and perceived mission on providing infrastructure
Implementation, System Architecture and Enterprise Architecture

Explicitly architect system and enterprise with characteristics that will ease implementation

Problems
Policy
Politics

Willingness
Capacity
Opportunity

• Strong leadership
• Support for architecture and technology from stakeholders (new stakeholders)
• Removal / negation of opposition (counterbalancing coalition)
• Organizational structure and behavior inline with objectives and incentives - split ITS responsibilities for implementation and unknown unknowns

Frameworks for Understanding Agenda Setting and Implementation

Examples of architecture characteristics
### Case II: Congestion Pricing: Purpose and General Approach: “Expanded Objective Function”

<table>
<thead>
<tr>
<th>Challenge</th>
<th>General Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downside uncertainty</td>
<td>Delay large investment, increase information</td>
</tr>
<tr>
<td>Upside uncertainty</td>
<td>System architecture and technology to create new opportunities</td>
</tr>
<tr>
<td>Implementation and stakeholder resistance</td>
<td>“Should a problem be too big to solve, then one should look to expand it” – Eisenhower → include new stakeholders</td>
</tr>
<tr>
<td>Unknown unknowns</td>
<td>Structure ITS organization to be a learning organization</td>
</tr>
<tr>
<td>Support for congestion pricing</td>
<td>Early experience with relevant ITS capabilities and new set of stakeholders with vested interested in implementation</td>
</tr>
</tbody>
</table>
**Case II: Congestion Pricing: Proposed Architecture**

**Actions**
- Phase in HOT Lanes using Smart Cards
- Expand # HOT Lanes
- Contract with industry for future non-transportation uses

**Effects**
- Voluntary consumer adoption of e-tolling technology
- Increase in consumer adoption

**Actions**
- Introduce non-trans. uses (parking, JIT, information sharing, retail, etc.)
- Create ITS org. to access environment

**Effects**
- Increased consumer interest in Smart Cards
- Increased stakeholder base and revenues
- Assessment of env.

**Actions**
- Continue to expand non-trans. uses
- Push for cordon congestion pricing – i.e. mandatory Smart Card usage

**Effects**
- Support from non-trans. stakeholders
- Increased revenue stream
- Congestion relief
Integrated Infrastructure and Operations ITS options

• Provide means to gather new information (operation of system or when combined with organizational changes long term trend data, or localities learning from one another)

• Can be structured to create non-traditional opportunities such as political support for future improvements or links to non-traditional transportation stakeholders (creates incentives through market forces to change system functionality and or operation of system)

• Functionality can be introduced in phases over time (cameras for red light enforcement, demand management, security) (inclusion of motor on cameras change system from red light enforcement to security system, or integration of different organizations’ operations to create comprehensive security system – assumes compatible infrastructure – different levels of compatibility possible (integration a priori, all cameras, camera / smart card based not compatible), aka Chicago)

• Easier to expand, grow, contract or abandon than fixed infrastructure (create potentials for growth through organization operation integration on demand- again Chicago)