Design, Evaluation, and Management of Flexible Systems

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Increasing system value through flexibility

Webex Presentation for LAI

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Contents

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  - **Research questions**
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- Research presentation

Uncertainty can result in future losses and gains, driving the need for flexibility. Some illustrative examples…

Losses can be large in inflexible systems when circumstances change

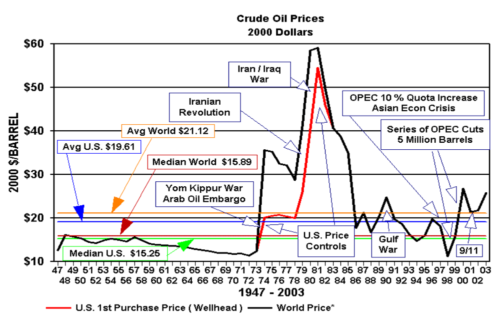
Montreal Mirabel Airport…

…over estimated passenger demand resulting in…

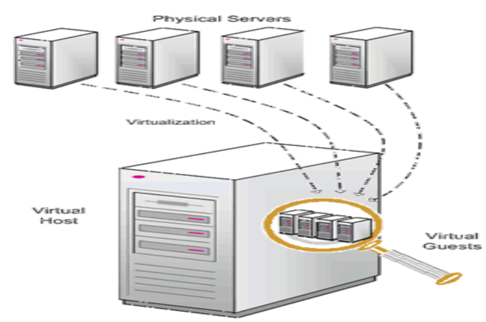
- Providing overcapacity of 17 million passengers per year; >5x overcapacity
- Unneeded government expropriation of 81,000 acres; 83% of total
- Cancelation of all passenger flights and conversion to a cargo only airport
- Total wasted costs in the billions over decades

Flexibility helps mitigate losses or take advantage of gains

Dual-fuel boilers limit loss against energy price fluctuations



Virtual servers allow increased demand to be met quickly and cheaply

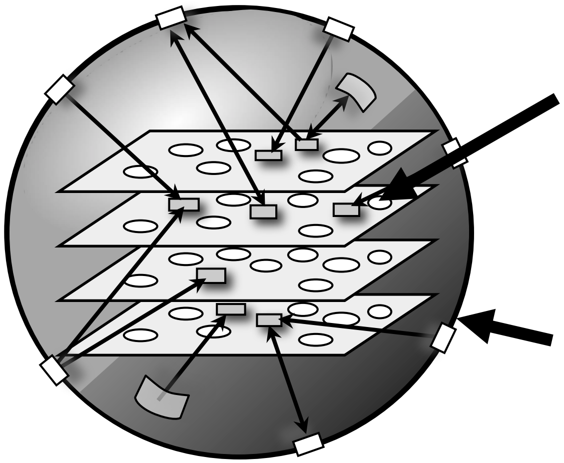


SOURCE: Kulatilaka (1993) The Value of Flexibility: The Case of a Duel-Fuel Industrial Steam Boiler;
de Neufville (2003) Airport systems: Planning, design, and management

Flexibility is a viable strategy to cope with uncertainty in complex systems

Area of interest for research

Uncertainty is a characteristic of complex systems



Physical systems are embedded in…

…enterprises and institutions

Complex systems typically…

- Contain many subsystems
- Display emergent behavior
- Behave non-linearly over multiple time scales
- Defy easy quantification
- Host interactions between multiple actors, each with: differing viewpoints, priorities and capabilities
- Exhibit difficult to predict future behaviors

Flexibility is one of many ways to address uncertainty

- Reduce or control uncertainty
  - Increase information and knowledge of system
  - Reduce system complexity
  - Manage demand
- Ignore uncertainty
  - Design for base load demand
- Increase robustness
  - Increase capacity or reserves
  - Decrease sensitivity to uncertainty
- Design in flexibility
  - Alter system configuration, based on future circumstances
  - Use concept of "Real Options" to operationalize flexibility

SOURCE: Sussman et al (2007) The CLIOS Process: A User's Guide; Sussman (2002) Collected Views on Complexity in Systems; Sussman (2000) Ideas on Complexity in Systems: Twenty Views; McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing 'Complex' Real Options

The research covers three questions about flexibility in complex systems

Focus of this presentation

- ***Technical:*** Can different technologies and technical architectures be designed to create flexibility in complex systems? If so, how do you quantify value created?
- ***System:*** What are the barriers to designing, evaluating, implementing and managing a flexible system and how can they be overcome?
- ***Process:*** What type of framework and tools are needed to support the design, implementation and management of a flexible system?

Several changes are needed to design, implement and manage flexibility

Research questions	Research findings	Research recommendations
Technical: How to create and quantify flexibility in systems?	▪ Many options exist but are not considered due to a lack of experience, resources and mandate ▪ Existing valuation tools are not adequate for complex systems	▪ Deploy tools to help designer's and decision makers envision and understand value of flexibility ▪ Use tailored combination of system analysis tools and option valuation methodologies
System: What are the barriers and how can they be overcome?	▪ Political considerations increase in flexible systems ▪ Existing enterprise and institutional architectures not compatible with flexibility ▪ Flexibility destroys value for some stakeholders	▪ Create rules to "lock-in" flexibility ▪ Change standard operating procedures to mandate and commonly value flexibility ▪ Assess options from perspective of multiple stakeholders to determine true system value

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Flexibility adds value by delaying decisions until information is available

Common questions about flexibility	Some answers
What is flexibility?	▪ The ability to: – Change the future configuration of a system – Postpone the adoption of a system configuration until a future date after additional information is available, i.e. uncertainties are resolved
Why use flexibility?	▪ Flexibility: – Allows the system to adapt to future circumstances that are not known ex ante – Adds value to the system
Why not use flexibility?	▪ Flexibility is not free; costs include: – Resources (time, upfront costs, capability) to design, implement and manage flexibility – Increased system complexity
How to use flexibility?	▪ Flexibility can be: – Added into the system in many places, i.e. technically, financially, management, politically, etc. – Operationalized with “Real Options”

Real options can be included into the design of a technical system

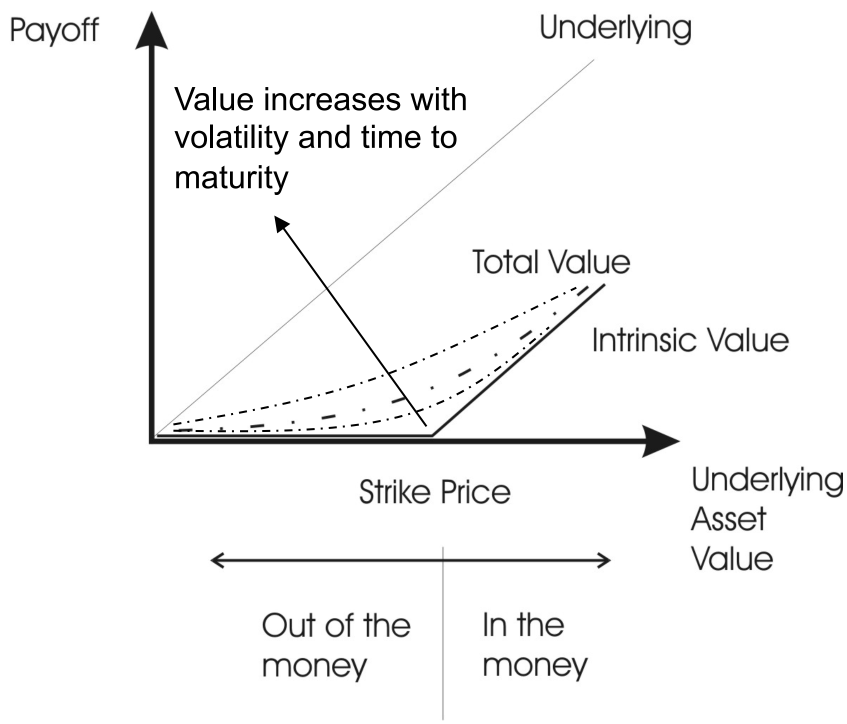
Area of interest for research

Option evolution	Description	Emphasis	Examples
Financial options	▪ Contract between a buyer and a seller that gives the buyer the right, but not the obligation, to buy or to sell a particular asset at a future date at an agreed price	▪ Developing and refining option valuation methodologies	▪ Call (put) option – The option holder has the right to buy (sell) IBM shares at $110/share on May 20, 2009
Real options	▪ Option on a physical, or real, asset; as opposed to a financial asset ▪ Originally used in capital budgeting to account for flexibility in decision making	▪ Applying options thinking to “real world” systems	▪ Option to engage in a multi-stage pharmaceutical research and development program ▪ Option to engage in exploration of an oil field
Real options “in” systems	▪ Designing flexibility into the technical specifications, i.e. the technical system is not treated as a “black box”	▪ Designing technical architecture to be flexible	▪ Option to switch fuel in an industrial steam boiler ▪ Option to add additional stories to a parking garage ▪ Option to expand a satellite constellation

SOURCE: de Neufville, R. (2004) Uncertainty Management for Engineering Systems Planning and Design

A few basics on option terminology and value

Payoff diagram for a call option



Basic option terminology

- **Underlying –** underlying asset on which option value is based
- **Strike price –** price at which option, if exercised, has value, i.e. exercise price
- **Out of the money –** underlying value at which option, if exercised, is worthless
- **In the money –** underlying value at which option, if exercised, has value
- **Volatility –** level of uncertainty surrounding underlying's future value
- **Total value –** total value of the option before exercise = Intrinsic value + time value
- **Intrinsic value =** current underlying asset value – strike price
- **Time value –** price the amount above the intrinsic value an investor is willing to pay for an option
- **Payoff –** value received from exercising an option, i.e. intrinsic value

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Example: How to design and value a flexible system is the topic of ongoing research

Focus of following slides

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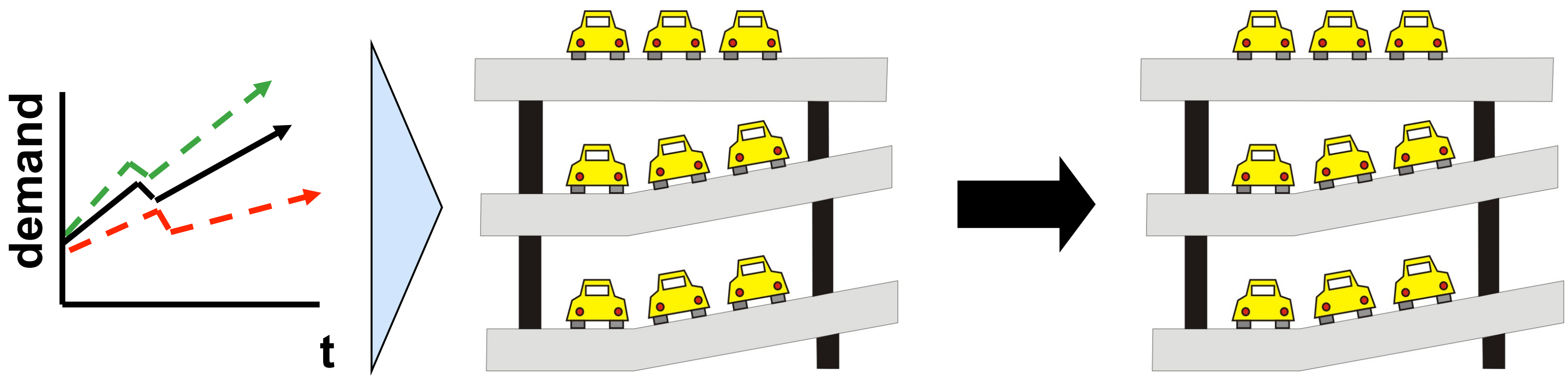
A simple example* shows value of building flexibility into a system (1/2)

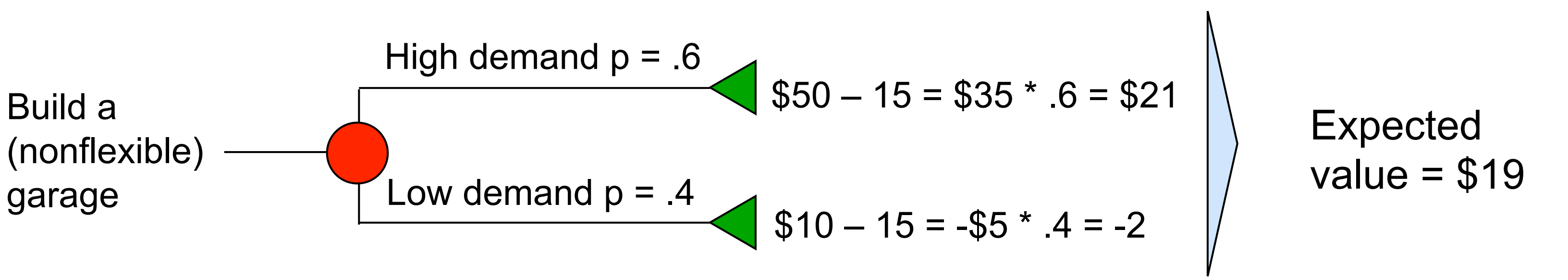
Technical architecture: Garage does not take into account demand uncertainty



Garage configuration at T_1

Garage configuration at T_2

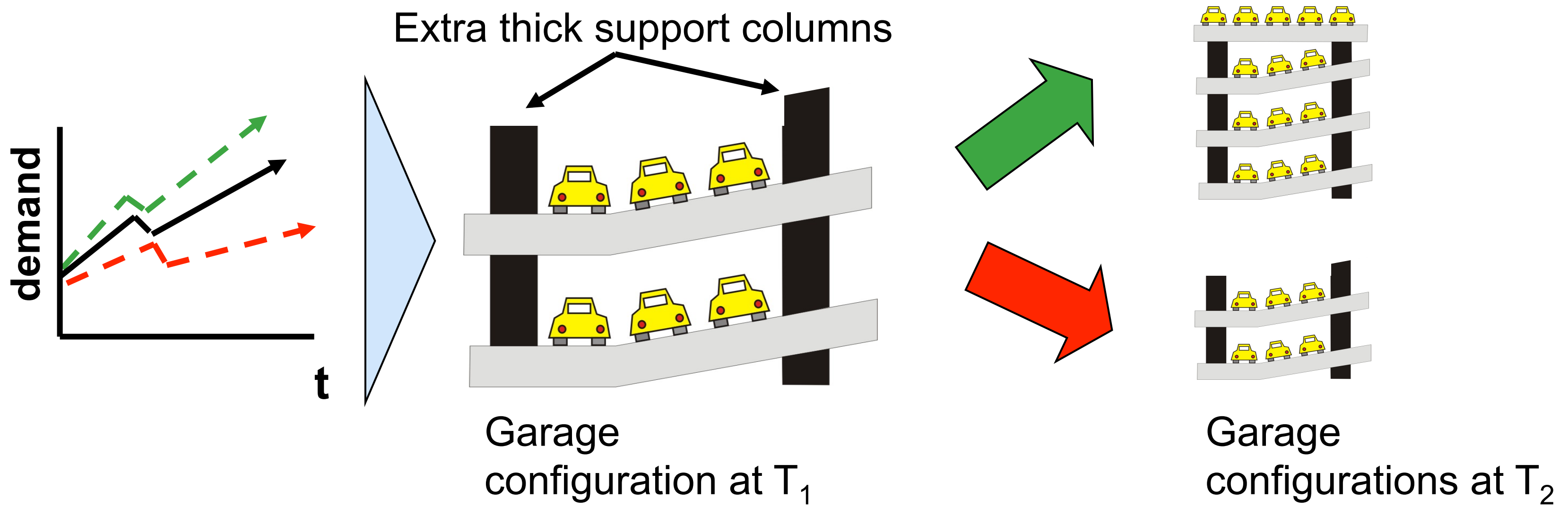
Valuation: Garage losses value when demand is low



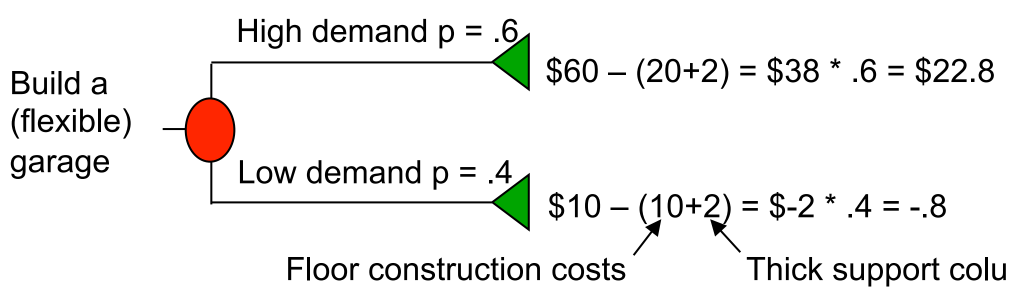
* Example based on Zhao and Tseng (2003) Valuing Flexibility in Infrastructure Expansion

A simple example* shows value of building flexibility into a system (2/2)

Technical architecture: Uncertainty addressed with thick columns and delay



Valuation: Value gained when demand is high and minimizes losses when low



Expected value = $22

Option value = $22 – 19 = $3

Is option valuable? $3>$2, so yes

* Example based on Zhao and Tseng (2003) Valuing Flexibility in Infrastructure Expansion

Example: Identifying and overcoming barriers to flexible systems is a topic of ongoing research

Focus of following slides

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- ***Process:*** What type of framework and tools are needed to support the design, implementation and management of a flexible system?

Several issues appear when applying options and to complex systems

Real options in theory	Real options in practice	Flexibility in transportation
The option holder…	Fragmentation of stakeholders: designer, evaluator, purchaser, owner, manager	Many diverse stakeholders with unique and contradictory goals; difficulty in design and decisions
…has the right, but not the obligation…	Prevention of or forced option deployment due to politics	Politics, economics and budgetary constraints prevent changes in the system
…to take some action…	Need for multiple actions over multiple domains	Actions often outside the domain of agencies, e.g. transportation agencies' operating systems
…now or in the future…	Changing actions and time horizons	Decades long system use; system decisions continually delayed; technology shifts
…at a pre-determined cost.	Changing costs	Costs underestimated; full system and stakeholder costs not evaluated

SOURCE: McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing 'Complex' Real Options

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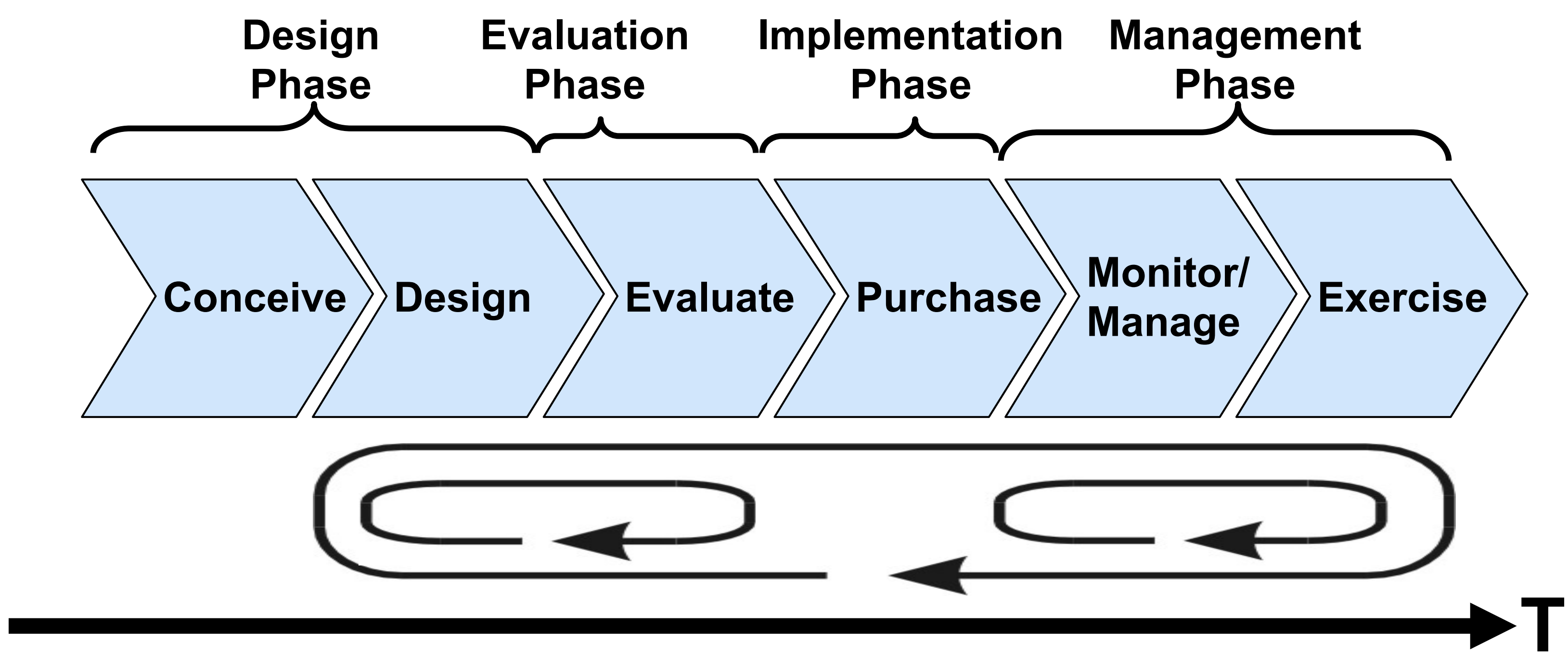
A life-cycle approach needs to be taken for options in complex systems

Option life-cycle



Compared to financial options, options in complex systems require:

- Multi-disciplinary approach, i.e., technical, financial, management, stakeholder management
- Activities and iterations over multiple time-scales
- Long-term planning and management

SOURCE: McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing 'Complex' Real Options

The research was structured to address all issues of flexibility in systems

Research structure covered both theory and practice

Literature Review
(Focused on Flexibility)

Life-Cycle Flexibility Framework

Case Study 1: Boeing BWB

Quantitative Model:
- System dynamics model of aviation industry
- Real Options Analysis (ROA)

Qualitative Analysis:
- Document search
- Interviews

Case Study 2: Houston Managed Lanes

Quantitative Model:
- Network demand and traffic flow model of Houston
- Real Options Analysis (ROA)

Qualitative Analysis:
- Document search
- Interviews

Conclusions
- *Case study generalizations*
- *Life-cycle flexibility framework*

Research contributions

Methodological Outcomes
- Developed Life-cycle flexibility framework

Quantitative Outcomes
- Demonstrated need for sophisticated modeling techniques
- Improved system dynamics model for aircraft industry

Qualitative Outcomes
- Improved knowledge of the challenges from flexible systems

Domain Applications
- Introduced new way of thinking about ITS and BWB capabilities

SOURCE: McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing ‘Complex’ Real Options

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Two case studies helped better understand flexibility in complex systems

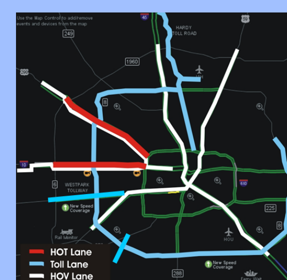
Focus of this presentation

Case study 1: Boeing Blended Wing Body

Research focus	Tools used
▪ Technical architecture of common sub-systems	▪ Existing Boeing design analysis
▪ Value of flexibility from commonality	▪ Aviation industry system dynamics ▪ Scenario & Monte Carlo analyses ▪ ROA
▪ Challenges of flexibility in global, private enterprises	▪ Document review ▪ Stakeholder interviews

Case study 2: Houston transportation network

Research focus	Tools used
▪ Technology impact of Intelligent Transportation Systems (ITS)	▪ Transportation network & demand models
▪ Value of flexibility from ITS	▪ Transportation network & demand models ▪ Scenario & Monte Carlo analyses ▪ ROA
▪ Challenges of flexibility in regional public and private enterprises	▪ Document review ▪ Stakeholder interviews



Case studies used to:
- Explore value of including flexibility in a system's technology/technical architecture
- Explore systemic effects through quantitative models
- Improve understanding of "real world" challenges and constraints

SOURCE: McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing 'Complex' Real Options

The research scope includes technical and enterprise/institutional issues

Institutional Architecture: Federal, state, and local governments and agencies

Political:
- Tx Legislature
- City of Houston
- Harris Country

Planning:
- Houston MPO
- Management Districts

Transportation:
- USDoT
- TxDOT
- METRO
- TranStar
- Harris Country Infrastructure

Extended Enterprise Architecture: Houston region stakeholder interactions

Land developers:
- Developer associations

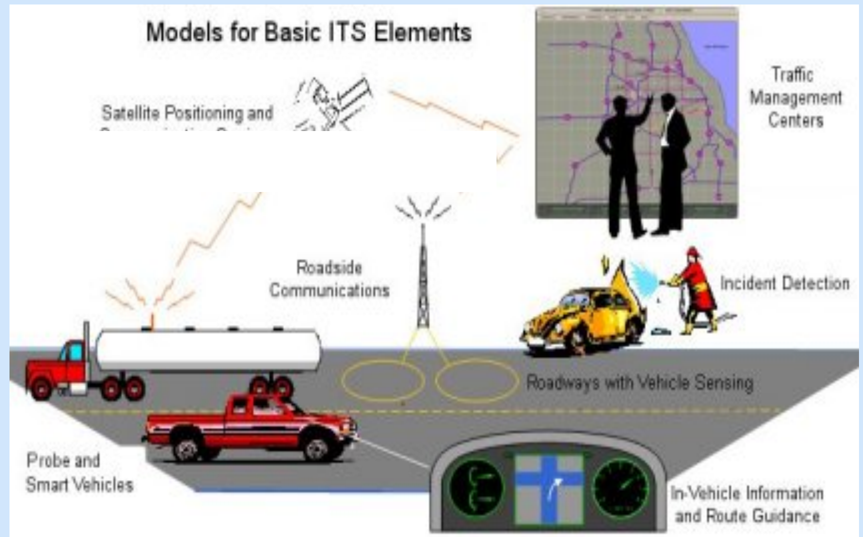
Commercial:
- Chamber of Commerce

Citizen:
- Citizen transportation and property right coalitions

Environmental:
- Houston Sierra Club

Enterprise Architecture

Technical Architecture & Technology:
Transportation network and ITS



Technical hypotheses:
- ITS can create flexible transportation networks
- Valuation requires ROA and network analysis
- ITS has inherent value and flexible value

System hypotheses:
- Major challenges are come from multiple stakeholders and their interactions, more than in non-flexible systems
- A portfolio of strategies is needed

SOURCE: McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing 'Complex' Real Options

How can ITS capabilities create flexibility and how can it be valued?

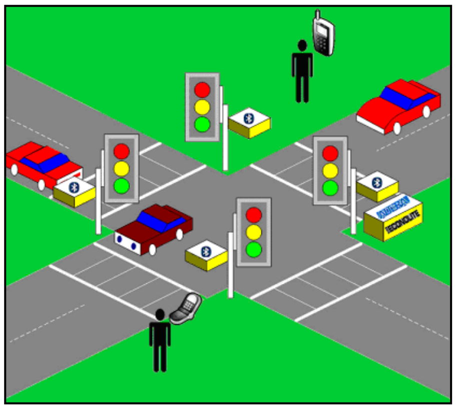
Focus of following slides

- ***Technical:*** Can different technologies and technical architectures be designed to create flexibility in complex systems? If so, how do you quantify value created?
- ***System:*** What are the barriers to designing, evaluating, implementing and managing a flexible system and how can they be overcome?
- ***Process:*** What type of framework and tools are needed to support the design, implementation and management of a flexible system?

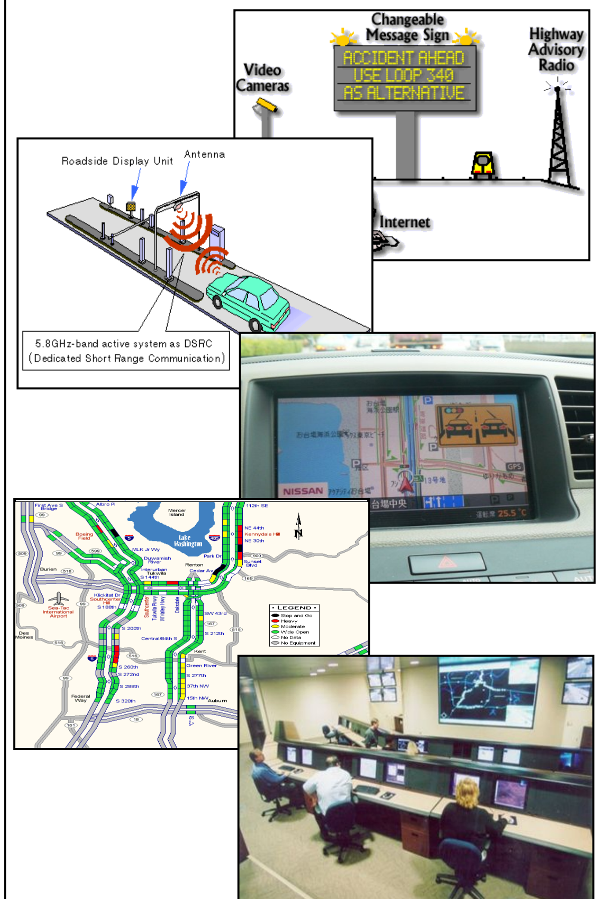
ITS is a new, low cost alternative for improving transportation systems

Inherent value of ITS

Combining traditional infrastructure and rolling stock…



…with ITS technologies…



+

…yields a transportation system that…

=

- Increases effective capacity
- Focuses on operations instead of capacity expansion
- Costs less during deployment
- Provides flexibility

ITS provides many opportunities for flexibility in transportation systems

Example on following pages

Option to…	Option description	ITS option example
Delay	▪ Right to postpone a decision	▪ Right to deploy ITS technologies to defer traditional infrastructure investments
Abandon / Sell	▪ Right to discontinue or sell a project	▪ Right to end specific types of ITS services—i.e. real time traffic information
Expand / Contract	▪ Right to increase or decrease the size of a project	▪ Right to enable new capabilities—i.e. laying fiber during construction for to-be-determined future use
Grow / Shrink	▪ Right to increase or decrease the scope of a project	▪ Right to add new services—i.e. electronic tolling tags also used to measure traffic congestion
Switch	▪ Right to change to a different project	▪ Right to change functions—i.e. cameras switch between traffic congestion, accident management or security functions

SOURCE: McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing ‘Complex’ Real Options

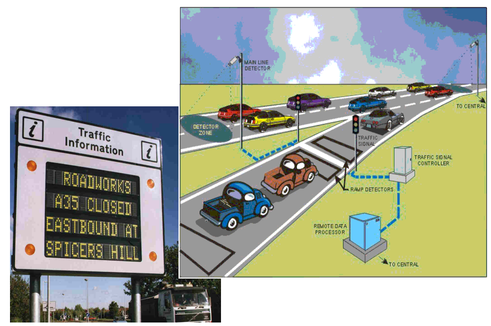
ITS technologies are one of several alternatives for alleviating congestion

Traditional approach for relieving congestion

Traffic congestion is a common condition…

…requiring a decision on alternatives to improve the situation

- Traditional infrastructure expansion



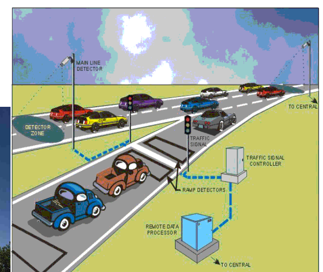
- ITS capabilities, e.g. traveler information or management systems

- "Do nothing"

Ignoring flexibility, ITS usually not as effective as capacity expansion

Current state

Future states



Future state valuations

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

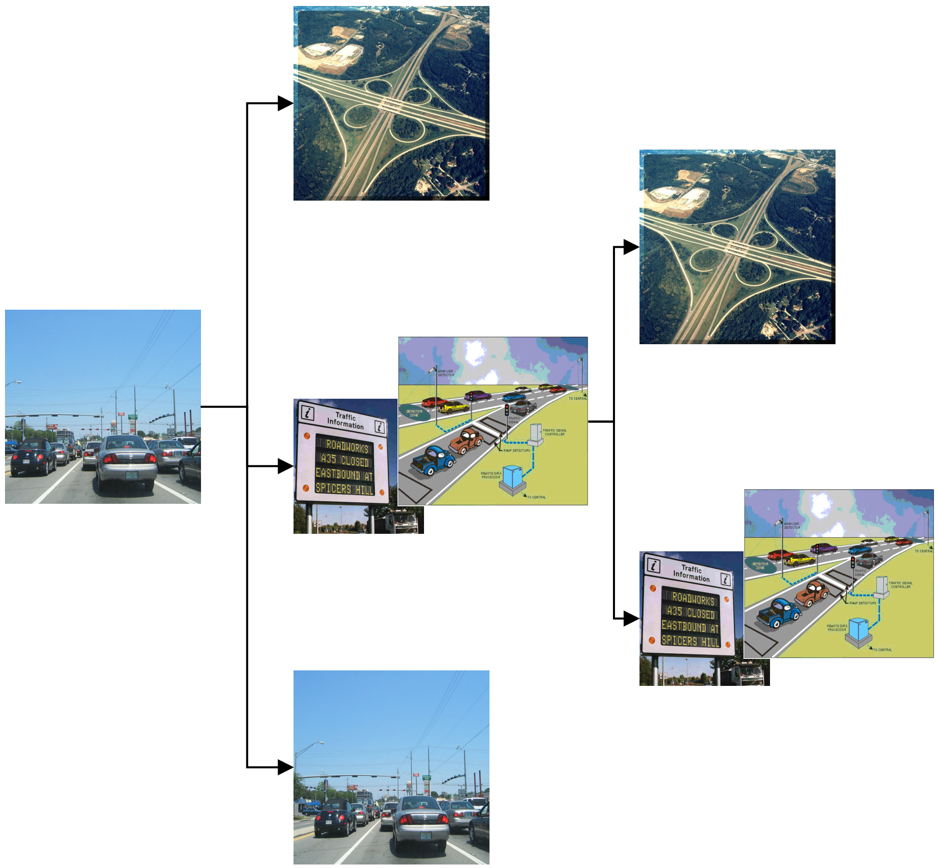
- EX NPV = $0.5 M
- B/C = 1.3

- EX NPV = - $10 M
- B/C = NA

- Only expected outcomes valued; flexibility is ignored
- Decision on alternative depends on metric
- Significant downside possible, i.e. “do nothing” or lower than expected congestion

With flexibility, ITS improves system value (1/2)

Current state | **Future states** | **Option to delay**



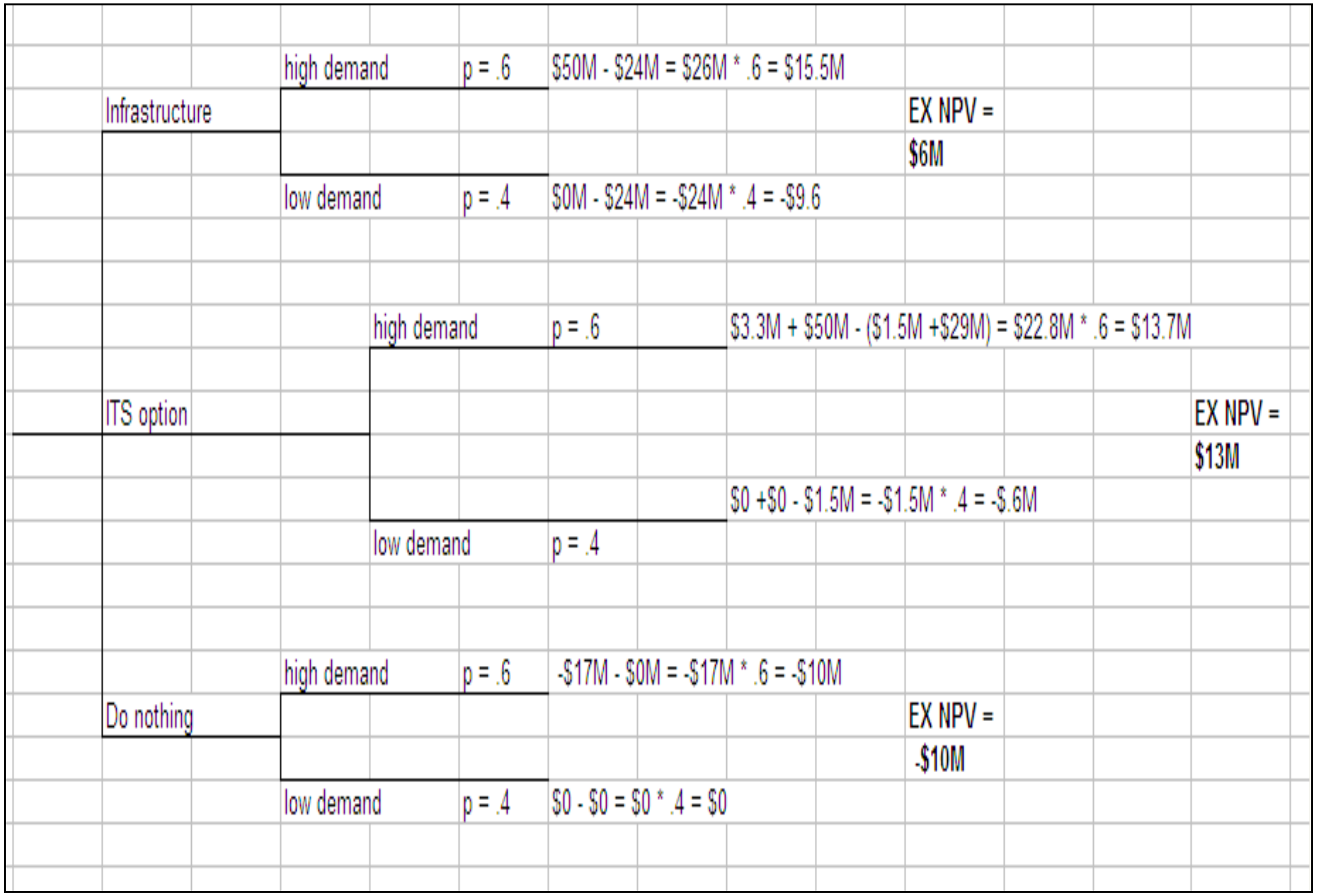
- T= 0: Deploy ITS
- T > 0: Build infrastructure if high demand materializes

- T= 0: Deploy ITS
- T > 0: No further action if high demand fails to materialize

- ITS creates value from flexibility
- ITS lowers initial capital outlay
- Capacity expansion decision postponed until additional information or funding is available
- ITS deployment prevents worst case scenario, e.g. "do nothing" and high demand
- Additional benefits include: improved information, political "cover", improved budget scheduling

With flexibility, ITS improves system value (2/2)

Simplified real options analysis

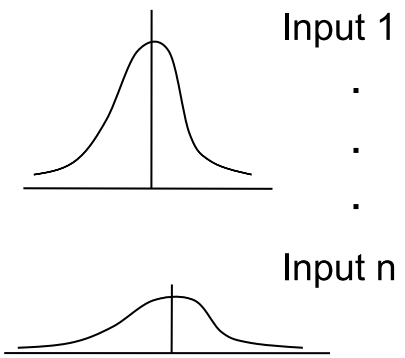


- EX NPV of ITS option = $13M
- EX NPV (ITS + infrastructure) = $6.5M
- Option value = $13M - $6.5M = $6.5M
- Option cost = $5M

Option viable as value > costs

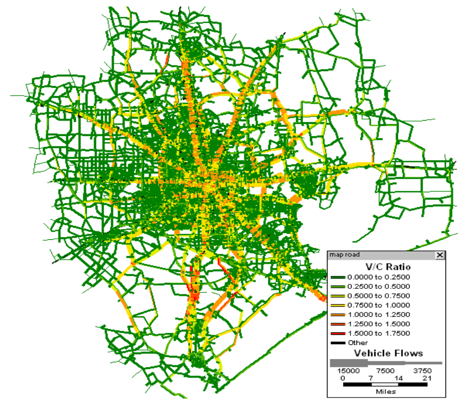
Option valuation in complex systems needs more sophistication (1/2)

Input data feeds…



- Flexibility evaluated as a function of:
  - traffic conditions
  - managed lane types
  - enterprise architectures
- Scenarios, demand models and Monte Carlo analysis used to define inputs

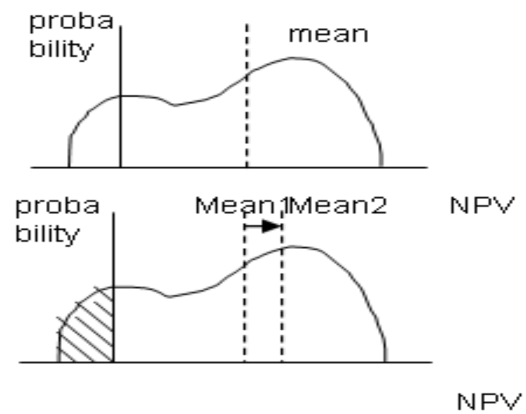
…into a network model…



Network model analysis calculates monetized values for:

- Time savings from congestion relief
- Revenues raised from new tolls

…with results analyzed by ROA



- Probability distributions created for EX NPV with and without flexibility
- Flexibility value calculated as difference in expected means*

* NPV of flexibility = NPV of project with flexibility – NPV of project without flexibility

Tufano and Moel 1997, Clemons and Gu 2003, Greden et al. 2005, Miller 2006

Option valuation in complex systems needs more sophistication (2/2)

Network demand model

Model characteristics

- Regional model of Houston area
- Same model and base predictions as used by local MPO
  - Network
  - Traffic demand
  - Mode split
  - Time of day and locations
- Used to understand and quantify
  - Travel behavior across the region
  - Presence of managed lanes
  - Managed lane design and operations
  - Enterprise architectures

System level analysis is needed to:

- Calculate system level values—i.e. improving traffic conditions on one corridor may worsen conditions on other corridors creating sub-optimal conditions
- Resolve system level interactions—e.g. enterprise architecture effects technical performance, i.e. private or public ownership of toll facilities and differing revenue goals
- Remove simplifying assumptions

What are the difficulties in using ITS to create flexibility and how can these be overcome?

Focus of following slides

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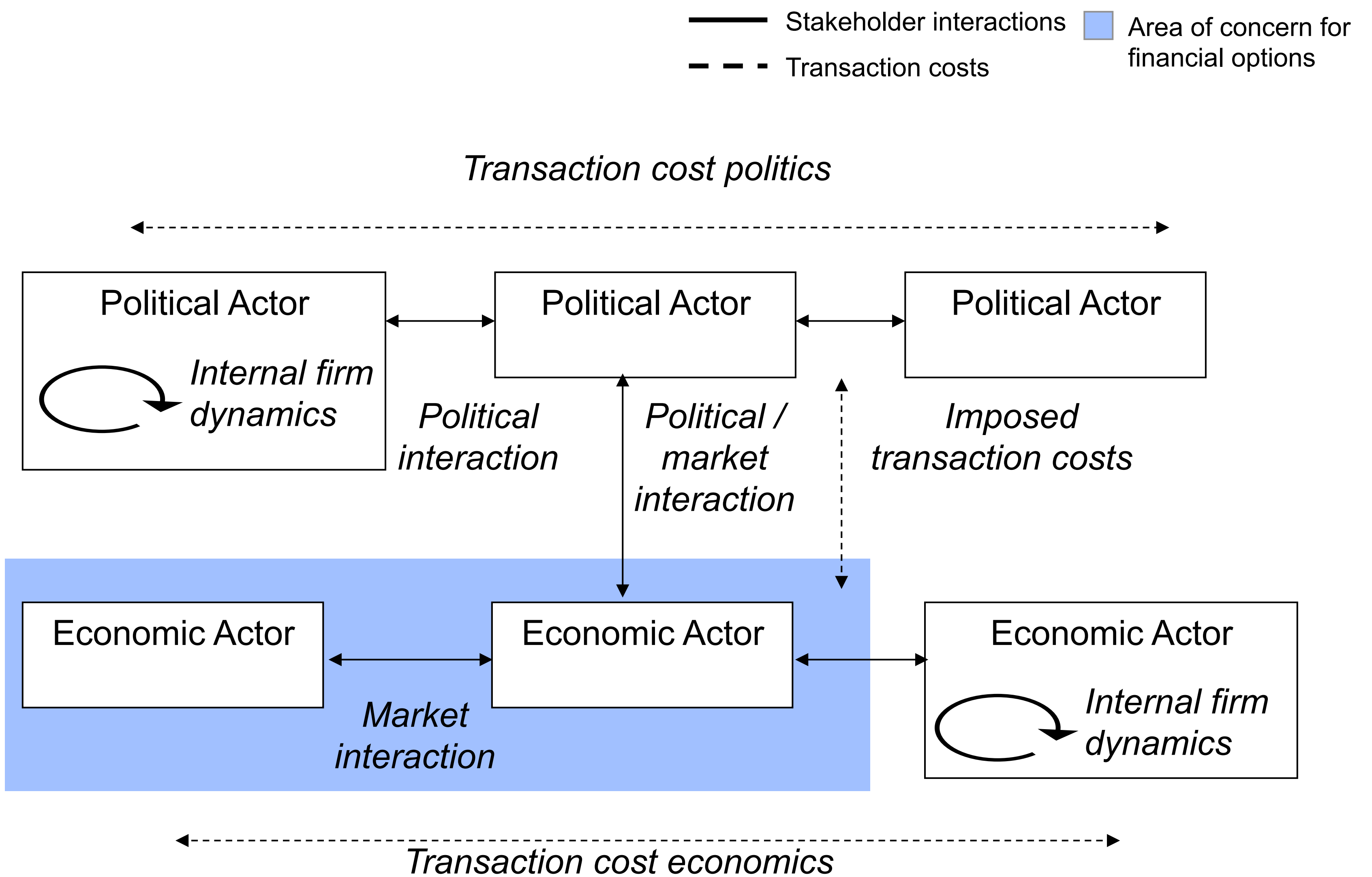
Options in complex systems require managing many divergent stakeholders and types of interactions



* Figure modified from Epstein and O'Halloran (1999) Delegating Powers: A Transaction Cost Politics Approach to Policy Making Under Separate Powers

SOURCE: McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing 'Complex' Real Options

Interdisciplinary solutions are needed to address issues with flexibility

During option life-cycle…	…many issues arise…	…but several potential solutions exist
Capability building	▪ Designers and decision makers not familiar with flexibility or real options analysis	▪ Educate stakeholders on benefits; provide training
	▪ Tools not available for flexible design or evaluation	▪ Determine needed tools; align with enterprise architecture, incentives and capabilities
Design	▪ Flexible designs appear “foreign” to enterprises	▪ Designate and empower champions ▪ Show quantitatively value derived from flexibility
	▪ Flexibility used to resolve or postpone politically contentious issues, i.e. option to postpone decision	▪ Design option with inherent value, e.g. ITS ▪ Lock in decision rules ex ante
Evaluation	▪ Cost for option a function of the stakeholder	▪ Perform life-cycle valuation along all dimensions ▪ Account for stakeholder costs and compensation
	▪ Stakeholders don’t see value in flexibility	▪ Tailor ROA process and outputs to the organization ▪ Translate outputs into standard metrics used
Implemen-tation	▪ Flexibility creates uncertainty for non-option holders	▪ Evaluate flexibility with respect to all stakeholders ▪ Accommodate stakeholders when possible, e.g. transparent decision rules, period for public comment, compensation, relax rules
Manage-ment	▪ Lack of information for option exercise	▪ Budget for operations in initial design ▪ Deploy options capable of self monitoring, e.g. ITS
	▪ No political will to exercise an option	▪ Lock in decision rules ▪ “Spin off” option to appropriate stakeholder

SOURCE: McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing ‘Complex’ Real Options

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Lessons learned: flexibility requires more effort and resources than just new design and valuation techniques

Multi-disciplinary analysis needed	Flexible systems require multi-disciplinary analysis; increased sophistication needed
Life-cycle planning necessary	Significant resources and capabilities are needed for flexible systems; life-cycle planning required ex ante
Active system management required	Flexible systems' need for active management is not aligned with current enterprise or institutional architectures; changes to mission and standard operating procedures needed
Multi-stakeholder analysis desirable	Flexibility destroys value for some stakeholders; multi-stakeholder view is needed
Clear decision rules need to be locked-in	"Flexibility" is often the continuation of political debates; ability to exercise and subsequent valuation is affected

SOURCE: McConnell (2008) Life-Cycle Flexibility: Designing, Evaluating and Managing 'Complex' Real Options

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My research, training and professional experience are interdisciplinary

Research

- Research includes:
  - Technical system design
  - Financial evaluation
  - Enterprise architecting
  - Policy and stakeholder analysis
- Research tools used:
  - System dynamics, network analysis
  - Real options analysis
  - Scenario analysis
  - Stakeholder interviews
  - Case studies
- Resulted in award of PhD from MIT, academic articles, book and book chapters

Training

- PhD in Technology, Management and Policy (1/3 engineering, 1/3 MBA, 1/3 public policy
- Masters degrees in:
  - Public policy
  - Aeronautics & Astronautics
  - Mechanical Engineering

Experience

- Management/business experience:
  - Senior consultant with supply chain consultancy
  - Senior consultant with McKinsey & Co.
- Policy experience
  - Adjunct consultant with IDA
  - Summer intern with US DoS London Embassy
- Technical experience
  - Engineer with NASA
  - Engineer with Draper Laboratory
  - Summer intern with Los Alamos, Kistler Aerospace