Systems Engineering Advancement Research Initiative

2009 SEAri Annual Research Summit

Research Report

"An Integrated Real Options Framework for Model-based Identification and Valuation of Options under Uncertainty"

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Cambridge, MA

Massachusetts Institute of Technology

Engineering Systems Division

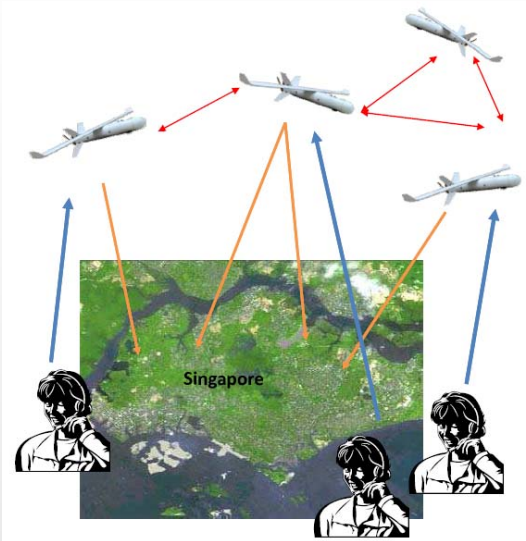
Outline

- Motivation
- Problem Statement
- Background, limitations in relevant areas
- Contribution: Integrated Real Options Framework
- Conclusions

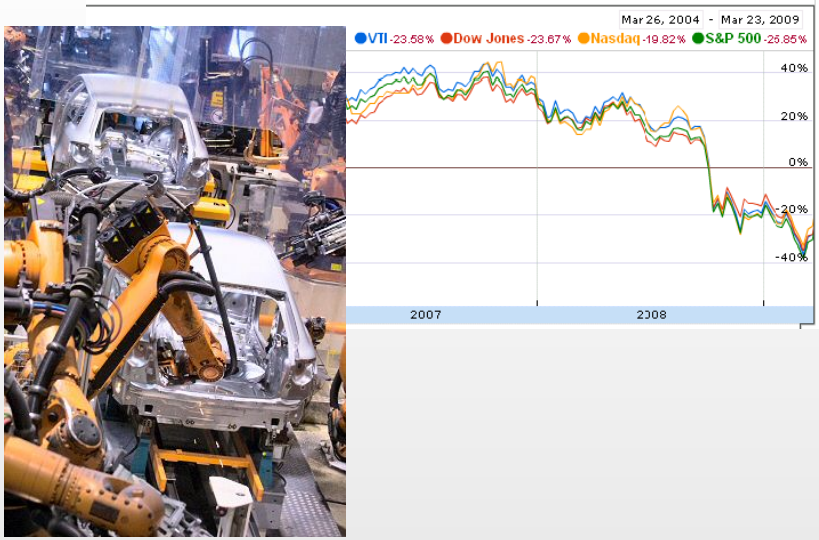
PhD in Aeronautics and Astronautics, June 2009
Thesis Committee:
Dean Daniel Hastings (Chair)
Prof. Deborah Nightingale
Dr. Donna Rhodes

Uncertainty Management for Complex Systems and Enterprises

uncertainty in operations and environment



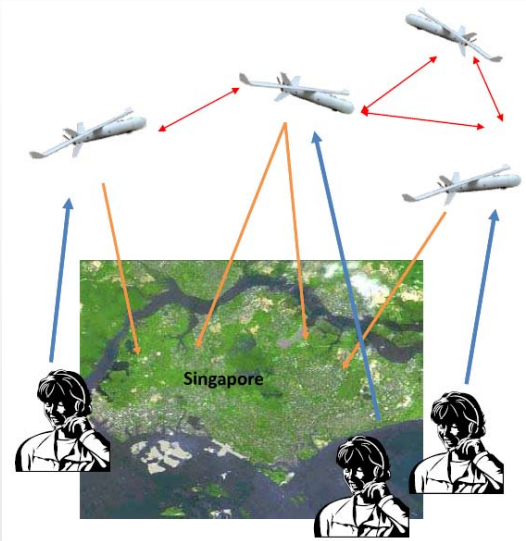
uncertainty in mission requirements



economic uncertainty, market demands cost of fuel

How to manage uncertainties facing enterprises that develop or operate complex systems?

The Need for Flexibility



flexibility to repair?
use alternative vehicle?

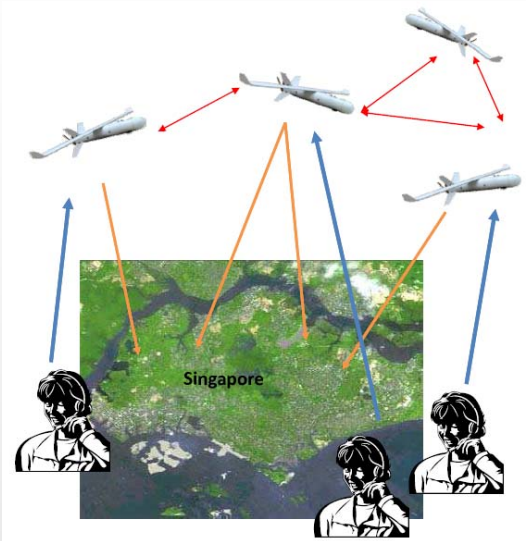
flexibility in UAV design?
swarm architecture?
use a satellite?

flexibility in manufacturing?
design (hybrid car)?
business strategy? purchasing?

Focus on flexibility as a means of managing uncertainties

Flexibility: ability to undergo change with relative ease

The Need for Flexibility



flexibility to repair?
use alternative vehicle?

flexibility in UAV design?
swarm architecture?
use a satellite?

flexibility in manufacturing?
design (hybrid car)?
business strategy? purchasing?

Challenge: holistic identification and valuation of flexibility

Terminology

Flexibility:
ability to undergo change with relative ease *

Real options analysis:
a means of modeling and valuation of flexibility

Real option:
right, but not the obligation, to take an action in the future

Enterprise:
defined scope of economic organization or activity, which will return value to the participants through their interaction and contribution *

* MIT Engineering Systems Division definitions

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Research Problem

How can real options be used for holistic decision making within socio-technical enterprises under uncertainty?

Develop a model based, holistic framework to systematically identify and value:

- What type of flexibility, if any, is desirable to manage uncertainty?
- How to enable flexibility?
- Where to enable flexibility in an enterprise?

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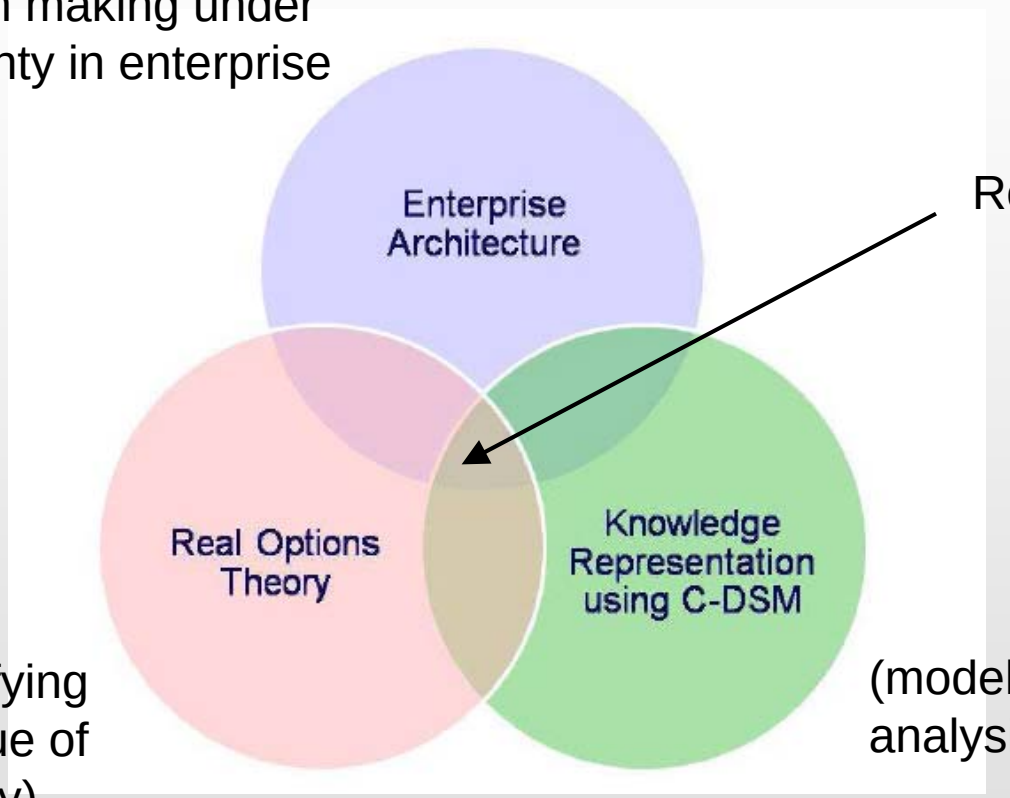
Research Focus

(decision making under uncertainty in enterprise context)



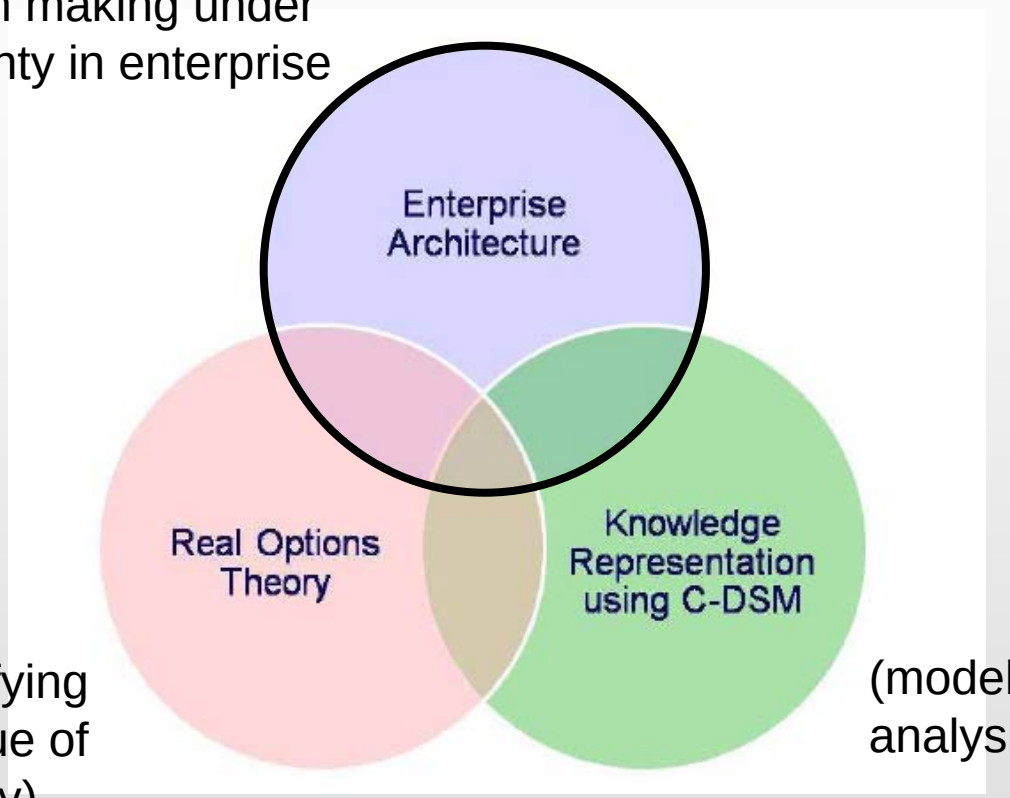
Research focus

(quantifying the value of flexibility)

(model based analysis)

Research Focus

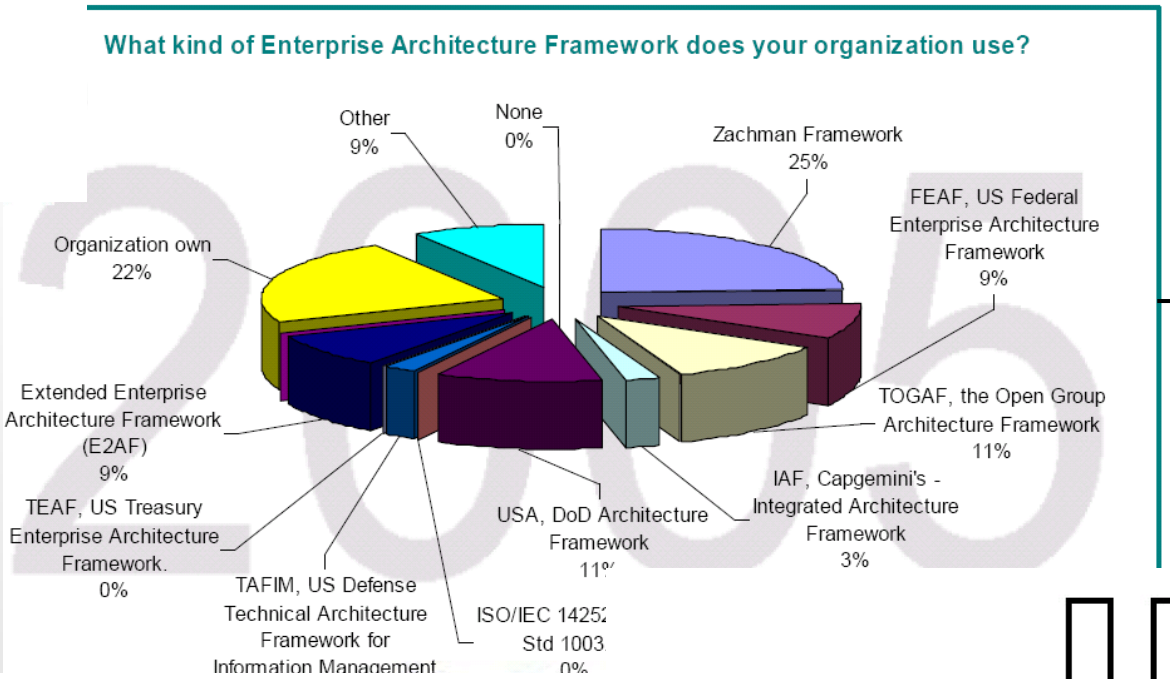
(decision making under uncertainty in enterprise context)



(quantifying the value of flexibility)

(model based analysis)

Architecture Frameworks



(J. Schekkerman, 2005)

Enterprise Architecture frameworks focus on the IT system

(Bartolomei, 2007)

Comparison of frameworks for representing complex engineering systems

Evaluation Criteria for Scope	QFD	UPP	Axiomatic Design	DSM	DSM/DMM Framework	DoDAF	CLIOS	ESM
Represents Social Domain	+	+		++	++	+	+	++
Represents Functional Domain	+	++	+		++	++	+	++
Represents Technical Domain	+		+	++	++	++	+	++
Represents Process Domain	+	++	+	++	++	++	+	++
Represents Environmental Domain	+	++				+	+	++
Represents Interactions within Domains	++	++	++	+	++	+	+	++
Represents Interactions across Domains	++	++	++		++	++	+	++
Conducive for Quantitative Analysis		+	+	++	++			++
Captures System Changes Over Time								++

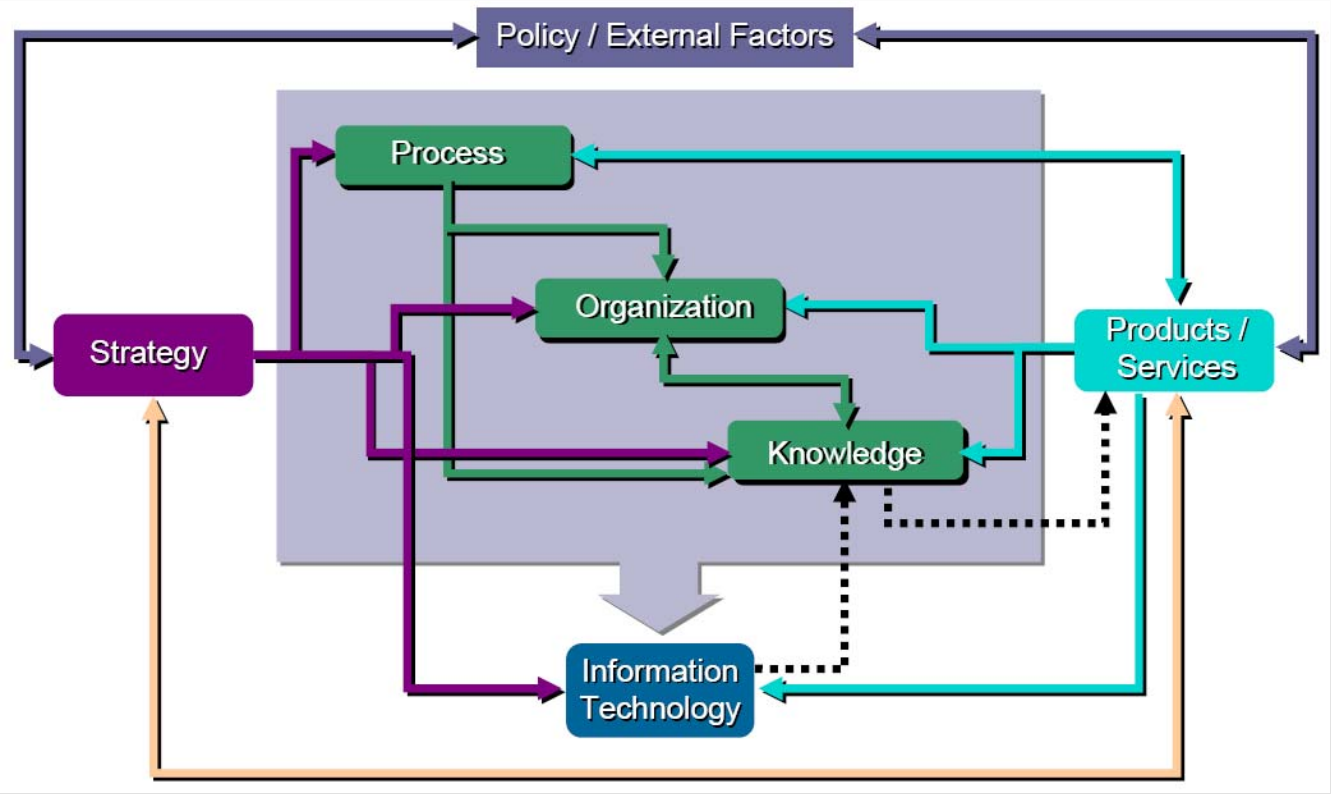
Eight Views of Enterprise Architecture

Strategy	The goals, vision and direction of the enterprise, including the business model and competitive environment.
Policy	The external regulatory, political and societal environments in which the enterprise operates, as well as policies internal to the enterprise.
Organization	The organizational structure as well as the relationships, culture, behaviors, and boundaries between individuals, teams and organizations.
Process	The core, enabling and leadership processes by which the enterprise creates value for its stakeholders.
Product	The product architectures of the enterprise. Traditional system architecture
Service	The architecture of the services of the enterprise, including service as a primary objective or in support of products.
Knowledge	The implicit and tacit knowledge, capabilities, intellectual property resident in the enterprise.
Information Tech.	The information needs of the enterprise including the flows of information as well as the systems and technologies needed to ensure information availability.

(Nightingale and Rhodes, 2007, 2009)

Traditional "enterprise architecture"

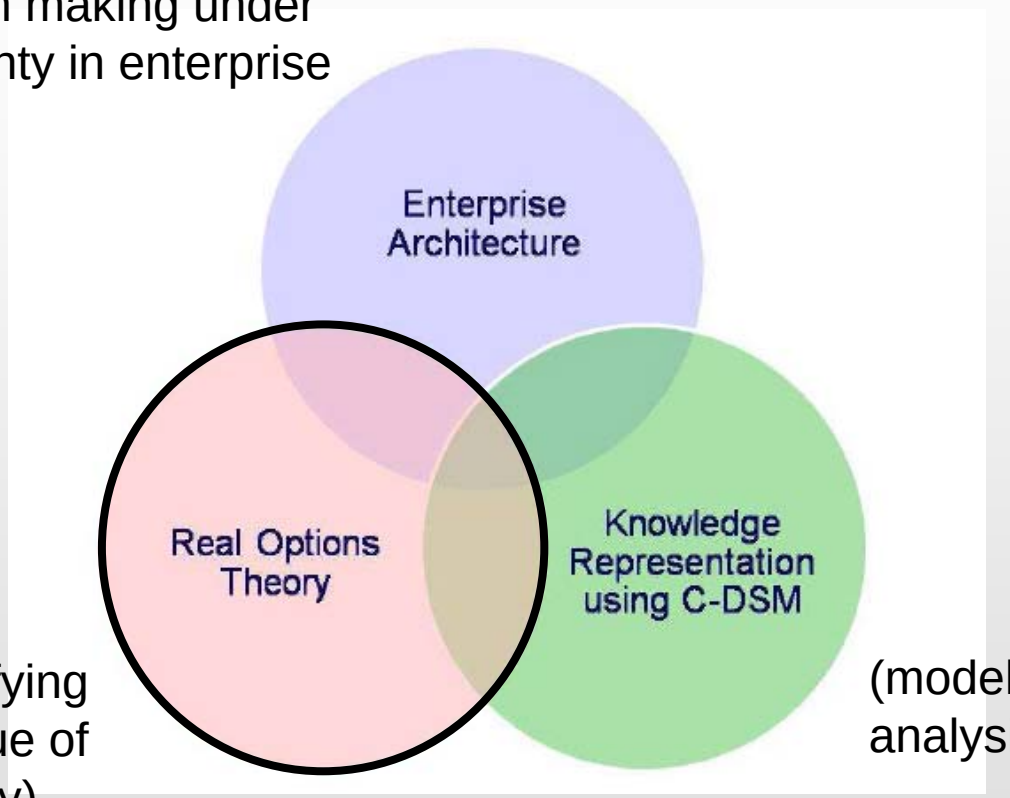
Eight Views of Enterprise Architecture



(Nightingale and Rhodes, 2007, 2009)

Research Focus

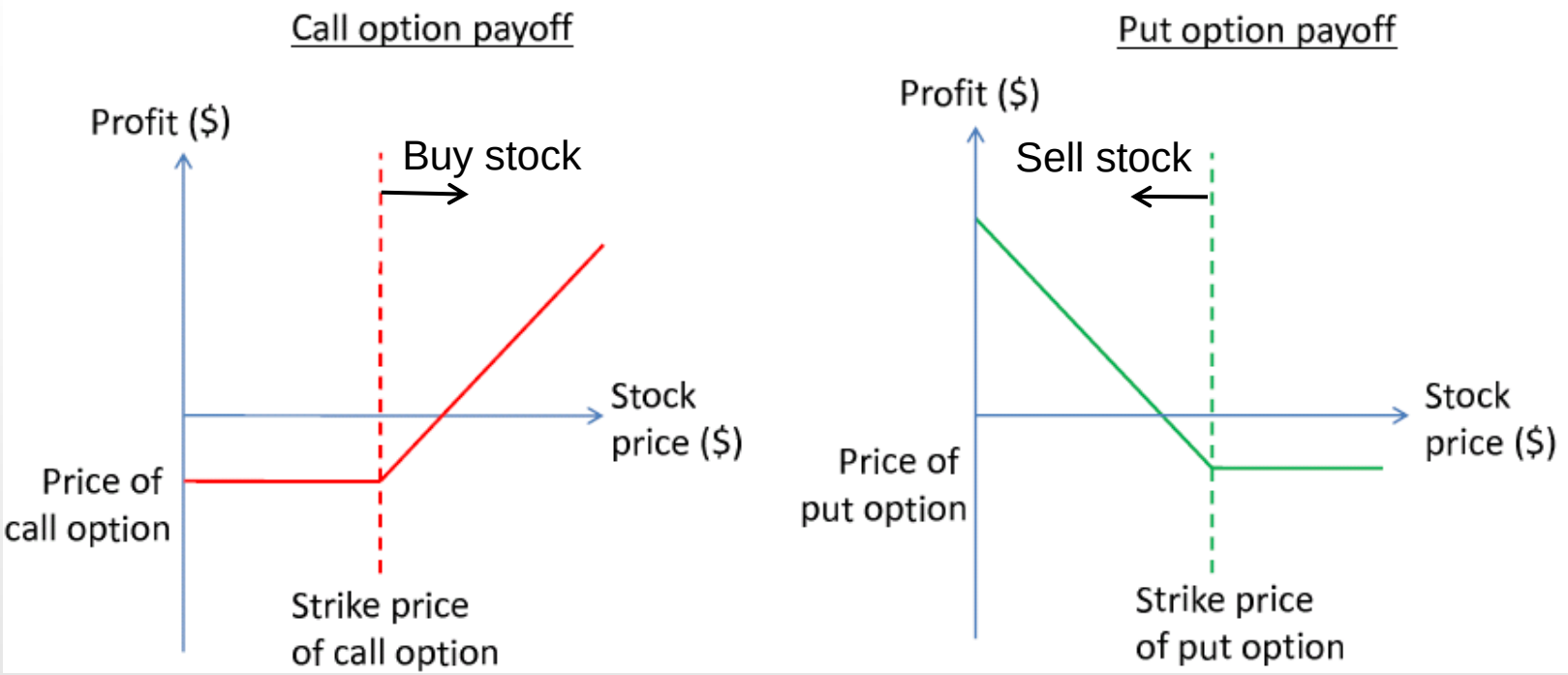
(decision making under uncertainty in enterprise context)



(quantifying the value of flexibility)

(model based analysis)

Simple Financial Options



Financial option: right, but not the obligation,
to buy or sell an underlying security at a specified price, on or before expiration date of the option

Real option: right, but not the obligation,
to take an action in the future

Methods for valuation of financial options: Black-Scholes, binomial pricing, Monte Carlo

Real Options Analysis (ROA)

Real options analysis is a means of modeling and valuation of flexibility

Classical ROA Application

$ ← "Real option" to abandon, expand

→ time

Example: invest in new manufacturing plant?

real option to abandon plant to manage demand uncertainty

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Example: invest in new manufacturing plant?

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Application of ROA in design

"Real option" in design → Flexibility to change design

→ time

Example: modular payload bay in mini air vehicle

switch payloads to manage requirements uncertainty

Real Options Analysis (ROA)

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Classical ROA Application

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Application of ROA in design

"Real option" in design → Flexibility to change design

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1. Isolated Applications of ROA
2. Varying uses of "real option" terminology

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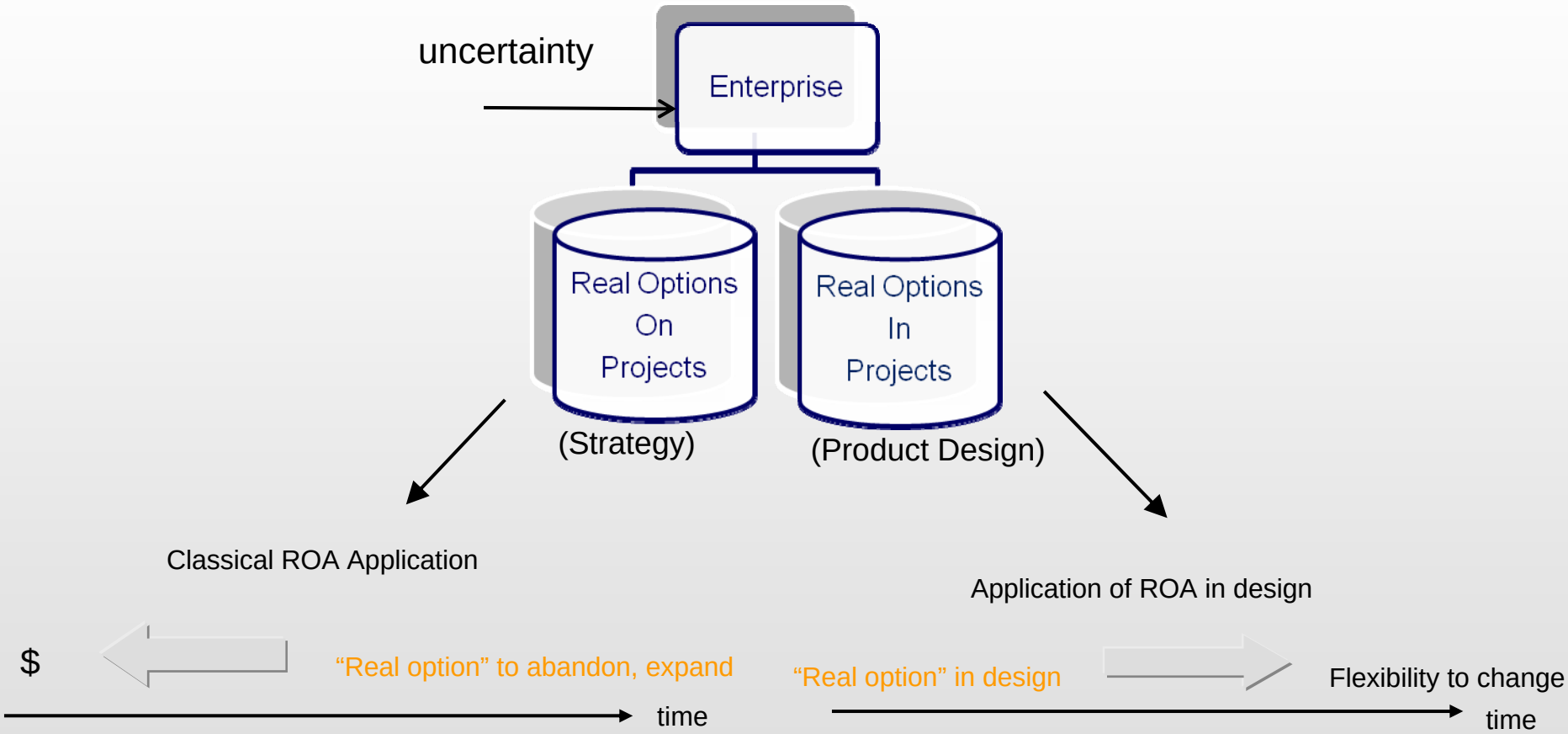
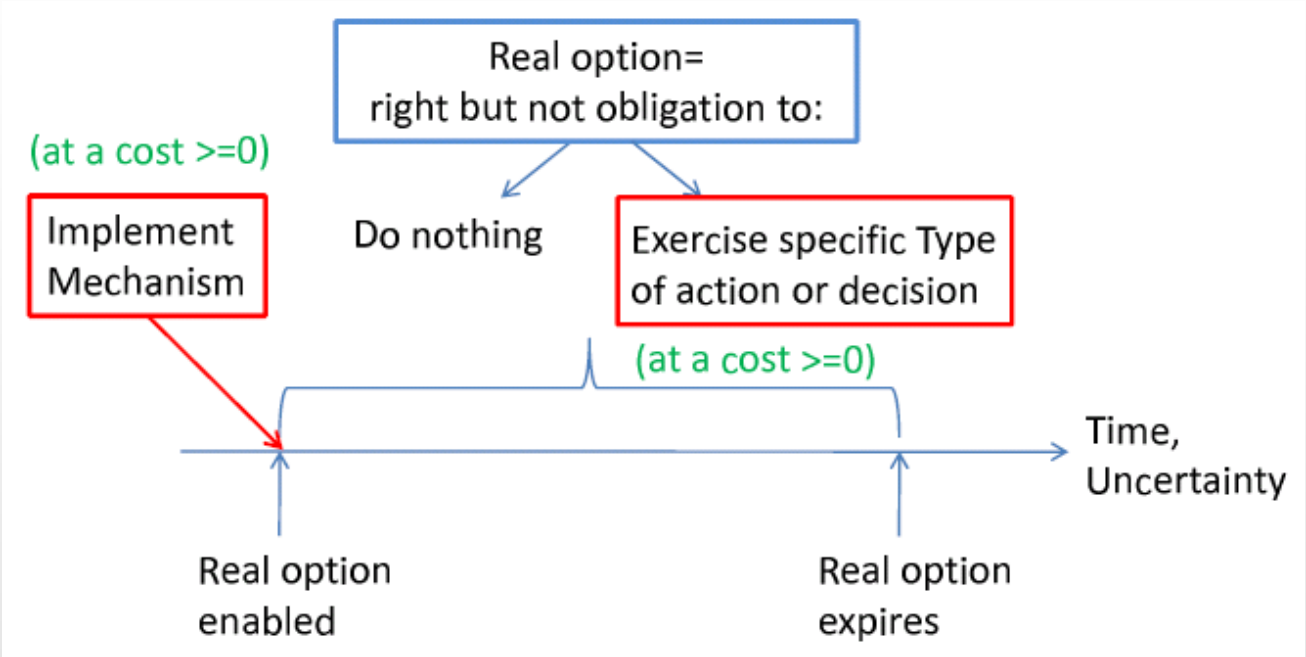
Real Options Silos



Emphasis on future flexibility

Emphasis on sources of flexibility

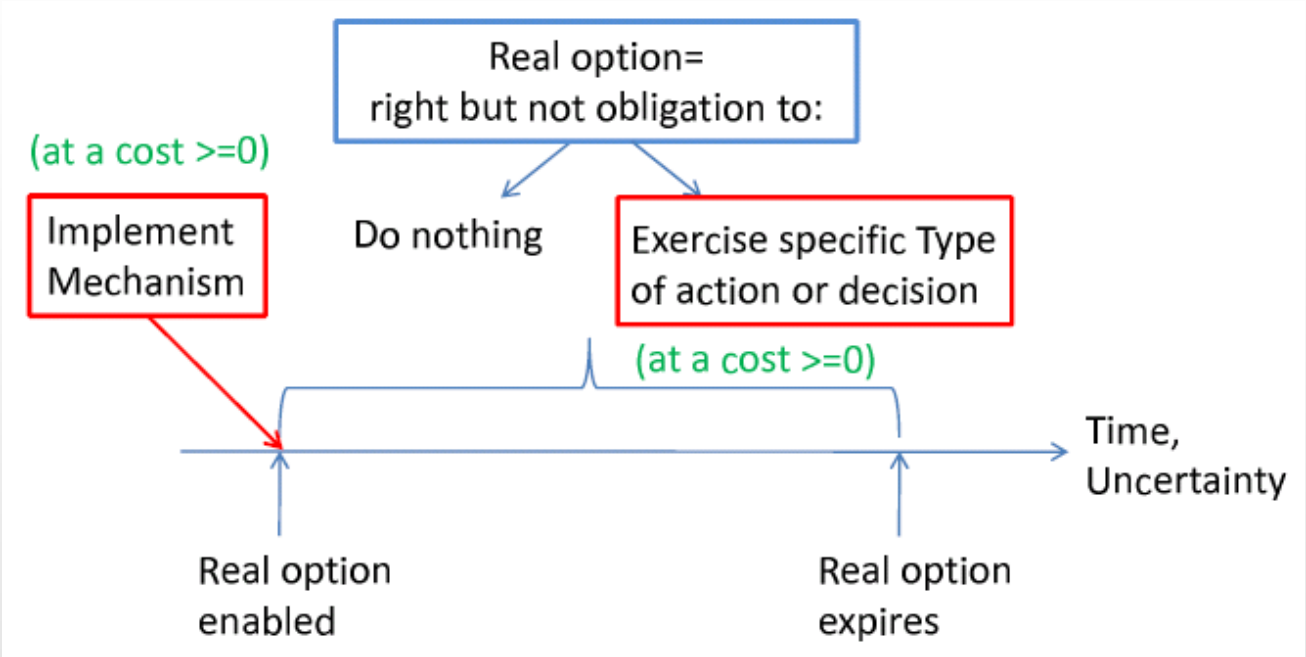
Real Options: Mechanisms and Types



1. Real Option Mechanism:
   actions/decisions that enable a real option

2. Real Option Type:
   actions/decisions that may be exercised by the owner of the real option

Real Options: Mechanisms and Types



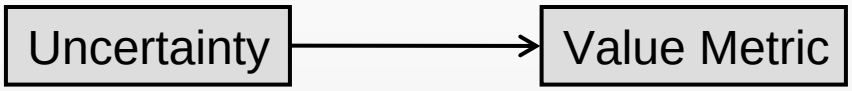
Examples:

Modular payload bay → Switch payload: to manage uncertainty in mission type

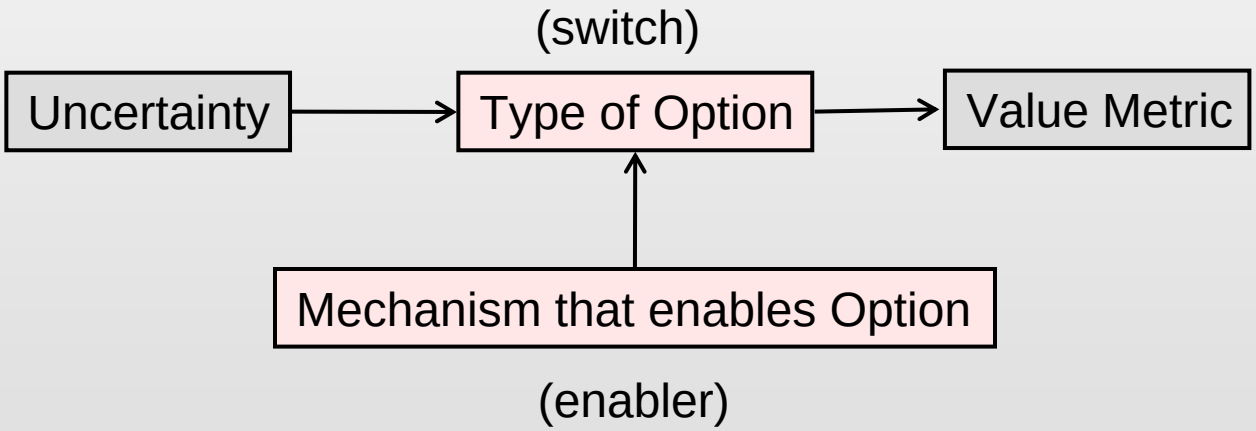
Patenting → License patent: to manage uncertainty in demand for technology

Managing Uncertainty with Options

Without option:

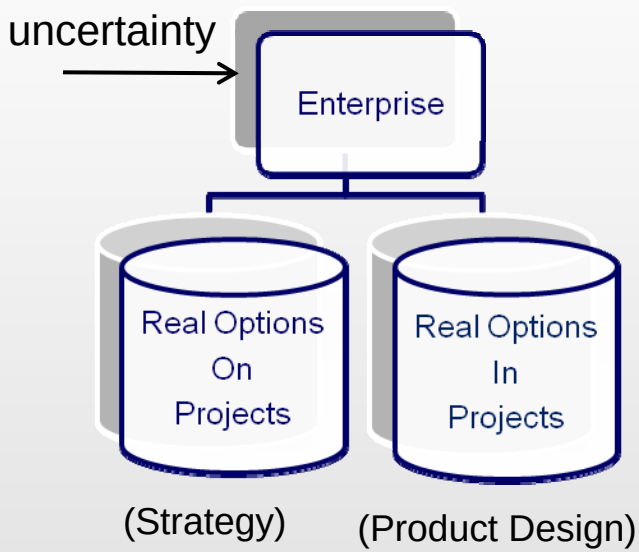


With option:



Integrating the Real Options Silos

Traditional View



Holistic View

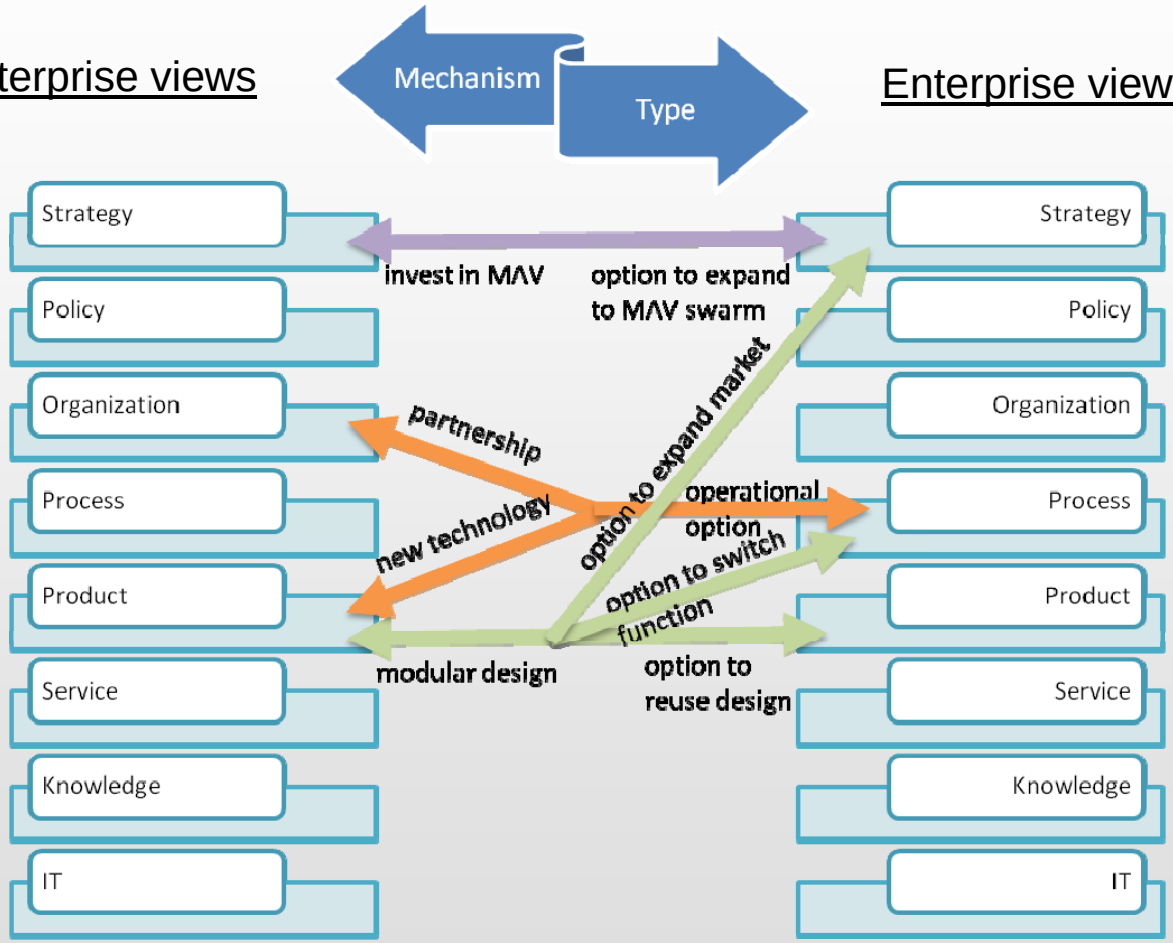
Real Option Mechanism	Real Option Type: In (Design)	Real Option Type: On (Strategy)
In (Design)	MAV design enables a reuse option in future design	MAV design enables future market expansion
On (Strategy)	MAV development partnership enables option to use new type of technology in design	Investment in MAV project enables option to expand development to swarm in future

MAV = Mini Air Vehicle

→ Explore interactions between "real option silos"

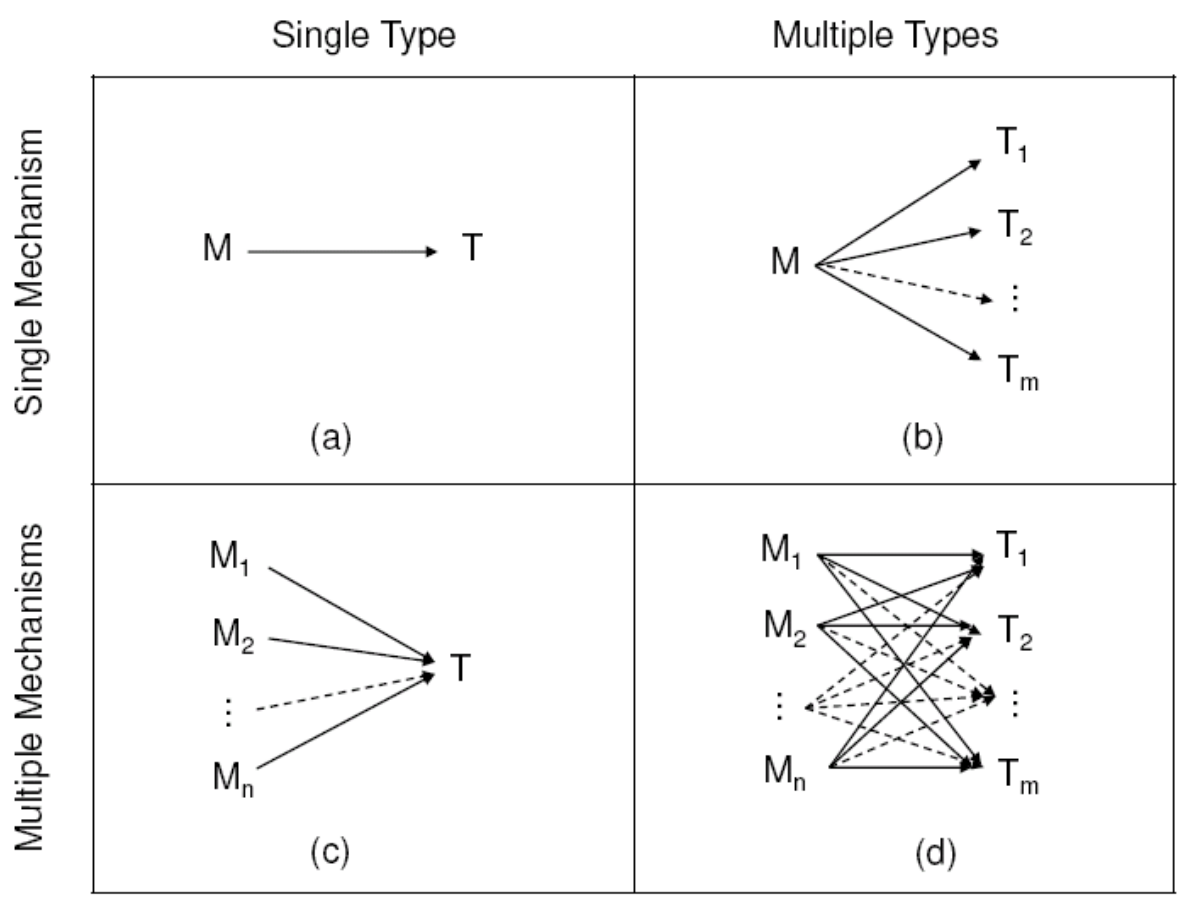
May "classify" the location of both the mechanism and type of real option

Mapping to Enterprise Views



→ Mechanisms, types may exist within any of the enterprise views

Relations among mechanisms and types of options



M = mechanism
T = type
V = enterprise view

$$M = \{M_i\}, i = 1..n$$

$$T = \{T_j\}, j = 1..m$$

$$(\forall M)(\forall n)(\forall i \in \{1..n\}) : (\exists V | M_i \in V)$$

$$(\forall T)(\forall m)(\forall j \in \{1..m\}) : (\exists V | T_j \in V)$$

Types of real options

Category	Description	Important in:
Option to Defer	Management has opportunity to wait to invest, and can see if markets warrant further investment.	Natural resources extraction, real estate, farming, technology.
Staged Investment	Staging investment creates the option to reevaluate and/or abandon at each stage.	R&D intensive industries, energy generation, start-up ventures.
Option to alter operating scale	If market conditions change, the firm can expand/contract or temporarily shut down.	Natural resources, fashion, real estate, consumer goods.
Option to abandon	If market conditions decline, management sells off assets	Capital-intensive industries, new product introductions in uncertain markets.
Option to switch	If prices or demand change, management can change product mix (product flexibility) or switch inputs (process flexibility)	Companies in volatile markets with shifting preferences, energy companies
Growth options	An early investment opens up future growth opportunities in the form of new products or processes, access to markets, or strengthening of core capabilities	High tech; industries with multiple product generations (drug companies, computers, strategic acquisitions).
Multiple Interacting Options	Projects involve a collection of various options—both put and call types. Values can differ from the sum of separate option values because they interact.	Many of the industries discussed above

(Fig. Source: D. Jenter)

Patterns of mechanisms

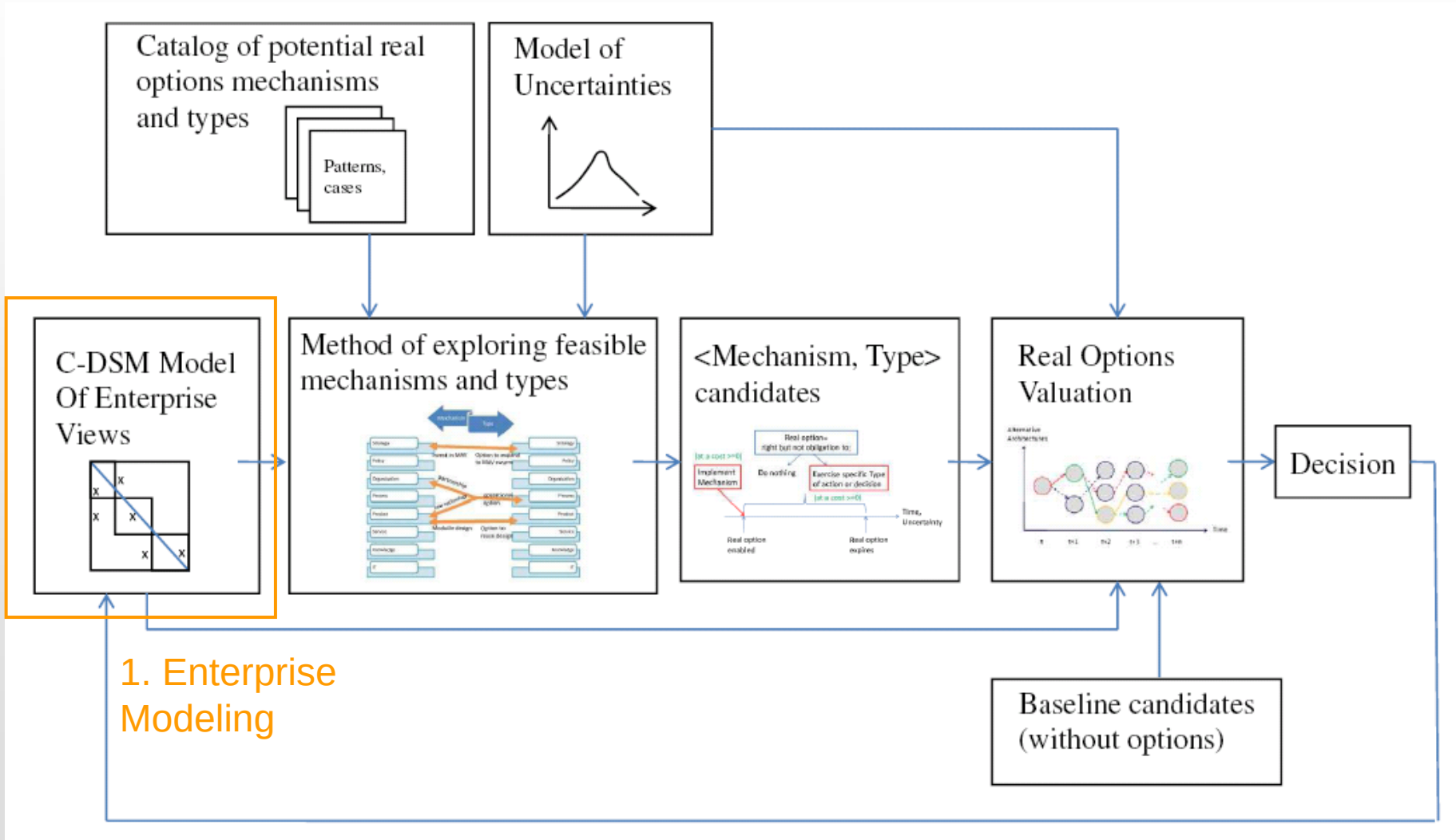
Some examples:

Mechanism Patterns	Instantiation Examples
Modularity	modular architecture (product)
	task clustering (process)
Redundancy	multi sourcing (strategy)
	spares (product)
Buffering	cross-training (knowledge)
	reserve funds (strategy)
Staging	R&D investment (strategy)
	staged deployment of satellites (process)

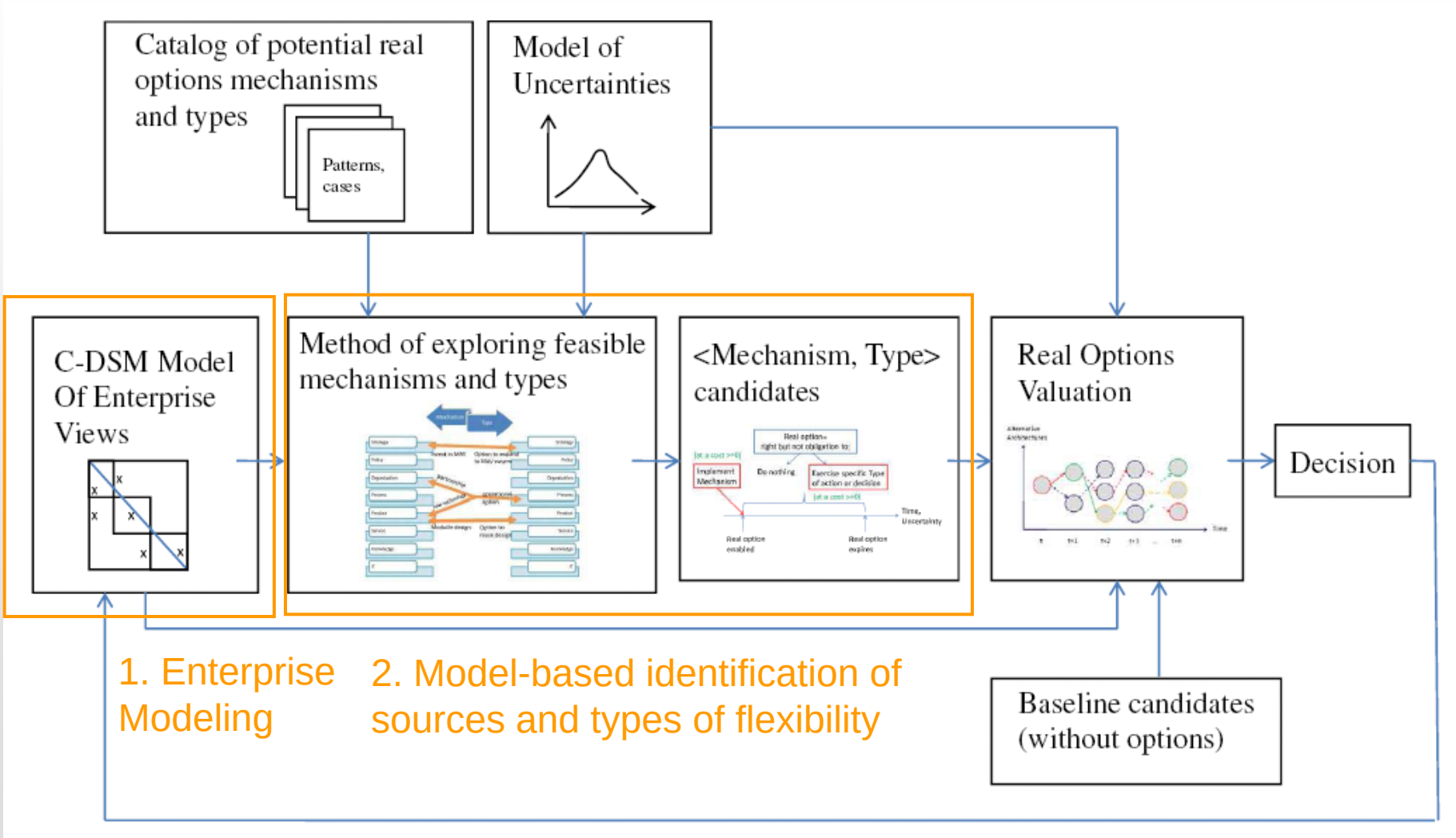
→ May be instantiated within one or more enterprise views

→ Support identification and creation of sources of flexibility

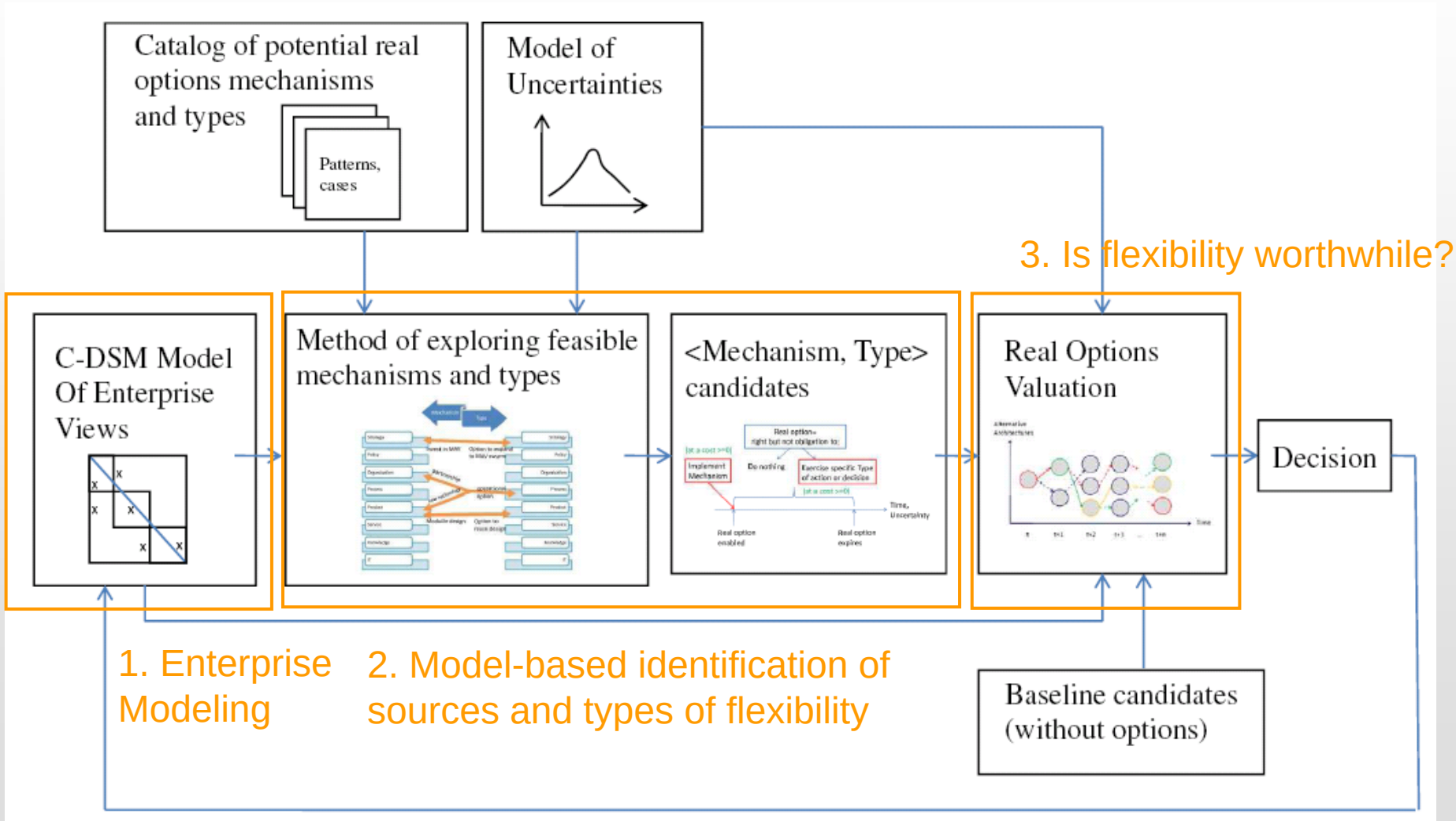
Integrated Real Options Framework



Integrated Real Options Framework

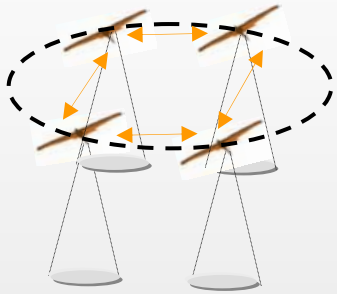
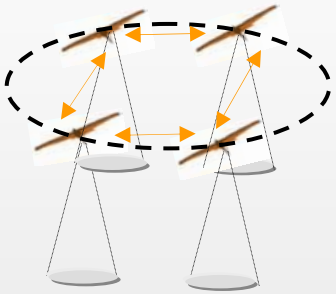
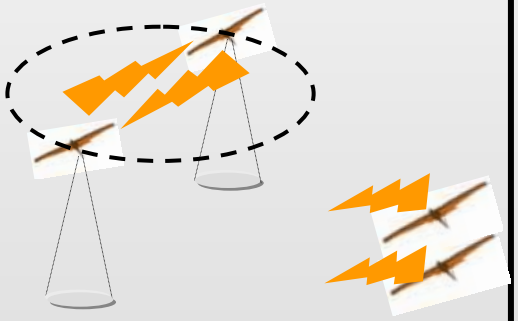
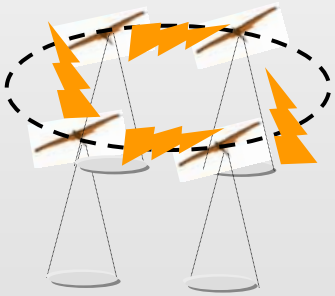
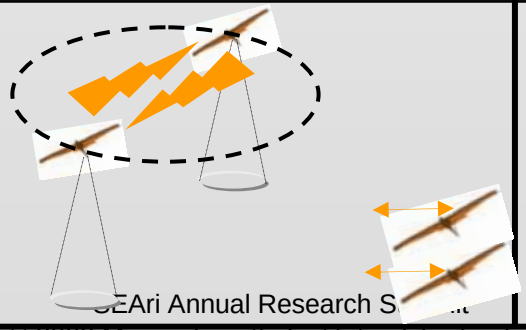
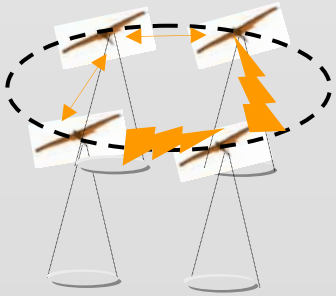


Integrated Real Options Framework



Deployment Scenarios

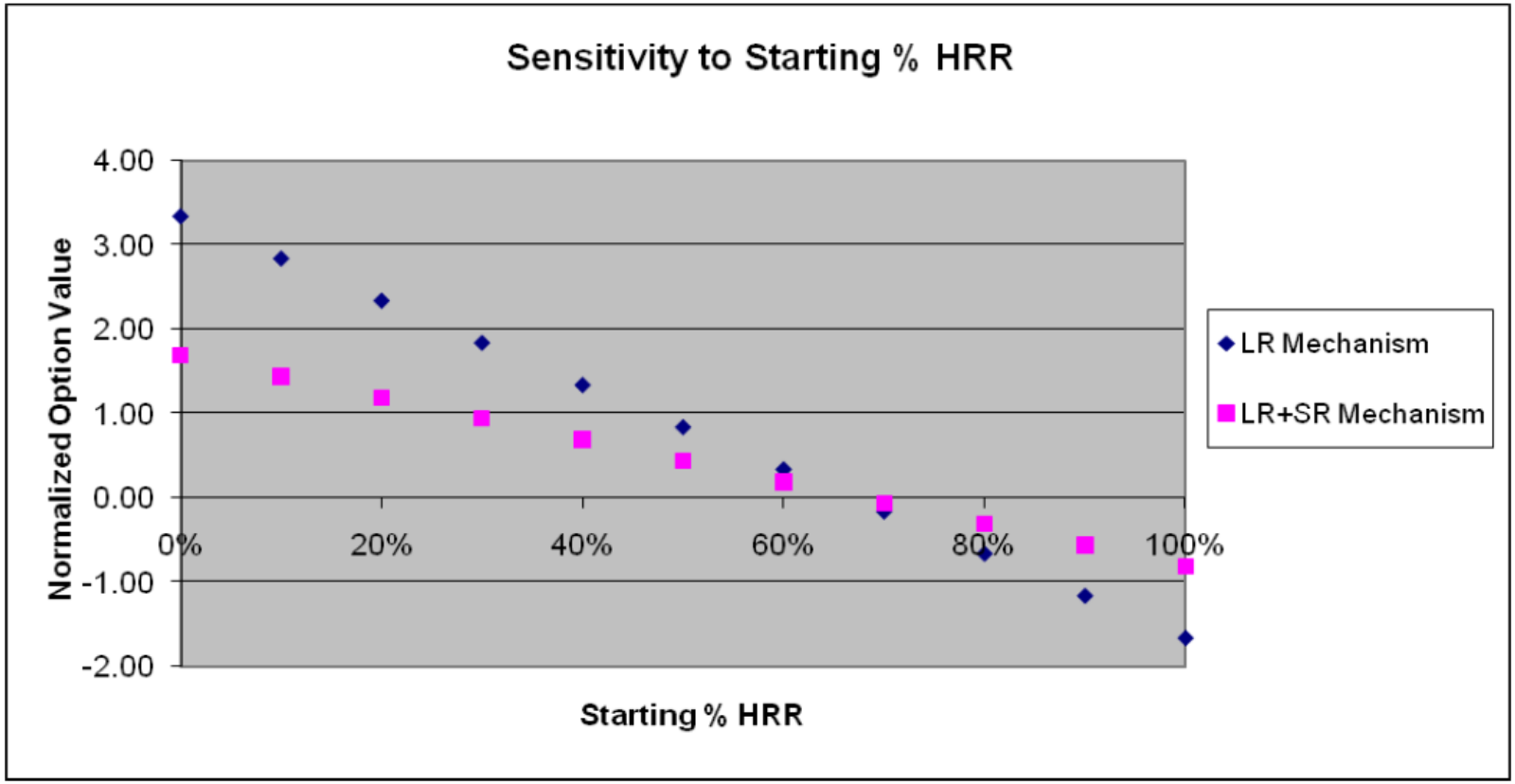
Short range comm.
Long range comm.

Swarm Configurations for LRR and HRR Missions		
Swarm	Low Revisit Rate	High Revisit Rate
Short range comm.		
Long range comm.		
Heterogeneous		

Mechanisms, types of options across enterprise views

	Mechanism that enables real option	Type of real option	
Strategy	**Acquisition of UAV Swarm (short range comm.)** **Acquisition of UAV Swarm (long range comm.)** **Acquisition of Heterogeneous UAV Swarm** **Acquisition of High Altitude UAV** **Acquisition of Satellites** **Acquisition of Spare Helicopters**		Strategy
Policy	**Regulations to integrate UAV operations into National Airspace**		Policy
Organization	**Create Satellite Operations Division** **Partner with peer organizations**	**Mobilize helicopter pilots**	Organization
Process	**Training of additional pilots**	**Deploy sparse swarm** **Deploy dense swarm** **Operate high altitude UAV**	Process
Product	**Develop UAV with adjustable range comm.**		Product
Service	**Subscribe to satellite imagery provider service**	**Request high rate satellite imagery** **Request low rate satellite imagery**	Service
Knowledge	**License patent for comm. system design**		Knowledge
IT/Resource	**IT system upgrade to acquire real time satellite imagery**		IT/Resource

Real Options Valuation



- Flexibility to change swarm density valuable when % high revisit rate missions is initially less than ~ 70%
- Heterogeneous swarm enables less valuable option than LR swarm in this case

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Conclusions

- The integrated real options framework enables holistic identification, synthesis and analysis of mechanisms and types of real options for uncertainty management in an enterprise
- <Mechanism, type> conceptualization should be adopted to emphasize sources of flexibility across the enterprise and support integration of real option silos
- Mapping of mechanisms, types of options and their relations to enterprise views is a generalized classification that encompasses many others and can promote systematic thinking about flexibility