



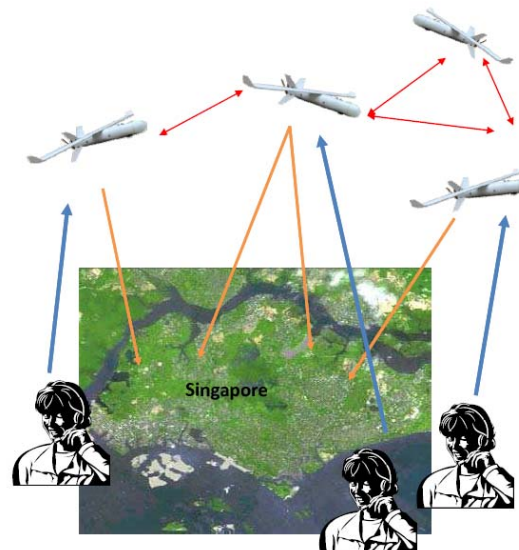
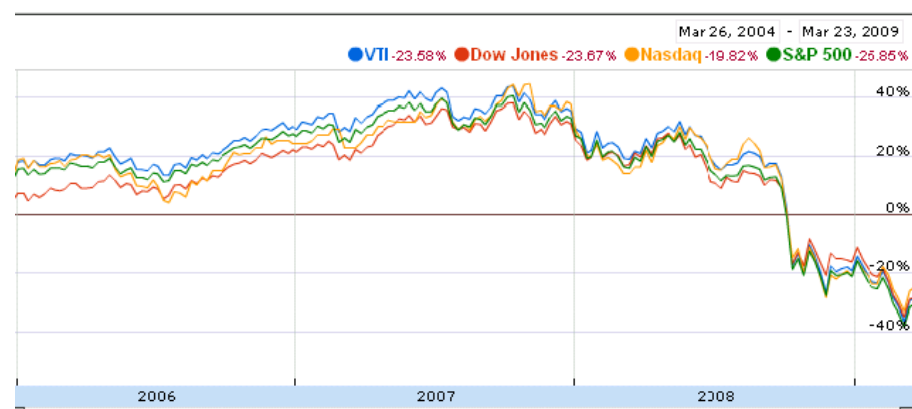
Systems Engineering Advancement Research Initiative

***Model-based Estimation of Flexibility and Optionability
in an Integrated Real Options Framework***

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Managing Uncertainties



Problem: How do we identify enablers and types of flexibility from a dependency model?

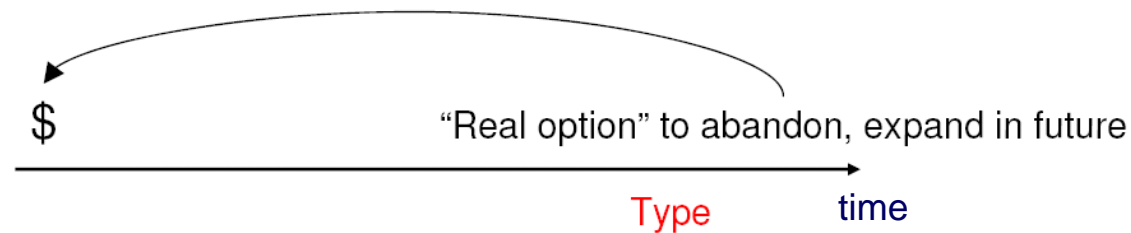
- Real Options
- Mechanisms and Types of Real Options
- Flexibility and Optionability
- Dependency Modeling of Enterprise
- Dependency Model-Based Estimation of Flexibility and Optionability
- Application to UAV swarm purchasing scenario

Background: Real Options

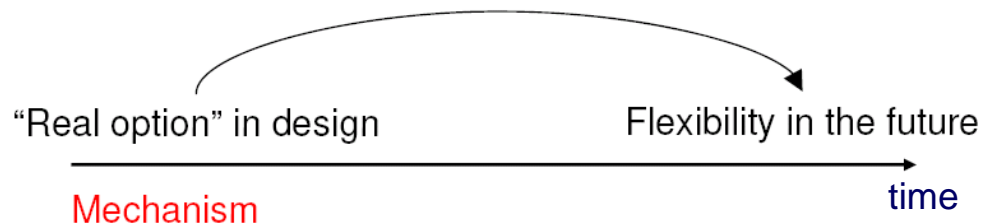
Real option: right, but not the obligation, to take an action in the future

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

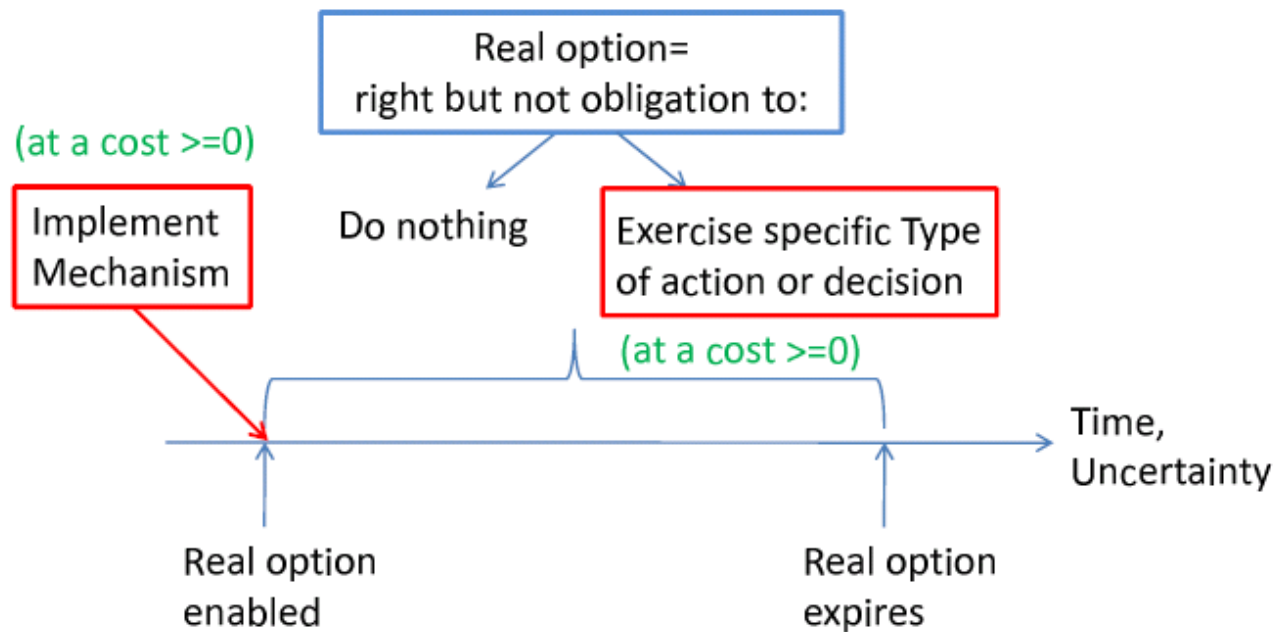
Classical ROA Application:



Application of ROA in design:



Real Options: Mechanisms and Types



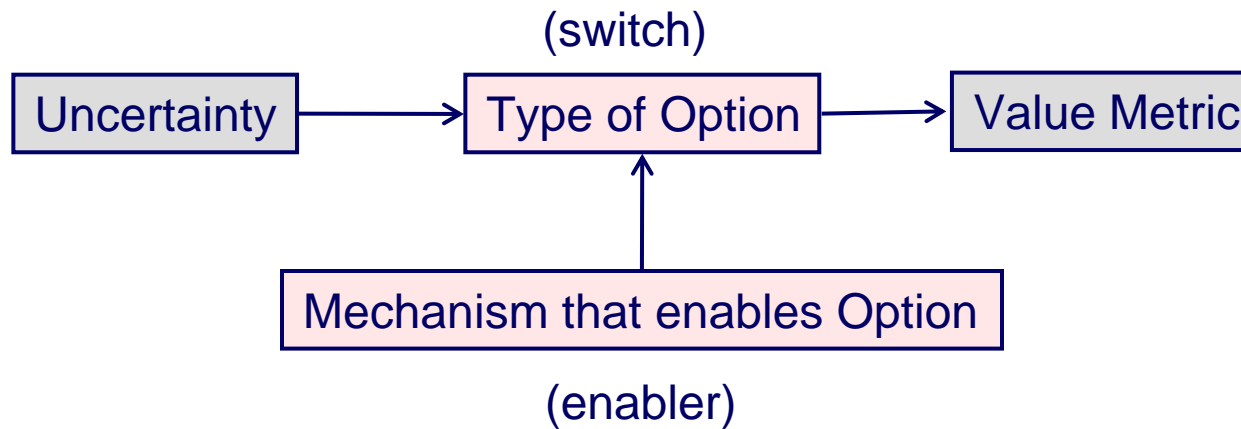
1. Real Option Mechanism:
actions/decisions that enable a real option
2. Real Option Type:
actions/decisions that may be exercised by the owner of the real option

Managing Uncertainty with Options

Without option:

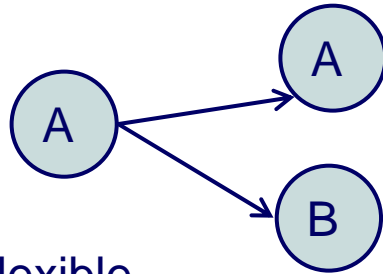


With option:

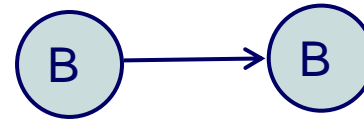


Flexibility vs Optionability

Flexibility

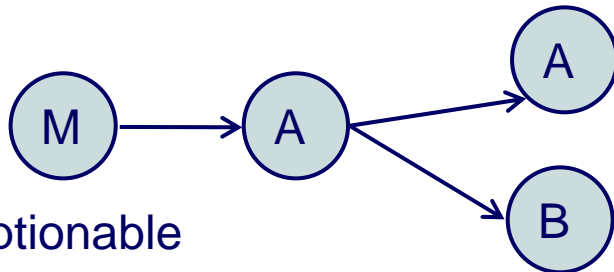


Flexible

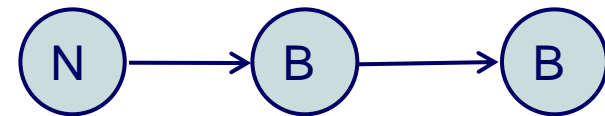


Not Flexible

Optionability



Optionable
(Embed a
Mechanism)



Not Optionable

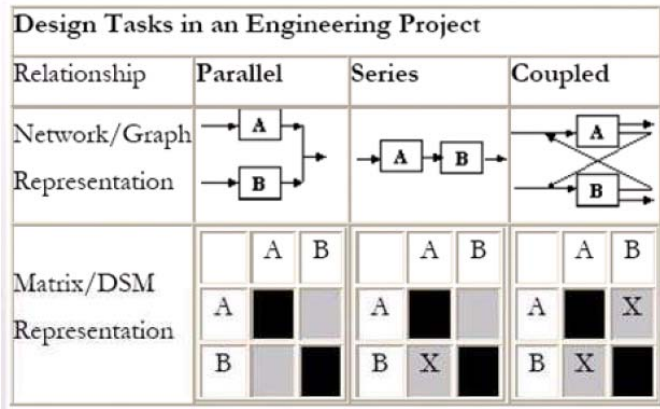
Identification of real options

1. Identification of types of options (flexibilities)
→ Metric for flexibility
2. Identification of mechanisms (enablers)
→ Metric for optionability

Note: Metrics based on a model

Enterprise C-DSM

Coupled Dependency Structure Matrix



Source: dsmweb.org

	Strategy	Policy	Organization	Process	Product	Service	Knowledge	IT/Resource
Strategy	■							
Policy		■						
Organization			■					
Process				■				
Product					■			
Service						■		
Knowledge							■	
IT/Resource								■

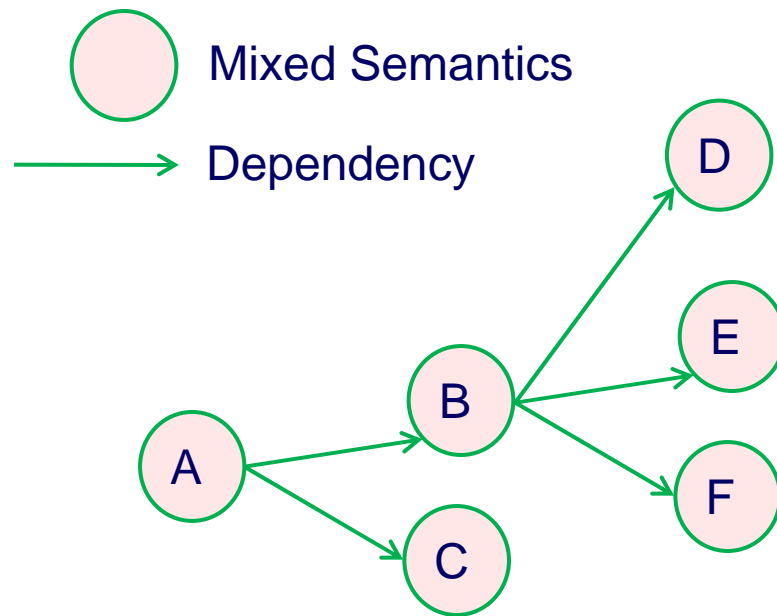
→ Why use a dependency model?

Question

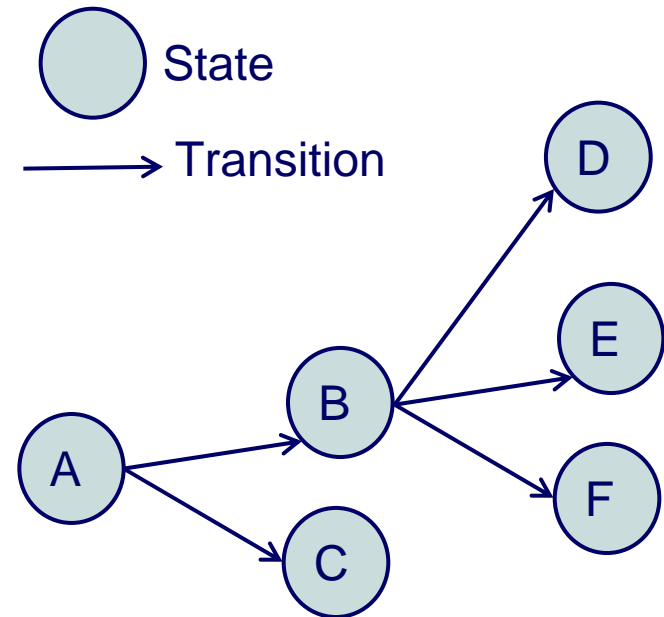
- Question: How do we estimate flexibility and optionability from a dependency model (C-DSM)?
- Why address this question?
 - Want to use enterprise C-DSM to identify types of real options (flexibility) and mechanisms of real options (optionability)

Semantics of the Model

- Question: How can we devise a flexibility metric for dependency model?



C-DSM = Dependency Network



State Machine Model

versus

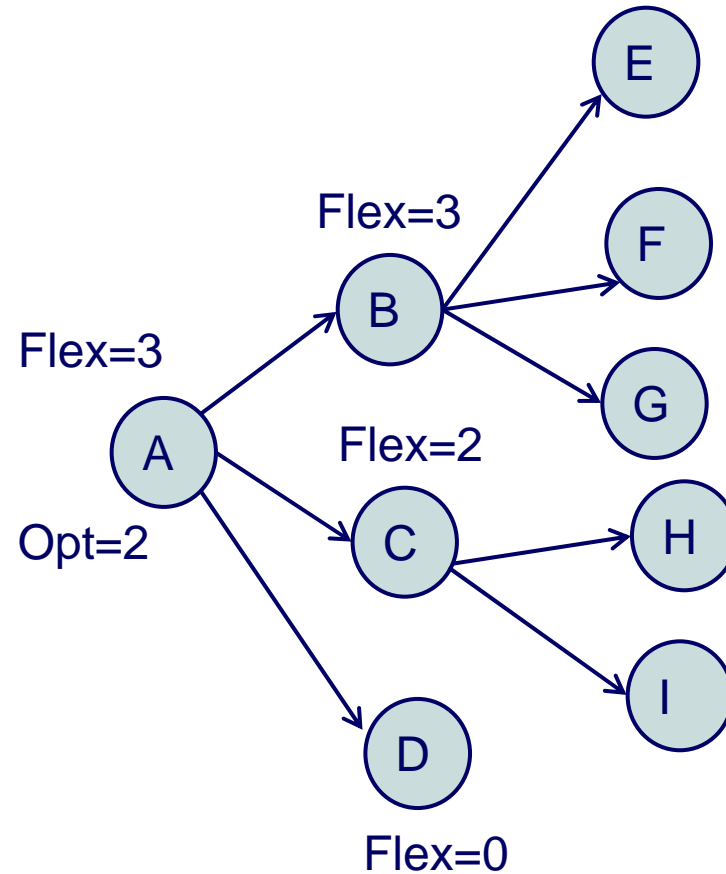
Example of Metrics for State Machine

Flexibility metric:

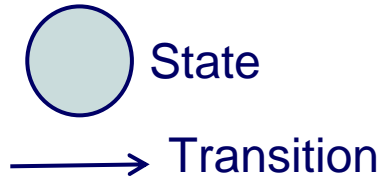
Number of outgoing edges from a node

Optionability metric:

Number of outgoing edges that lead to nodes with Flex > 1

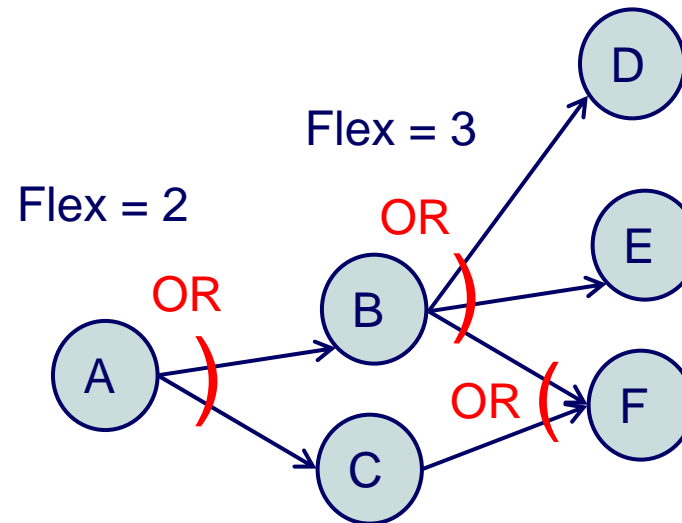


Closer Look at State Machine (assuming mutually exclusive states)



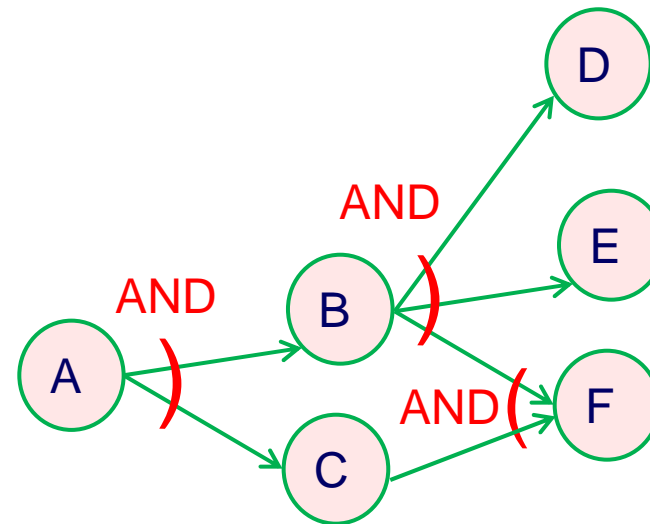
Transition model:
Logical OR Relationship
(Choice)

Flexibility indicator:
Number of OR transitions



State Machine

Closer Look at Dependency Model

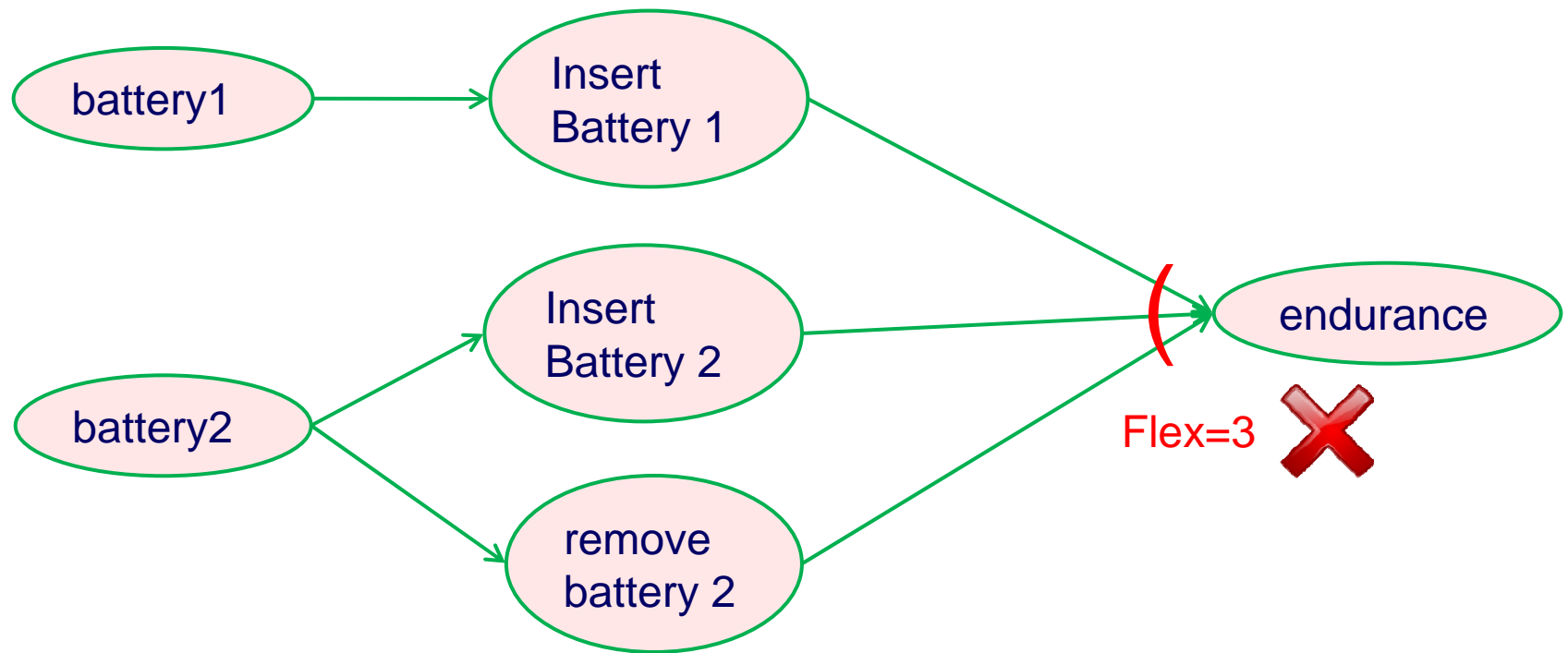


Dependency model:
Logical AND Relationship

Flexibility indicator: 
Number of AND transitions

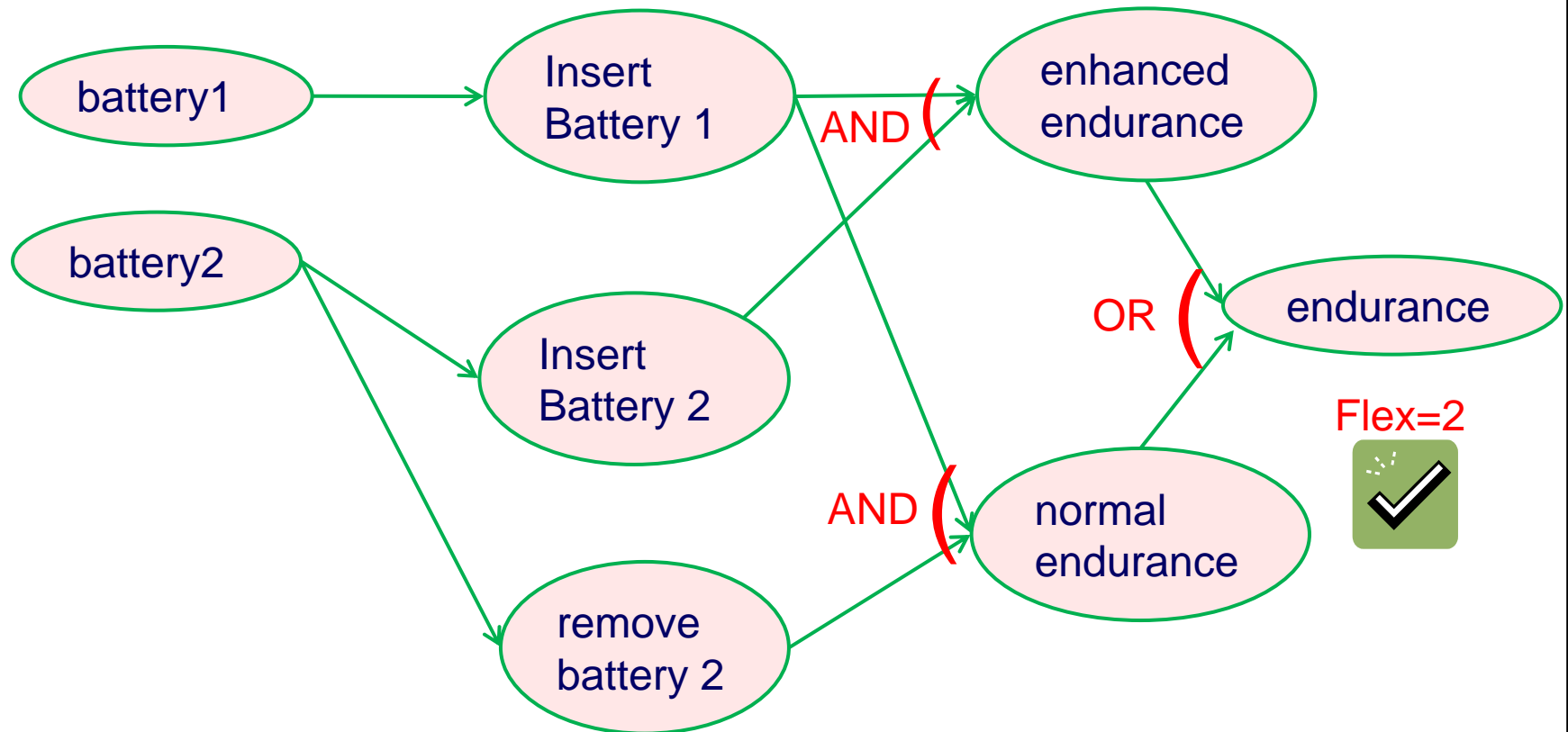
Because A is going to affect BOTH B AND C, can't choose whether to impact B OR C => NOT FLEXIBLE!

Example



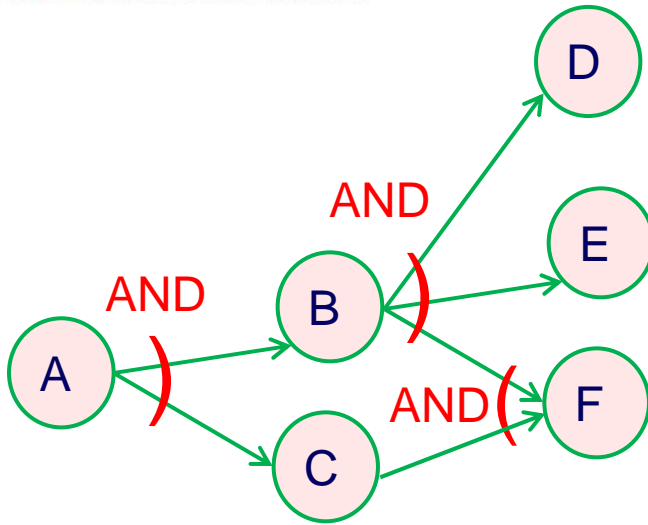
Dependency model is an AND relationship:
“Insert Battery 1”, “Insert Battery 2” and
“Remove battery 2” all affect the
endurance metric

Need to Isolate OR's

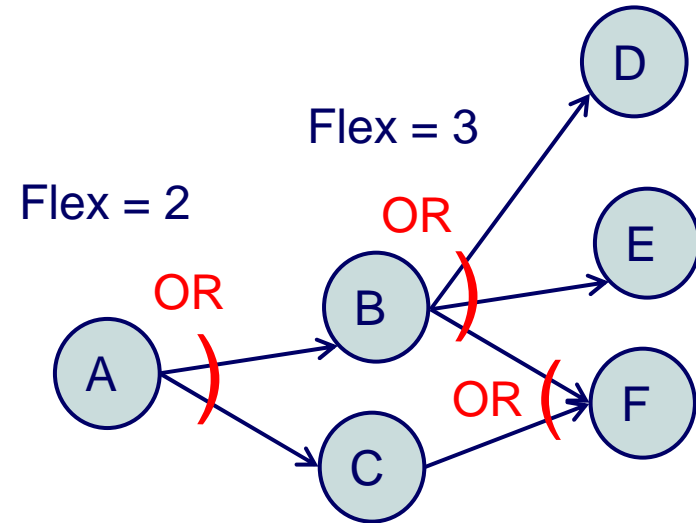


- No flexibility in achieving enhanced endurance
- No flexibility in achieving normal endurance
- Flexibility of achieving the endurance objective: estimate based on OR relationship

Summary



C-DSM = Dependency Network



State Machine

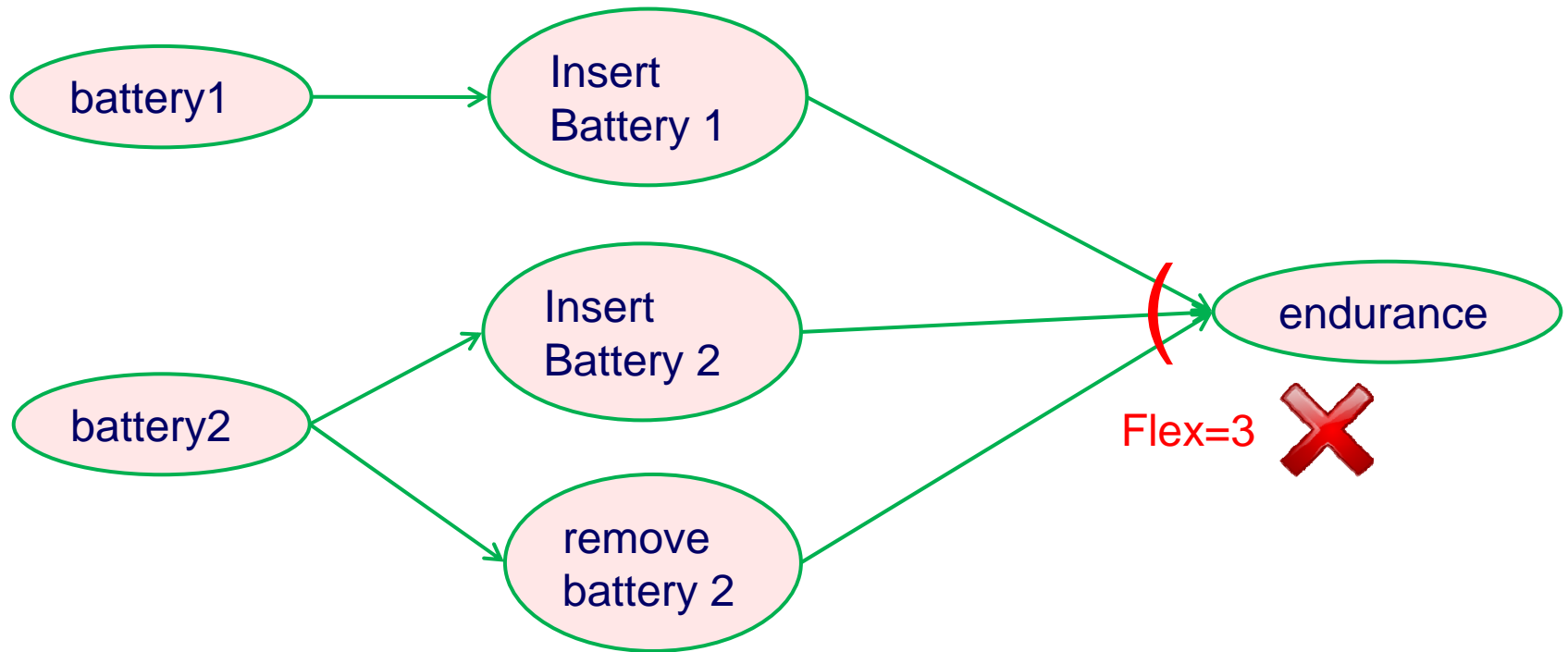
versus

- Dependency model does not distinguish AND's and OR's
- Flexibility metric evaluation based on OR's



Need to Isolate AND's and OR's in dependency model!

Augmenting Dependency Model with Logical Dependency Structure



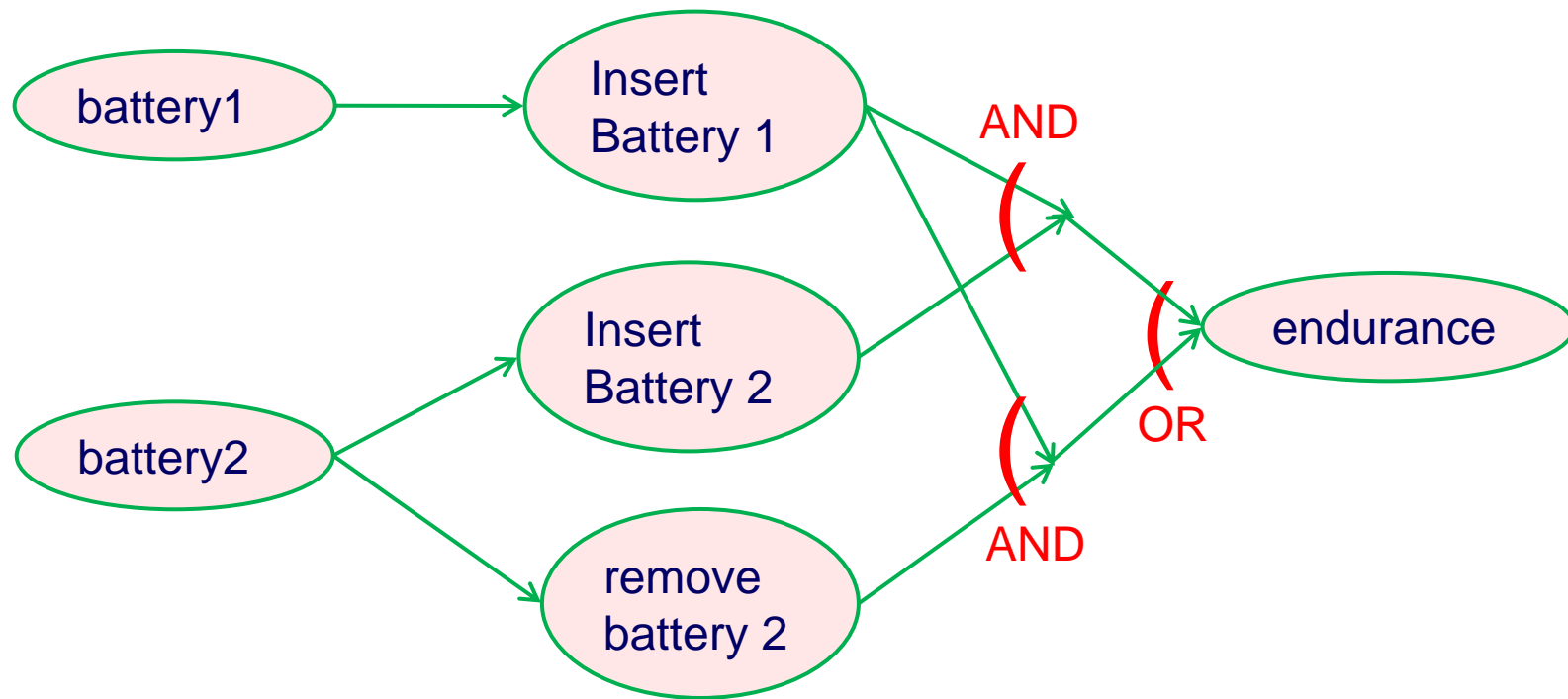
(Insert Battery 1)

AND

[(Insert Battery 2) OR (remove Battery 2)]

Logical dependency structure

DNF for Isolating OR's



Disjunctive Normal Form (DNF)

A logical formula consisting of disjunction of conjunctions where no conjunction contains a disjunction.

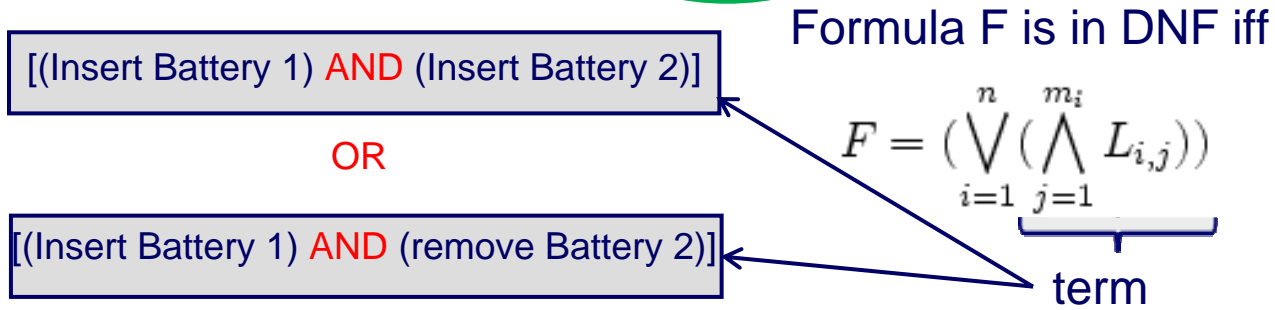
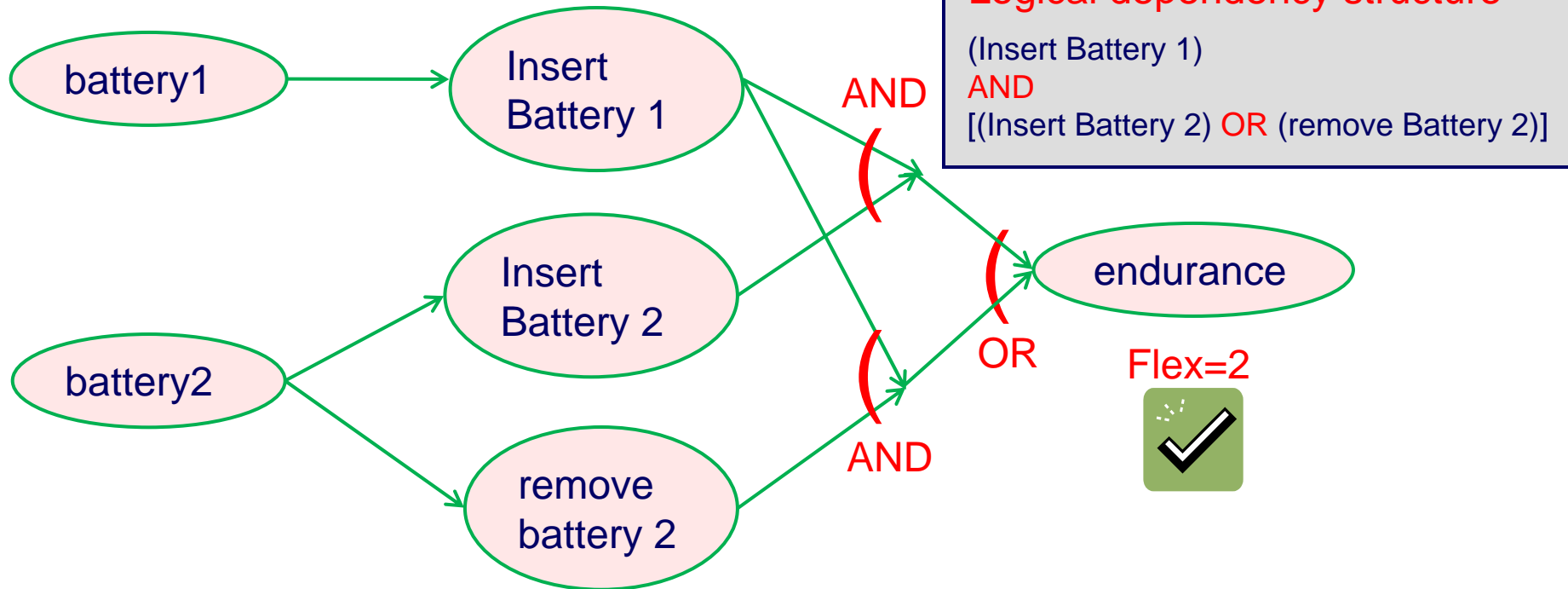
(Source: online dictionary of computing)

Formula F is in DNF iff

$$F = \left(\bigvee_{i=1}^n \left(\bigwedge_{j=1}^{m_i} L_{i,j} \right) \right)$$

where $L_{i,j}$ is a literal

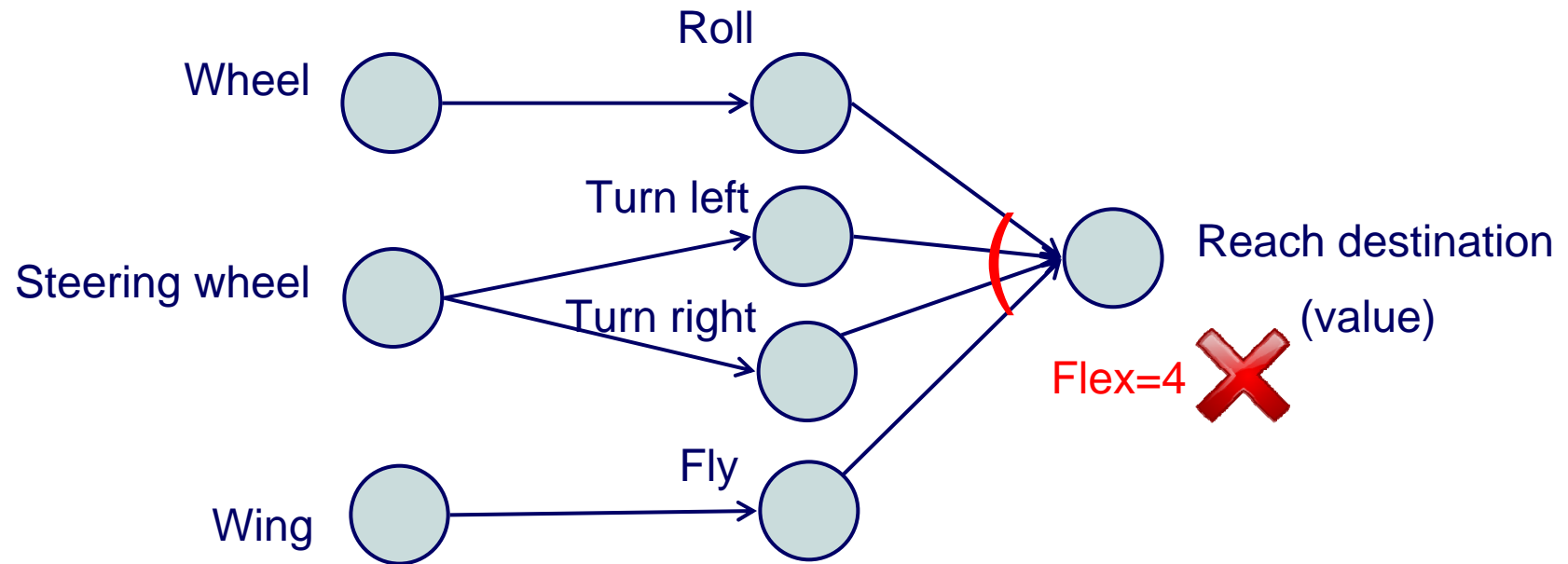
Flexibility Metric for a Dependency Model



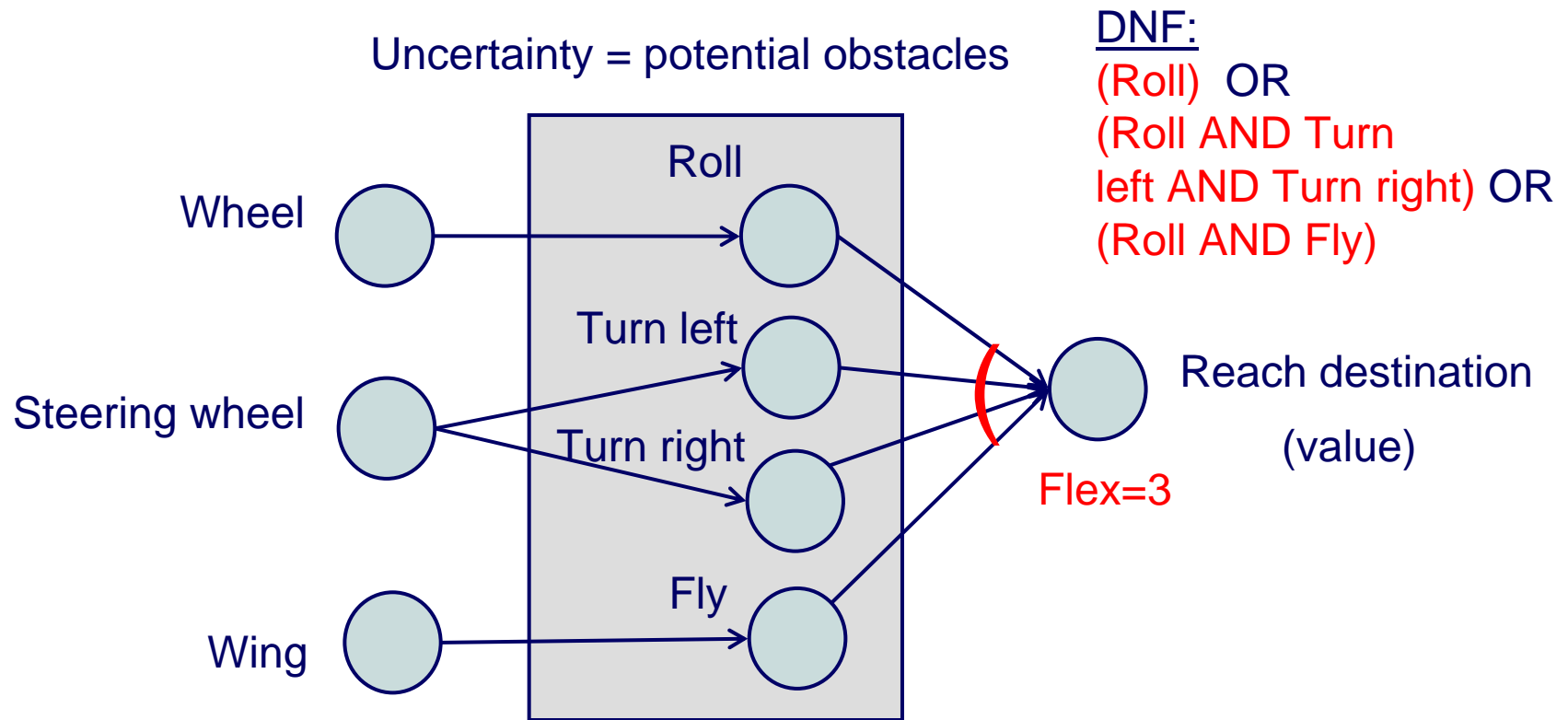
Flex metric =
 number of terms in
 disjunctive normal
 form

Another Example

Uncertainty = potential obstacles



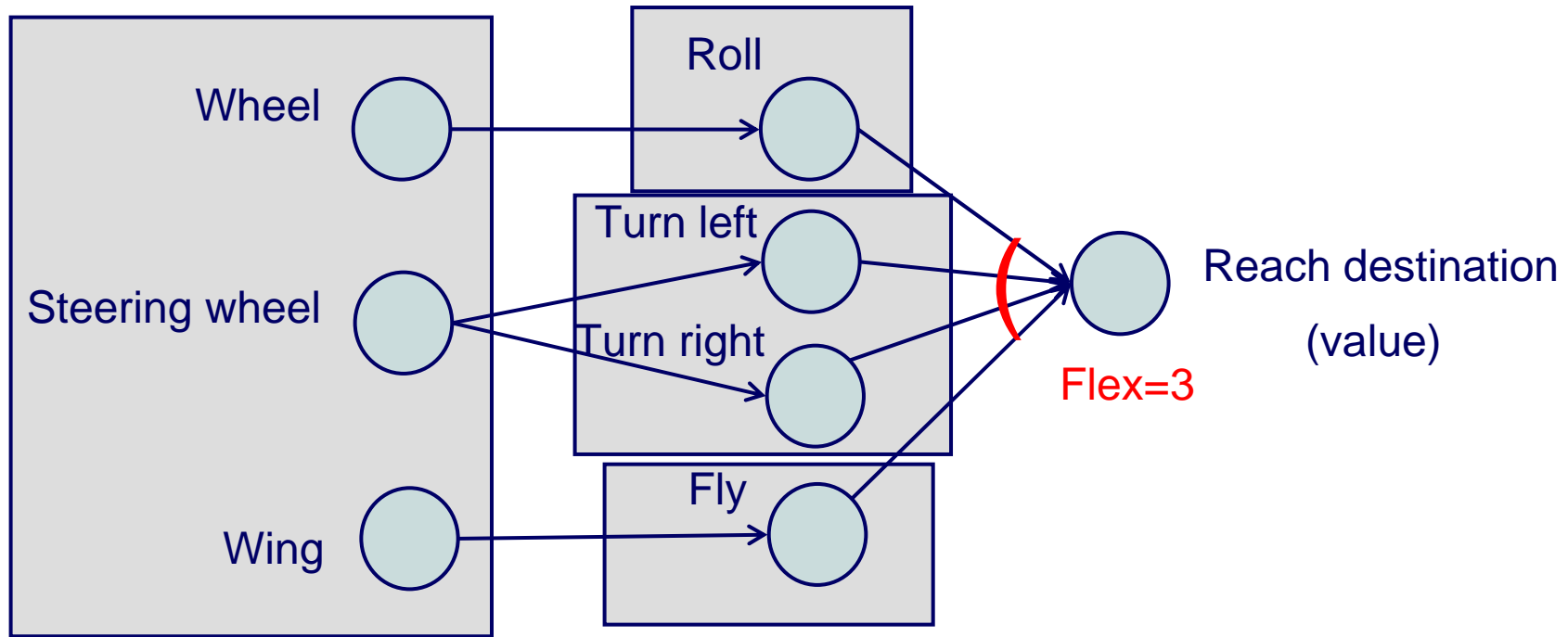
Types of Options



Types of Options
= represented by nodes that
participate in the DNF of
a successor node with
Flex > 1

Optionability Metric

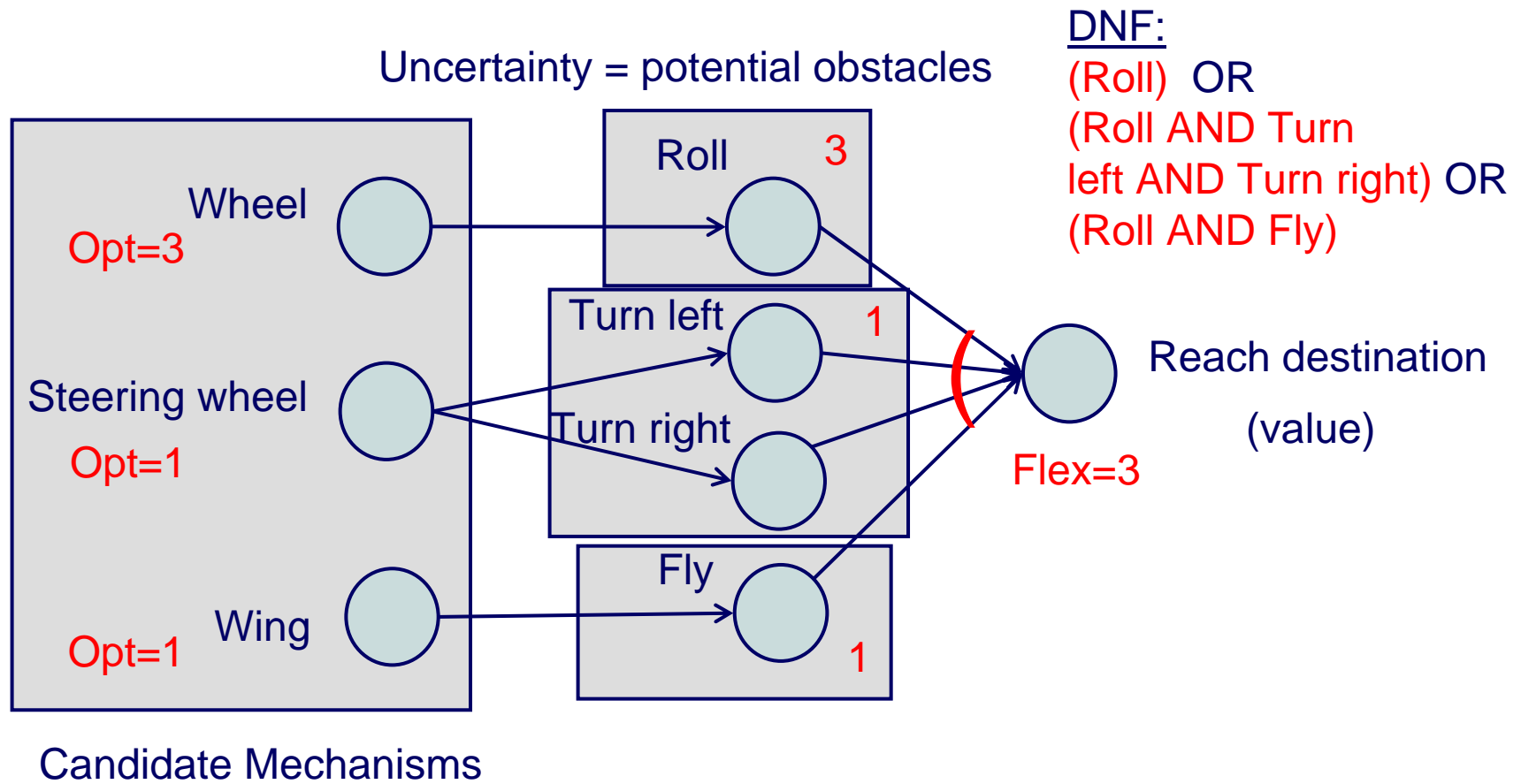
Uncertainty = potential obstacles



Candidate mechanisms

1. Group outgoing edges and target nodes from each mechanism being considered into a set S.

Optionability Metric



DNF:

(Roll) OR
 (Roll AND Turn
 left AND Turn right) OR
 (Roll AND Fly)

Optionability metric (for mechanism M) = number of DNF terms that contain elements of the set S (literals), where the set S is dependent on the mechanism M.

Application to Purchasing UAV Swarm

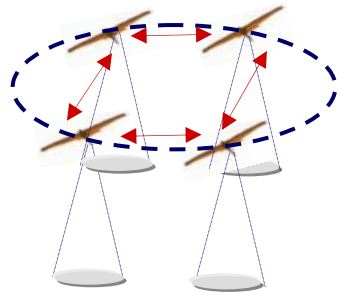
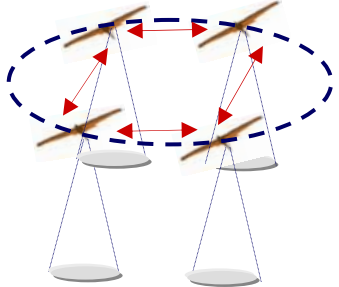
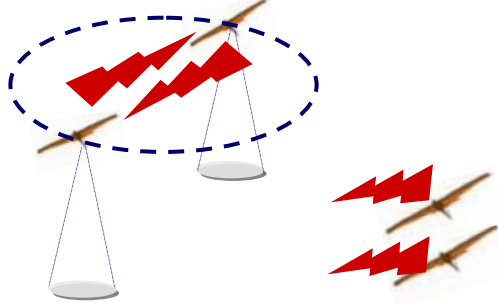
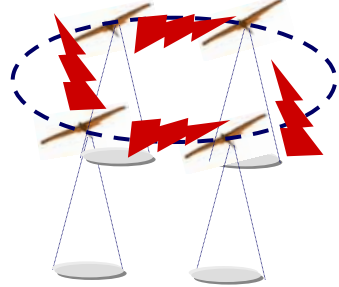
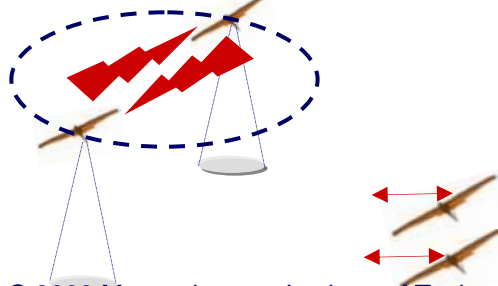
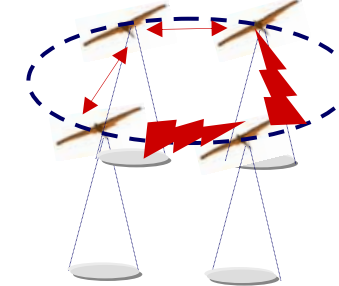
Mechanisms

Nodes in logical C-DSM	Ility Metrics		
	<i>Flexibility</i>	<i>Optionability</i>	<i>Realizability</i>
Purchase UAVs with long range comm. sys.	--	2	--
Purchase UAVs with short range comm. sys.	--	1	--
Purchase heterogeneous UAVs (half with long range comm. sys.)	--	2	--
Deploy dense swarm	--	--	3
Deploy sparse swarm	--	--	2
Maintain comm. link and surveillance at an uncertain revisit rate	2	--	--

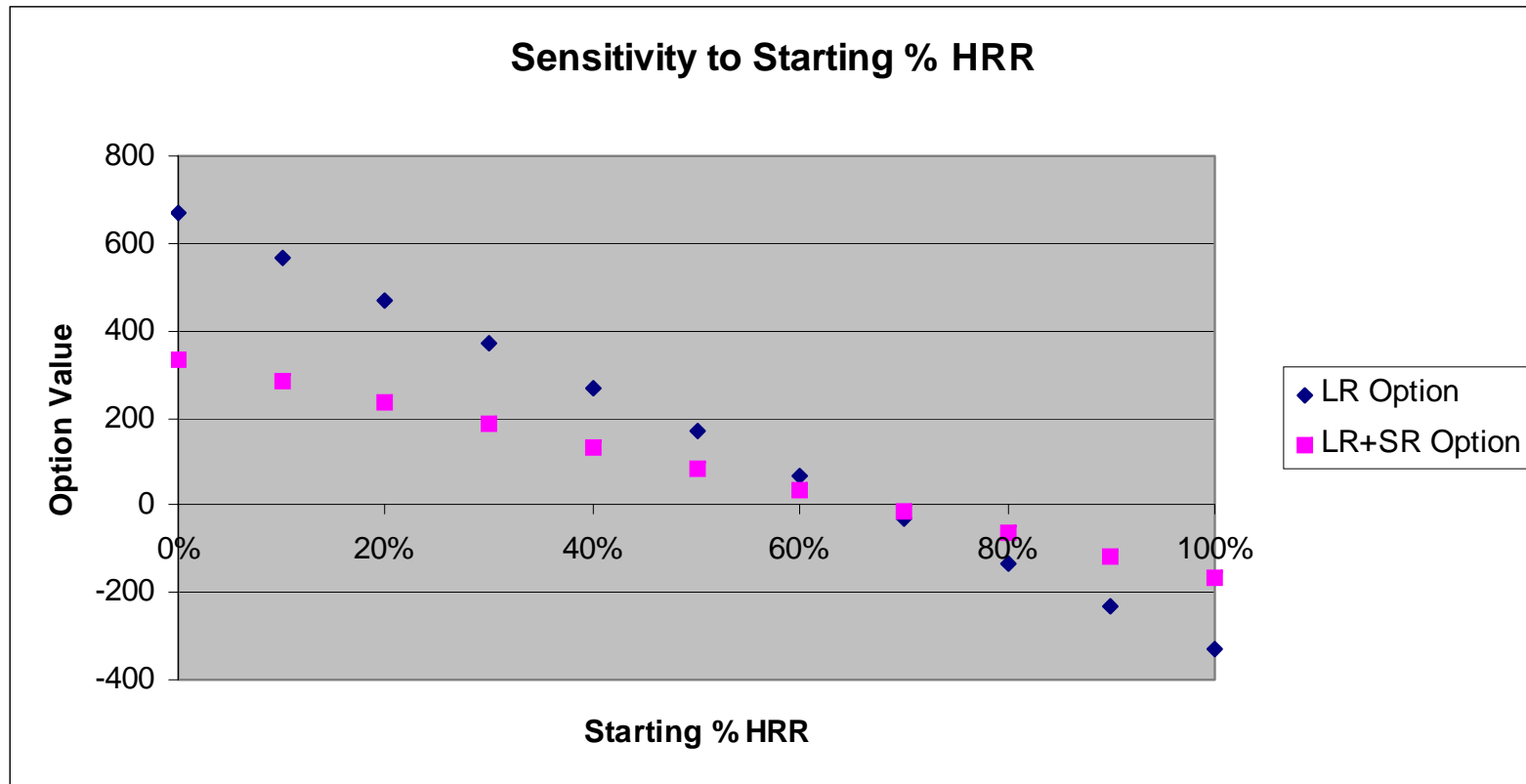
Objective →
Affected by
Uncertainty

-- indicates that metric is not calculated.

Deployment Scenarios

Swarm Configurations for LRR and HRR Missions		
Swarm	Low Revisit Rate	High Revisit Rate
Short range comm. Not optionable		
Long range comm.		
Heterogeneous		

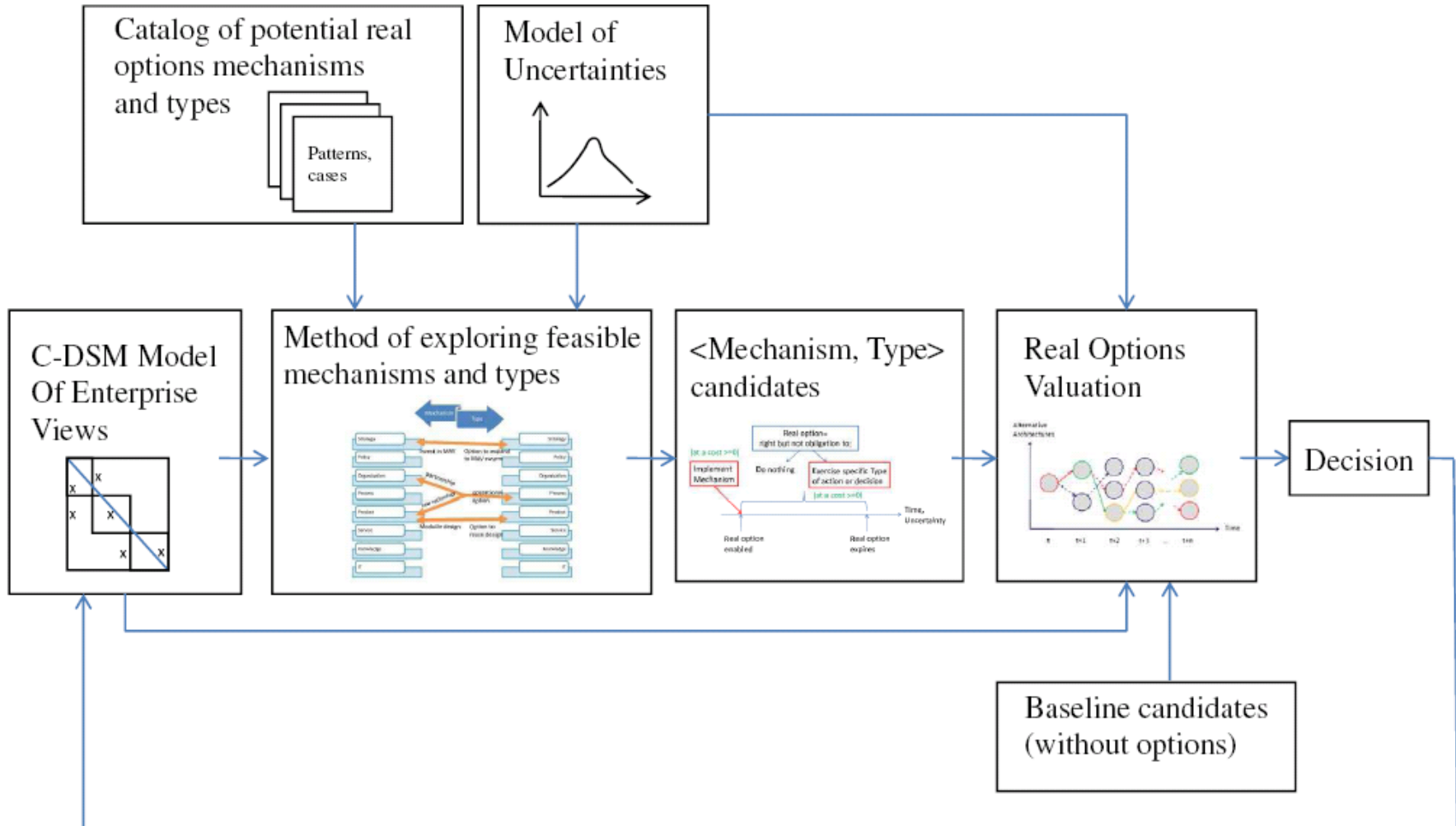
Valuation: Real Options Analysis



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

The Framework

Holistic identification of real options mechanisms and types that encompass all views of an enterprise



Conclusion

- C-DSM models dependencies
 - semantics not compatible with options modeling
 - logical dependency structure modeling offers a solution
- Flexibility:
 - need to isolate OR's to identify options;
 - metric defined as number of terms in DNF
- Optionability:
 - indicates number of options enabled by implementation of a mechanism.
- Realizability:
 - indicates number of different ways to enable an option
- How metrics are used:
 - in a procedure for identifying potential mechanisms and types of options to address uncertainties based on C-DSM data
 - holistic approach to identifying mechanisms and types in enterprise