Effects-Based Design of Robust Organizations

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Outline

- Introduction
- Modeling Mission Environment
- Markov Decision Processes for Mission Environment
- Monte Carlo Control Method
- Robust Organization Design
- Summary and Future Work

(Monte Carlo Control Method and Robust Organization Design: Illustrative Example)

Design Problem

Effects-Based Design of Robust Organizations

Objective:

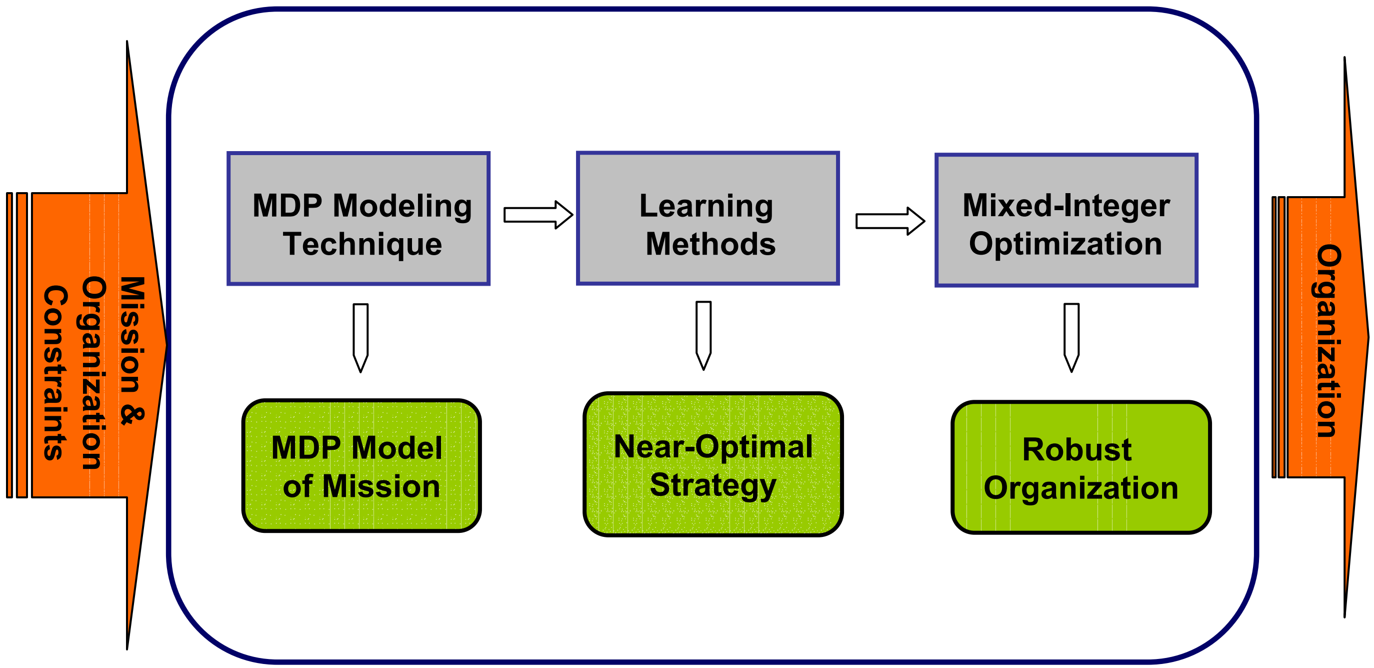
Design robust organizational structures and strategies to account for a *dynamically changing mission environment*

Methodology:

- **Mission Model**: Finite-state Markov Decision Process
- **Methods**:
  - Robust strategies
    - Monte Carlo Control Methods
  - Robust structures
    - Mixed Integer Nonlinear Programming

Design Methodology

Robust Organization Design Methodology:



Modeling Mission Environment 1/3

Characteristics of *dynamic* and *stochastic* environments:

- Parts of the environment *cannot be controlled* directly
- Various *exogenous events* may impact the environment
- Consequences of actions *cannot be predicted* a priori with certainty

Reqs. for organizations coping with stochastic environments:

- Plan for potential contingencies
- Maintain ***Congruent*** with the dynamic mission environment
- Be ***Robust***

Modeling Mission Environment 2/3

Dynamic Stochastic Mission Environment:

- **Effects:** the desired effects, with some serving as the end goals
- **Exogenous events:** uncontrollable random events
- **Actions**: controllable influences to achieve the desired effects, and minimize the adverse effects of exogenous events

Organization:

A team of Decision Makers (DM)

- Human or automated system
- Limited resource handling capability (workload threshold)

Modeling Mission Environment 3/3

Command Control Mission Environment and Organization

Task:

- Resource Requirement Vector: $[R_{i1}, R_{i2}, \ldots, R_{iL}]$

Mission Tasks → Effects

Time critical tasks
"Mosquito" tasks → Exogenous Events

Platform (Asset):

- Resource Capability Vector: $[r_{m1}, r_{m2}, \ldots, r_{mL}]$

Asset-Task Allocation → Actions

Organization:

- Ownership of Platforms

MDP for C2 Mission Environment

Markov Decision Process for C2 Mission Environment

States: $S = \{s_1, s_2, \ldots, s_z\}$

- **Status of effects and exogenous events:**

$$s_i = (M_i, E_i) \quad \begin{cases} M_i \subseteq M & \text{Achieved effects} \\ E_i \subseteq E & \text{Unmitigated exogenous events} \end{cases}$$

Actions: $A = \{a_1, a_2, \ldots, a_k\}$, Platform to task allocation

Transition Probability Matrix: $\wp^a_{ss'} = pr(s_{t+1} = s' \mid s_t = s, a_t = a\}$

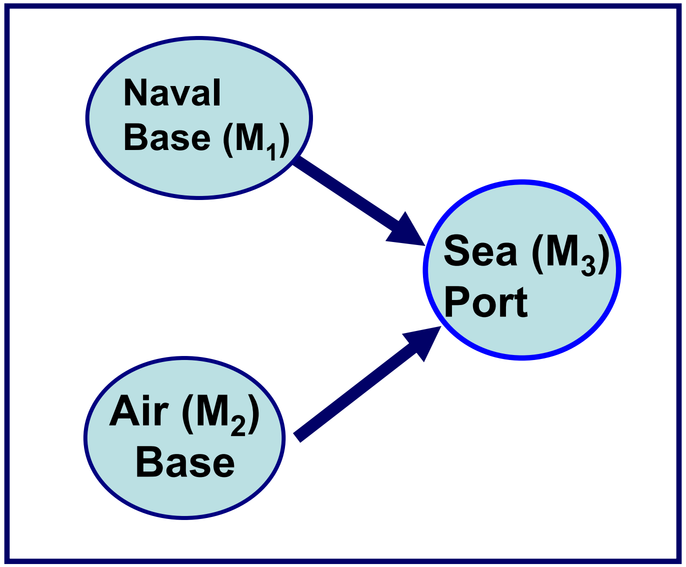
Reward Mechanism:

- **Reward:** ***desired*** end effect is reached $r(s_e) > 0$
- **Penalty:** ***undesirable*** end effects are reached $r(s_h) < 0$
- **Cost :** action is pursued $C(a_i) > 0$

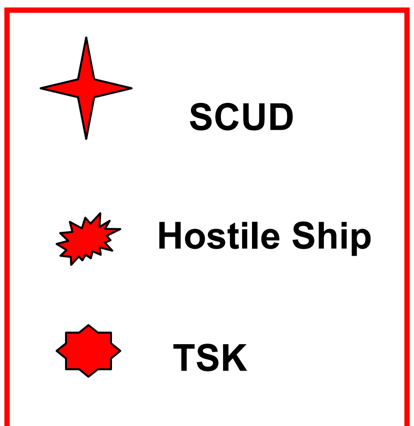
Optimal Action Strategy:

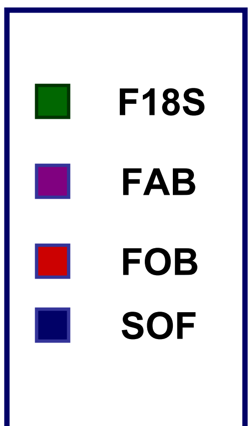
- **Mapping from *states* to *actions*, maximizing the expected *net reward***

Illustrative Example



Platform	Name	Number	ASUW	STK	SOF	Cost
P_1	F18S	3	0	2	0	100
P_2	FAB	5	1	0	0	80
P_3	FOB	3	1	1	1	160
P_4	SOF	2	0	0	1	60
Reward (Win)			5000			
Penalty (Lose)			-3000			





Task	Name	ASUW	STK	SOF
M_1	Naval Base	2	0	2
M_2	Air Base	0	6	0
M_3	Sea Port (final)	2	2	0
T_1	SCUD – missile	1	1	0
T_2	Hostile ship	1	0	1
T_3	TSK –complex group task	0	1	1

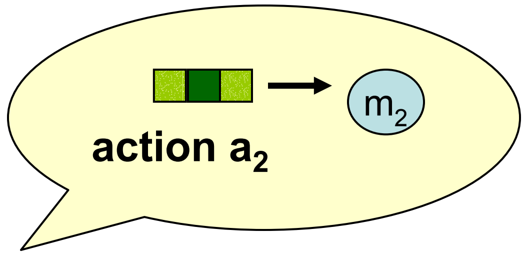
Monte Carlo Control Method – 1/4

Objective: Learn Optimal Action Strategy

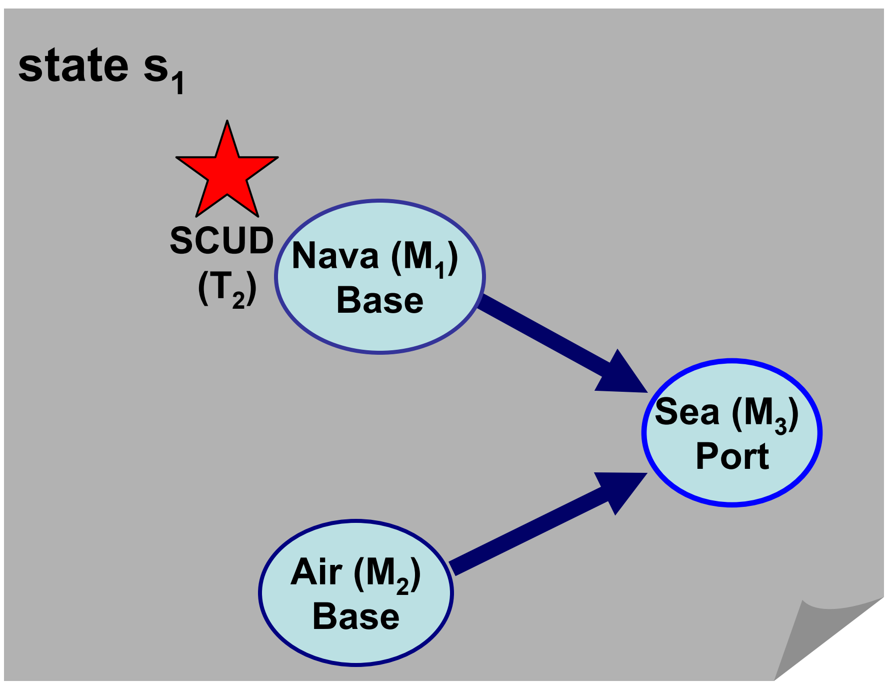
- Mapping from *states* to *actions*, maximizing the expected *net reward*

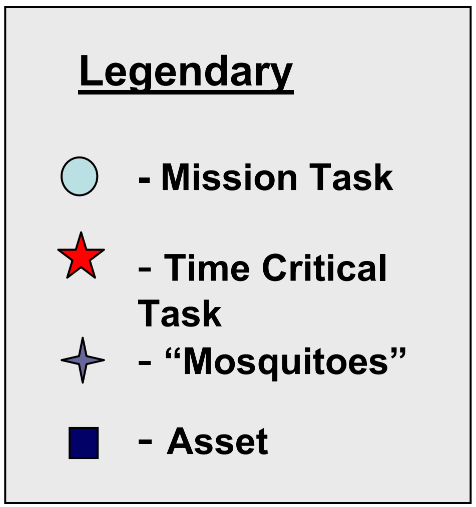
Epsilon-greedy method: Selects best action with probability of 1 - ε

- Avoiding local minimum



State	Action	S-A Value
—	—	—
$S_1(T_2)$	a_1(<2P2+2P4> →m1)	1560
	a_2 (<3P1> →m2)	**2000**
—	a_3 (<P3> →T2)	1320
	—	—

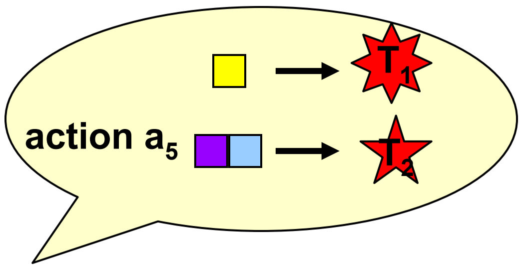




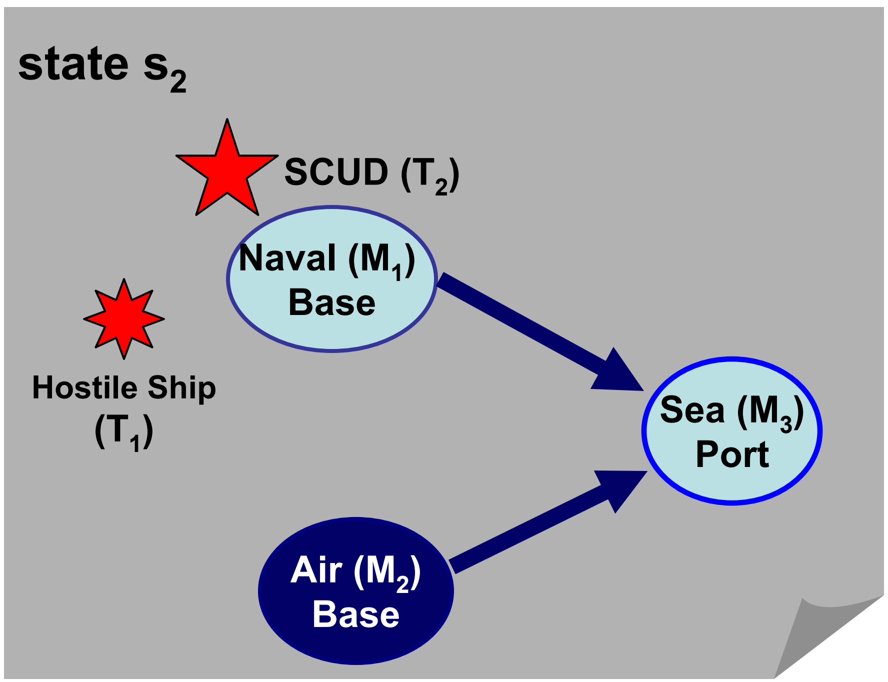
Exploration method for finding a start state:

Episode starts from a randomly selected initial state

Monte Carlo Control Method – 2/4



State	Action	S-A Value
—	—	—
$S_2(M_2,T_2)$	$a_1(<2P_2+2P_4> \rightarrow m_1)$	1200
	$a_3\,(<P_3> \rightarrow T_2)$	700
	$a_4(<P_2+P_4> \rightarrow T_1)$	1020
	$a_5(<P_3> \rightarrow T_1, <P_2+P_4> \rightarrow T_2)$	**1400**
—	—	—



Legendary

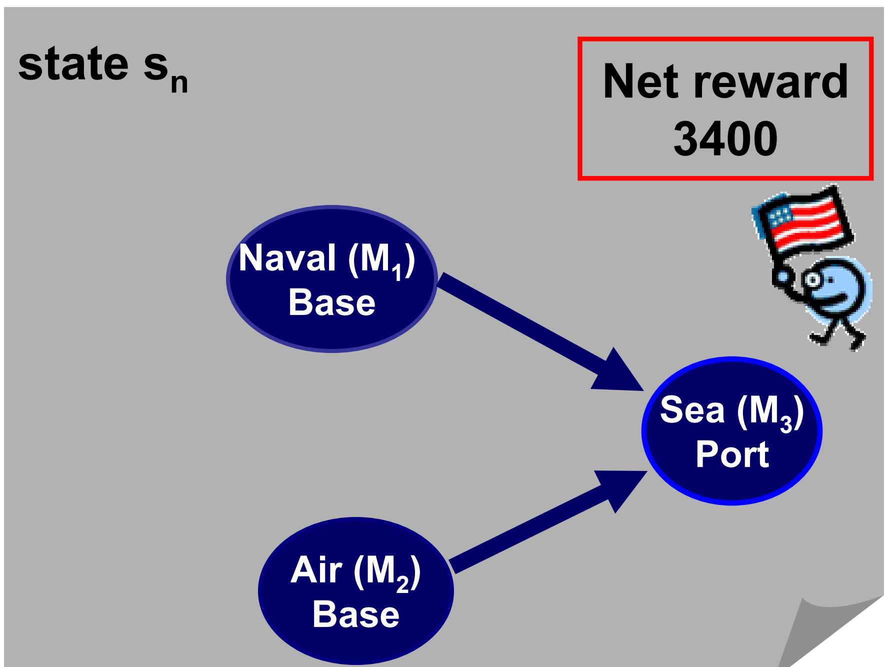
- Mission Task
- Time Critical Task
- "Mosquitoes"
- Asset

Monte Carlo Control Method – 3/4

Update

state-action value

State	Action	S-A Value
—	—	—
$S_1(T_2)$	$a_1(\langle 2P_2+2P_4\rangle \rightarrow m_1)$	1560
	$a_2(\langle 3P_1\rangle \rightarrow m_2)$	**2170**
	$a_3(\langle P_3\rangle \rightarrow T_2)$	1320
$S_2(M_2,T_2)$	$a_1(\langle 2P_2+2P_4\rangle \rightarrow m_1)$	1200
	$a_3(\langle P_3\rangle \rightarrow T_2)$	700
	$a_4(\langle P_2+P_4\rangle \rightarrow T_1)$	1020
	$a_5(\langle P_3\rangle \rightarrow T_1, \langle P_2+P_4\rangle \rightarrow T_2)$	**2800**
—	—	—



Monte Carlo Control Method – 4/4

Converged state-action values

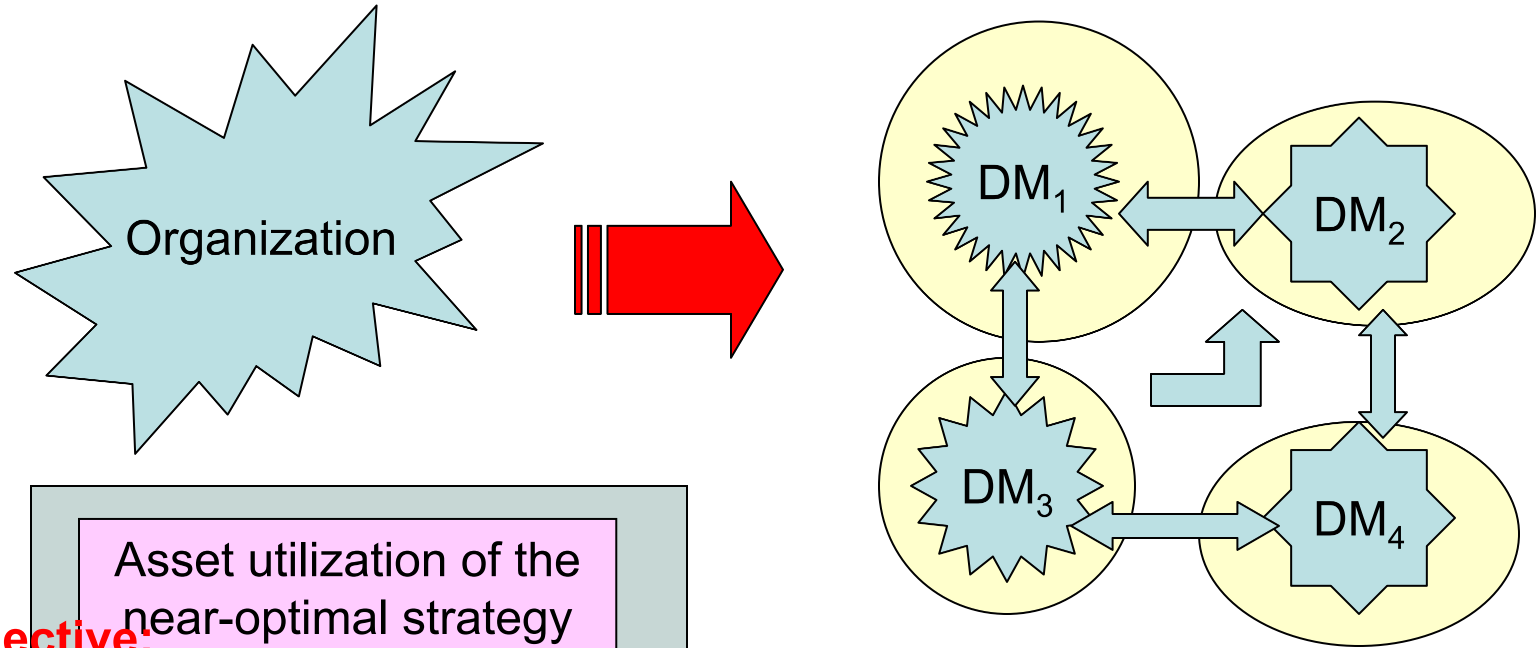
State	Action	State-Action Value
T_2	a_1	**2115**
	a_2	1780
	a_3	930
M_2, T_2	a_1	323
	a_3	1356
	a_4	1454
	a_5	**3020**
		—

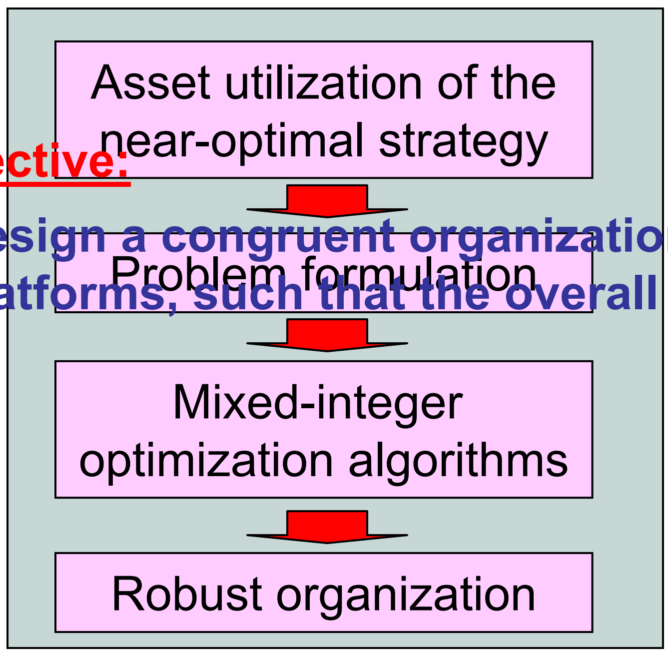
Optimal Strategy

State	Optimal Action
ϕ	$P_1+P_2+P_3+3P_4$
M_1	$3P_1$
M_2	$2P_2+2P_4$
T_1	$P_1+2P_2+P_4$
T_2	$2P_2+2P_4$
T_3	P_1+P_4
T_1, T_2	P_1+P_2
—	—
M_2, T_2	$P_2+P_3+P_4$
—	—

Optimal Strategy: Mapping from states to actions

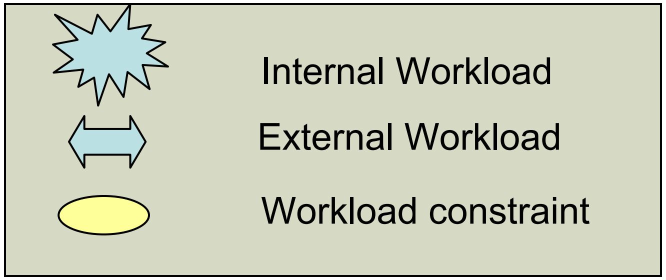
Robust Organization Design 1/2





Objective:

Design a congruent organizational structure in terms of DM ownership of platforms, such that the overall workload is minimized



Robust Organization Design 2/2

Integer Optimization Problem:

Objective: Minimize overall workload

Subject to:

1) Each DM cannot exceed his workload constraint
2) Each platform has to be assigned to a DM

Workload of DM_k :

$$WL_k = \text{Internal Workload} + \text{External Workload}$$

$$\text{Internal workload} \propto \sum_{i=1}^{m} \{(\text{platform class } P_i \text{ activity})^* (\text{number of platforms of platform class } P_i \text{ owned by } DM_k)\}$$

$$\text{External workload} \propto \sum_{i=1}^{m} \sum_{j=1}^{m} \{(\text{platform classes } P_i\ P_j \text{ cross activity})^* (\text{number of platforms of platform class } P_i \text{ owned by } DM_k)^* (\text{number of platforms of platform class } P_j \text{ not owned by } DM_k)\}$$

Illustrative Example - Revisit

Near- Optimal Strategy

Statistics of Platform Utilization

	P_1 (3)	P_2 (5)	P_3 (3)	P_4 (2)
	1	1.08	0.33	1.34
P_1	1.5	0.75	0.25	1.00
P_2	0.75	1.916	0.25	1.58
P_3	0.25	0.25	0.33	0.67
P_4	1.00	1.58	0.67	2.67

Expected Platform Utilization

Expected Platform Coordination

Mix-integer nonlinear programming algorithms

$P_1+3P_2+P_3+P_4$	DM_1
$P_1+P_2+P_3+P_4$	DM_2
$P_1+P_2+P_3$	DM_3

Robust Organizational Structure

Summary

- Proposed a methodology for designing robust organizations for *dynamic* and *stochastic* environments
- Modeled the mission environment as a finite state Markov Decision Process
- Applied Monte Carlo control methods to obtain a near-optimal action strategy
- Utilized mixed-integer optimization technique to design organizational structure congruent to the strategy

Future Work

Modeling Parameters:

- Incorporate more realistic mission environments into MDP model
  - Task locations
  - Platform locations, velocities

Space Reduction in Learning:

- Generalization (Function Approximation)
- Abstraction (Factored Representation)

Organizational Design:

- Include additional organizational structure elements into the design process
  - Command structure
  - Information flow structure

Thank You