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Facilitating Decision Choices with Cascading Consequences in Interdependent Networks

Anita Raja
Department of Software and Information Systems

Mohammad Rashedul Hasan
Department of Software and Information Systems

Mary Maureen Brown
Department of Political Science and Public Administration

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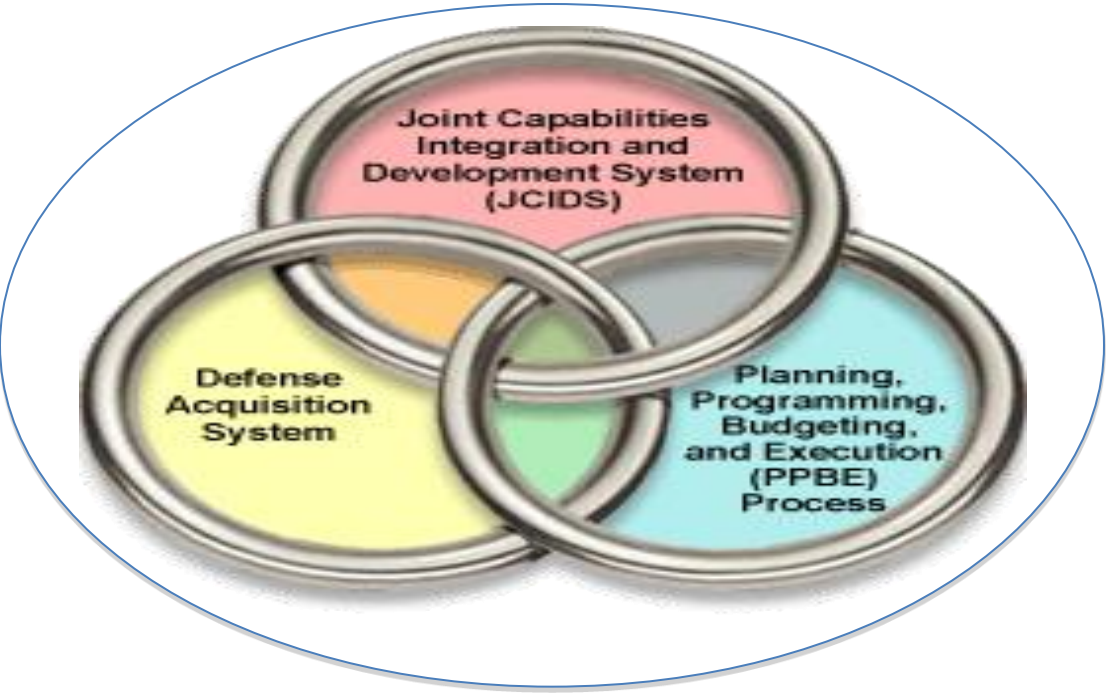
Joint Capabilities



The future operating environment will continue to be characterized by uncertainty, complexity, rapid change, and persistent conflict, =>
DoD leadership has explicitly sought the capability to act jointly

An integrated approach to strategic planning, capabilities needs assessment, systems acquisition, and program and budget development.

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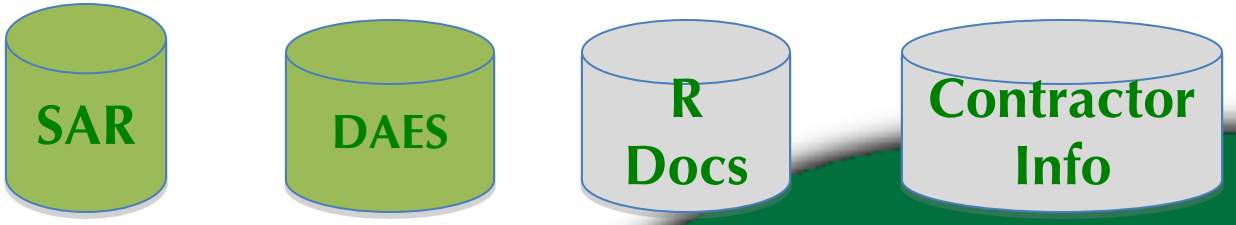
MDAP Interdependency

- Defined as dependence on an external source for
  - data,
  - money,
  - staff,
  - facilities, or
  - requirements

  beyond the normal acquisition workflow.
- Data sources



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Perspectives

- **Local (endogenous)**
  - how will my costs overrun this year affect my performance next year?
- **Non-local (exogenous)**
  - what if my partner reneges on a funding obligation?
  - how will my cost overrun affect my neighbors?

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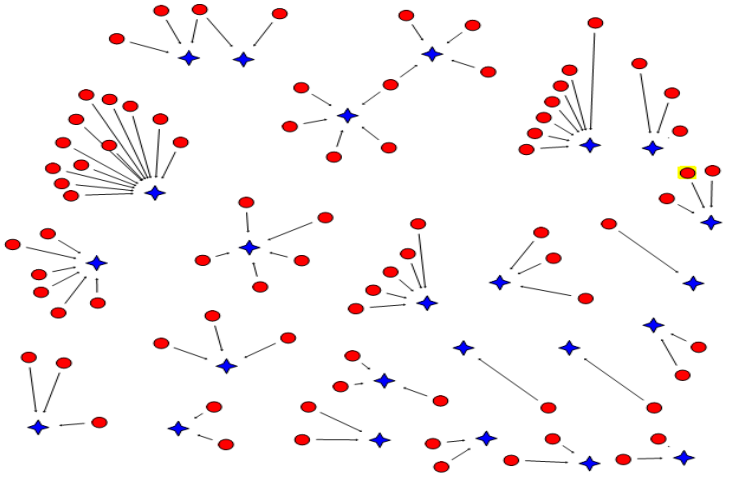
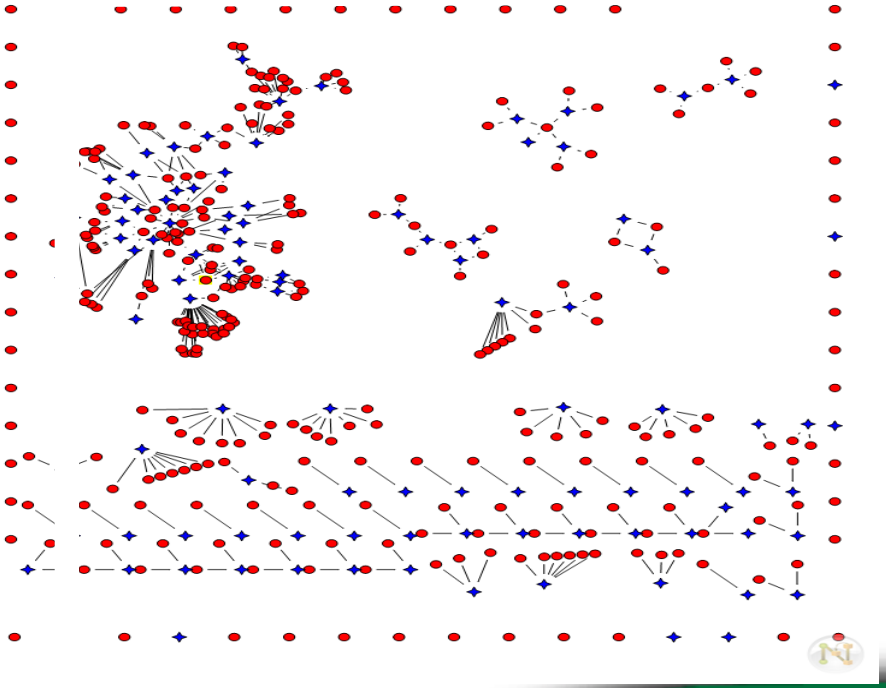
Program Element Interdependencies

Growing Interdependencies and Complexity



PE MDAP Relationships 1997



PE MDAP Relationships 2007

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Data Interdependencies

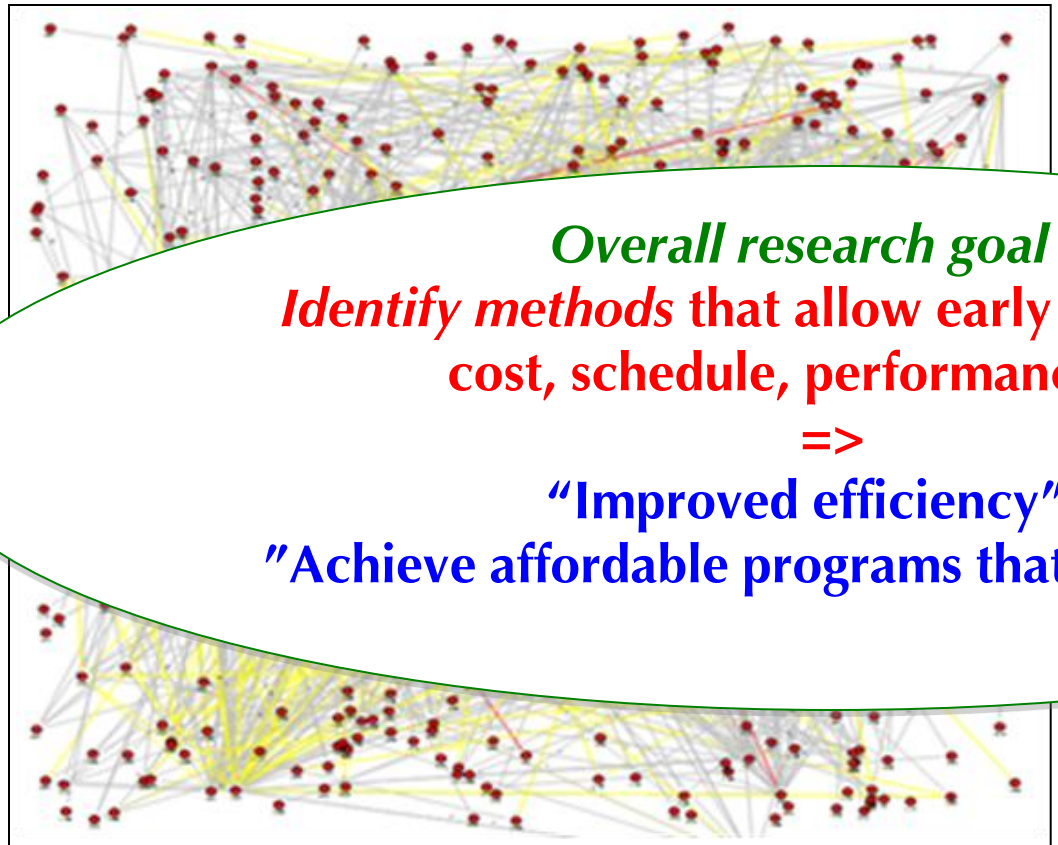

Figure 1: MDAP Data Interdependencies in 2005

Overall research goal is:

***Identify methods* that allow early observation of cost, schedule, performance risk!**

=>

"Improved efficiency" &

"Achieve affordable programs that execute well"

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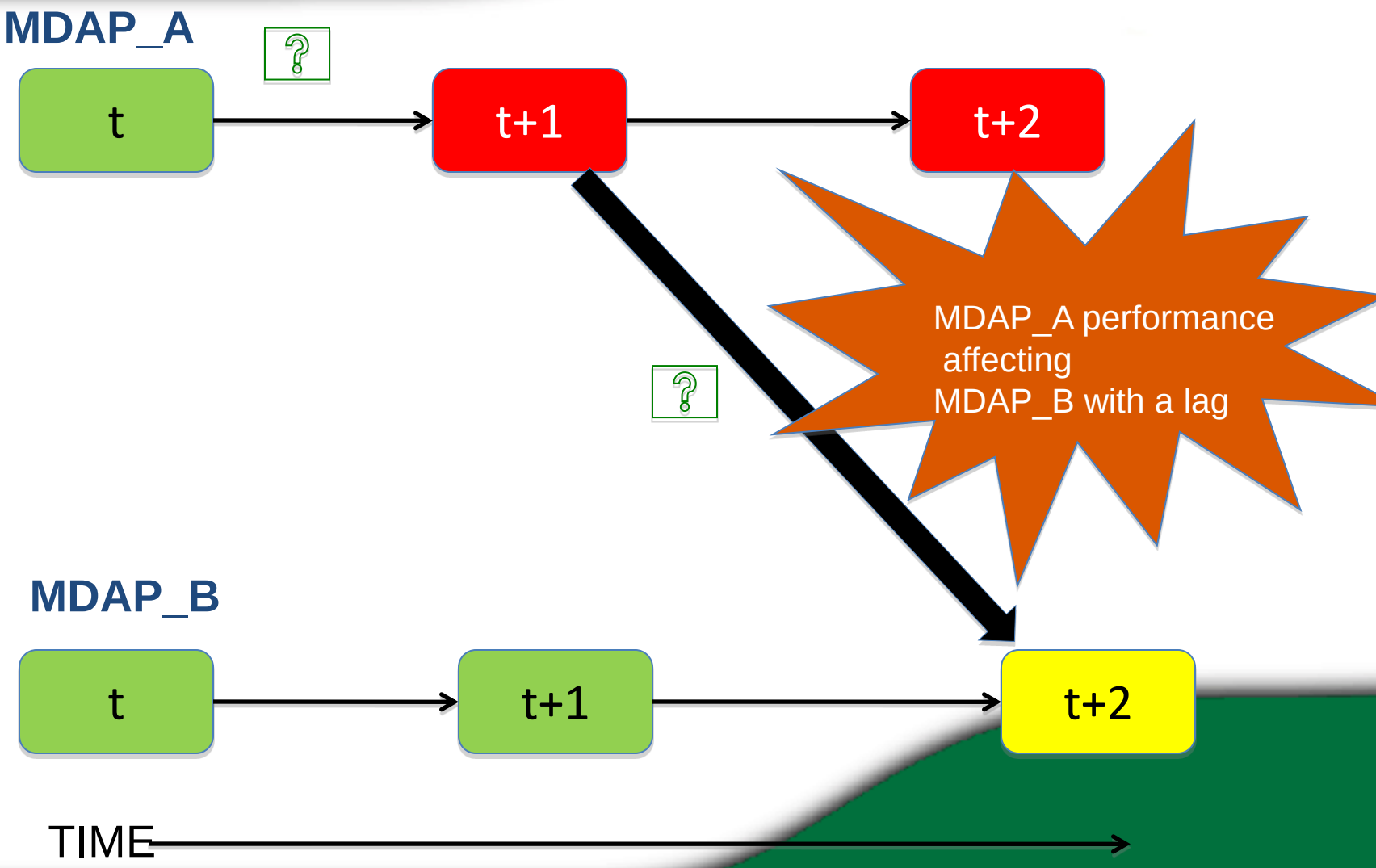
Cascading Effect: Hidden Dynamics



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Specific Goals

1. Identify highly dependent parts of the MDAP network.
2. Study effectiveness of current mitigation forecasting.
3. Develop a mathematical model to describe and predict non-linear cascading effects from one MDAP to another.
4. Understand the data collection process and challenges:
   - missing, inaccurate data etc.

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Solution Paths

- Deterministic/Linear Methods (Brown, Flowe 2010, 2011, 2012)
  - Use correlation to show cascading effects and interdependence.
  - Data: Entire network of MDAPs over several years.
  - Top-down approach; bird's eye view.
- Non-deterministic/Non-linear methods (this work)
  - What-if mathematical models.
  - Data: Case-study of a small set of MDAPs over several years.
  - Bottom-up approach; careful analysis of individual programs and their interdependencies.
  - Uncover early indicators of interdependency risk to isolate appropriate governance oversight methods.

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Main Contributions

1. Existing data features facilitate multi-perspective study.
2. Identify factors that cause mitigation forecasting to falter.
3. Non-local factors affect program outcomes:
   - "program-centric" + "program network approach" for acquisition and management is advantageous.
4. Cascading effects can be recast as a sequential decision problem
5. Identify challenges inherent in the data collection process.

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Three-phase Methodology

Phase 1: Identify "critical" programs
[APB breaches & %ΔPAUC]

Phase 2: Study local reasons for missed performance estimates

Phase 3: Study non-local reasons for missed performance estimates

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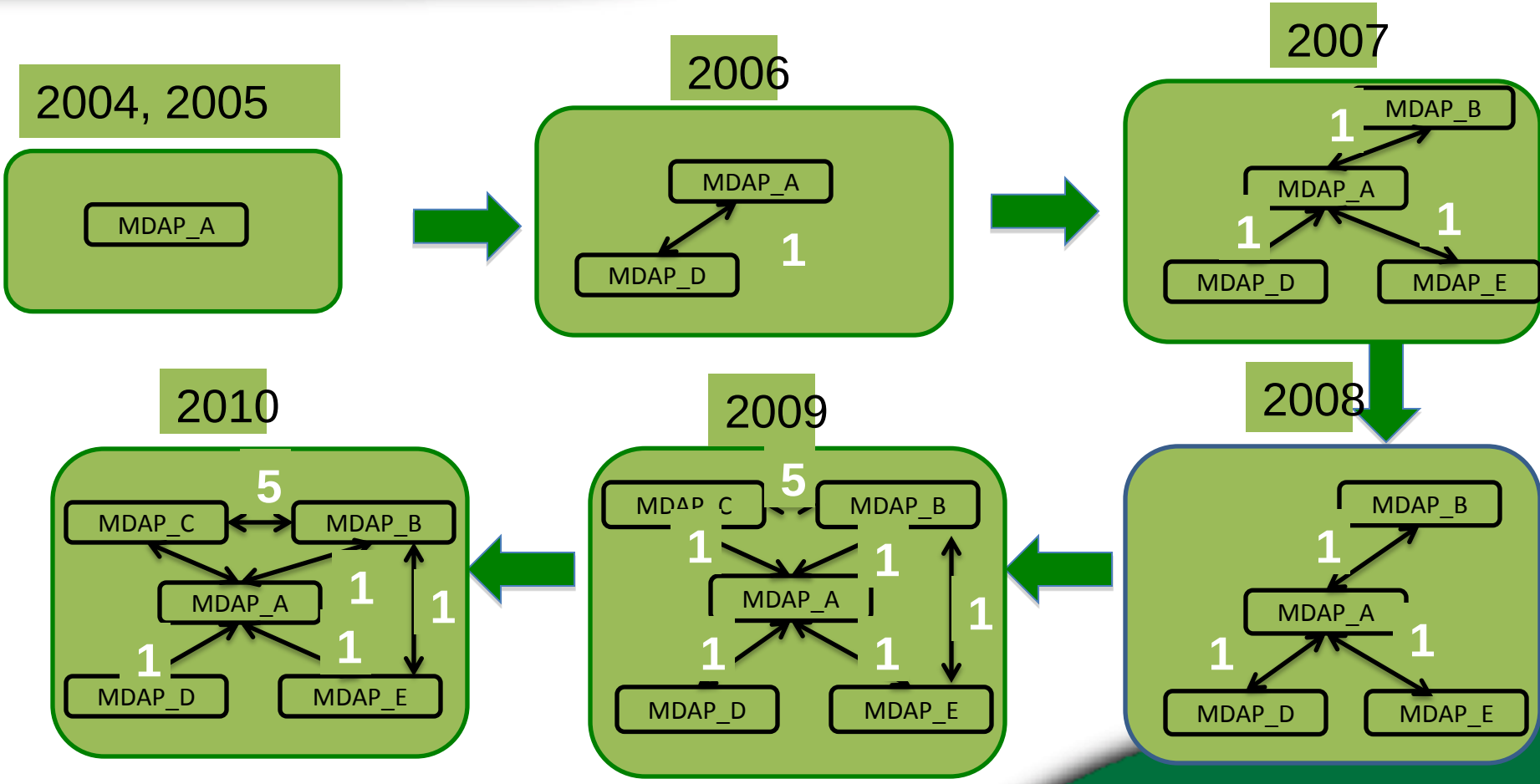
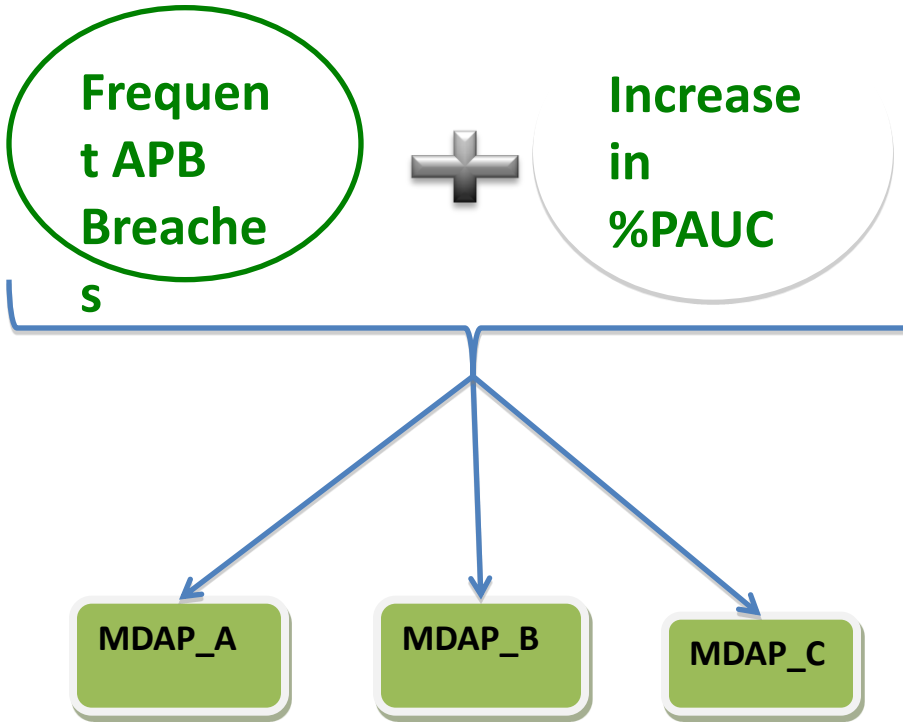
CASE STUDY: Evolving Funding Neighborhood



Phase 1: "Critical" programs (SARs 2004-2010)

	APB Breach				
MDAP_A	Schedule	Performance	RDT&E	Procurement	PAUC
2004	None	None	None	None	None (-9.98%)
2005	None	None	None	None	None (-11.65%)
2006	Yes	Yes	Yes	None	None (-6.14%)
2007	None	None	None	None	None (-1.24%)
2009	Yes	None	Yes	None	None (3.14%)
2010	Yes	None	Yes	None	None (3.82%)
MDAP_B					
2004	None	None	None	None	None
2005	Yes	Yes	Yes	None	None (3.85%)
2006	Yes	Yes	Yes	None	None (3.85%)
2007	None	None	None	None	None (7.69%)
2009	Yes	None	None	Yes	None (-26.92%)
2010	Yes	None	Yes	Yes	None (-19.23%)
MDAP_C					
2005	Yes	None	None	None	None (6.51%)
2006	None	Yes	None	None	Yes (13.22%)
2007	Yes	None	None	None	None (0.93%)
2009	Yes	None	None	Yes	None (-37.79%)
2010	Yes	None	None	Yes	None (-26.75%)
MDAP_D					
2009	None	None	None	None	None (2.45%)
2010	Yes	None	None	None	None (1.05%)
MDAP_E					
2006	None	None	None	None	None (-10.685%)
2007	None	None	None	None	None (-4.81%)
2009	None	None	None	None	None (-3.98%)
2010	None	None	None	None	None (-11.24%)



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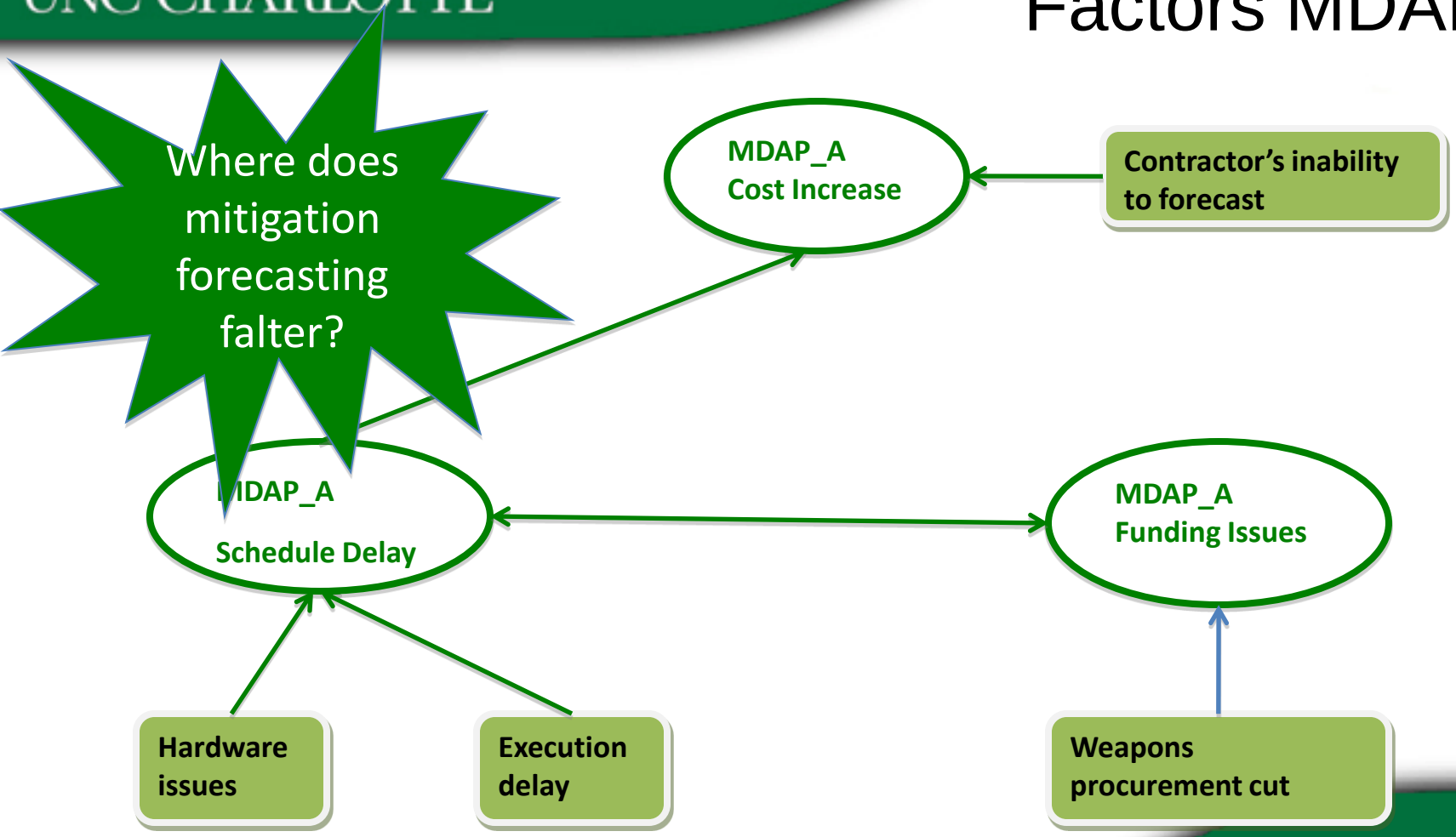
Phase 2: Local Factors MDAP_A



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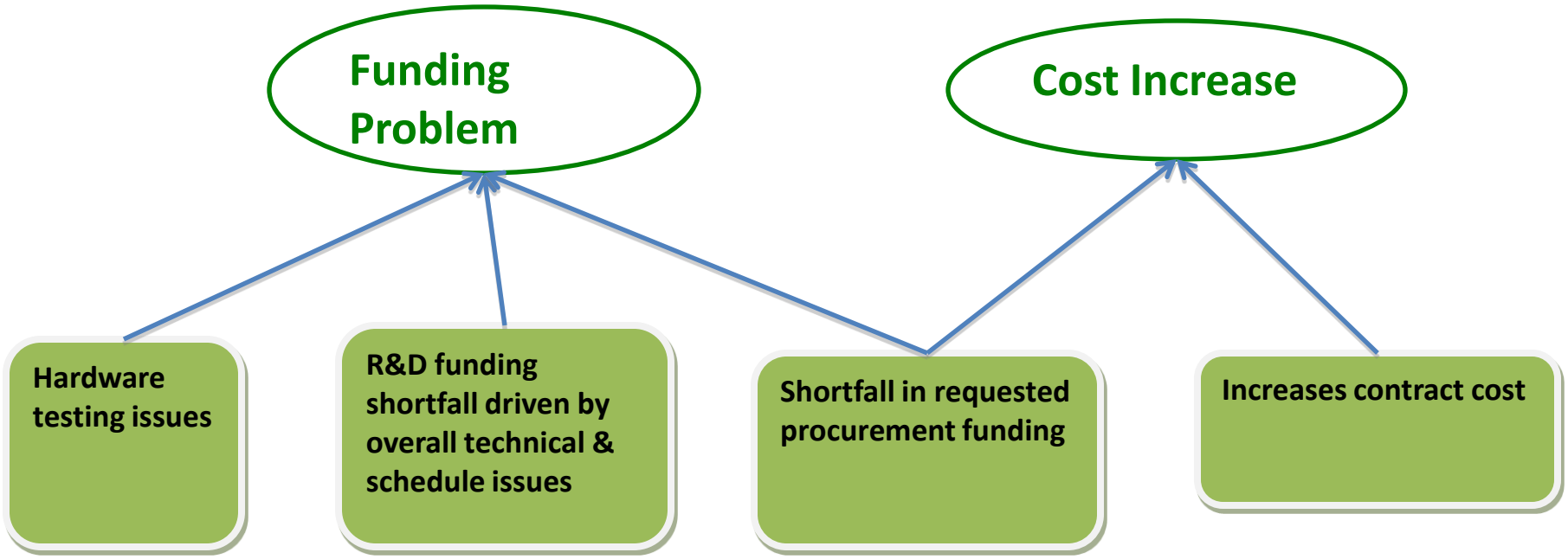
Phase 2: Local Factors MDAP_B



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Phase 1 & 2 Results

- MDAP can have more than one type of APB breach in a year and %PAUC can still decrease:
  - Lag from previous year.
  - PMs may leverage project management triangle model (Bethke, 2003).
- Main cause for MDAP_B's cost and funding problems => Shortfall in requested funding.
- DAES reports do not provide obvious local (endogenous) reasons for this shortfall in funding:
  - For e.g. no new breaches.
- Investigate the overlapping region between MDAP_A and MDAP_B to identify possible non-local cascading effects.

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Funding Summary (2004-2010)

MDAP_A	Baseline Quantity	Current Quantity	%PAUC	Current Year Required Funding (x)	Received Funding (y)	Delta (y - x)
2004	6	6	-9.98		221.1	
2005	6	6	-11.65	598.5	579.8	-18.7
2006	6	6	-6.14	1012.1	997.3	-14.8
2007	6	6	-1.24	1588.4	1574.6	-13.8
2009		6	3.14	3163.2	3006.3	-156.9
			3.82		.2	62.5

Summary ($BY

		ntity			Funding	Delta (y-x)
2004		329574	0	44.2	4.2	0
2005	329574	328514	3.85	137.2	135.5	-1.7
2006	329574	328514	3.85	255.5	250.3	-5.2
2007	329574	95961	7.69	350.5	348.1	-2.4
2009	329574	215961	-26.92	644.1	593.2	-50.9
2010	329574	221978	-19.23	751.6	711.1	-40.5

Table: **MDAP_B** SAR Funding Summary ($BY) for the period 2004-2010

MDAP_A
2007 %PAUC increase

MDAP_B
2009 Funding Shortfall

MDAP_B
2010 Cost breach

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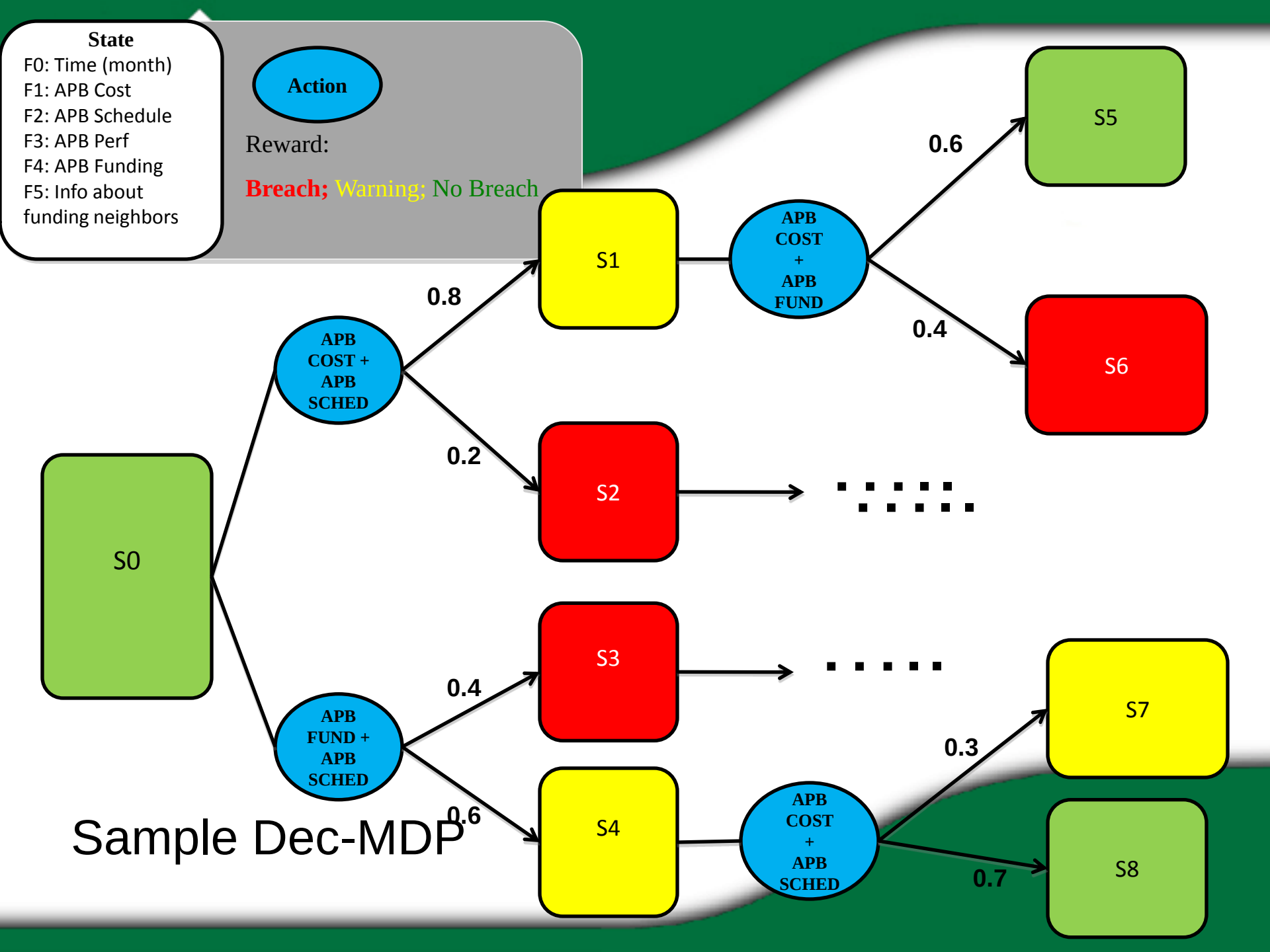
Decision Theoretic Model

- **Reasoning explicitly about uncertainty is key:**
  - Must anticipate various possible outcomes over time to support effective decision making.
- **MDPs provide a rigorous foundation for sequential decision making:**
  - Hedging allows managers to (a) test their decisions to avoid possibility of failure and (b) to choose actions that ensure higher overall expected rewards
  - Computing optimal policies will support non-myopic decisions.
  - Address partial-observability using a derivative called DEC-MDPs.
- **Build Pattern Knowledge:**
  - Capturing role of interdependencies, past performance and action outcomes across MDAPs in the MDP.


State
F0: Time (month)
F1: APB Cost
F2: APB Schedule
F3: APB Perf
F4: APB Funding
F5: Info about funding neighbors
Action
Reward:
Breach; Warning; No Breach
S0
APB COST + APB SCHED
APB FUND + APB SCHED
0.8
0.2
0.4
0.6
S1
S2
S3
S4
APB COST + APB FUND
APB COST + APB SCHED
0.6
0.4
0.3
0.7
S5
S6
S7
S8
Sample Dec-MDP

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Analysis Results (1/2)

1. Contractor either underestimates or cannot accurately estimate the technical challenges and the amount of required funding.
2. Budget cuts → delay schedule → cost increases.
3. Procurement funding shortfall leads to cost and funding problems.

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Analysis Results (2/2)

4. Instances of cascading effects suggest:
   - "program-centric" + "program-network" approach -> acquisition management and oversight
5. Recurring local issues => either the root cause is not captured in the DAES or the cause is exogenous to the program boundary:
   - PARCA: Important ongoing work in root cause analysis is encouraging.
6. Critical need to design automated data extraction and analysis methods.

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Data Characteristics and Needs

Significance of the Data set	Needs wrt Structure of the Data	Availability of Data
• The available data offers significant insight about each individual program.	• Capture more information on interdependencies. • Provide comparative status of programs. • Provide summary status of the data neighbors in DAES reports. • Uniformity in DAES report format across programs.	• Complete data set for MDAP_A network is available only for the years 2008 and 2009. • Existing programs sometimes stop reporting after operating for a certain number of years.

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Next Steps

- Study the Structural Properties of the MDAP Network:
  - Continue to refine criteria that identify most “critical” MDAPs and root cause analysis.
  - Include PE docs, contractor data etc.
  - Study temporal behavior of cascading vector over time.
  - Measure path length (n/w diameter) and its influence on cascades.
  - Determine cost of “jointness” and associated risk levels.
- Data Extraction & Analysis:
  - Automate data extraction process.
  - Populate DEC-MDP model automatically and compute distributed policy.
- Data Needs:
  - Complete Data for a subset of MDAPs would be very useful.
  - Ideally take a deep dive studying a few selected programs.

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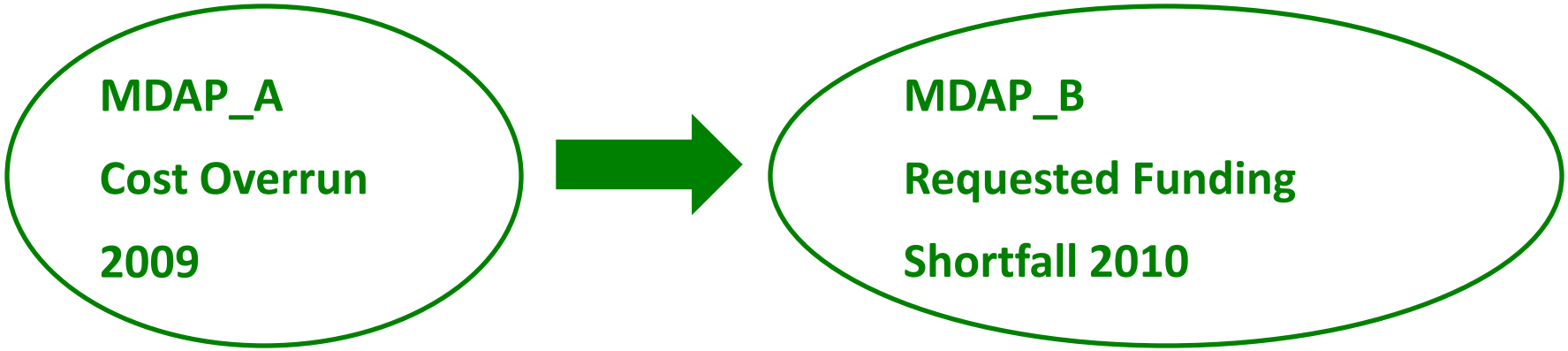
Phase 3: Non-local factors MDAP_B



This observation, even if it may not be conclusive, is suggestive of cascading effects between neighboring MDAPs.