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Modeling Uncertainty and Its Implications in Complex Interdependent Networks

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Modeling Uncertainty and Its Implications in Complex Interdependent Networks

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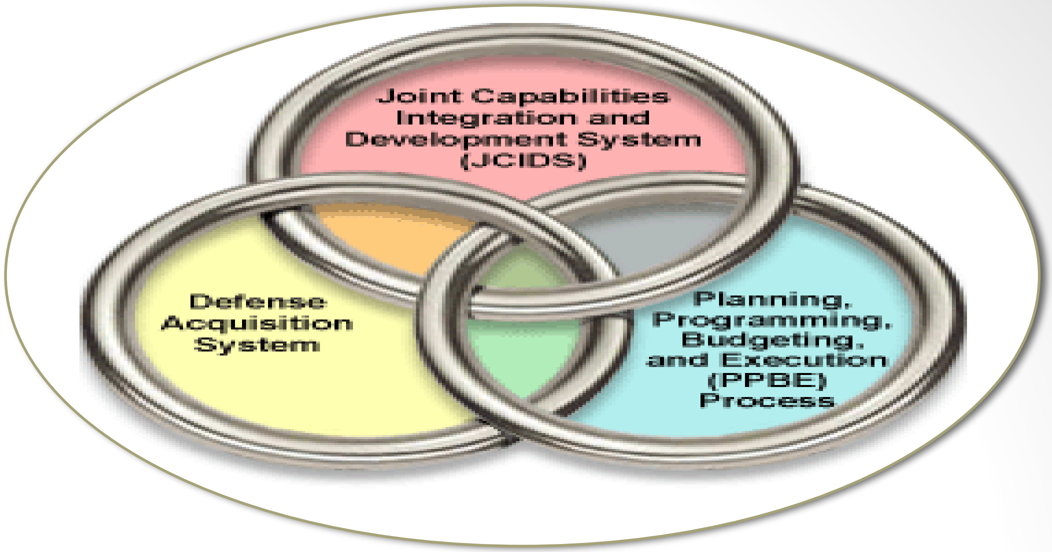
Motivation



- Background:
  - Joint Capabilities.
  - Operating environment: uncertainty, complexity, rapid change and persistent conflict.
  - Integrated approach (WSARA 2009).
- Definition:
  - Cascading risk: Propagation of programmatic issues across networked programs due to the interdependency of one program upon the other.
- Research Question:
  - Study and quantify the impact of network characteristics on cascading risk.

Main Contributions

Hypothesis: The programmatic interdependencies between MDAPs have a profound influence on large-scale network performance over an extended period of time.

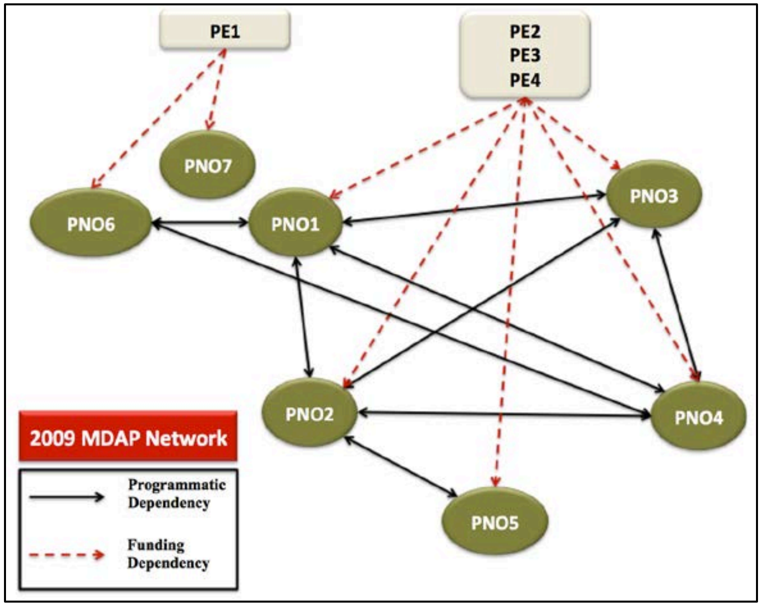
1. Define a metric to quantify influence of network characteristics on program performance.

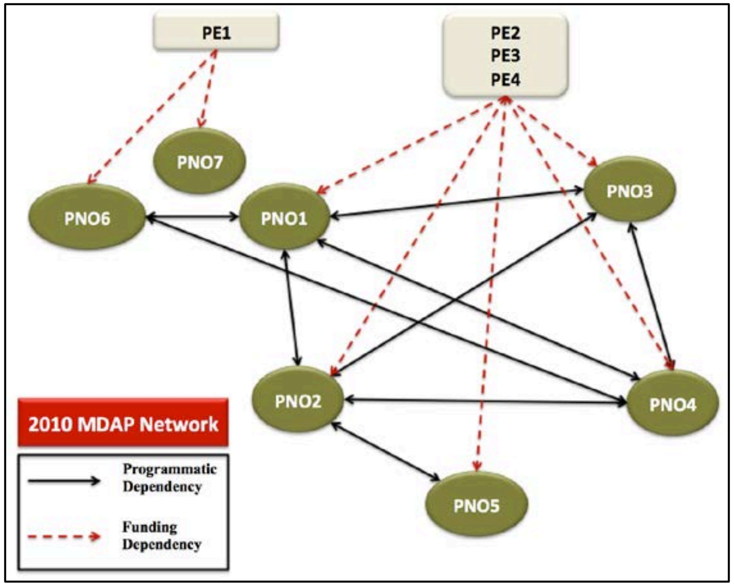
1. Determine if it is possible to formulate mathematical models that capture dynamics of complex networks and provide prescriptive actions.

Task 1: Risk Computation

- Probabilistic Risk Analysis (Lewis 2009) :
  - Compute risk to identify and manage critical nodes.
  - Why critical nodes?
  - Leverage network topology (extended PRA)
  - Extended risk for n-node network is $r_{ext}=\Sigma^{n}_{i=1} g_i V_i C_i$ where
    - g: Degree
    - V: Vulnerability
    - C: Consequence

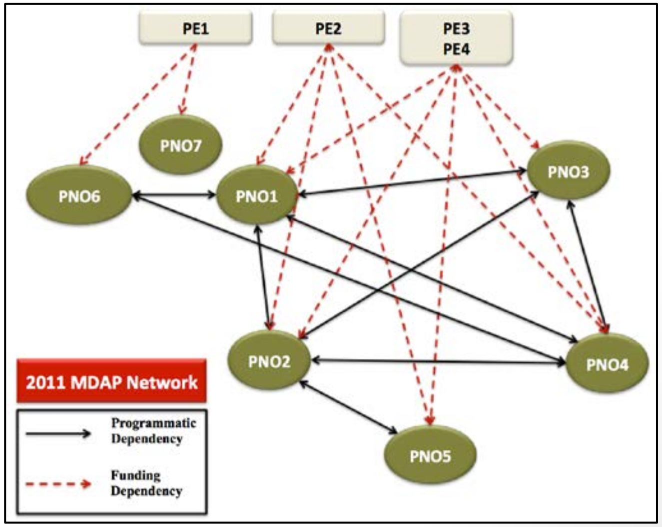
Case Study of a multiplex network



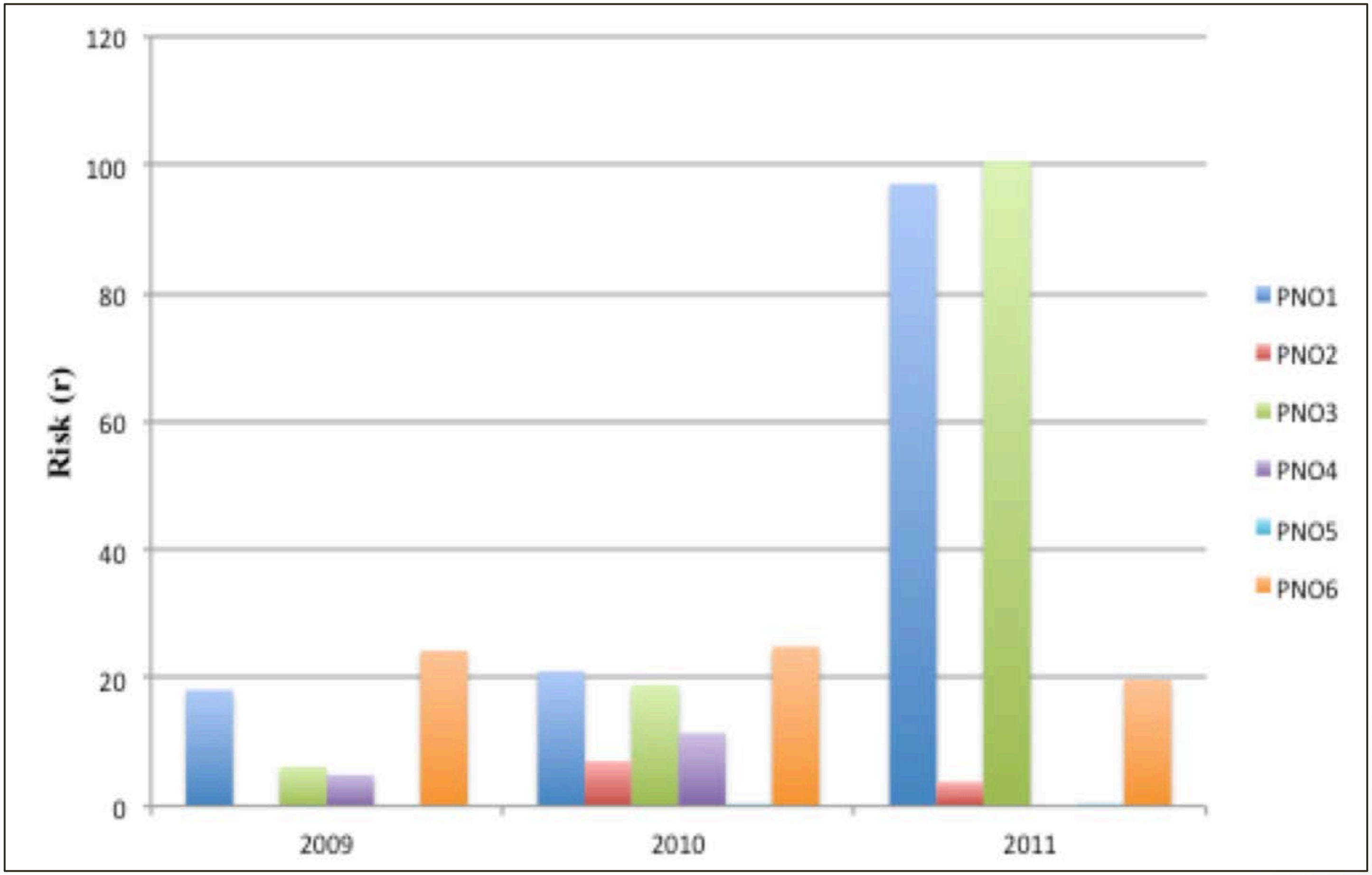


Critical Node Analysis for multiplex network

	Risk (r)		
	2009	**2010**	**2011**
PNO1	18.11	21.02	97.05
PNO2	0	6.97	3.75
PNO3	6.16	18.89	100.52
PNO4	4.88	11.39	0
PNO5	0	0.17	0.48
PNO6	24.22	24.9	19.7



Critical Node Analysis

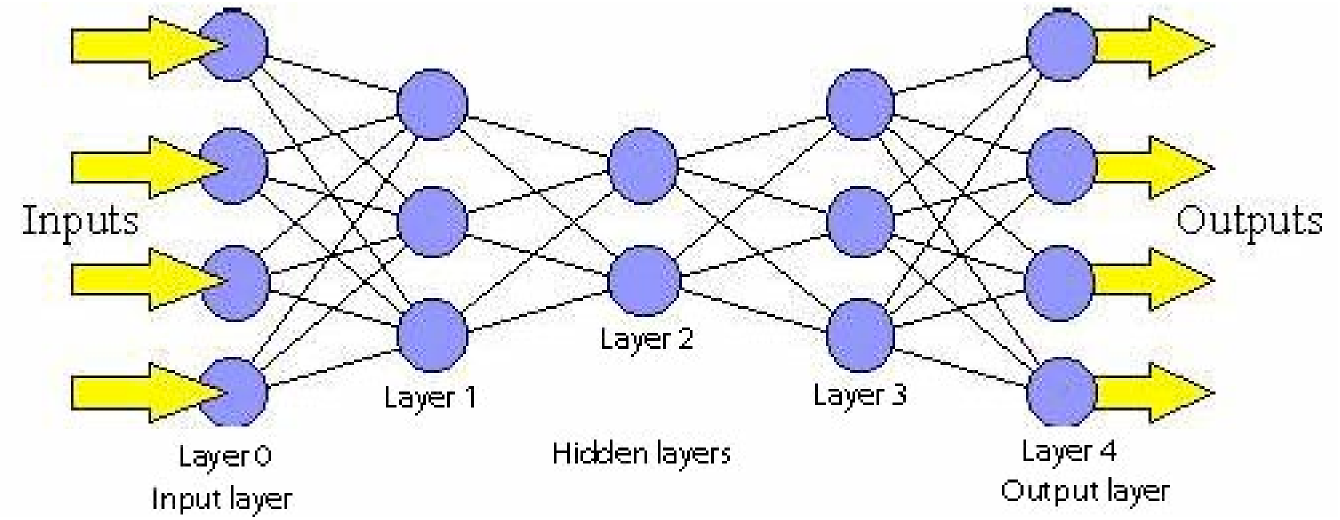


Task 1: Observations

- Network-centric approach helps capture exogenous effects on program performance.
  - Underscores importance of addressing multiplex network relationship among MDAPs.
  - Uses data from various reports (DAES, SAR, R Docs) to define multiplex network and vulnerability parameter for PRA analysis.
- Extended PRA technique
  - identifies critical (risky) programs in the multiplex network.
  - could be used to forecast a program’s performance and avoid negative cascading effects.

Task 2: Feasibility Study

- Modeling interdependent networks as a coupled dynamical system and potentially adapting related algorithms.



- Does the system have any attractive equilibria?
- If good equilibria were discovered, an outcome could be to recommend a funding strategy that maintains equilibrium or guarantees a rapid convergence toward it.

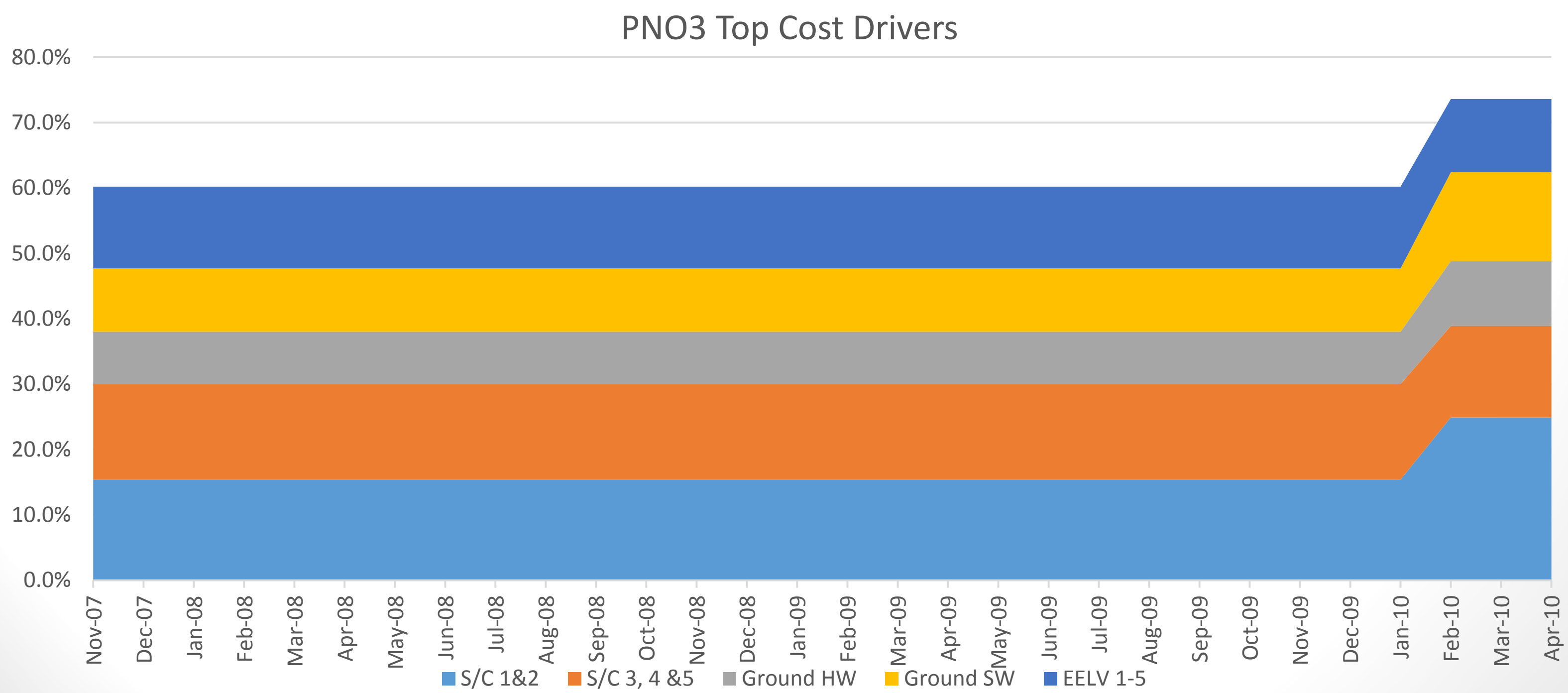
  - Ack: Prof. Stan Minchev, Eui Seong Han.

Methodology

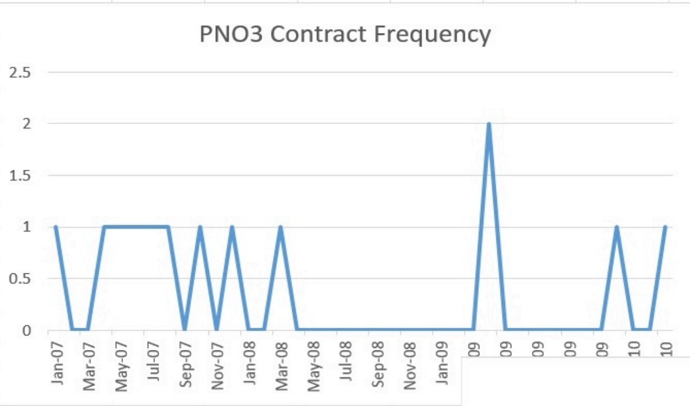
- Goal: Determine a network model
  - Centrality measure.
  - Strength of network connections including a precise form of the coupling formalism.
  - State features and action options (as in Raja 2012).
  - Reward optimization model capturing network dynamics.
- Process:
  - Determine variables that **evolve over time** and can be **measured numerically**, i.e., real numbers on a well-defined scale
  - Find time series of data on the variables chosen above.

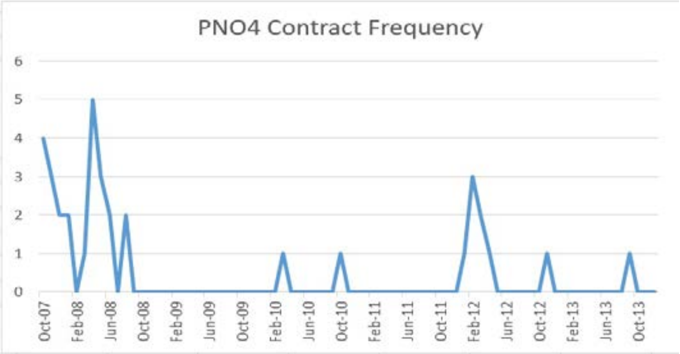
E.g.: Top Cost Driver

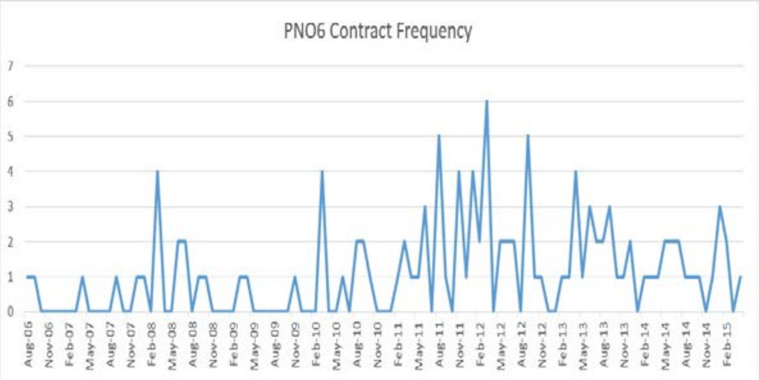
- Data source:
  - DAES reports of several MDAPS collected over a decade
  - Program Status, Top Cost Drivers, KPPs, Finley Charts.



Churn in Contract Data







- July 2008: new cost and schedule breach occurred per the PNO6 DAES data. We are investigating if spikes in the contract churn data predict a future breach.
- Missing data problem.
- 2009, 2010, 2011 PNO6 SARS show Schedule and Cost RDT&E APB breaches with varying levels of explanations.

Task 2 Observations

- Allusions that various DAES and SARS quantities are quantitatively obtainable through formulas or calculations. However unclear
  - how this is actually done;
  - what the numerical values/ranges would be;
  - whether these definitions are consistent across all programs.
- Given time lag (DAES reports are generated monthly) and the level of data captured, often there was not variation in the data from one month to the next.
- Churn data has the evolutionary characteristics that could facilitate network modeling process.

Future Work

- Risk computation: Further study the impact of network topology on risk propagation and our methodology to quantify it.
- Delve further into contract data and investigate effect on future performance wrt breaches.