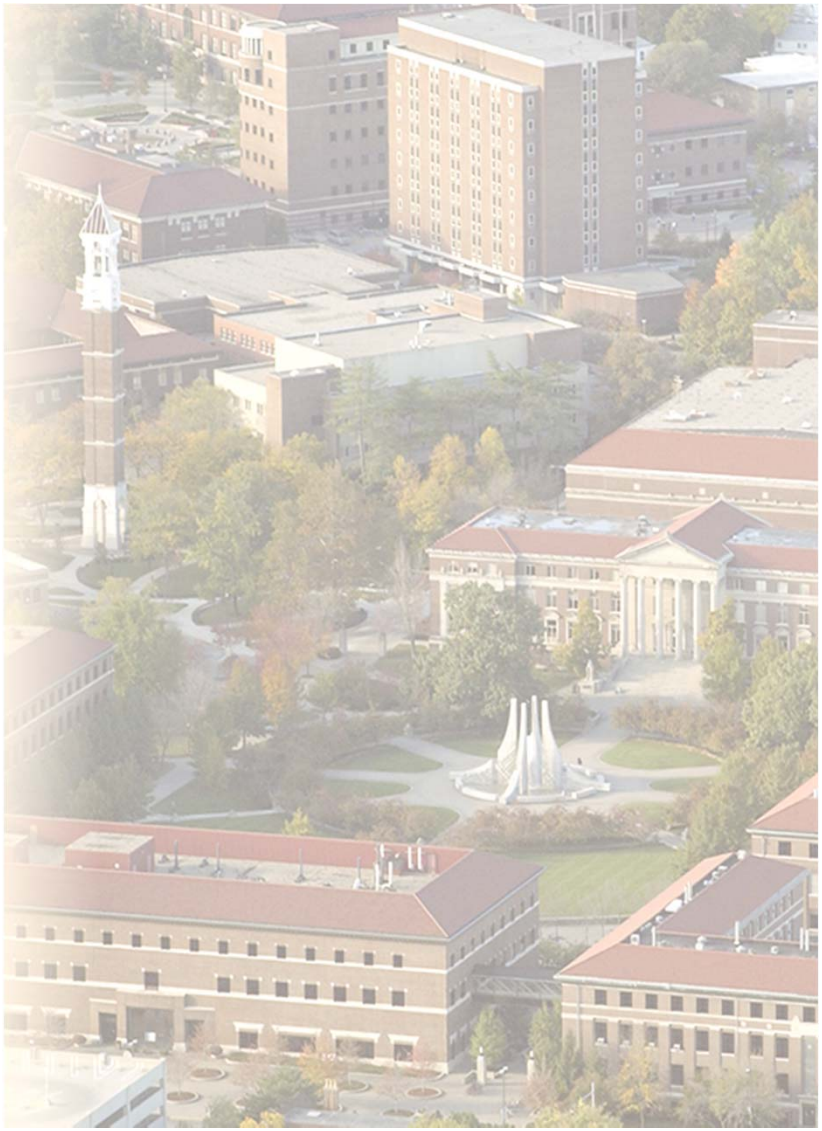
Panel:
Research on Complex Enterprise Systems of Systems



Complex Adaptive Systems Conference
14-NOV-2013

Dan DeLaurentis
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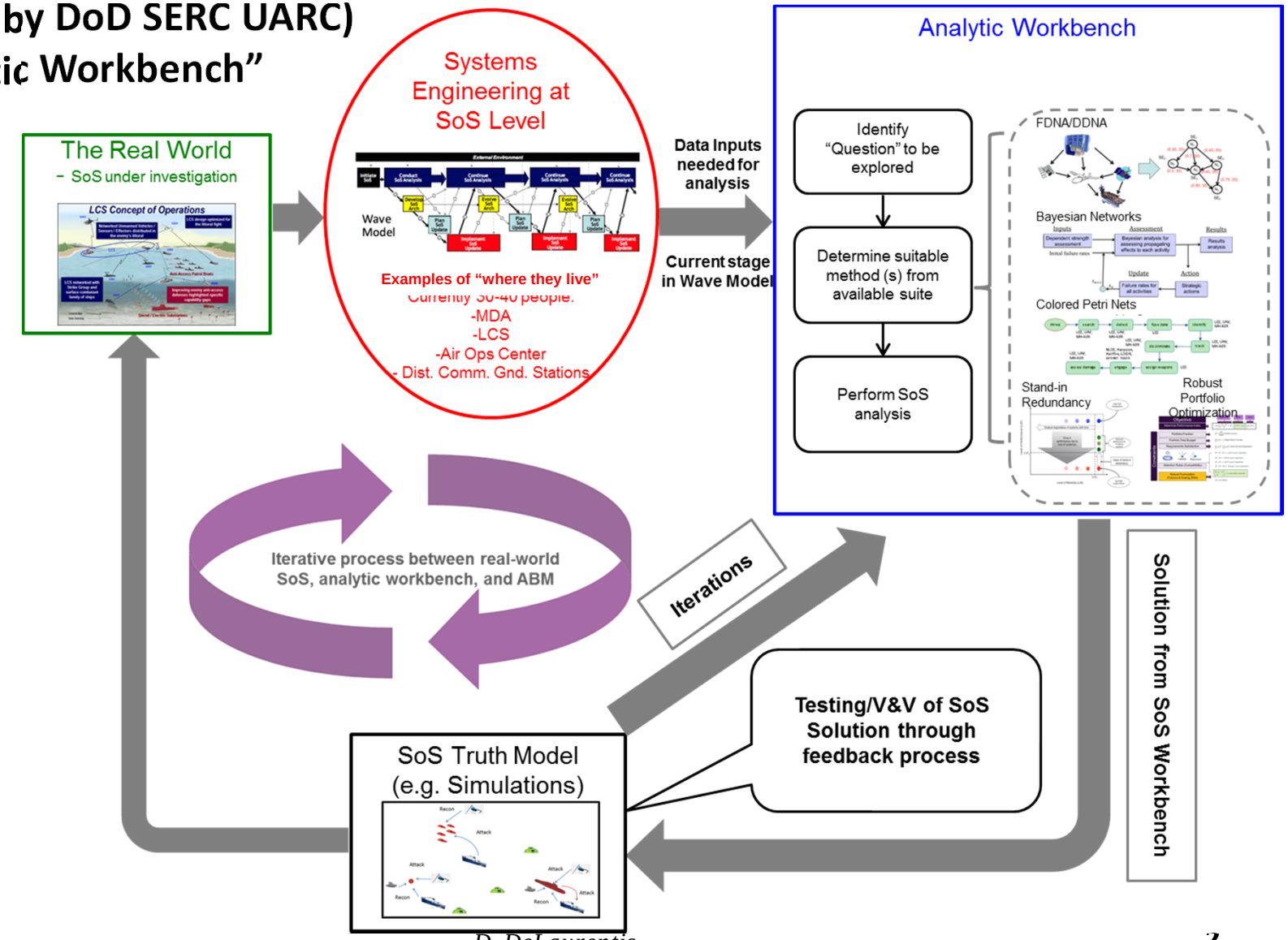
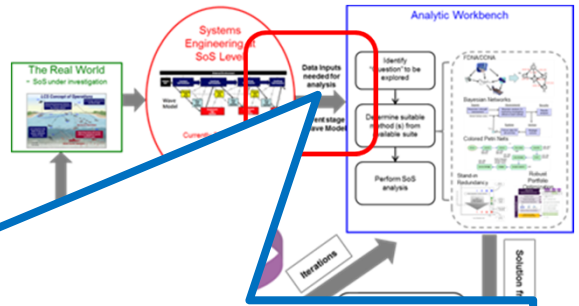
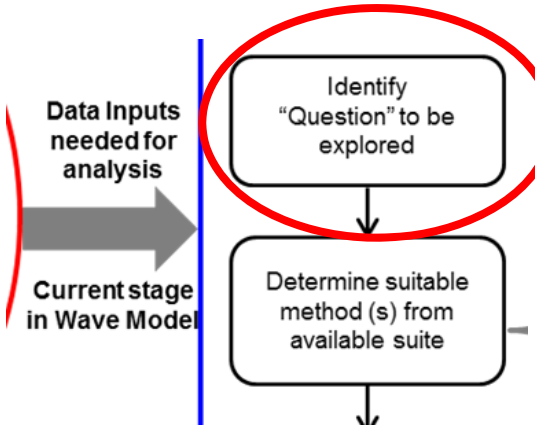
Purdue Project RT-44b (RT-108) (sponsored by DoD SERC UARC) "SoS Analytic Workbench"



Archetypal Analysis Questions: Support *Acquire, Evolve* (for Systems and the SoS)



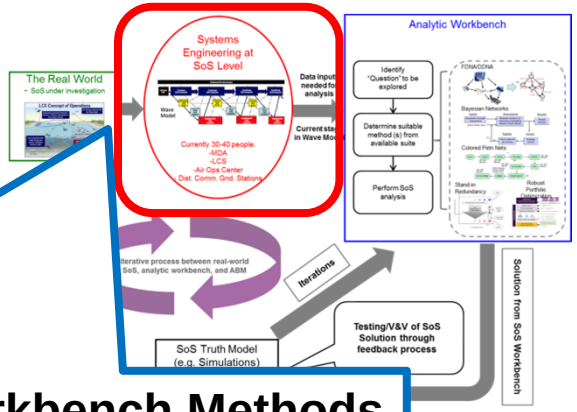


Reflects SoS Practitioners Architectural queries at planned SoS Update

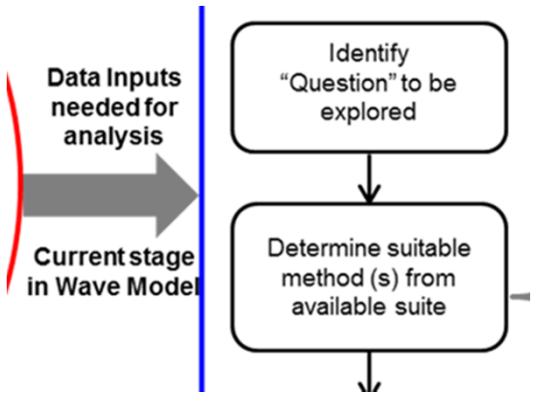
Archetypal Analysis Questions

- How to assess direct consequences due to potential changes in architecture?
- Where, what and how much do my risks change with (operational/developmental) changes?
- How do I mitigate the risks by making the SoS architecture resilient/robust to potential evolution events?
- How do I objectively choose from a multitude of potential architectures based on metrics?

Analytic Workbench – Rich set of MPTs for *Modeling*



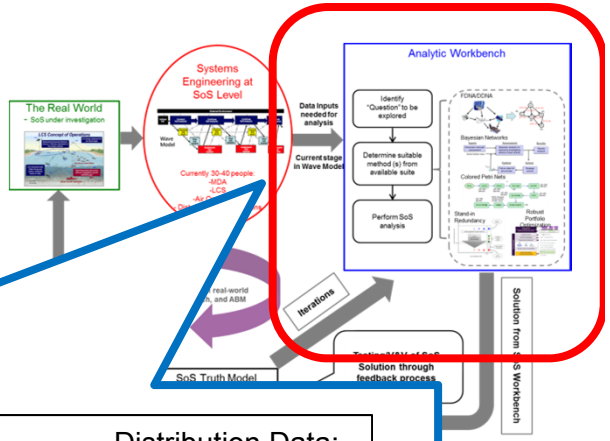
Archetypal Analysis Questions



Mapping to Workbench Methods

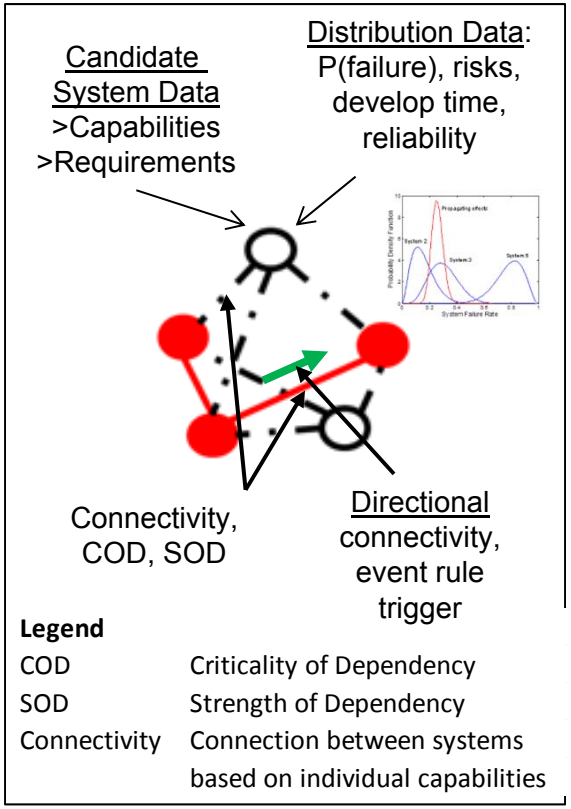
	FDNA/DDNA	Bayesian Networks	Robust Portfolio Optim.	Colored Petri Nets	Stand-In Redundancy
How to assess potential consequences / improvements due to change in architecture?	X	X		X	X
Where and what are my risks in the(operational/developmental) of my systems?	X	X			
How do I exploit dependencies and mitigate cascading effects?			X		X
How do I objectively choose from a multitude of potential architectures based on metrics?			X		

Analytic Workbench – Inputs for Analysis

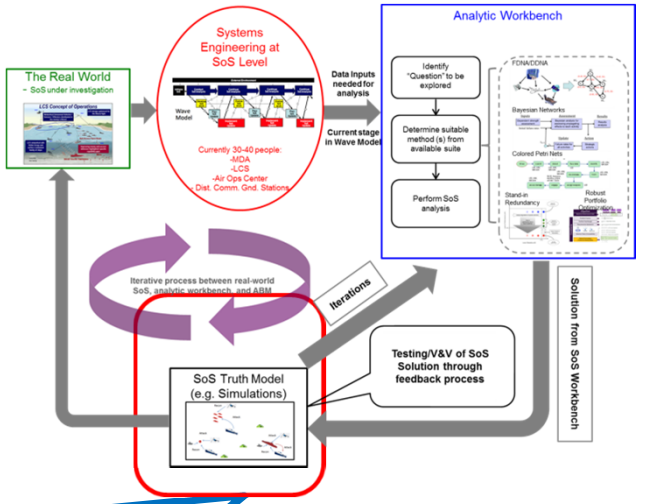


Data elements for analysis

Methods	Inputs for Method
FDNA/DDNA	Criticality of Dependency (COD), Strength of dependency (SOD), Connectivity
Bayesian Networks	Failure probabilities of constituent systems, directional connectivity Architecture alternatives
Robust Portfolio	Capabilities, Development & Integration time for each system System compatibilities, cost
Petri Nets	System capabilities, rules for event triggering Architecture alternatives
Stand-In Redundancy	System reliability data, system capabilities System costs (operating, downtime, cost), Architecture alternatives

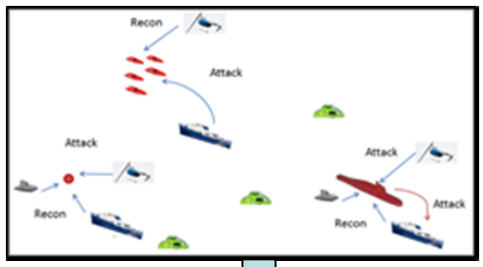


Analytic Workbench - Outputs for Decision *Verification & Validation*



Workbench – Verification via 'Truth Model'

(e.g. Agent Based Model)

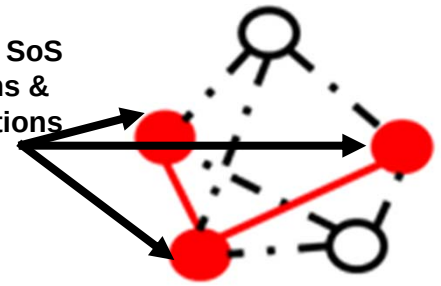


Inputs to 'Truth Model' (e.g. system capabilities, connections) of 'new architecture'

SoS Performance evaluation based on 'new architecture'

Output of SoS Analysis

Chosen SoS systems & connections



SoS new architecture

RT-44b: Recent Dissemination and Outreach

- Journal papers
  - "A robust portfolio optimization approach to system of system architectures", submitted to the INCOSE Systems Engineering Journal
  - "Resilience in System-of-Systems: A Multidisciplinary Review and Agenda for Future Research", submitted to the IEEE Systems Journal
  - “Evaluating System of System Resilience using Interdependency Analysis and Competing Risk Model,” IEEE Systems Journal

- Conference on System Engineering Research (CSER) 2014:
  7 abstract submitted / 7 abstract accepted
  - An Analytic Workbench Perspective to Assessing Impact of Disruptions in System of Systems Architectures
  - An Analytic Portfolio Approach to System of System Evolutions
  - Managing System of Systems Architecture Evolution using Approximate Dynamic Programming
  - Exploiting stand-in redundancy to improve resilience in a system-of-systems
  - Bandwidth Allocation in Tactical Data Networks
  - Communications, Information, and Cyber Security in Systems-of-Systems: Assessing the Impact of Attacks Through Interdependency Analysis
  - Integrated Analysis of Functional and Developmental Interdependencies to Quantify and Trade-off *Ilities* for System-of-Systems Design, Architecture, and Evolution

- AIAA Space Conference 2013
  - Presented the paper "Maintenance and Recycling in Space: Functional Dependency Analysis of On-Orbit Servicing Satellites Team for Modular Spacecraft".

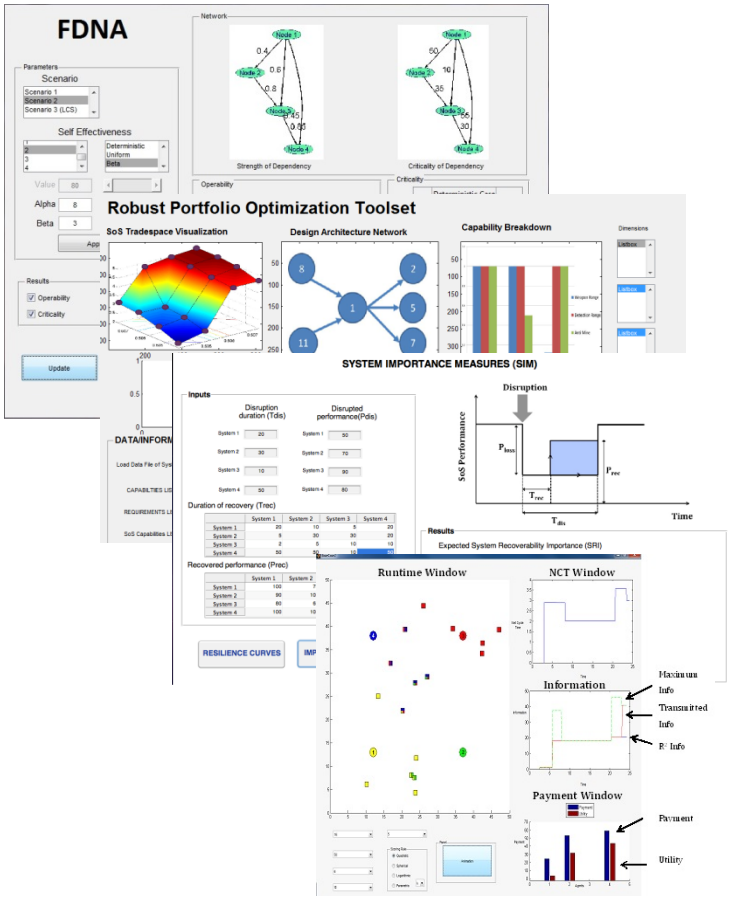
- IAF International Astronautical Congress (IAC) 2013
  - Presented the paper "Dependency Network Analysis: Fostering the Future of Space With New Tools and Techniques in Space Systems-of-Systems Design and Architecture".

- Webinars/Workshops
  - SoSCIE (10th October 2013) - A Portfolio Approach to System-of-Systems Acquisition and Architecture
  - SEI hosted workshop on SoS, Washington DC
  - EU-US Collaborative Strategic Research Agenda in Systems of Systems
  - ERS (Engineering Resilient Systems) Workshop Washington D.C.
  - SERC SSRR (Nov 2012) Washington DC

Strategic Agenda: Ongoing and Beyond

- Development of Graphical User Interface (GUI) for demo deployment of Analytic Workbench
  - Initial rapid GUI prototyping in MATLAB
  - Collaborator preliminary feedback will drive interface 'look, feel and functionality'
  - Refinement of NWS agent simulation as part of demo package for user experience

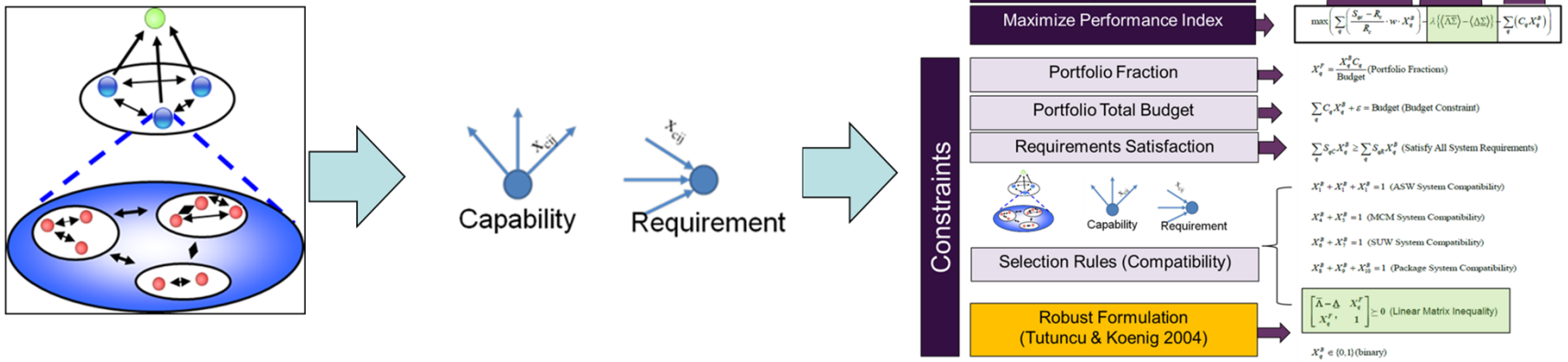
- Exploration of HUBzero platform environment as potential deployment platform for AWB engagement with larger community
  - Deployment of AWB MATLAB GUIs within HUBzero host
  - Active collaborative environment for users of workbench

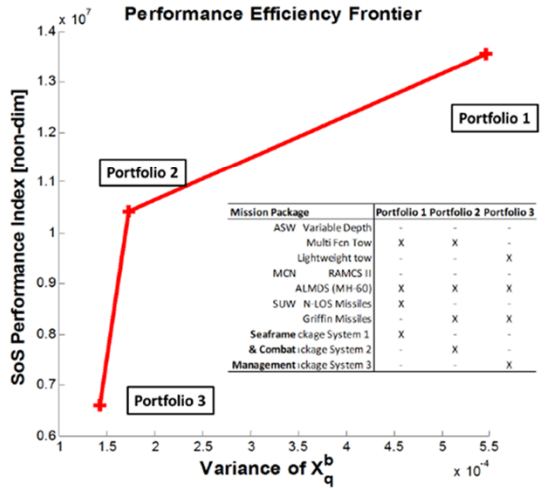


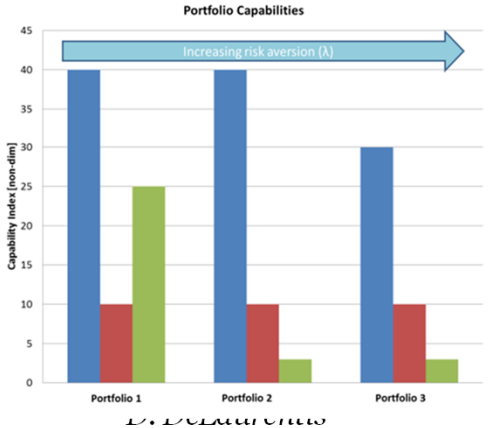
*Actual workbench GUI snapshots

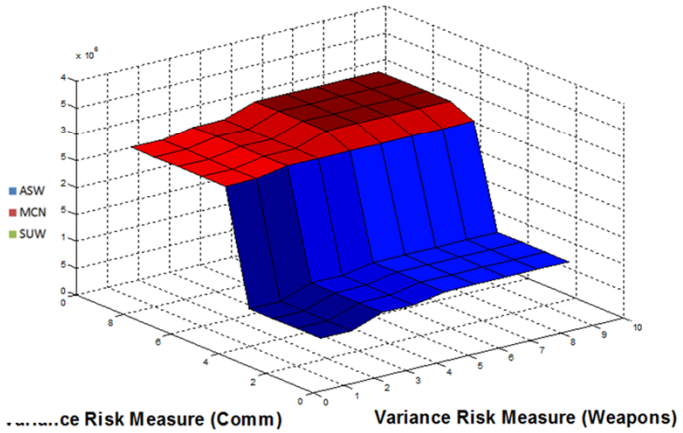
Robust Mean Variance Portfolio Optimization

Decision support approach from financial engineering/operations .
Balancing 'rewards' of acquisition with interconnected 'risks' of development time









Functional/Developmental Dependency Network Analysis (FDNA/DDNA)

Data driven methods to analyze and quantify interdependencies and cascading effects of risks through networks of systems.

FDNA (developed by Garvey & Pinto, MITRE)

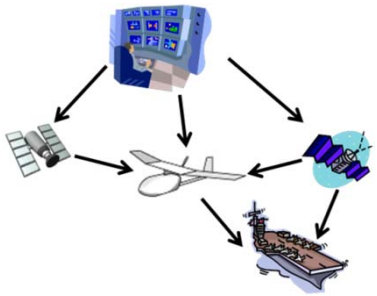
Assess the **effect of operational dependencies** when partial failures (degraded operability) occur in operational networks (FDNA); *Purdue created stochastic version*

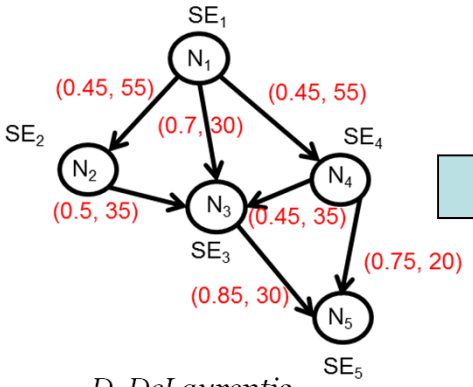
DDNA (Purdue extension)

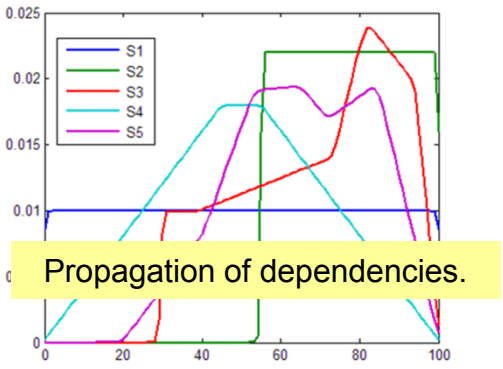
Assess the **effect of development dependencies** when delays occur in development networks

- Directed acyclic networks
- **Links are operational/developmental dependencies**
- **Nodes can be systems or capabilities**

- **Strength of Dependency (SOD):** α_{ij} is the fraction of the operability of node N_j due to the dependency on node N_i. Ranges between 0 and 1.
- **Criticality of Dependency (COD):** β_{ij} is the maximum level of operability reachable by node N_j when the operability of node N_i is 0. Ranges 0-100.







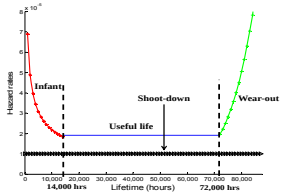
Propagation of dependencies.

Bayesian Networks (in the operational domain)

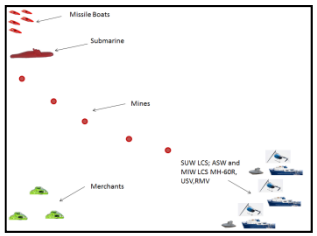
Data driven methods to evaluate the resilience of SoS design alternatives in the face of failures during operations.

Inputs:

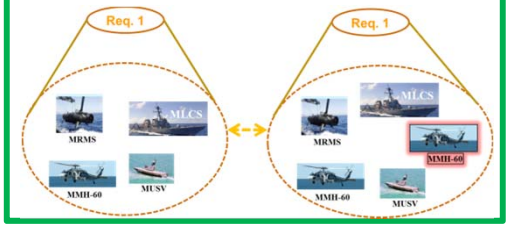
- Failure probabilities of constituent systems



- Conditional probabilities

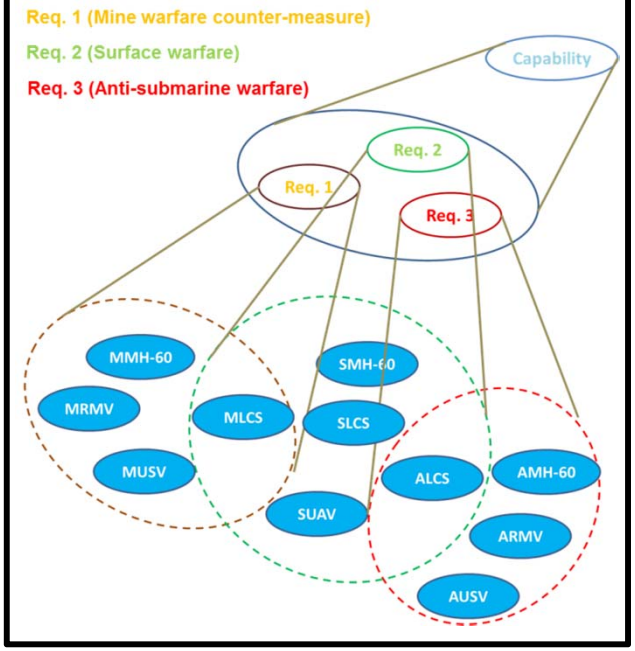


- Architectures



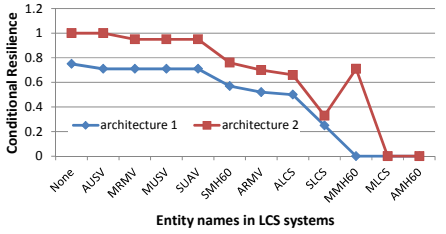
Bayesian Networks Model

Assumption:
- Directional graph

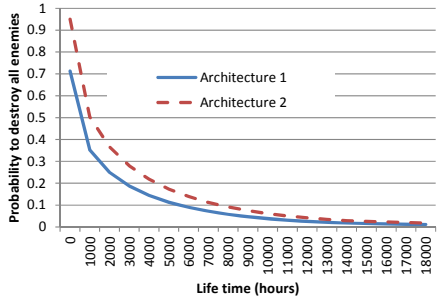


Outputs:

- Critical systems (Criticality of systems)



- Resilience patterns



SoS Resilience via Stand-In Redundancy

Quantitatively assessing impact of compensating for a loss of performance in one or more constituent systems through re-tasking of remaining systems.

- Traditional reliability analysis tools not suitable for SoSs:
  - Heterogeneity, geographical distribution, interdependencies
  - Backup systems are costly and impractical
- Using stand-in redundancy, systems can:
  - Contribute to SoS-level capabilities in ideal case, and
  - "Stand-in" for failed functions during disruptions