PURDUE UNIVERSITY

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Acquisition Management for Systems-of-Systems: Exploratory Model Development and Experimentation

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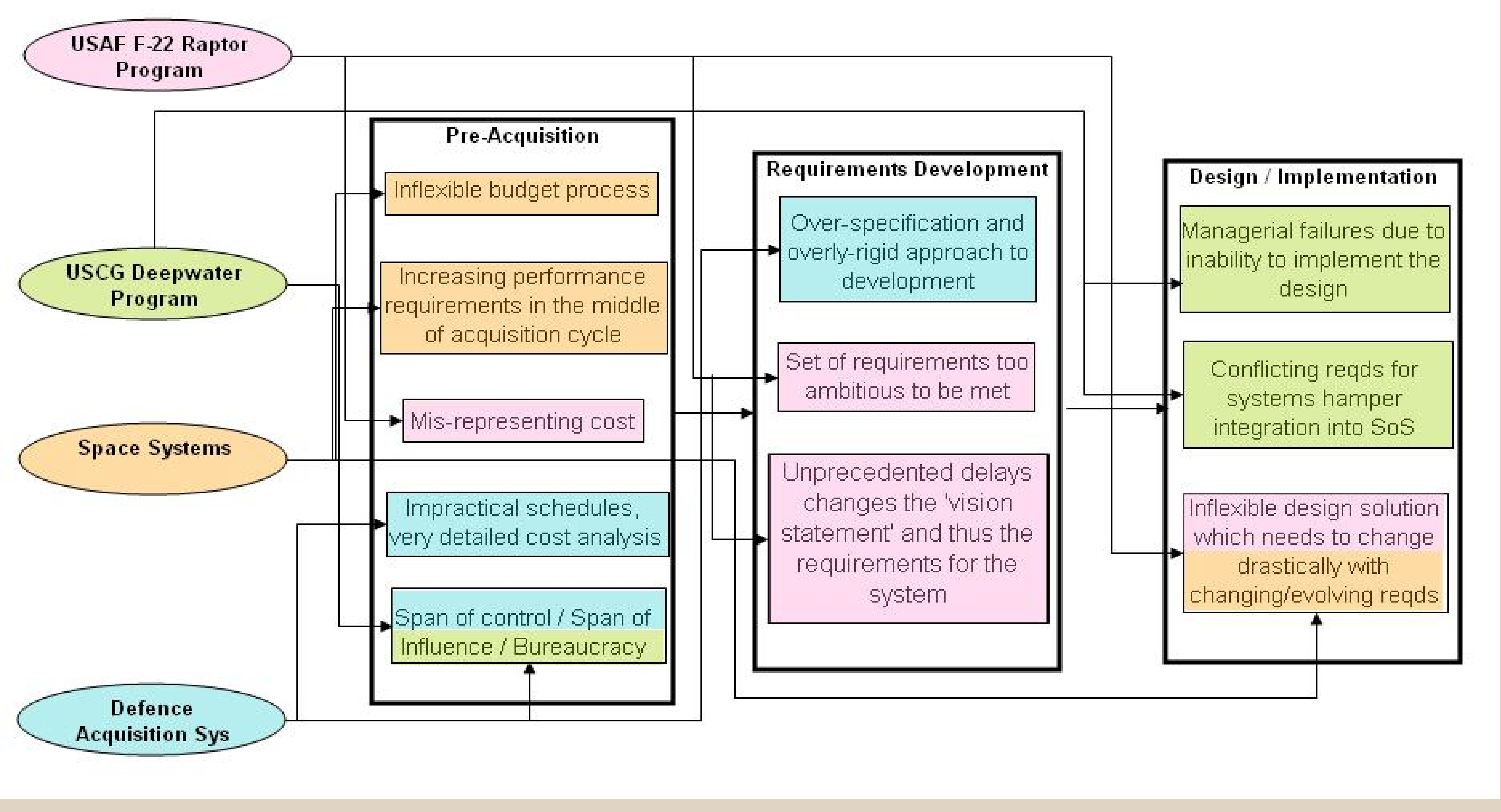
Overview of Agenda/Presentation

- Motivation and problem statement
- Recap from prior work
  - Conceptual model based on OSD's SoS SE Guide
  - Computer simulation: Exploratory SoS Acquisition Model
- Snapshots from illustrative problems
  - Dynamic impacts of requirement interdependency, risk, span-of-control
  - Incorporating network structure characteristics in model
  - Monte Carlo simulation of example problem to observe outcome statistics
- Summary and ongoing research

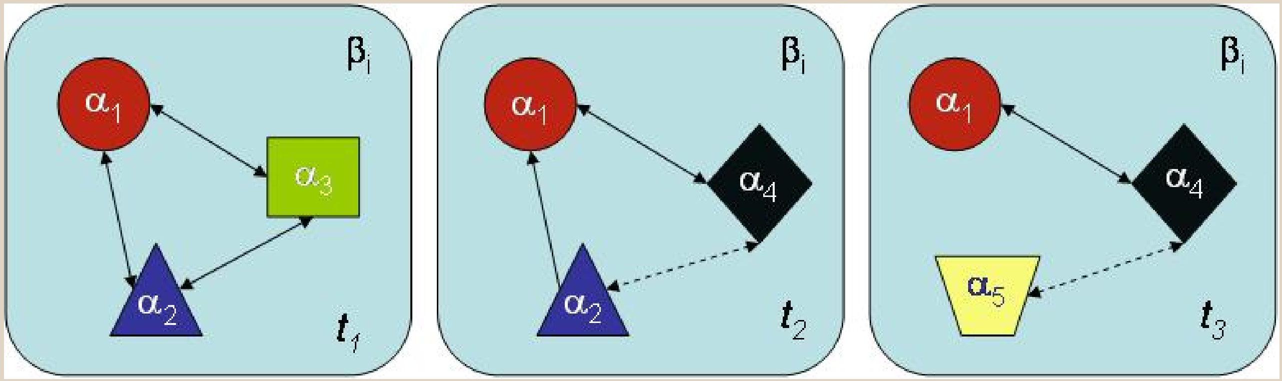
Motivation

Literature on recent history indicates a variety of challenges for SoS acquisition



SoS Sources of Complexity

Working Definition for Complexity:
the amount of information necessary to describe the regularities in a system effectively



- Dynamic and Uncertain Connectivity
  - **between** levels of abstraction
  - **across** scope dimensions
  - multiple time scales
  - emergence (unforeseen interdependencies)
- "Porous" boundary
  - Changes in constitution of SoS
  - Evolving nature of an 'open system'
- Heterogeneity & Multiplicity
  - Multiplicity of perspectives: A root cause of interoperability issues
  - Heterogeneity of participants (within and between Human & Technical); Socio-Technical Systems

Root Causes of Failure
(within acquisition processes)

- *Misalignment* of objectives among the systems
- Limited *span of control* of the SoS engineer on the component systems of the SoS
- *Evolution* of the SoS
- *Inflexibility* of the component system designs
- *Emergent behavior* revealing hidden dependencies within systems
- *Perceived complexity* of systems
- Challenges in *system representation*

Used categories from Rouse, W. (2007, June). Complex Engineered, Organizational and Natural Systems. *Systems Engineering*, 10, 3., pp. 260-271

Recap: Research Goals

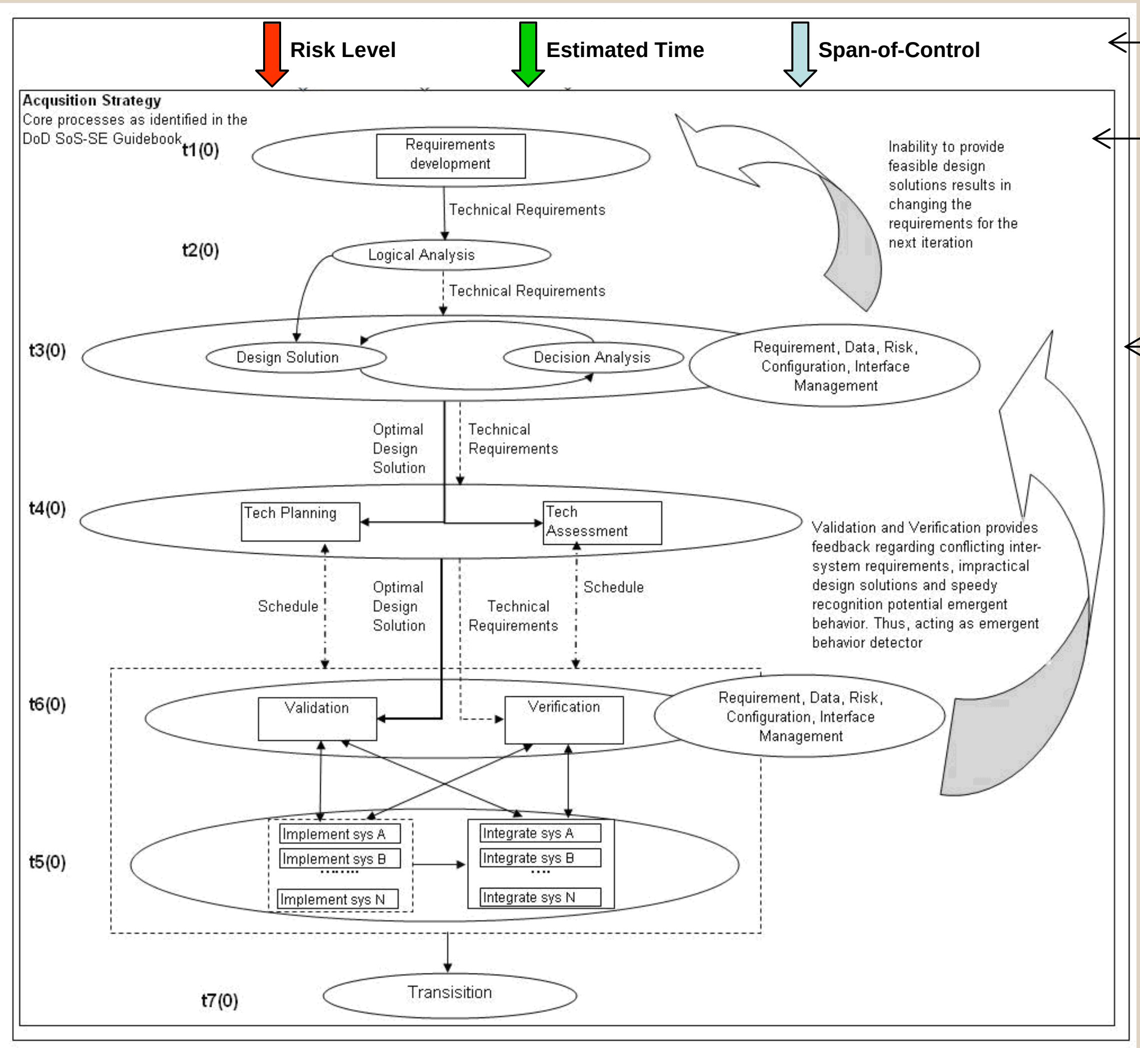
- Uncover underlying functions affected by complexities due to evolution in SoS acquisition and span-of-control
- Capture Dynamics: Exploratory SoS Acquisition Model
  - Depicts the processes (SoS SE Guide) in a hierarchical setting
  - Show the flow of control between the processes throughout the acquisition life-cycle
  - Interactive computational model: allow users to ‘explore’ complexities
- Experiment: Generate insights and approaches to improve the probability of program success
- Mapping of Operational Views (OV) to Systems Views (SV)
  - System capabilities and their interconnections

Recap: Development of a Dynamic, Exploratory Model for SoS Acquisition

1. *Pre-Acquisition Model (not included here)*
   - Understand the influence of external stakeholders on the acquisition process

2. *Acquisition Strategy Model*
   - Based on the 16 technical management and technical systems engineering processes outlined in the Defense Acquisition Guidebook (5000 series) applied to an SoS environment (SoS-SE Guide)
   - Conceptual model depicts the processes in a hierarchical setting to show the flow of control between the processes throughout the acquisition life-cycle

Recap: Acquisition / Development – The Paper Model
(based on SoS SE Guide)



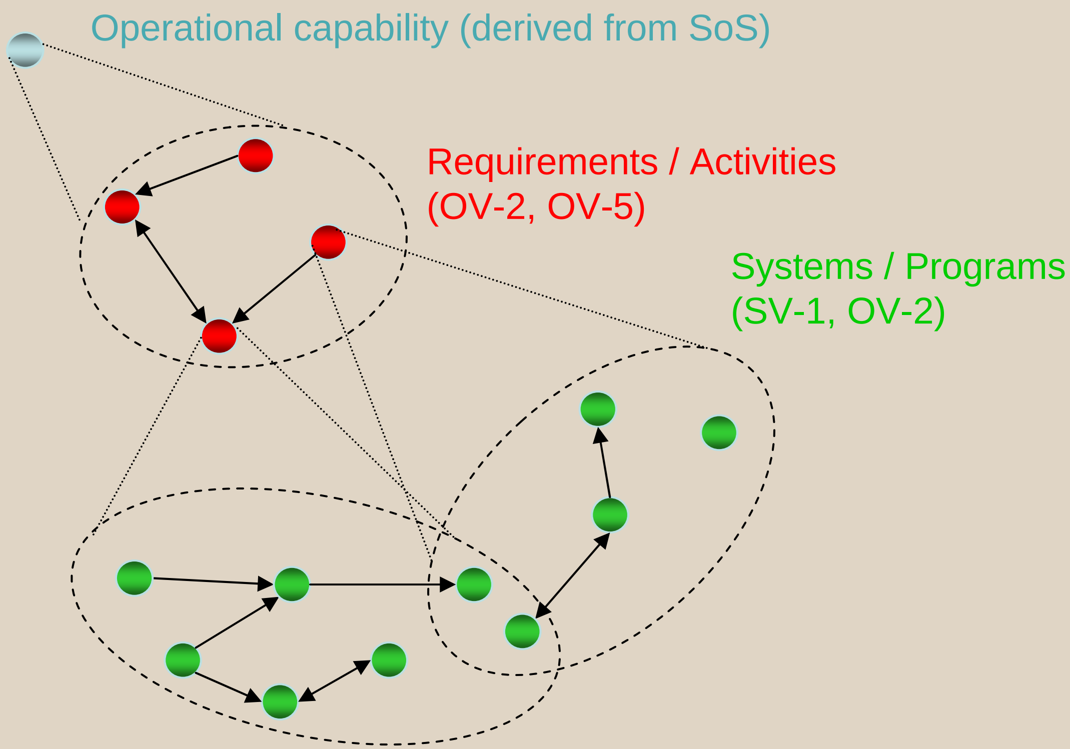
Project-level (SoS)
Risk profile: low, med, high
Span-of-control: low, high

Requirement-level
- Number of requirements
- Requirement dependency
- Probability of disruption

System-level
- System dependency
- Initial completeness level
- Int/Imp time
- Probability of disruption (comes from risk-profile)

Output
Completion time

Methodology Abstraction



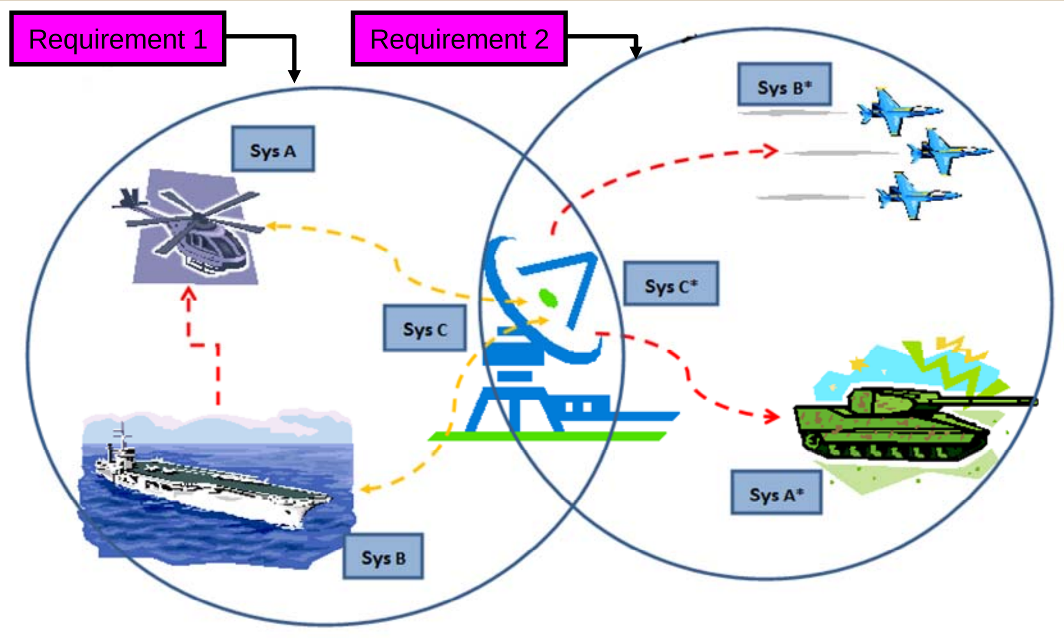
Operational (OV): systems work together to provide a capability

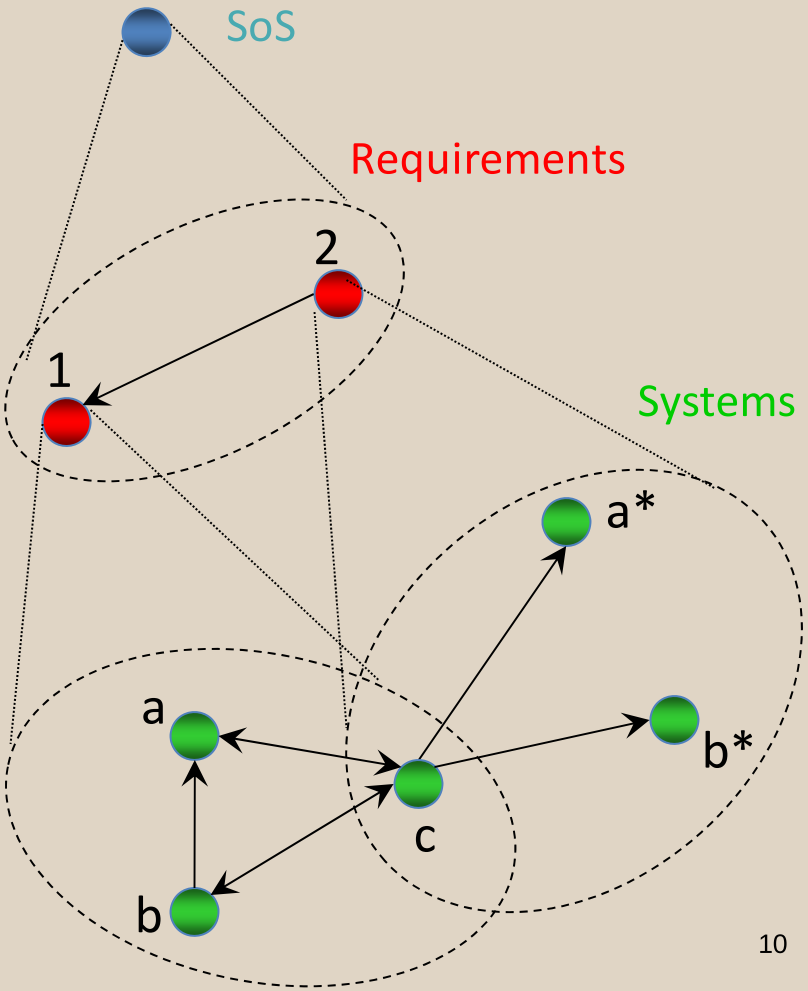
System (SV): define nature of interaction between systems

Programmatic: relationship between systems during development

- Discrete-event simulation with probabilistic behavior of systems
- Levels have predetermined probability of disruption
  - Requirement-level disruptions: affect design solutions (i.e. design solution of system X cannot meet requirement)
  - System-level disruptions: affects completeness level of system and completion time (i.e. set back in implementation phase of system X results in longer time)

Illustrative Example





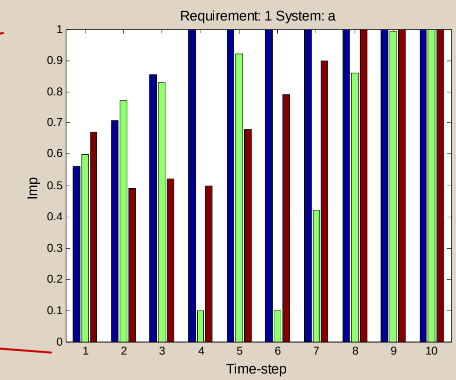
System Dep (R1)

$$\begin{bmatrix} 0 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix}$$

System Dep (R2)

$$\begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$

Effect of Requirement Dependency

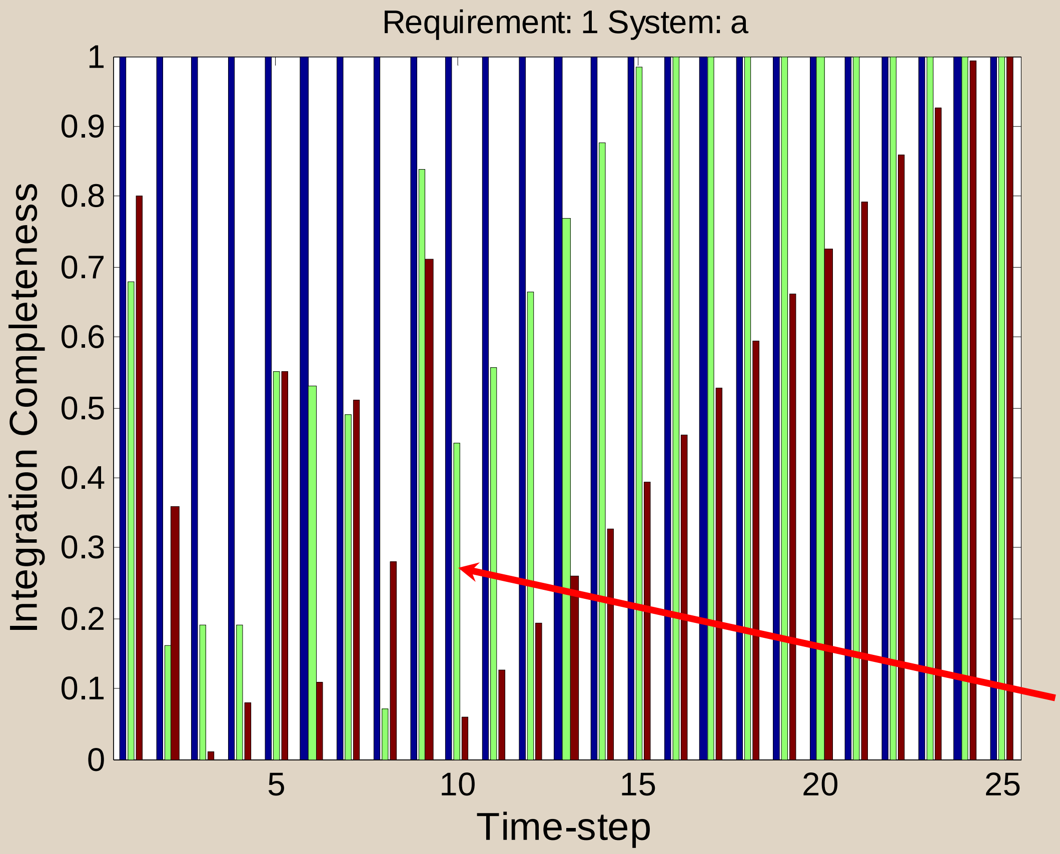


***Decision Analysis* rejecting Design Solution as infeasible (Requirement-level disruption)**

Requirement 2 waiting for Requirement 1 to complete (reach *Testing*)

Effects of Disruptors (system-level)

- Inevitable disruptions on both system-level and requirement levels will occur
- *Technology Assessment* is able to immediately trace and resolve the problem
  - This prevents the development from stalling or regressing over multiple time-steps

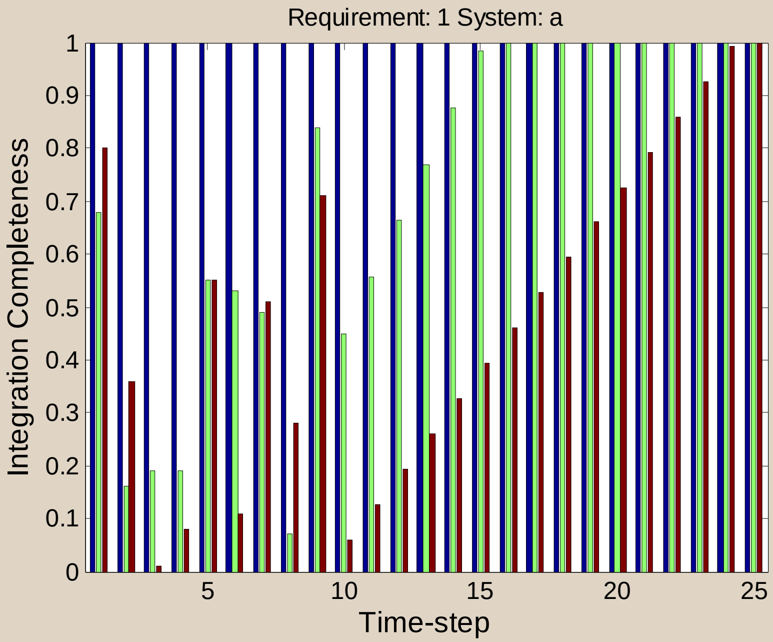


Each color represents an individual system (system 'a' is blue)

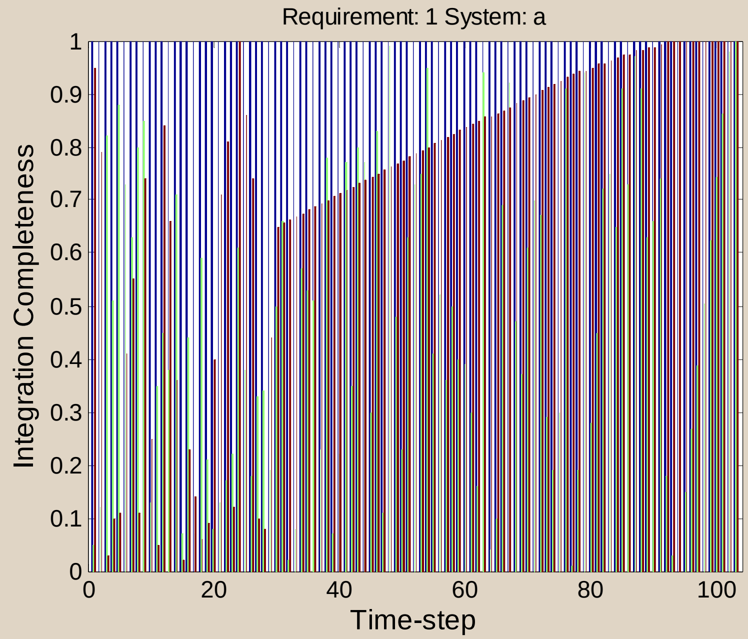
Negative disruptions correspond to system re-engineering and lower completeness level in Integration (and Implementation) phase

Effect of Project Risk

(determines probability of disruption in Integration and Implementation phase)



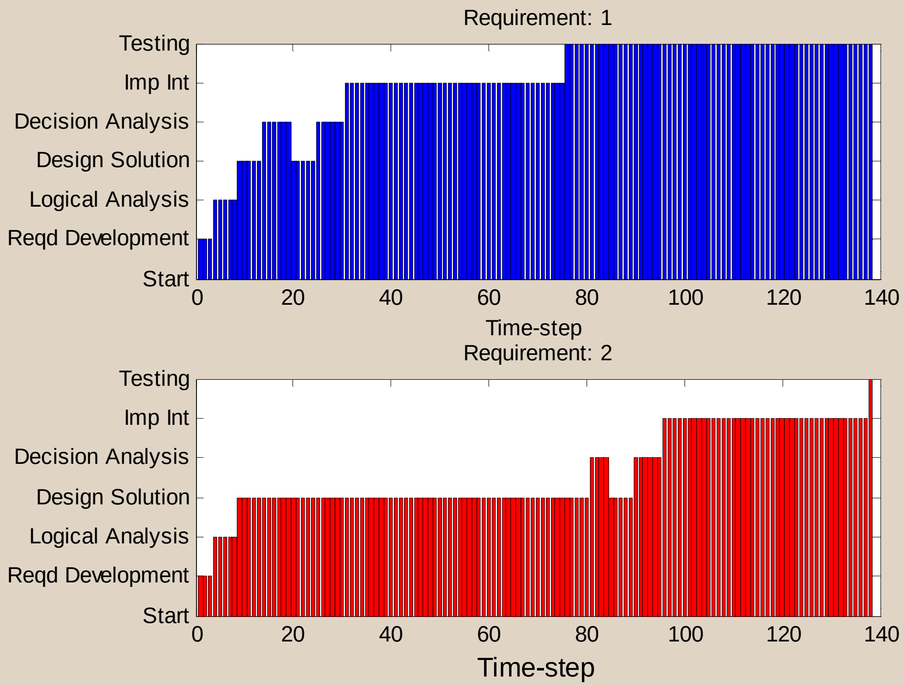
Low-risk instance



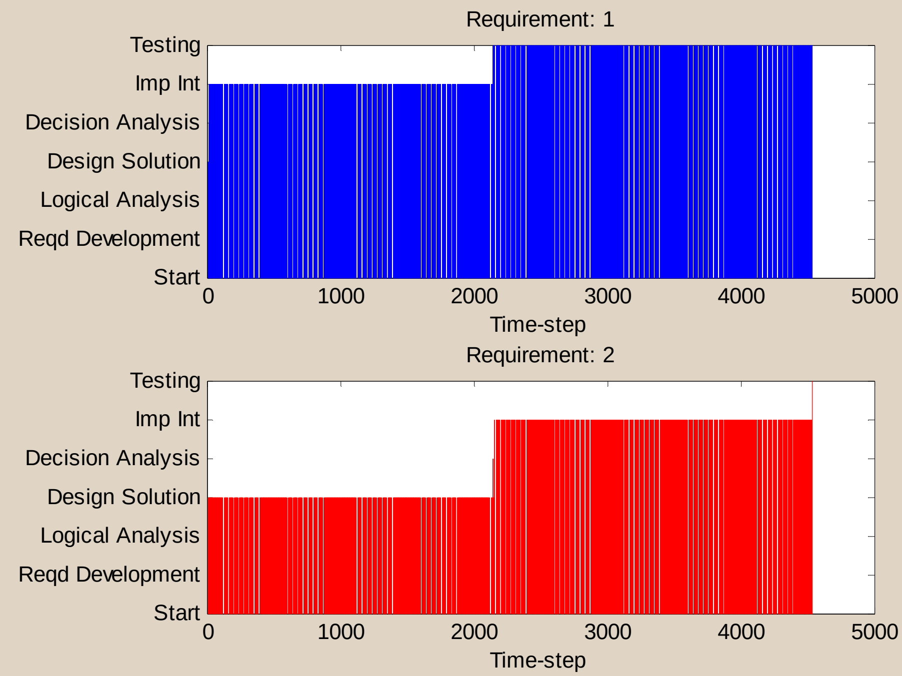
High-risk instance

- Some systems have a much higher risk factor
  - They are more vulnerable to negative disruptions in their development
- Higher risk of disruptions implies more time to complete the stage
  - In fact, completion may fail → return to Design Solution

Effect of Span-of-Control



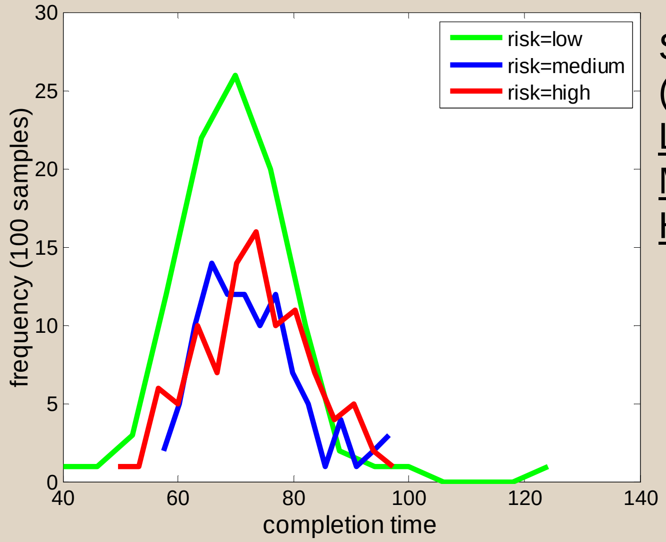
High Span-of-control



Low Span-of-control

- Span-of-control has large impact on project time
  - High span-of-control → SoS level authority, can implement in parallel
  - Low span-of-control → less coordination, implement in series, results in longer completion time

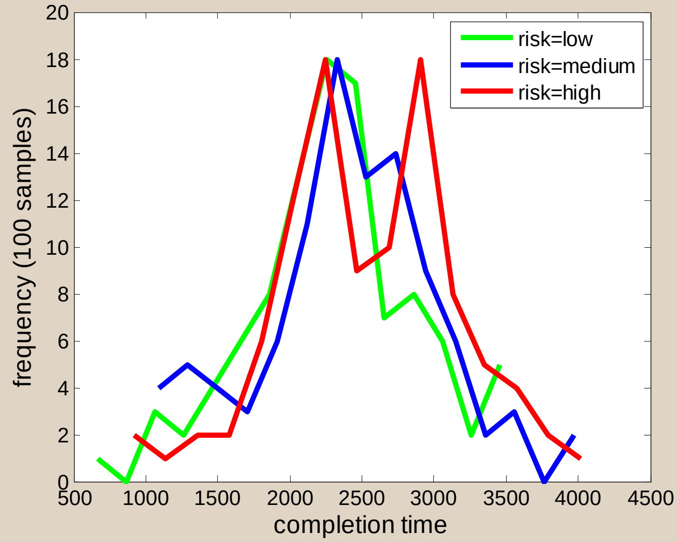
Monte Carlo Simulation (Outcome Statistics from 100 runs)



Independent Requirements & high span-of-control

System-level disruptions (uniform distribution):
Low-risk: with 0.01 probability
Mid-risk: with 0.10 probability
High-risk: with 0.15 probability

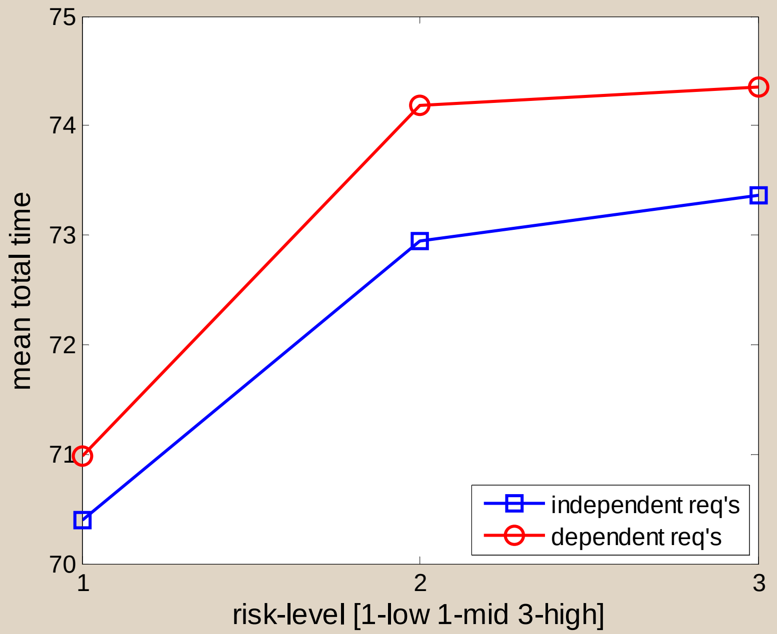
Decision Analysis disruptions:
Independent of risk
With probability 0.1 or 0.2 (each is equally likely)



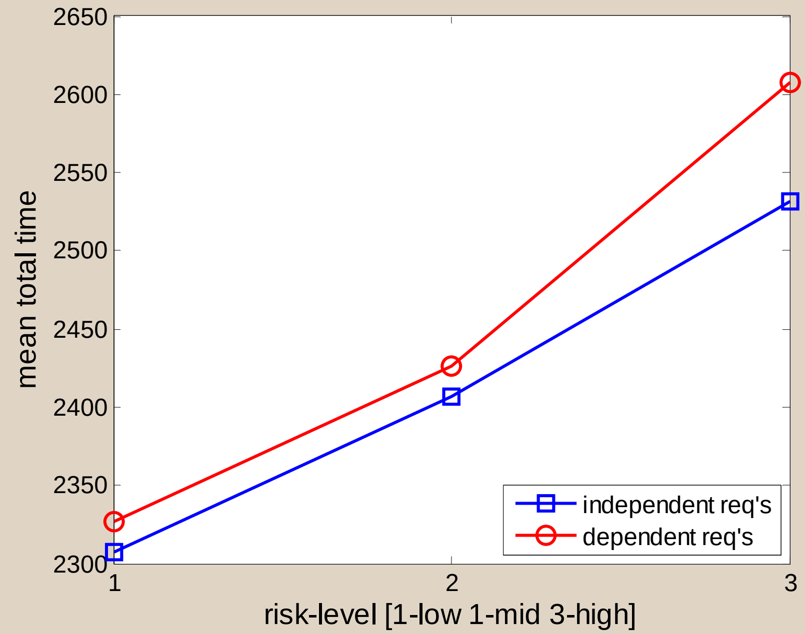
Independent Requirements & low span-of-control

- Span-of-control has large impact on completion time
- Distribution of results nearly normal
- How do the mean values compare for different control parameters?

Result Analysis



High Span-of-control

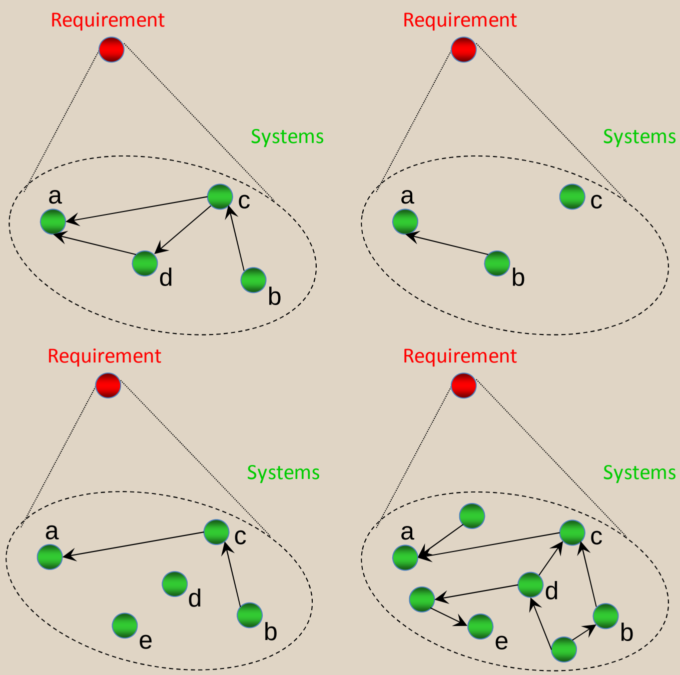


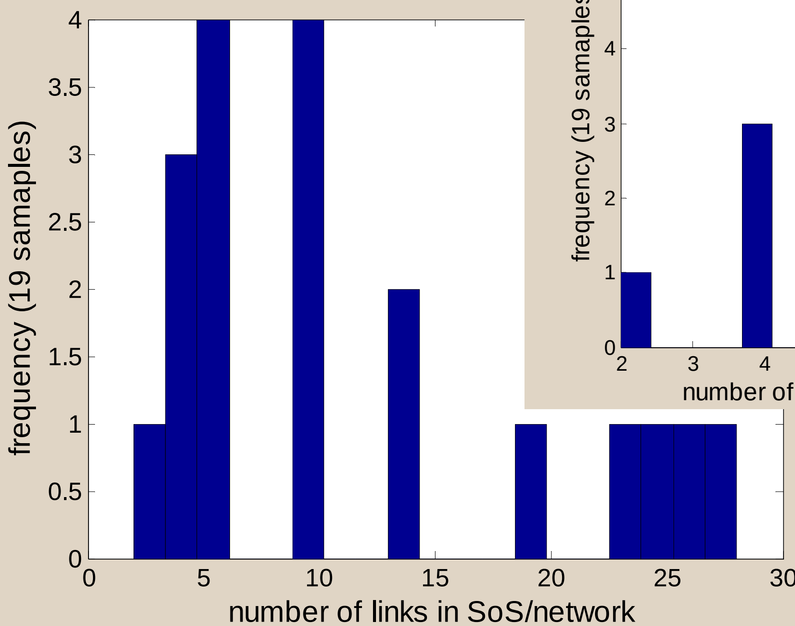
Low Span-of-control

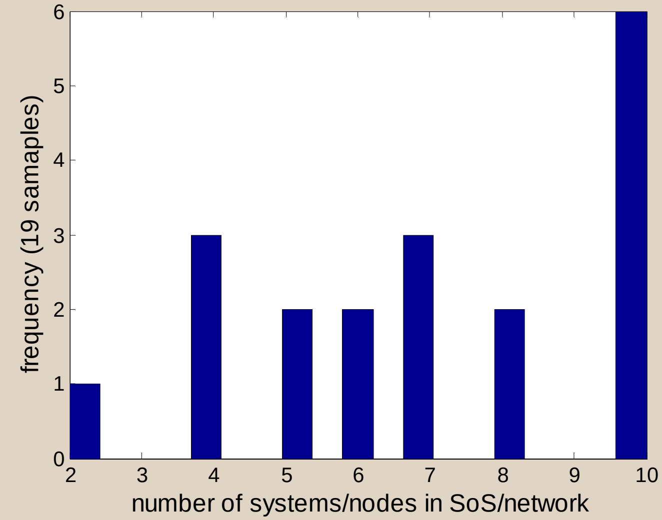
- Span-of-control overshadows risk-level and requirement interdependency
- Impact of dependency and risk-level multiplied when coupled with span-of-control

SoS Configuration Scenarios Considered

- Consider 19 randomly generated SoS configurations
  - Uniformly random selection of number of systems (up to10 systems)
  - Random selection of links between systems with correlation of 0.25
- Simulate acquisition process 50 times for each SoS



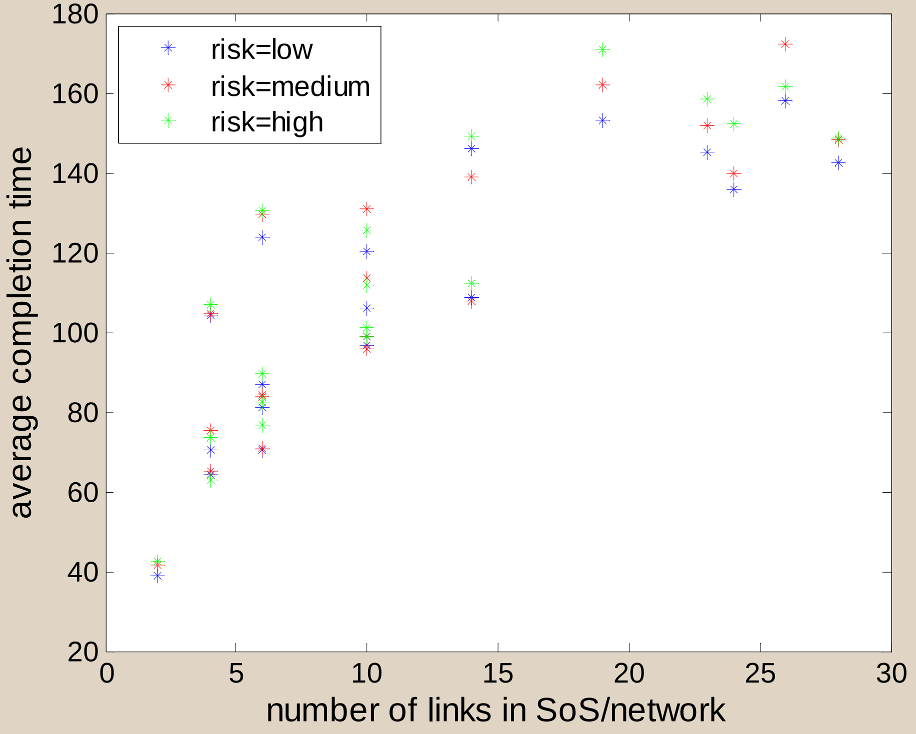


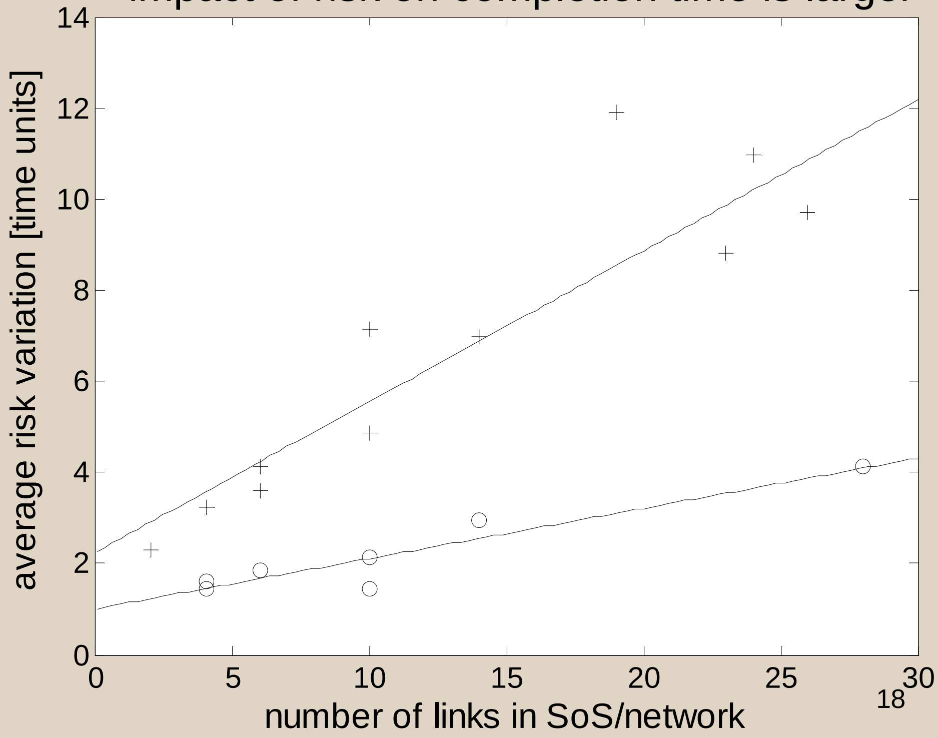


Impact of System Interdependency
(high span-of-Control)

- Higher number of links means higher completion time
- Impact of risk appears relatively small when compared to impact of network size

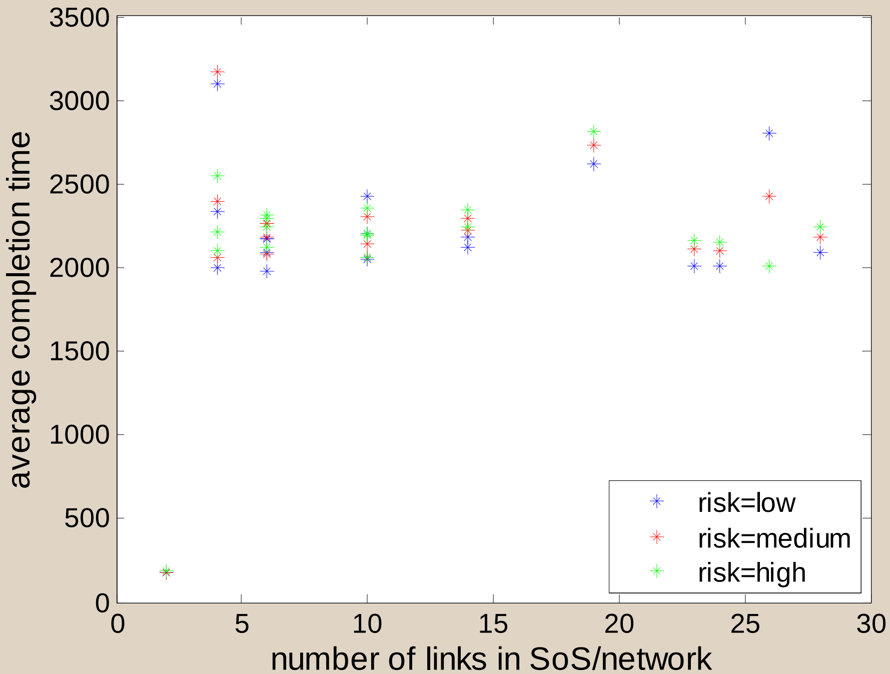
- Average risk variation is the average different between low, mid, and high risk
- On SoS with more nodes /systems ('+' symbols) but same number of links, the impact of risk on completion time is larger

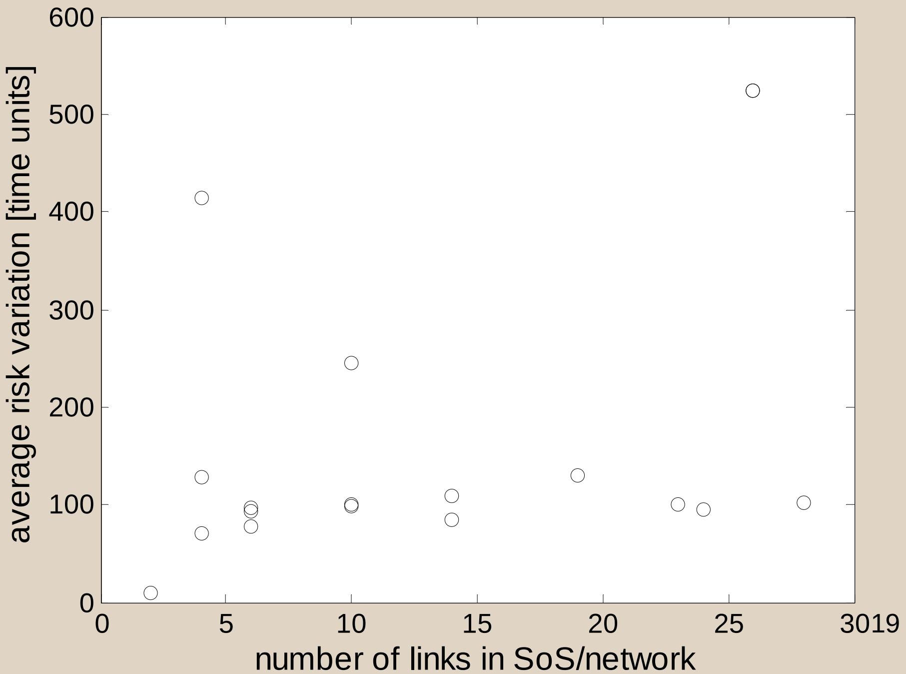




Impact of System Interdependency
(low span-of-control)

- Span-of-control (low) overshadows impact of SoS complexity
  - Average completion time not affected by increased system interdependency (complexity)
  - Different risk-levels give nearly same average completion time





Reflections

- Exploratory model is intended to enable acquisition professionals and program engineers to learn about complexities, dynamics, and disruptions, identifying markers of failure and success
  - Evolution of interdependencies
  - Network structure and span-of-control of SoS
- What role should the SoS engineer play in relation to the program managers?
  - Understand the system dynamics so that a motivator for PMs is identified
- Understand cascading effects of budget (risk) and requirement changes
  - Ability to react quickly (agility) with-in requirement cycle

Ongoing/Future Work

- Use real acquisition data in model
  - Collaborating with Interdependence Risk Study project of Rob Flowe at ODUSD(AT&L) SSE/SSA
  - Presently are incorporating data from DAES charts in model
- More detailed description of risk and its impact at the SoS level
  - Risk due to: technology, advocacy, schedule, funding
  - Investigate structure and dynamic of program data as a dynamic network model
  - Second and third degree impacts of risk that depend on network structure
- Dynamic time-scales: Investigate partial/gradual implementation or development of requirements
  - Stable intermediate forms
  - Risk may be reduced because it is also a function of time

Thank You

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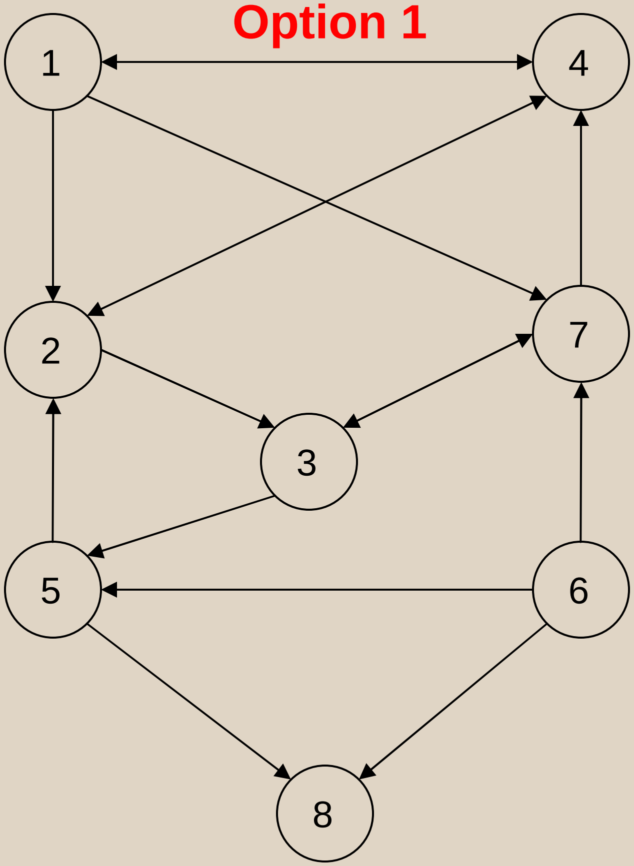
Extra Slides I

Operational vs. Acquisition Risk

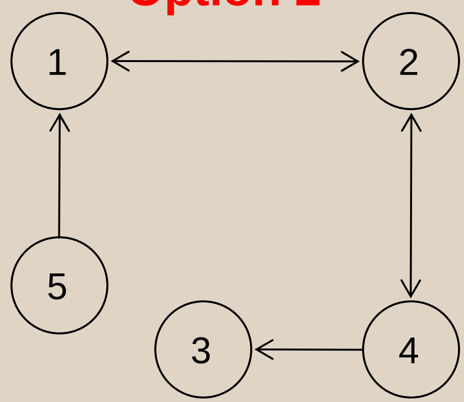
Static Example

- Each network represents a potential SoS that can meet a given requirement
  - These are five options available to the SoS engineer
- Which SoS should be chosen?
  - What is the tradeoff between operational and acquisition risk among the five options?

Option 1



Option 2



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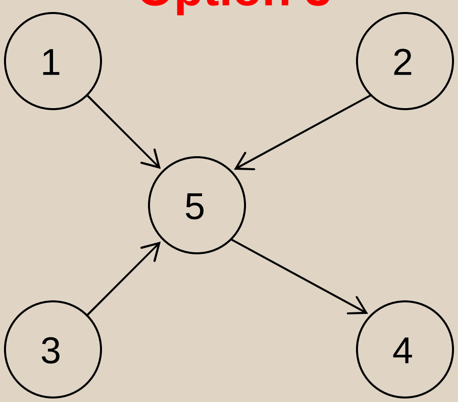

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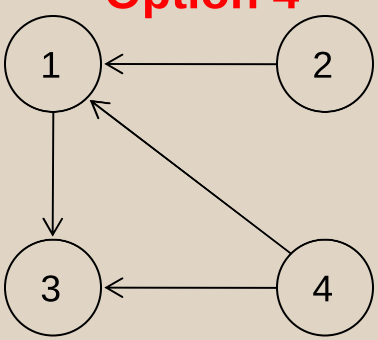

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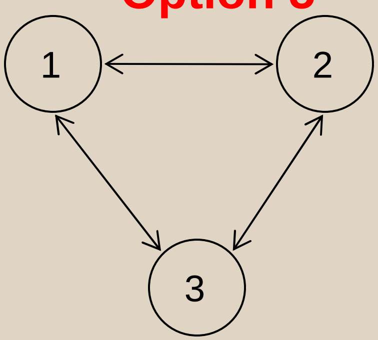

Operational vs. Acquisition

- Each point is the absolute risk (1st, 2nd, … order of risk based on network structure) of the five SoS presented earlier
- Robustness is assumed to be the inverse of risk