Distributed Decision Making in Systems of Systems

Nirav B. Shah, PhD in Aeronautics and Astronautics (expected 2010)

Committee: Prof. Daniel Hastings, chair; Prof. R. John Hansman; Dr. Donna H. Rhodes; Prof. Joseph Sussman

nbshah@mit.edu

Biography

Nirav B. Shah is a graduate student at MIT pursuing a Ph.D in Aeronautics and Astronautics. The objective of his doctoral work as a member of SEAri is to explore the use of formal model in understanding the complex socio-technical dynamics the underlie systems of systems. Nirav has worked at Los Alamos National Laboratory and with Booz Allen Hamilton. He received an S.B. (2001) degree and an S.M. (2004), both in Aeronautics and Astronautics, from MIT.

Related Publications

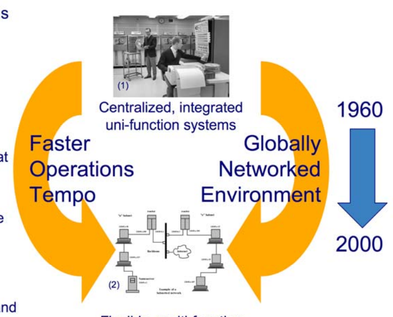
Shah, N.B., Richards, M.G., Broniatowski, D., Laracy, J., Springmann, P., and Hastings, D.E., "System of Systems Architecture: The Case of Space Situational Awareness," AIAA Space 2007, Long Beach, CA, September 2007.

Shah, N.B., Hastings, D.E., and Rhodes, D.H., "Systems of Systems and Emergent System Context," 5th Conference on Systems Engineering Research 2007, Hoboken, NJ, March 2007.

Shah, N.B. "System of systems architecture: Attraction Basins and Stability in Multi-stakeholder Preference Space," MITRE-MIT Enterprise Modeling Exchange EME 2008, McLean, VA, September 2008.

Research Questions

- Defining the System of Systems (SoS) problem
  - What are SoS?
  - Why are they important?
- Descriptive research
  - What is SoS architecture?
  - What is the structure of the decision making processes that underlie SoS?
- Prescriptive research
  - How can the SoS architect use their influence to effect the structure and behavior of the SoS?
  - How can modeling aide the practitioner in understanding and managing the complex socio-technical dynamics in SoS?



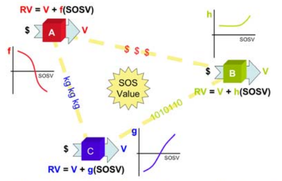
(1) http://www.electrohype.org/press/pionjar/IBM_System360_Mod_50.jpg
(2) http://www.washington.edu/R870/img/Network.gif

Existing state of SoS literature

- Dominated by case and experience based discussion of prior and current SoS
  - Generated many useful heuristics and guidance for practitioners but lacks rigor and consistency (Maier 1999, Krygiel 1999, Sage 2001, Keating 2003)
- Modeling of SoS is an emerging field
  - How can models be used to understanding the limits of these heuristics -- especially in cases where existing case literature is lacking? (DeLaurentis 2006)

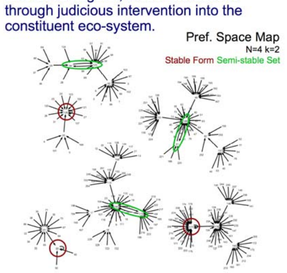
Maier MW (1999) "Architecting Principles for Systems-of-Systems" *Systems Engineering*
Krygiel AJ (1999) *Behind the Wizard's Curtain: An Integration Environment for Systems of Systems*
Sage AP; Cuppan CD (2001) "On the Systems Engineering and Management of Systems of Systems and Federations of Systems" *Information Knowledge System Management*
Keating C; Rogers R; et al. (2003) "Systems of Systems Engineering" *Engineering Management Journal*
DeLaurentis, D (2006) "Modeling and Simulation: Spanning the Life Cycle of a System of Systems" Methods for Designing, Planning and Operating Systems of Systems Workshop at Purdue University

Constituent interaction

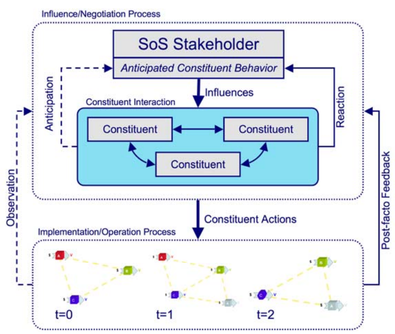


- **Example:** Stable forms in a small network construction problem
- Simulation used to produce a map of the joint preference space of the constituents for the various network configuration
- Nodes represent network configurations, edges show transitions between configurations that arise from interactions between constituents
- Three stable (length 1 cycles) and three semi-stable forms (length > 1 cycles) were revealed along with the basin of attraction of unstable forms around them

- Constituent interaction gives rise to the underlying structure from which the SoS is built
- SoS value emerges from those interactions
- SoS architects, by understanding these interactions, can account for, or even take advantage of, these interactions through judicious intervention into the constituent eco-system.



Distributed Decision Making

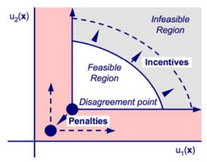


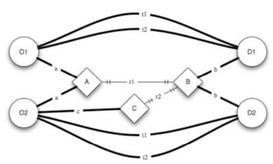
- Decisions in an SoS are distributed among a set of **constituents** and **SoS stakeholders**
- **Anticipation** and **reaction** between these two result in the choices (actions) taken by the constituent that **lead to changes in SoS** structure and operation
- **Anticipation** is the **feed-forward belief** of the SoS stakeholder regarding the constituent response to a set a set of influences
- **Reaction** is the **feed-back response** of the constituents to those influences
- Anticipation and reaction form a **negotiation process** between these two groups that **determines which constituent actions are implemented**

Extended from Schneeweiss (2003) *Distributed Decision Making*

Influence as an SoS design tool

- Inter-constituent interactions can be affected by the SoSE
- Incentives make feasible otherwise inaccessible value should the constituents participate
- Penalties reduce the utility of not participating



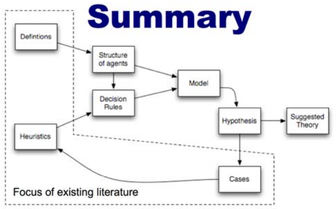


Example: Transportation
- Road and rail carriers compete on an interlinked network
- Intermodal service (road+rail) offers advantages over unimodal

Incentive: Tax breaks

Penalties: Usage fees for long haul truckers

Summary



- Objective
  - To describe the decision making processes that underlie SoS and provide prescriptive guidance rooted in the case literature and validated through agent-based modeling
- Method
  - Synthesis of disparate case literature on SoS into core practitioner recommended practices
  - Agent-based model that captures the essential features of decision making in an SoS vs. systems in general
- Anticipated Contributions
  - SoS influence mechanisms that can be used to modify constituent behavior
  - New potential heuristics focused on constituent behavior

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http://seari.mit.edu