Influence Strategies for "Constituent-Competitive" Systems of Systems

Nirav B. Shah, Ph.D. in Aeronautics and Astronautics (expected 2012)

Committee: Prof. Daniel E. Hastings (chair); Prof. Joseph M. Sussman (thesis Advisor); Prof. R. John Hansman; Dr. Donna H. Rhodes

Biography

Nirav B. Shah is a graduate student at MIT pursuing a Ph.D in Aeronautics and Astronautics. His doctoral work as a member of SEAri explores the interaction between social and technical domains in 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.

nbshah@mit.edu

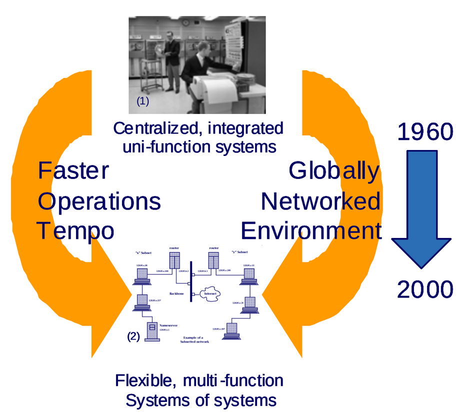
Related Publications

Shah, N.B., et. al., "Systems of Systems and Emergent System Context," CSER 2007.

Shah, N.B., et. al., "System of Systems Architecture: The Case of Space Situational Awareness," AIAA Space 2007.

Motivation

- Many new systems use networks (information, transportation, etc.) and/or combine pre-existing components
  - Components need not to be co-located to form systems
  - Decision making is more diffuse as component development need not be synchronized with system development
- Traditional SE does not adequately address such systems
  - Often assumes centralized decision making and hierarchy that may not be present in these systems
  - Need new approaches for both the technical and managerial challenges that arise from this emerging class of systems
  - Focus of research is management strategies for systems that are composed of other systems, i.e., systems of systems, where the constituents systems are independent and, in fact, competing with each other.



Research Questions

Descriptive research

- What types of relationships and interactions occur among SoS constituents and how do they determine SoS behaviors?

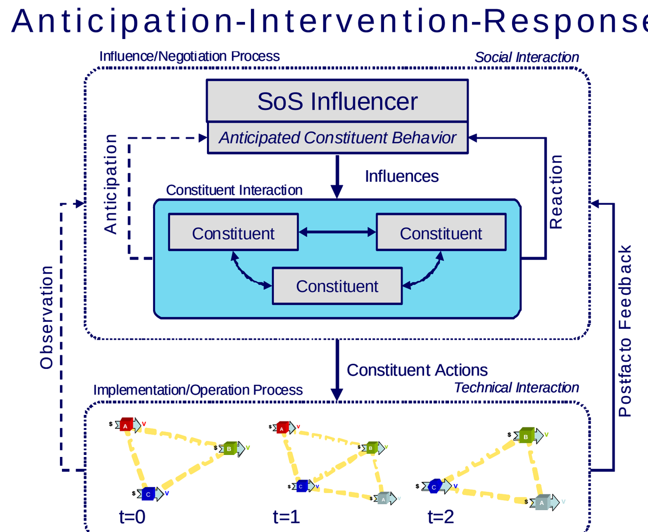
Prescriptive research

- How can SoS influencers affect the structure of the SoS and behavior of the constituents?

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

AIR Framework for SoS

Anticipation-Intervention-Response



Extended from Schneeweiss (2003) *Distributed Decision Making*

- Decisions in an SoS are distributed among a set of **constituents** and **SoS influencer(s)**
- **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**

Influencing Constituent Decisions

Incentives to put greater value on desired actions → Reallocation of x's to agents

$$\max_{x^i} I(x^i) + u^i(x^i, \hat{x}^{\cdot})$$

(Social) Institutions to impose and/or relax constraints on actions →

$$\text{such that} \quad g^i(x^i, \hat{x}^{\cdot}) \leq 0, \quad h^i(x^i, \hat{x}^{\cdot}) \leq 0$$

(Technical) Infrastructure to impose and/or relax constraints on actions

Information to vary the estimate of externals

Approach	As applied in case study
Change the payoffs through **incentives** or penalties	Tax on use of roads
Change decisions by providing additional **information**	Publishing prices to reduce information delay
Redefine the relationships between the constituents through **integration** or reallocation	Allowing cooperative routes
Change the **institutions** under which the constituents interact and the system is operated	Allowing cooperative routes
Change the **infrastructure** through which the constituent systems interconnect	Investing in terminal technology

Case Study: Intermodal Freight

Background

- Transportation system that involves multiple modes (i.e. rail + road)
- Key issue in supplying the hinterland regions that are not easily accessible from border/seaports
- Van Der Horst(2008), looking at the Netherlands, found a variety of coordination mechanism are in use to connect mode operators into intermodal chains
  - Some arose endogenously from within the SoS, while others required an external party to support the effort
- Good example for SoS as the constituents are truly operationally and managerially independent companies whose participation is not assured

Challenge

- Intermodal traffic is increasing due to improvements in technology and shipper's pressure for lower costs
  - Better IT for coordination
  - More efficient container handling
- Shippers want more choices with truck-like service quality and rail-like cost
- Governments have an interest in increasing intermodal freight usage to reduce logistics cost and encourage economic growth

How can a government or similar actor influence mode operators to change service offerings so as to increase the shipper traffic flow on underutilized intermodal railroad links?

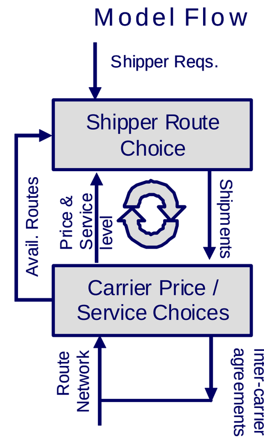
Van Der Horst, M. R. and De Langen, P. W. (2008). Coordination in hinterland transport chains: A major challenge for the seaport community. Maritime Econ Logistics, 10(1-2):108–129.

Model of a Transport Market

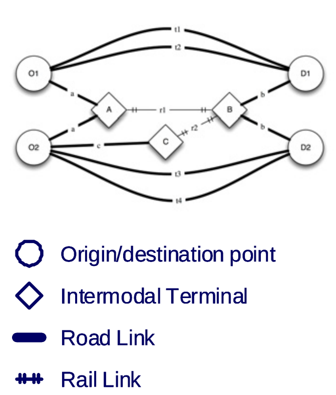
Approach

- Research existing intermodal transport system and identify approaches used to improve utilization
- Model a simplified transport network incorporating key characteristics of both shipper and carrier decision making
  - Shippers choose routes based upon an estimate of total logistics cost that accounts for price and service quality
  - Carriers choose prices and service levels to maximize expected profit
  - There are transaction costs and information delays when making changes
- Intent is not to replicate numeric results, rather match qualitative behaviors
- Use the model to examine the effects of different influence strategies

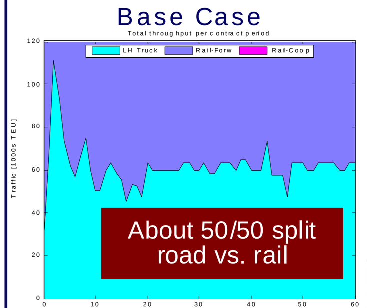
Model Flow



Transport Network



Base Case



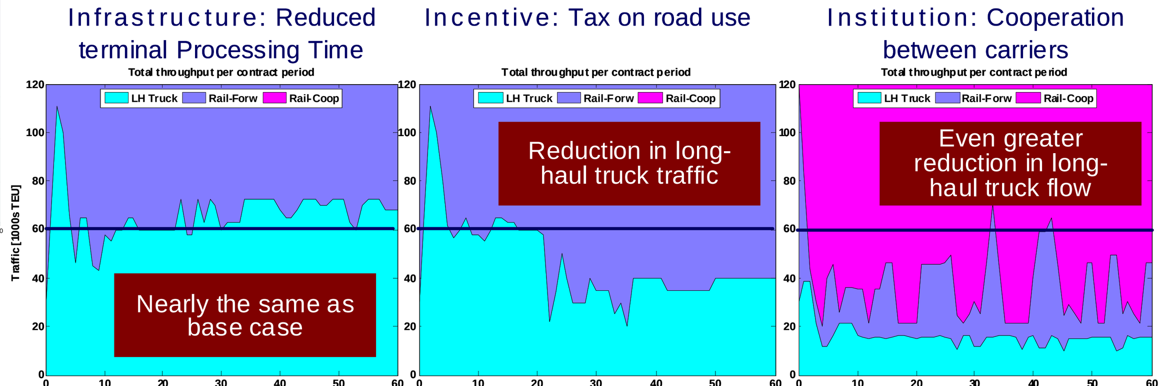
50/50 split between road and rail traffic and the rail road is under utilized even though rail has lower costs. Underutilization arises from a combination of access, quality of service and pricing issues.

Three Influence Strategies

Infrastructure: Reduced terminal Processing Time

Incentive: Tax on road use

Institution: Cooperation between carriers



Effect of Strategies on Stakeholders

	Truck Revenue	Railroad Revenue	Truck Cost	Railroad Cost	Truck Profit	Railroad Profit
Base	3.46	0.69	2.88	0.84	0.58	-0.14
	Total	**4.15**	**Total**	**3.71**	**Total**	**0.44**
Co-op	1.61	1.74	1.43	1.26	0.19	0.48
	Total	**3.35**	**Total**	**2.68**	**Total**	**0.67**
Tax	3.56	0.98	2.74	1.02	0.81	-0.04
	Total	**4.54**	**Total**	**3.77**	**Total**	**0.77**

- Total revenue, cost and profit are shown in $B
- Consider three stakeholder groups:
  - **Shippers:** Lowest transport costs under co-op strategy
  - **Truckers:** Make more in tax case. While their costs surely did increase, traffic moved to short haul routes where short haul operators had greater price leverage. Really dislike co-op option as it is in effect a wealth transfer to the railroads.
  - **Railroad:** Make more in co-op case. They have control over the common portion of co-op routes and can get a better share than they would having to sell ala carte service.

Conclusions

- **Decision making in systems of systems** can be characterized as the **interplay** between a network of **social interactions** between constituents (and influencers) and a network of **technical interfaces** between systems that they operate and manage
- **Influencers** can **use** a variety of **strategies** to change the behavior of constituents including: **incentives, information, integration, institutions and infrastructures**
- **Modeling** can **aid in understanding** the interactions between decision strategies that are being employed by constituent and their responses to influences, however, it is unlikely to be fully predictive
- **Successful implementation** of influence strategies depends upon understanding the **effect of strategies on** all involved **stakeholders**

Research Opportunities

- What about **constituent participation choice**? Case study assumed fixed constituent population. What if **constituents** can **enter/leave**?
- Framework took the view that decision making is a value maximizing activity. What about **stakeholders** who are **satisficing while minimizing risk**? Potentially true for infrastructural elements in SoS.
- What about **multiple influencers** who are acting at the same (or different) time either **competitively** or **cooperatively**?
- **Does this approach scale**, or will **constituents** needed to be **grouped into populations** as **larger SoS** are considered? How does the principal/agent problem change as the number of agents and/or principals becomes large?

For more information, please visit: http://seari.mit.edu