Influence Strategies for Systems of Systems

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Agenda

- Background and Questions
- A principal-agent framing of constituent and SoSE decision making
- Five basic influences
- Case Study: Intermodal Transport
- Conclusions and Research Opportunities

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SoS Research Agenda

- Background work in SoS
  - Definitions/foundation (Maier 1999, Sage 2001, Boardman 2006, Dahmann 2008)
  - Case studies of SoS (Kryiegel 1999)
  - Managing the technical interaction between constituents (Haimes 2007, Crossley 2004)
  - Modeling SoS Architecture (Sloane 2007, Biltgen 2007, Dagli 2007)
- More recent focus on the decision making within SoS and how to manage it given that it is distributed

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Questions

1. Given an extent SoS with a fixed set of constituent decision-makers each operating and managing one or more constituent systems, what are the **feedback relationships** between behavior of the constituent systems, the decisions made by the constituent decision-makers to change the constituent systems under their control and any external influencers who wish to affect the SoS via the constituents?

2. What **approaches** can be used by external SoS influencers to cause constituent decision makers to **change constituent systems** so as to **induce** a desired **behavior from the SoS**?

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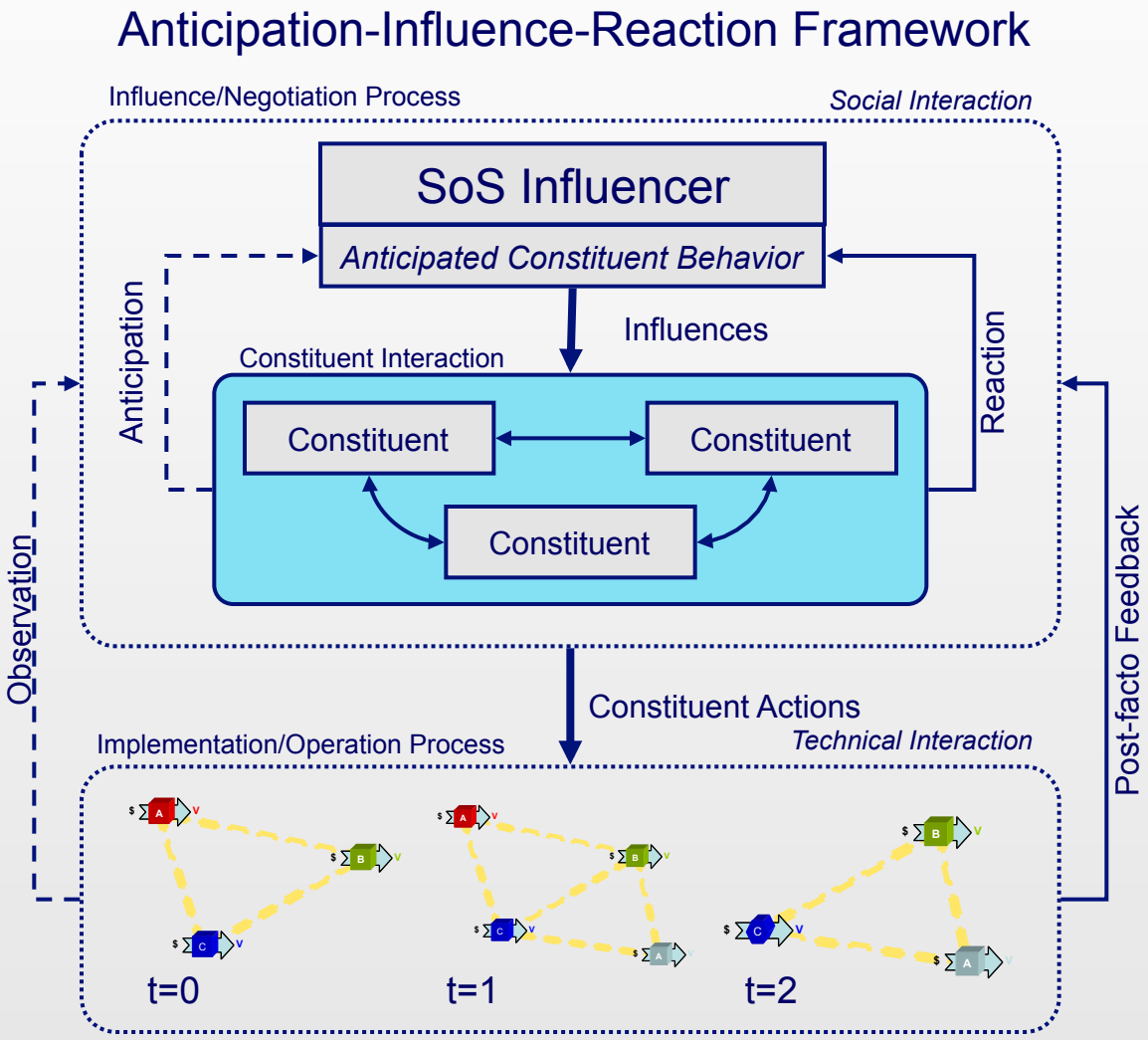
AIR Framework for SoS



- 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**

Extended from Schneeweiss (2003) *Distributed Decision Making*

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Applying to Real World SoS

- How does this work apply to real world SoS?
  - What are the limitations of the approach?
- Examples
  - Google/Craigslist Housing Maps (today)
  - GEOSS (in the paper)
  - Level 3/Cogent Peering dispute, Army Task Force XXI and more (in the thesis)

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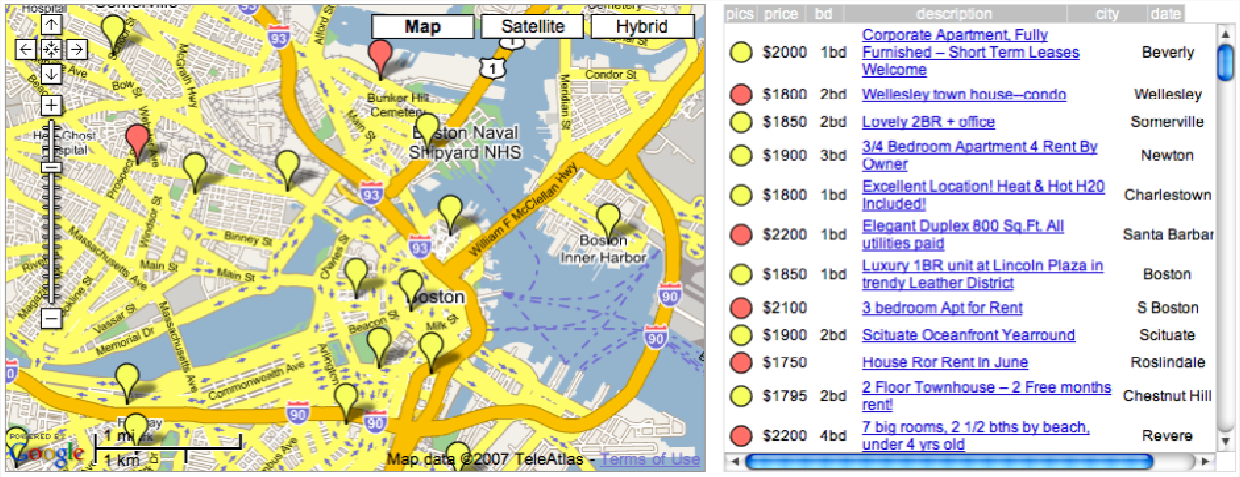
Example: HousingMaps



pics	price	bd	description	city	date
	$2000	1bd	Corporate Apartment, Fully Furnished – Short Term Leases Welcome	Beverly	
	$1800	2bd	Wellesley town house--condo	Wellesley	
	$1850	2bd	Lovely 2BR + office	Somerville	
	$1900	3bd	3/4 Bedroom Apartment 4 Rent By Owner	Newton	
	$1800	1bd	Excellent Location! Heat & Hot H20 Included!	Charlestown	
	$2200	1bd	Elegant Duplex 800 Sq.Ft. All utilities paid	Santa Barbar	
	$1850	1bd	Luxury 1BR unit at Lincoln Plaza in trendy Leather District	Boston	
	$2100		3 bedroom Apt for Rent	S Boston	
	$1900	2bd	Scituate Oceanfront Yearround	Scituate	
	$1750		House Ror Rent In June	Roslindale	
	$1795	2bd	2 Floor Townhouse – 2 Free months rent!	Chestnut Hill	
	$2200	4bd	7 big rooms, 2 1/2 bths by beach, under 4 yrs old	Revere	

- Website connecting Google Maps and Craigslist
- Allows users to see Craigslist rental listing overlaid on Google Maps
- First example of a “Mashup”

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The HousingMaps Story

1. Paul Rademacher completes his computer science PhD at UNC
2. Gets job at Dreamworks as a 3D animator
3. Needs to find apartment in the Bay area, but is annoyed at Craigslist interface and the need to go back and forth between mapping software and listings
4. Reverse engineers protocol for Google Maps annotation by monitoring TCP traffic on his machine
5. Without permission or even acknowledgement from Google or Craigslist, develops a tool that maps Craigslist listings onto Google Maps
6. HousingMaps.com is born as a *virtual* SoS.

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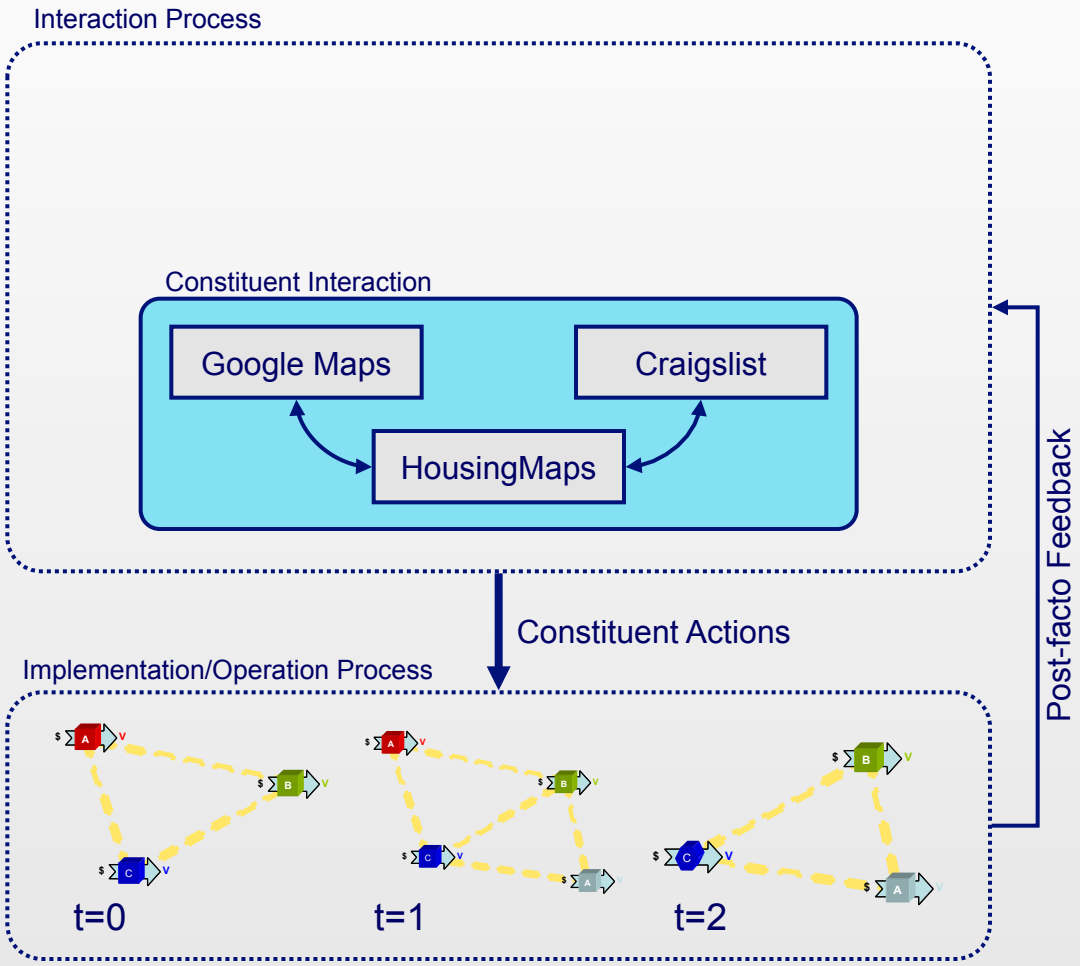
HousingMaps as Virtual SoS



- Initial structure is a virtual SoS as none of the constituents is trying to influence or, in some cases, even aware of the whole
- HousingMaps operates successfully and sparks many imitators as Rademacher shares his techniques with like minded coders
- Eventually, this spate of imitators, is noticed by Google and they release an API so that they can control and influence this emerging SoS

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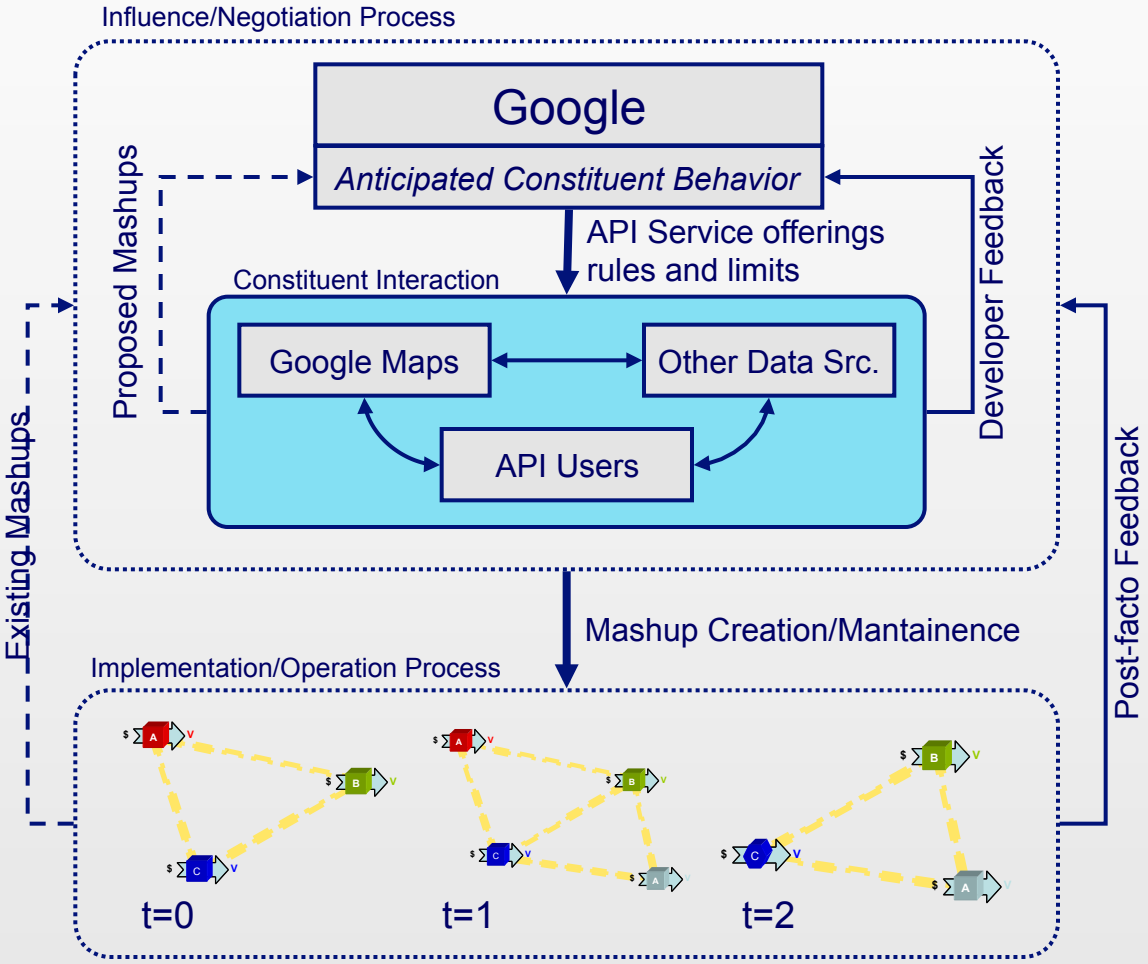
Housing maps as an acknowledged SoS



- Google develops API for maps
- Allows control of impact of mashups on Maps service as a whole
- Allows monetization of service via contextualized advertising
- Developers provide feedback as API goes through multiple revisions
- Becomes collaborative SoS as other map providers begin to offer similar services

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Observations from HousingMaps

- **Postscript:** Google goes on to hire Rademacher and he was the lead engineer on the Google *Earth* web API
- AIR framework can be used to describe the decision making that occurs within an SoS
- Virtual SoS can become acknowledged when feedback from un-coordinated constituent action has localized effects
- Response to those effects can encourage a constituent to attempt to influence the whole thereby creating an acknowledged SoS
- A potential descriptive SoS principle:

A virtual SoS can become an acknowledged SoS when a constituent is impacted by the extent but unseen SoS behavior and attempts to influence that behavior from their position within the SoS

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Limitations of AIR

- Only considers a fixed set of constituents
  - Can be extended by including participation decision making (Baldwin 2012)
- Doesn't help you with determining what the desired state should be – focuses on implementing a *specified* desired state
- May best be viewed as a set relationship that should be included in larger SoS characterization efforts
  - Ongoing work on integrating AIR with more comprehensive frameworks

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Research Questions

1. Given an extent SoS with a fixed set of constituent decision-makers each operating and managing one or more constituent systems, what are the **feedback relationships** between behavior of the constituent systems, the decisions made by the constituent decision-makers to change the constituent systems under their control and any external influencers who wish to affect the SoS via the constituents?

2. What **approaches** can be used by external SoS influencers to cause constituent decision makers to **change constituent systems** so as to **induce** a desired **behavior from the SoS**?

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Constituent Decision Problem

- Searching for utility maximizing x given the decision of others
- u^i is the constituent's utility function
- x^i are the constituent's decision variables
- g^i are the constraints on choice of x^i
- $\hat{x}^{\cdot}$ are the estimates of the x's chosen by others

$$\max_{x^i} \; u^i\left(x^i, \hat{x}^{\cdot}\right)$$

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

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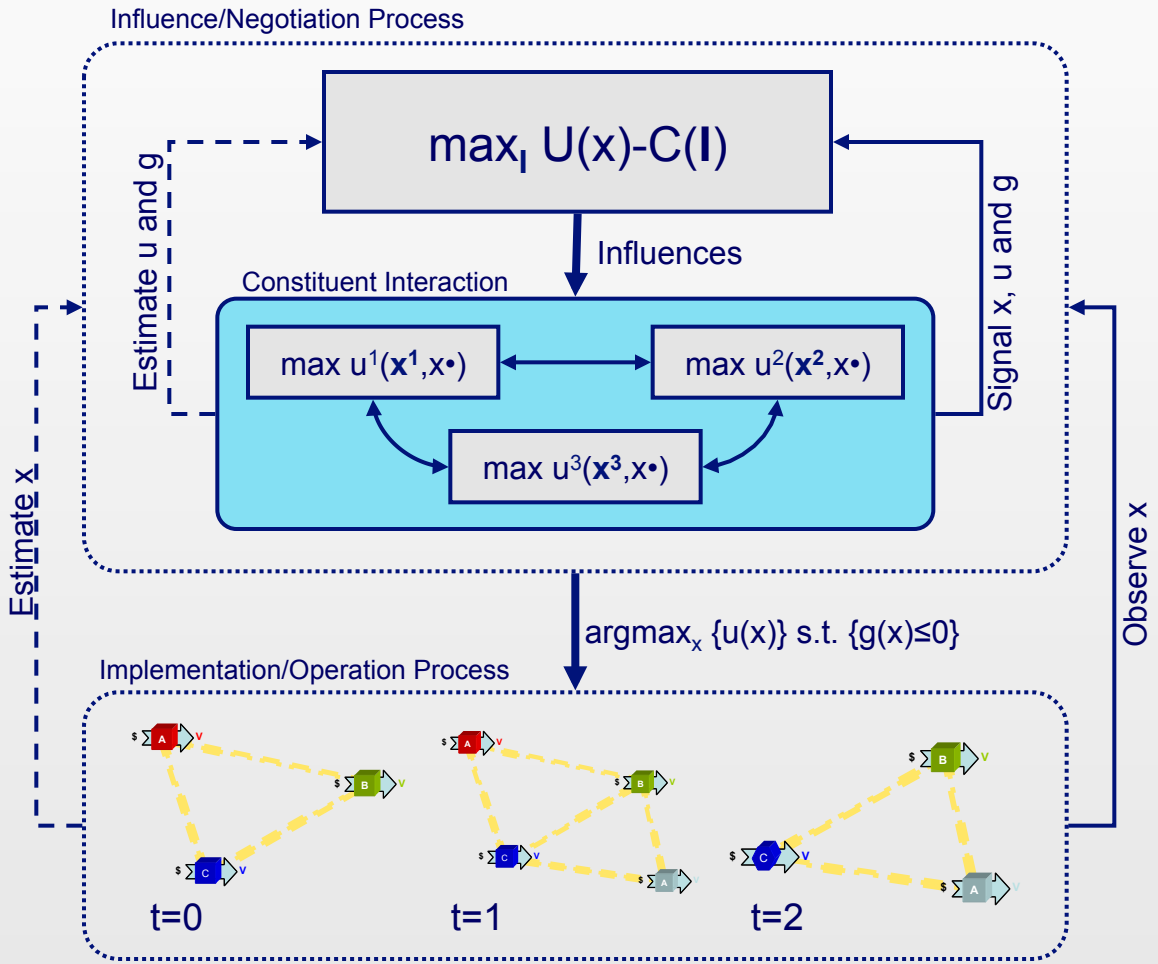
Principal Decision Problem



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Influence types aka 5 I's

Incentives to put greater value on desired actions

Reallocation of x's to agents (**Integration**)

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

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

$$h^i\left(x^i, \hat{x}^{\cdot}\right) \leq 0$$

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

Information to vary the estimate of externals

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

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Google and the 5 I's

- Incentives
  - Provide easier access to map tools thereby increasing value to website builders
- Information
  - Use API keys to track and make websites aware of usage level
- Integration
  - Off load certain functions such as smart caching onto Google so that usage works better with Google infrastructure
- Infrastructure
  - Provide API functions to standardize use of maps and thereby introduce control points into the interaction with websites
- Institutions
  - Use the API terms of service to formalize the relationship between websites and Google to provide transparency in terms of QoS and responsibilities of each party to ensure mutual benefit

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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.

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AIR in the case study

- **Anticipation**
  - Modeling the intermodal systems
- **Influence**
  - Assessing various influence strategies within the model
- **Reaction**
  - Comparing the impact on different stakeholders of the influences

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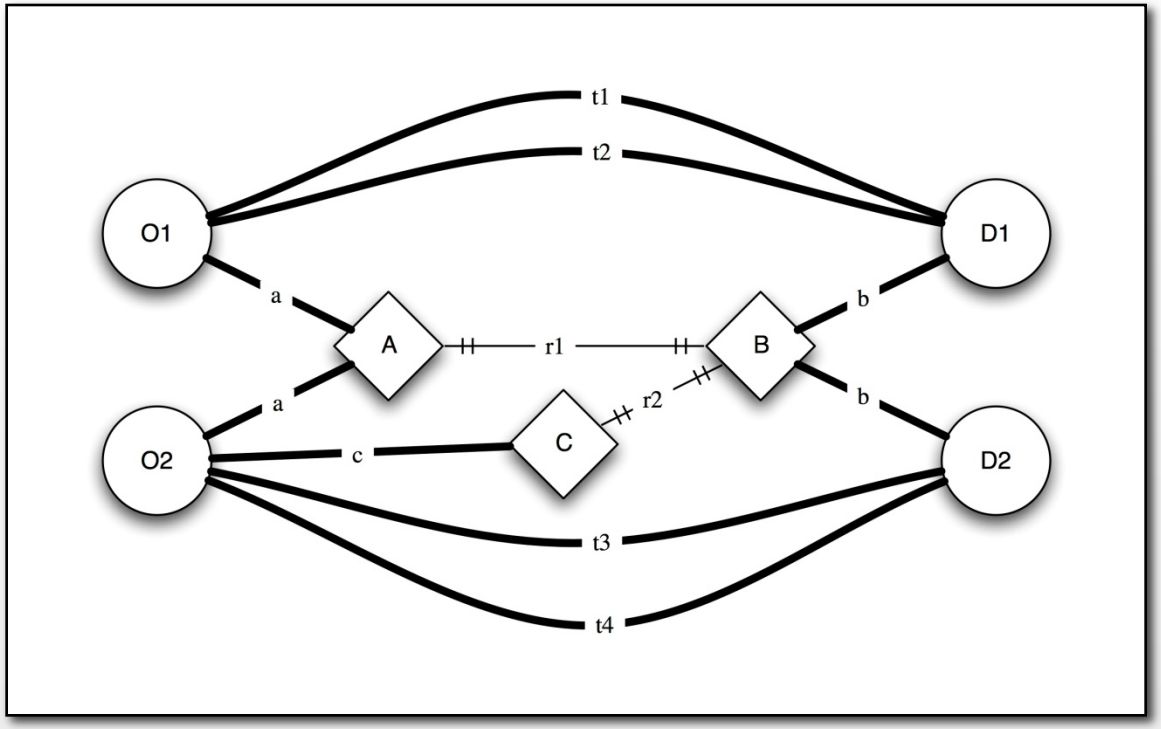
The "island" transport system



Origin/destination point

Intermodal Terminal

Road Link

Rail Link

- Links indicated are the only links available
- A single carrier may operate one or more link
- Shipments modeled represent the entire transport market

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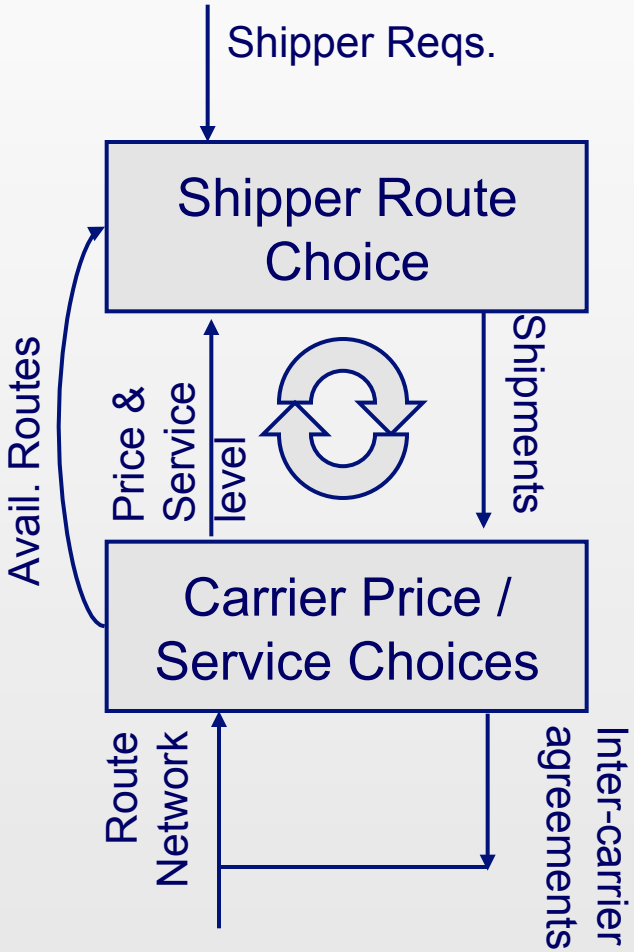
Model overview

- **Objective:** Create a notional SoS representation of an intermodal transport network to examine intervention strategies that can influence constituent behavior
- **Constituent systems:** Rail network, Road network
- **Constituent Stakeholders:** Rail carriers, Road Carriers
- **System Behavior driver stakeholder:** Shippers

Model Flow



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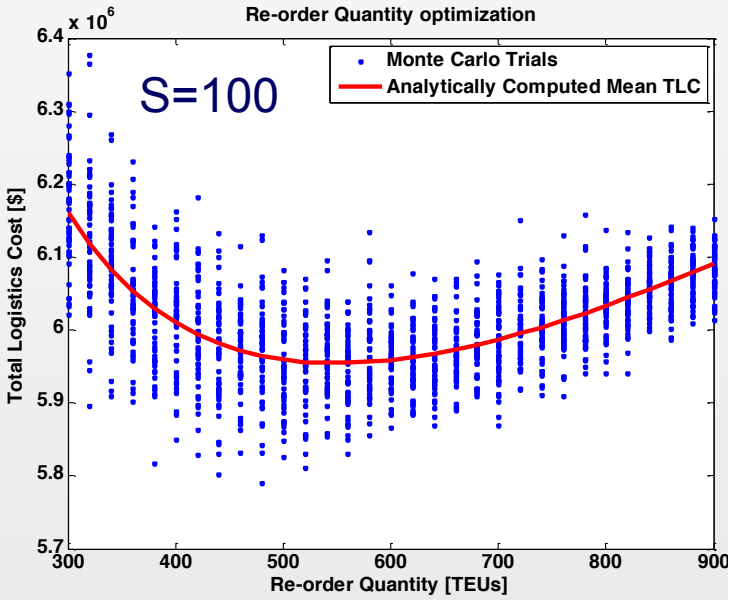
Shipper's Problem

Objective: Minimize Total Logistics Cost

TLC(reorder quantity, trigger level) = Order Cost + Inventory Cost + In-transit Inventory Cost + Shortfall Cost + Transport Cost

- **Control Variables:** Reorder Quantity (Q), Trigger Level (s), transport route

- **Approach:**
  1. Observe services between desired O and D.
  2. Minimize expected TLC for each routing
  3. Allocate traffic to routing with smallest TLC
  4. Should all traffic not fit on best solution, allocate remainder to second best and so on.
  5. Re-evaluate routing choice after a specified contract period
- **Key Assumptions:**
  - Use computed mean TLC for choosing routes
  - Require at least 0.5% change in TLC to shift from current route to a new route
  - No inventory size constraint
- **Example:**
  - Shipping 10,000 units over 90 days worth $5000 / unit
  - Inventory and shortfall cost are 40% of the per unit value
  - Transport option is intermodal with mean travel time 0.8 +/- 0.13 days
  - Optimum reorder level: s=191 units
  - Optimum reorder quantity: Q=84 units
  - minimum mean TLC = $5.2 million



Approach based on Kwon 1998

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Carrier decision making

Truck

Objective: max profit = revenue - cost
Control Variables: Price
Approach:

1. Estimate each players future actions by exponentially forecasting (two period delay) from their past pricing decisions
2. Find new price using a heuristic that combines the carrier experienced cash flow, the pricing trend seen in the market and a four estimated profit/price pairs

Key assumptions

- Independent owner/operator cost model
- Carriers can source trucks/drivers as needed don't need to keep a fleet
- Not capacity constrained
- 75% duty cycle

Rail

Objective: max profit = revenue - cost
Control Variables: Train Freq, Price
Approach:

1. Estimate each players future actions by exponentially forecasting (two period delay) from their past pricing decisions
2. For various train freq (+/- 2 from current freq) compute new price using heuristic
3. Choose train Freq (and corresponding optimal price) that maximize profit

Key assumptions

- Fixed costs are modeled using straight line depreciation with a 10yr/1MM mile lifetime for equipment
- Labor costs and costs for repositioning empty cars (i.e. backhaul) are included
- 75% duty cycle
- Investment is not modeled. Additional capacity is available on demand, but changing capacity is rate limited

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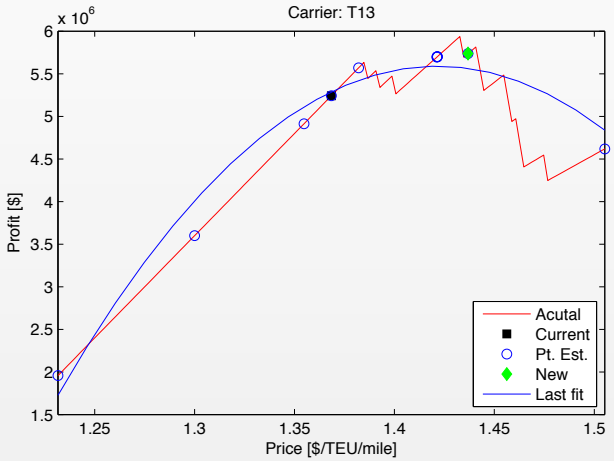
Example optimization

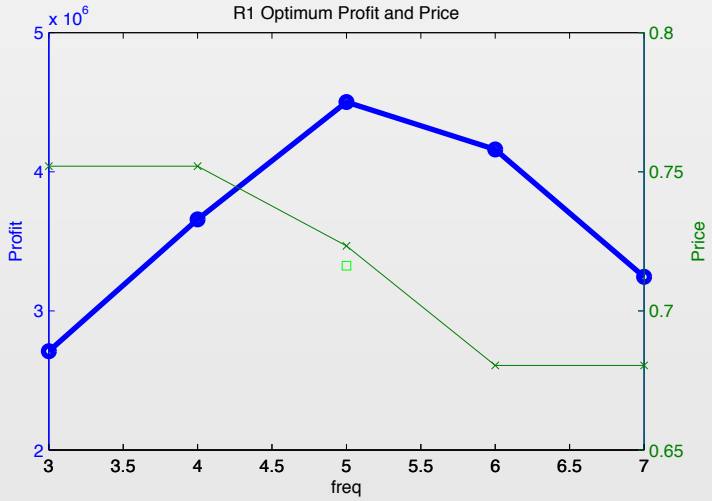


Truck Example

- Jagged line from shippers choosing other routes
- Blue curve is fit from history
- Blue dots predictions
- Green dot new price

Rail Example

- Initially, profit increases as capacity increases and price is lowered
- At more than 5 trains per day, there isn't enough new traffic to cover the additional costs of capacity and so profit decreases



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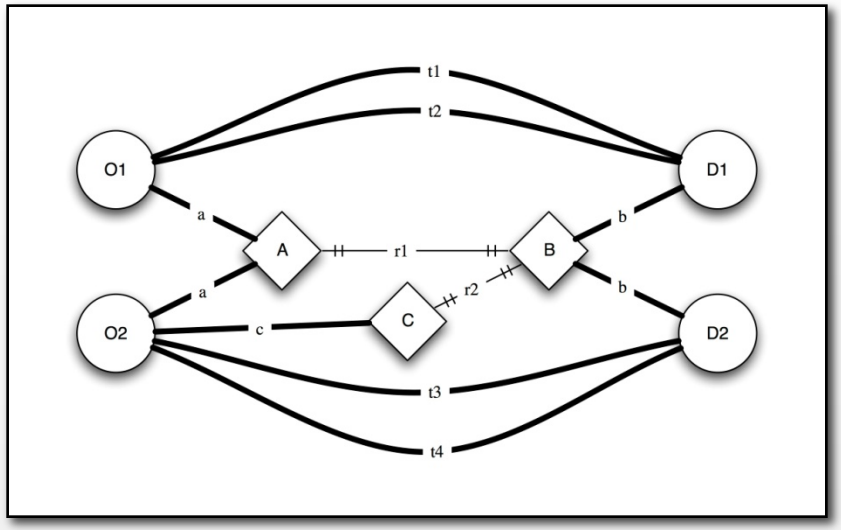
Scenario



Origin/ destination point

Intermodal Terminal

Road Link

Rail Link

- There are 50 shippers moving a total of 100,000 truckloads per quarter
- Half ship O1 to D1 and half O2 to D2
- Inventory costs uniformly distributed between 10% and 40%
- Shipment value varies logarithmically from $2000 to $100000
- All other costs are constant across shippers

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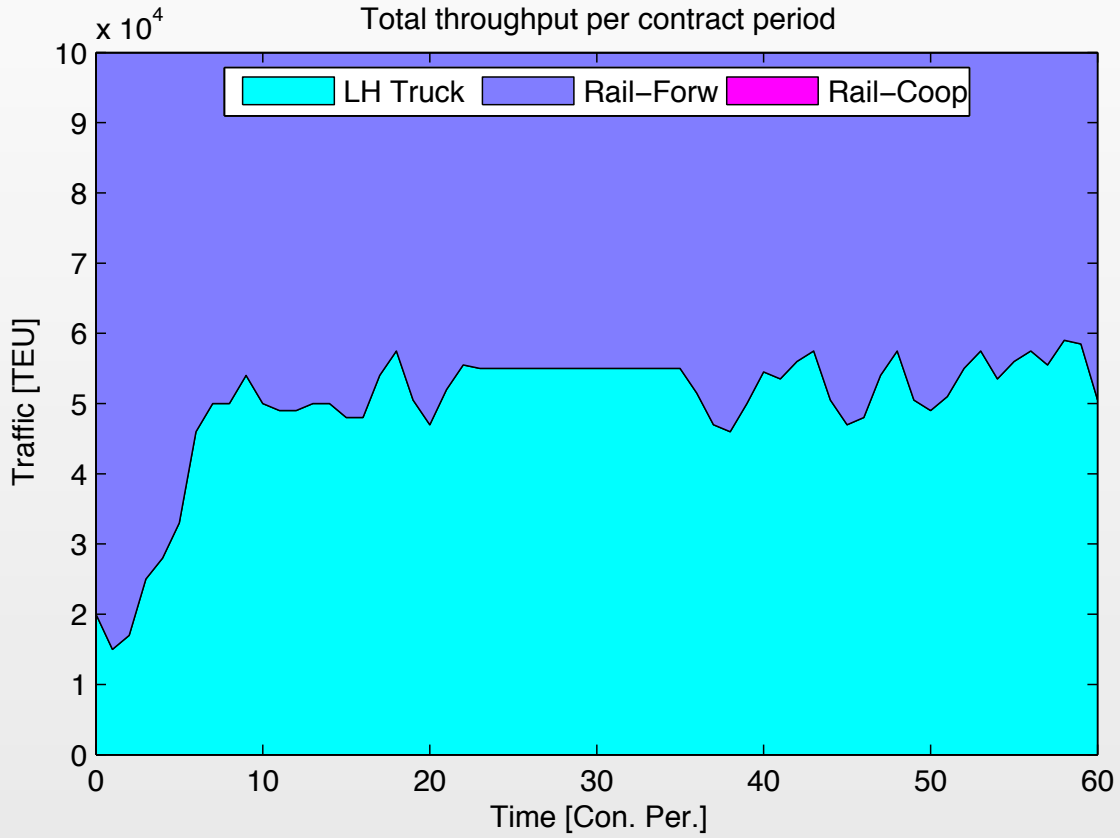
Base case allocation results



After an initial transient, about 50/50 split between long haul truck and intermodal rail

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Influence Mechanisms

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

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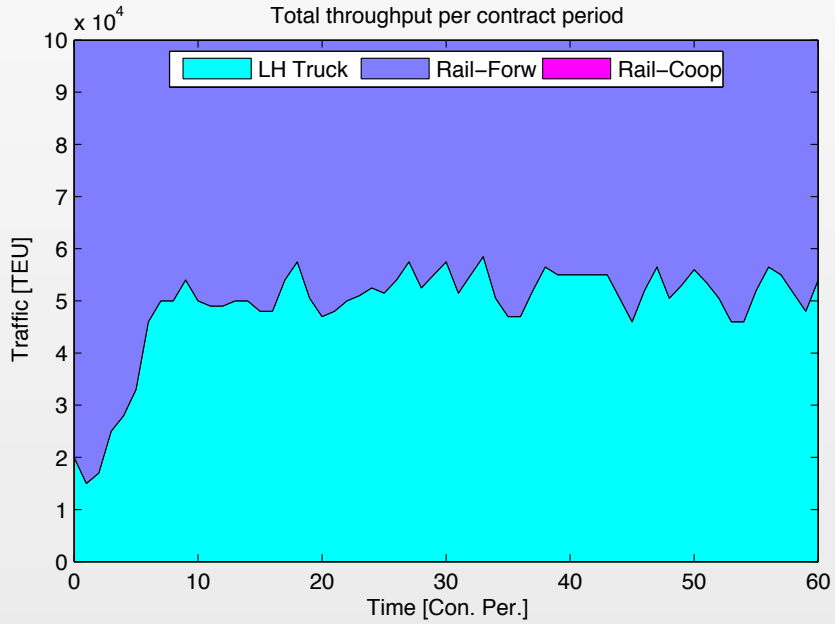
Allocation (Speed-up Terminals @ 20)



- Not much change in allocation despite 50% reduction in transfer time
- Logistics cost benefit of improved throughput counteracted by higher prices charged by the short haul road operators
- Many shippers weren't sensitive to travel time (dealt with it via inventory)

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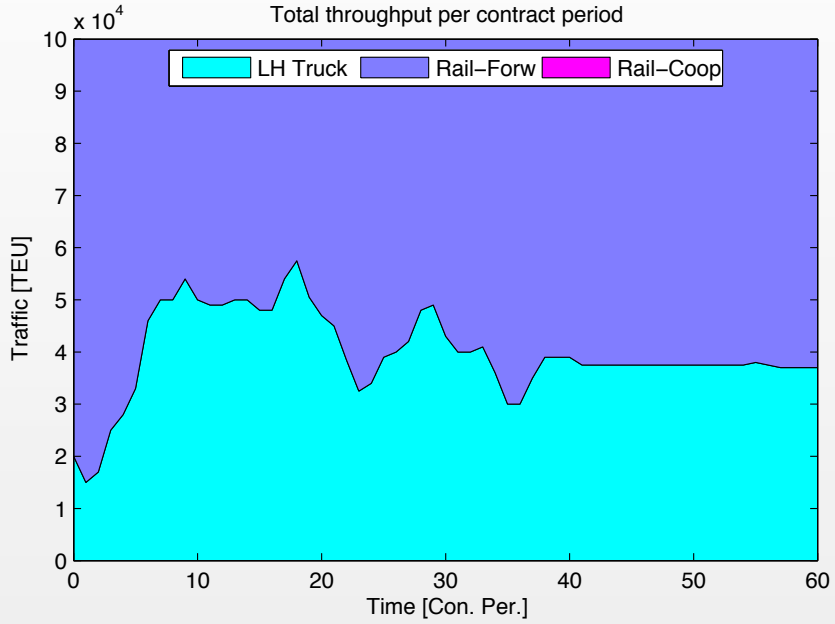
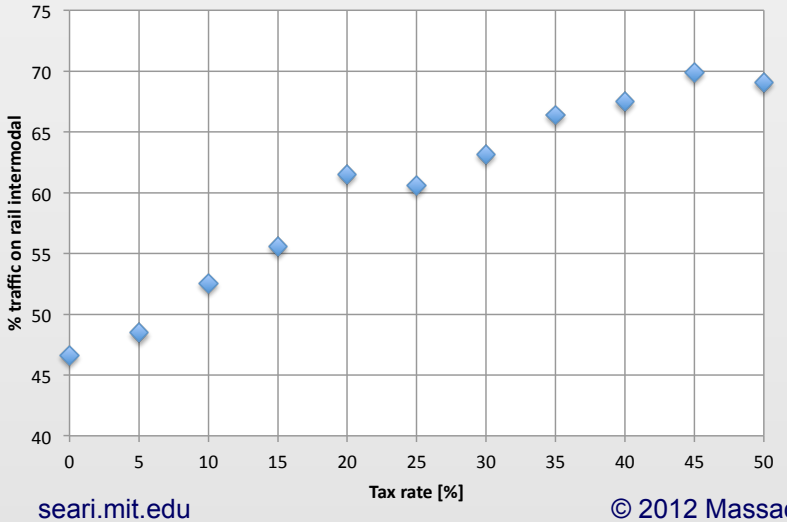
Allocation (Tax @ 20)





- Tax had an effect increasing rail traffic to ~60%
- Increasing the tax size increases the effect
- However, this stretches the assumption that shippers always ship

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Cooperative Routes

- Railroad and truckers can also form cooperative intermodal routes
- Model only considers agreements between pairs consisting of a long haul truckers and a railroad
- Possible cooperation agreements are assessed at each time step
- When an agreement is struck, it lasts for one year (4 steps)
- Nash's bargaining solution is used to determine if an agreement is made and the revenue split between the trucker and railroad

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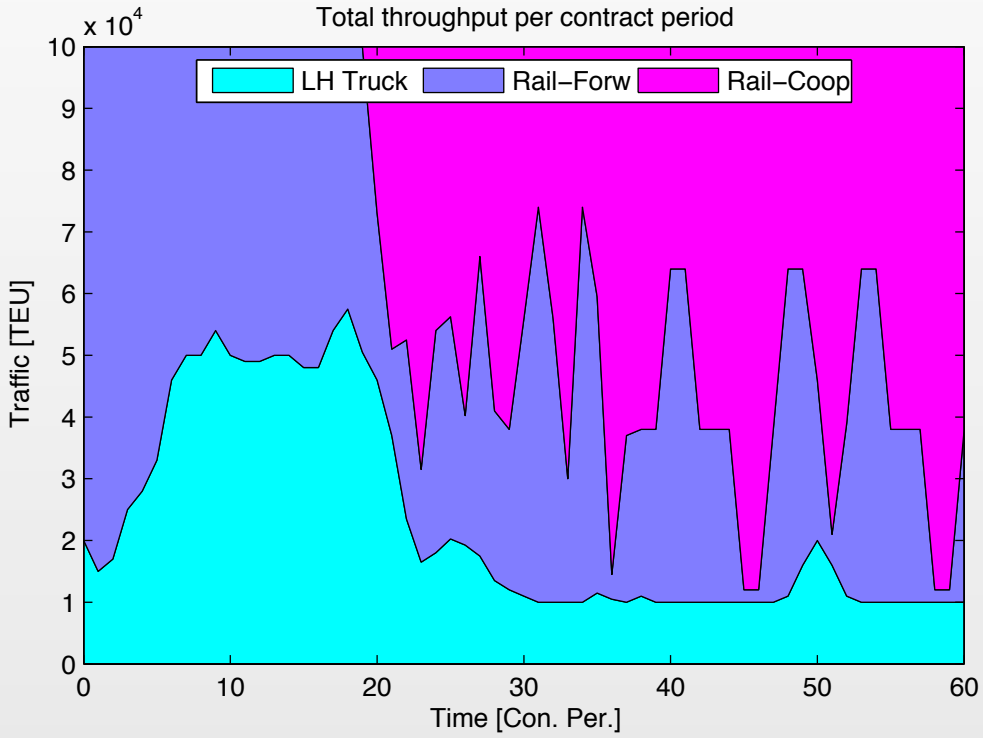
Allocation (Co-op allowed)



- With cooperative routes allowed dramatic and sustained shift to intermodal
- Prices on short haul routes are finally kept in check by the cooperative partners
- R1 fills up
- R2 is used to about half capacity
- Remaining shippers are service quality sensitive

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Comparing Strategies

	Truck Revnue	Railroad Revenue	Truck Cost	Railroad Cost	Truck Profit	Railroad Profit	Uni-modal Truck %	Inter-modal %
Baseline	2.454	0.937	2.119	0.991	0.335	-0.054	**53.381**	**46.619**
	Total	**3.391**	**Total**	**3.111**	**Total**	**0.281**		
Term. Subsidy	2.463	0.945	2.105	1.000	0.358	-0.056	**52.667**	**47.333**
	Total	**3.408**	**Total**	**3.106**	**Total**	**0.302**		
Term. Speedup	2.446	0.948	2.100	1.007	0.346	-0.059	**52.381**	**47.619**
	Total	**3.394**	**Total**	**3.107**	**Total**	**3.39**		
Road Tax	2.613	1.168	2.084	1.149	0.530	0.019	**38.500**	**61.500**
	Total	**3.781**	**Total**	**3.232**	**Total**	**0.549**		
Coop	1.780	1.291	1.576	1.264	0.264	0.026	**21.345**	**78.655**
	Total	**3.071**	**Total**	**2.840**	**Total**	**0.291**		

- 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. Traffic moved to short haul routes where they had greater price leverage. Really dislike coop 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.
- Which is best? Is there a best?

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Implications for SoS from the intermodal transport case

- Agent based model with complex decision rules reveals non-intuitive SoS dynamics
- Three types of strategies analyzed
  - Social: allow/encourage collusion between constituents
    - Can work well (as it does here) if competitive pressure is leading to local optimization
    - *Need to be aware of interaction between decision logic of constituents*
  - Economic: incentivize desired behavior
    - Also works, but limited by size of incentive which may be limited by other factors
    - *Incentives are expenses for someone in the SoS*
  - Technological: introduce a change in the SoS to make the desired behavior more appealing
    - Did not work well here since the shippers were insensitive to the changed variable
    - *Find out what the sensitive variables in terms of behavior when making technological investments*

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Limitations of Intermodal case

- Terminal improvement results hampered by vastly simplified terminal model
  - Such models are an active area of research in the transportation community
- Single class of service and pricing
  - More complex pricing strategies could allow market segmentation
- Modeling of investment decisions by constituents
- Impact of coordination on operational performance
- Scaling up model to real-world cases

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SEARI
Systems Engineering Advancement Research Initiative

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?

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Questions?

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