RT-110 Enterprise Systems Analysis

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Michael Pennock, William Rouse, Doug Bodner, Chris Gaffney, Mehrnoosh Oghbaie

Stevens Institute of Technology
Georgia Institute of Technology

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Agenda

• RT-110 Scope
• Model Composition Discussion
  – Motivation
  – Phase Shifts
  – Congestion Pricing Case Study
  – State of theory
• Visualization Summary
• Counterfeit Parts Update
The Enterprise Dilemma

• A Challenge of Enterprise Systems Engineering
  – The complexity of the social components of enterprise systems fundamentally limits their predictability
  – Traditional engineering depends on prediction

• Solutions based on a false assumption of predictive accuracy will likely result in a fragile system that could actually be worse than doing nothing

• Consequently, the dilemma changes from
  – How can we use models to predict the behavior of enterprise systems?
  to
  – How can we use models to support organizational strategy development to influence enterprise systems?
Motivation

- Many of the challenges that confront the Department of Defense (DoD) are characterized by the intersection of complex social, political, economic, and technical phenomena where conventional modeling techniques are inadequate. For example:
  - Combating the proliferation of counterfeit parts in military systems
  - Managing joint and international acquisition programs
  - Coordinating disaster and humanitarian responses involving governments, NGOs, and US agencies
  - Sustaining the defense supplier base in the face of declining acquisition quantities
  - There are also many applications outside of DoD: city resilience against natural disaster, health care systems, the stability of the financial system, etc.
RT-110 Objectives

• Enterprise problems are a challenge to conventional modeling and simulation approaches because they involve unpredictable social behavior and many interacting elements. Consequently, our objectives are to:

• Develop a modeling methodology that will help analysts to focus their efforts in a way that allows complex elements to be identified and mitigated

• Enable key stakeholders to “Drive the Future” before they commit to changes

• Providing means for experimentation and creation of response surfaces for key tradeoffs

• Creating an interactive environment for discussion and debate of strategies, policies & plans
Supporting Efforts

• Model composition
  – Traditional approaches to modeling may be misleading
  – E.g., congestion pricing case study

• Interactive visualization
  – Need to facilitate decision maker and stakeholder exploration of complex policy space
  – Design principles for building visualizations

• Counterfeit parts case study
  – Motivating test case for methodological development
  – Significant DoD interest in addressing counterfeit parts
MODEL COMPOSITION DISCUSSION
Model Composition

• Evaluating an enterprise policy option often requires the simultaneous consideration of multiple models
• Starting to see the issue arise frequently
  – DMMF study
  – IBM Splash
  – Journal of Simulation had a special issue on the topic
• Sometimes it seems to work, other times it fails, why?
• This is an area where experts have a good intuition regarding what will work and what will not
  – Can we formalize that intuition?
State of the Domain

• There appear to be two types of work in multi-modeling
• Extremely abstract, borderline philosophical discussions of modeling and related issues
  – Theoretical work on modeling in general from 70s and 80s
  – Dynamical systems theory and bifurcation
  – Complexity science investigations into phase transitions
  – Tolk and colleagues applying “model theory” to simulation composition
• Very practical, “this is how I solved this particular problem” type of work
• There is a substantial gap between these two bodies of work
Model Uncertainty

• Uncertainty plays a fundamental role in the model composition issue
  – Aleatory: random phenomena that can be modeled using probabilities
  – Model: the model may have moved out of the zone where it is applicable, but you don’t know it

• We have tools to deal with aleatory uncertainty

• Our concern is model uncertainty
  – How do we know when a given model “bifurcates” from other models and/or reality?
Model Bifurcations

- Application of term evolved from dynamical systems theory
  - A better term is phase shift
- Example: We can model ice as a rigid solid...until the temperature gets above 32°F
  - We know where the bifurcation points are, but
  - There are also transition zones that are hard to model
Model Bifurcations

• Enterprise systems undergo multiple phase shifts at multiple levels of abstraction
  – The problem is that we don’t necessarily know the analog of “melting point” for a social system
  – How do we know when the stock market has undergone a phase shift?
    • E.g., High frequency trading
Model Bifurcations

Model 1  Overlap  Model 2
Congestion Pricing Case Study

- The problem of traffic management and congestion pricing provides a clear example of an enterprise system with many of these issues
  - Requires the integration of social/economic models with technical models
  - Many cases of Phase Shifts
  - Highlights the choice between different levels of abstraction
    - Agent-based versus Differential Equation based modeling
Congestion Pricing Case Study

- The issues of model uncertainty are critical to pricing and traffic modeling
  - Traffic jam formation
  - Phase Shifts in driver response to pricing, traffic flow through networks, etc.
Congestion Pricing Case Study

• Dynamic Congestion pricing is widely seen as a good approach to reducing traffic congestion
  – Reduces road demand by
    • Encouraging public transportation/carpooling/walking, or
    • Spreading out demand to non-peak hours
  – Can provide a speedy alternative to free lanes
  – It is based on the typical economic assumption that consumer demand will fall with increasing prices
    • So if traffic is too heavy at the current toll rate, increasing the toll should reduce demand
    • But reality does not always conform to economic expectations.....
A dynamic congestion pricing scheme was implemented in Minneapolis in 2005

- High Occupancy Toll (HOT) lanes with dynamically priced tolls run along side non-tolled lanes
- The toll rate is based on HOT lane traffic density; adjusted upward when density increases and downward when density decreases
Congestion Pricing Case Study: Minneapolis

• In late 2012 and early 2013, several experiments were performed to test driver response to tolling
  – Researchers from the University of Minnesota were allowed to adjust tolls at their discretion, without public knowledge of the experiment
  – Tolls were increased at lower than normal thresholds, effectively increasing toll prices
Congestion Pricing Case Study: Minneapolis

• Contrary to expectations, HOT lane usage increased with the higher tolls
  – It seems that drivers viewed higher toll prices as an indication of congestion in the non-tolled lanes
  – One way to explain this is that the demand function undergoes a phase shift at some toll level
Congestion Pricing Case Study: Minneapolis

• Takeaways:
  – Demand functions are more complicated than it may seem
    • Reasonable to expect that there are (higher) toll levels where the typical economic assumptions hold
    • In other words, the demand function undergoes a phase shift
Congestion Pricing Case Study: Minneapolis

• Takeaways:
  – Economic assumptions such as perfect rationality are not so easy to maintain in practice
    • Physical issues, for one, can prevent humans from rational behavior even if they are capable of it
    • For a driver to respond “rationally” to congestion pricing they need to accurately judge time savings from HOT lane use, convert that judgment to a dollar value, and compare that value with the toll price
Enterprise Modeling Issues

• Sources of enterprise modeling “phase shifts”
  – Abstractions are bifurcations (Casti 1985)
  – Increasing complexity (Complexity = # of bifurcations)
  – Overlapping representations
  – Parameter shifts
  – Feedback loops and adaptive behavior
Enterprise Modeling Issues

• Some “phase shifts” can be detected through modeling
  – Comparing different model approaches to bound the bifurcation point
  – Agent based modeling
  – Leading indicators: e.g., transfer entropy
  – Supports an adapt or hedge strategy

• Some “phase shifts” can only be detected through experimentation
  – True unknown unknowns – must use acceptance strategy
Visualization Update

• Performed extensive literature review
• Emphasis on complexity and ambiguity
  – The existing work in visualization does not address the problem of inference over multiple conceptual models
• Intention is to perform a series of experiments
  – Outputs will inform design principles for enterprise visualizations
• Long-term applications for C4I
Visualization Concept

Foraging Loop

Ambiguity

Causal/Logical Inferences
Logical/Rational Inferences
Faulty Inferences
Rational Inferences
Logical/Rational Inferences
Causal Inferences
Causal Inferences

Complexity

Sense Making

User
Immersion Lab
Counterfeit Parts Case Study

Enterprise perspective
- Policy-makers and supporting organizations
- Agencies and services
- Contractors and supply base

Understanding
- Different perspectives
- Important vs. unimportant aspects of enterprise
- Trade-offs
- Policy options, effectiveness and secondary effects

Purpose of Counterfeits Parts Roundtable

Semi-Autonomous Organizations

Tiered Supply Chain

System & WBS

…
# Representations

<table>
<thead>
<tr>
<th>Category</th>
<th>Phenomena</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational systems &amp; constituents</td>
<td>Agent-based model with constituents modeled as attribute objects in an object-oriented framework and with operational behaviors modeled via state-charts. Cohorts modeled rather than individual systems.</td>
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<tr>
<td>Supply chain flows</td>
<td>Either agent-based model of systems and constituent with locations and flows modeled via state-charts and attributes, or process-based discrete-event model with entities linked to agents representing systems and constituents. Supply network and counterfeiter network modeled to evolve over time.</td>
</tr>
<tr>
<td>Enterprise actors</td>
<td>Agent-based model with actors modeled as complex agents and relationships modeled by arcs (synchronized with supply chain flows for supplier relationships). Economic models embedded within agents to model supplier and counterfeiter adaptation.</td>
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<tr>
<td>Policy</td>
<td>Global variables set by analyst with an associated agent-based model to enable policy adaptation.</td>
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<tr>
<td>Exogenous environment</td>
<td>System dynamics model representing trends in technology progress, technology off-shoring.</td>
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Counterfeit Parts Concept
Counterfeit Parts Update

• Engaged with stakeholders for enterprise perspective
• Formulated an enterprise modeling framework
  – Systems, supply chains, operational decision-makers, policy decision-makers, exogenous environment
• Implemented framework using
  – Primarily agent-based
  – System dynamics modeling for exogenous environment
• Used synthetic dataset with limited GIDEP counterfeit support
  – Percentage of suspects reported
  – Percentage of counterfeits identified as suspects
  – Does a downward trend mean fewer counterfeits, worse enforcement and identification, or better counterfeiter ability?
Next Steps

• Experiment to assess efficacy of interactive visualization
• Investigate the applicability of non-classical economic models
• Investigate applicability of “complexity” literature to inform strategy formation
• Adapt the mathematical frameworks developed for modeling in general into rigorous descriptions of these practical composition issues
• Use these descriptions to develop model composition guidance for common enterprise modeling situations