Understanding and Designing Complex Sociotechnical Systems

MIT SDM Systems Thinking Webinar Series

April 8, 2013

Joseph M. Sussman
Interim Director of Engineering Systems Division
JR East Professor of Engineering Systems
and Civil & Environmental Engineering, MIT
Some problems are so complex that you have to be highly intelligent and well informed just to be undecided about them.

Lawrence J. Peter (of Peter Principle fame)
TWO LINKED CONCEPTS

CRITICAL CONTEMPORARY ISSUES

AND

COMPLEX SOCIOTECHNICAL SYSTEMS
Critical Contemporary Issues (CCI)

- Global Climate Change
- Energy/Environment
- Developing Country Megacities
- Global Economy
- National Security
- Productivity
- Mobility and so forth
Lady Bird Johnson found that in dealing with highway beautification it was like “picking up a tangled skein of wool; all the threads are interwoven – recreation and pollution and mental health. And the crime rate, and rapid transit and the war on poverty, and parks... everything leads to something else.”

Complex Sociotechnical Systems

Let's parse this
Systems

- Composed of interconnected components and subsystems
- Often structured in a hierarchical manner
- Usually interacts with the environment external to it
Sociotechnical

- Containing technology subsystems and components central to its performance

and

- Having societal/ political/ economic relevance and impact
Some Types of Complexity

> **Structural complexity**
  – The number of components in the system and the network of interconnections between them

> **Behavioral complexity**
  – The type of behavior that emerges due to the manner in which sets of components interact

> **Evaluative complexity**
  – The competing perspectives of stakeholders who have different views of “good” system performance

> **Nested Complexity**
  – The interaction between a complex “physical” domain and a complex “institutional” sphere
Nested Complexity

- Physical system
  - More quantitative principles
  - Engineering & economic models
- Institutional “sphere”
  - More qualitative in nature and often more participatory
  - Stakeholder evaluation and organizational analysis
- Different methodologies are required
  - within the physical system
  - between the institutional sphere and the physical system
  - within the institutional sphere
Herbert A. Simon


People Making→System→Performance

“Rational” Choices
An Approach to the Study of Complex Sociotechnical Systems

*Systems-Oriented Methods

Integrative Domain Knowledge

**Social Sciences, Management & Planning

Deep
Quantitative
Engineering
Science
BEYOND “STUDY” TO “DESIGN”

• We are not simply observers
• Our Complex Sociotechnical Systems are purposeful
• We have a normative view – what does good performance mean?
• We have a prescriptive view – how do we make our system perform better?
• But humility needs to be part of this process
An Approach to the Design of Complex Sociotechnical Systems

*Systems-Oriented Methods

Integrative Domain Knowledge

**Social Sciences, Management & Planning

Deep Science
Quantitative Engineering
The Intellectual Content of Integration I

An integrated view of a domain (e.g. transportation or energy.....)

The integration of various methodologies

• Systems-oriented methods
• Social Science, Management and Planning
• Engineering Science

So, is there intellectual content here?
MEXICO CITY: Transportation and the Environment

• One of the largest megacities in the world and the economic engine of Mexico
• Severe mobility problems, with productivity implications
• Important Technological Aspects
• Severe environmental problems, with health issues
• Social equity issues
• The institutional sphere is complex indeed and sometimes dysfunctional
The Intellectual Content of Integration II

• There would seem to be little question that there is intellectual content in integrating when one considers problems of the scale and complexity of Mexico City.

• But there is a *more important test*: Are there principles and core underlying concepts for creating this integrated approach *across* domains? Is there a transferable “residue”? 
Principles and Concepts: A Work in Progress I

- The micro/macro question
- The enterprise viewpoint
- Life-cycle properties -- the “ilities”
- A flexibility/resilience perspective
- Sustainability as an overarching design principle

  Economic Development, Environmental Protection and Social Equity
Principles and Concepts: A Work in Progress II

- Using qualitative and quantitative methods rigorously and in tandem
- Focusing on feasibility – optimality is beyond the pale
- Understanding and measuring complexity in a sociotechnical context
- Using system architecting as an organizing principle
Principles and Concepts: A Work in Progress III

- Identifying and quantifying uncertainties and creating strategies for dealing with them
- Recognizing system safety as an emergent property
- Recognizing the importance of context
“Only connect” was the constant admonition of the great English novelist, E. M. Forster............

the ability to connect thus to raise the yield of existing knowledge is learnable.....

Peter Drucker
Complex Sociotechnical Systems

- This field of study did not fall from the sky
- There is a significant history with distinguished progenitors
  Simon, Weiner, Forrester, Schumpeter, von Neumann
Collected Papers of Jay W. Forrester

Foreword by Dean Gordon Brown

“This book might appropriately be titled 'Seeking to Understand Today's Complex Society.'”

“stated succinctly, we live in a world where everything affects everything else”

“Scholars in many disciplines have addressed themselves to seeking solutions to these dilemmas. The disciplines of operations research, econometrics, behavioral science, statistics –to name a few – have been developed and applied. But our problems escalate. New and more powerful approaches are urgently needed.”
So why now?

People have talked for decades about cutting across disciplines to study Complex Sociotechnical Systems – why is it especially important now?
• Critical Contemporary Issues framed as Complex Sociotechnical Systems are endemic and can only grow in importance

• We have the tools, technologies, and some principles and concepts to work effectively across disciplines
Engineering Systems

They are, by our definition **Complex, Sociotechnical Systems**
- Technologically enabled networks which transform, transport, exchange and regulate Mass, Energy and Information
- Large-scale
  - large number of interconnections and components
- Sociotechnical aspects
  - social, political and economic aspects
- Exhibit Nested complexity
  - technical complexity nested within institutional complexity
- Dynamic
  - involving multiple time scales, uncertainty & lifecycle issues
- They require deeply rigorous quantitative and qualitative approaches
Examples I

- Transportation and Air Quality in Mexico City
- Extracting Information from Blogs for Strategic Planning in Advanced Technologies (e.g. Cloud Computing)
- Cape Wind-- Off-shore Renewable Energy in Nantucket Sound: Understanding Stakeholder Views
- Organizational Infrastructure and Technology for Air Combat
Examples II

- Provision of Broadband Telecommunication Services by Municipal Electric Utilities (MEUs)
- Regional Strategic Transportation Planning (RSTP) as Coupled to Supply Chain Management (SCM)
- Providing High-Speed Broadband Internet Access in Developing Countries: The Case of Kenya
The Future of Engineering Systems/Complex Sociotechnical Systems

We address critical contemporary issues using the Engineering Systems/Complex Sociotechnical Systems world view.

This integrated interdisciplinary approach is a pathway for relevance of universities in a society where relevance is demanded of all institutions.

Only by considering Engineering Systems/Complex Sociotechnical Systems as a field of study can we make continuing contributions to critical contemporary issues.
Thank you for your attention.

Any comments or questions?
BACKUPS
The **CLIOS** [Complex, Large-Scale, Interconnected, Open, Sociotechnical] Process

A three-stage structured process.

- Representation
- Design, Evaluation and Selection
- Implementation
1. Representation

“Defining the problem may be the most important element in making effective decisions ... The right answer to the wrong problem is very difficult to fix ... once the problem has been correctly defined, the decision itself is usually pretty easy.”

Peter Drucker

3. Implementation: develop bundles of strategic alternatives and select among them.

Implicitly, there is iterative behavior throughout.
The CLIOS Process

1. Describe CLIOS System: Checklists & Preliminary Goal Identification
2. Identify Subsystems in Physical Domain & Groups on Institutional Sphere
3. Populate the Physical Domain & Institutional Sphere
   4A. Describe Components
   4B. Describe Links
5. Transition from Descriptive to Prescriptive Treatment of System
6. Refine CLIOS System Goals & Identify Performance Measures
7. Identify & Design Strategic Alternatives for System Improvements
8. Identify Important Areas of Uncertainty
9. Evaluate Strategic Alternatives & Select “Bundles”

Design and Implement Plan for:

10. Physical Domain / Subsystems
11. Institutional Sphere
12. Evaluate, Monitor & Adapt Strategic Alternatives for CLIOS System

Complex
Large
Interconnected
Open
Sociotechnical

First order understanding of CLIOS System
Mental mapping of physical & institutional systems
General insights regarding CLIOS System structure & behavior
More detailed & quantitative understanding of system behavior
Deeper understanding of and appreciation for system possibilities, limits, uncertainties, and sensitivities
Updating of prior beliefs/models regarding system goals, structure, & behavior

The **Mirroring Hypothesis** (Carliss): Aligning the “technical architecture” with the “organizational architecture” leads to better system performance.
CLIOS Process Ideas I

• Sustainability as an overarching design principle

• Separate “organizations” from other components – CLIOS Process world view

• Distinguish between representation and modeling
  Representation related to visualization
  Think carefully about when to quantify – when to “model”

• Recognize different kinds of complexity

• Emphasis on dealing with uncertainty
CLIOS Process Ideas II

- Emphasis on stakeholder roles
- Strategic alternatives
- Robust bundles of strategic alternatives
- Strategic alternatives are needed for implementation as well
  - In the physical domain
  - On the institutional sphere -- change management
- Monitoring the outcomes is central to the CLIOS Process
- The CLIOS Process as iterative among all the stages
Was 3.11 an “unknown unknown”? 
A “this changes everything” event? 
Dealing with High Impact, Low Probability Events
PRINCIPLES FOR PROCESS FORMATION FOR COMPLEX SOCIOTECHNICAL SYSTEMS
Principles for Process Formation for Complex Sociotechnical Systems I

- Keep institutional changes on the agenda (recognizing the difficulties)
- Optimization is a will-o’-the wisp
  - Too hard to find an optimum
  - Oft-times not even sure what we are optimizing
- Uncertainty dominates
  - Known unknowns
  - Unknown unknowns
Principles for Process Formation for Complex Sociotechnical Systems II

- Understanding Structure is Vital
  - Don’t rush to quantify

- There is no silver bullet
  - Bundles of strategic alternatives

- Thinking about flexibility

- Explicit consideration of stakeholders at all stages of the process

- The need for iteration of the process: revisiting earlier work and decisions

- Scale and Scope, Function, Structure, Temporality (de Weck, Roos and Magee)