Application of Complex Adaptive Systems of Systems Engineering to Tobacco Products

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June 9, 2011
• What is the problem
• What are our aspirations
• How does that frame the problem/solution for us
• What are we doing – project overview
**Introductory Information: Why examine tobacco use?**

- **Significant Problem:**
  - Cigarette smoking is the leading preventable cause of death in the United States: tobacco-related illnesses are responsible for 443,000 premature deaths each year [CDC 2008, CDC 2002]. Smoking rates for U.S. adults have declined since the mid 1960s, but rates of decline have diminished in recent years.

- **Exemplifies a Complex System:** Tobacco use exists within a set of interwoven and evolving personal, social and economic systems.
  - Social networks, cultural and familial associations, personal identity, physical addiction.
  - Tobacco industry provides jobs, U.S. GDP, tax revenues.
  - The tobacco control and regulation communities seek to reduce harm caused by tobacco use through advocacy, education and regulatory oversight; their challenge is to act effectively.

- **How can we influence a CASoS in socially beneficial directions?**
  - Generating conceptual models of the system can help define achievable aspirations for influencing the tobacco products CASoS. These aspirations can be mapped to interventions specifically designed to influence the tobacco products CASoS in a direction that lowers mortality, morbidity and costs associated with tobacco use.
Tobacco Products Exist Within Larger Socio-Economic-Technical System

Who are the relevant entities?

• Entities Include (not comprehensive list)
  - The public (smokers, non-smokers)
  - Product growers and manufacturers
  - Government entities (gov’t offices that collect and use taxes, regulators, health monitors/advocates (e.g., CDC, NIH)
  - Health care providers
  - Insurers
  - Retailers

How are they connected? How do they influence one another?

• Connected by
  - Goods
  - Money
  - Services
  - Information
  - Social networks

Other influences

• Affected by
  - Personal identity
  - Addiction
Tobacco Products Exist Within Larger System

Highlighted area shows (roughly) portion currently being analyzed
Complex Systems

- Complex systems:
  - Composed of interdependent components
  - Interactions via local rules yields emergent structure and behaviors.

- Complex system behavior:
  - Is generated by many entities interacting via simple, often nonlinear rules.
  - Exhibits dynamics over a wide range of time scales, complicating prediction of system behavior and design of effective interventions.

- A key property of complex systems is irreducibility –
  - The behavior of the complete system cannot be understood through analysis of only individual system components. This property is sometimes described as system behavior being greater than the sum of the parts.

By inspection – the tobacco system we just examined meets this definition.
Tobacco Project Development Overview

- Subsystem Diagram: Identify most relevant players and processes
- Comparative effects of policy “levers” on measures.
  - Interventions act at the individual level, therefore they are based in the IBM.
  - How individual decision-making process and cognitive biases impact policy results.
  - IBM provides shorter term, local results.
- Population Structure Model (formerly referred to as the SD model/Aging Chain)
  - Assesses impacts of changes over time; uses input from IBM or hypothetical changes
  - Conversion from prevalence to morbidity and mortality
- Feedback-rich SD model shows possible futures, role of continued policy pressure
- Examination of historical data for parameter values and model evaluation

- Economics analysis: costs associated with morbidity and mortality
  - Economic analysis goals: 1) Evaluate the tobacco-related disease treatment costs (or cost savings) associated with different policies; and 2) Provide economic foundations for individual decision making when necessary (taxes for example).

- Effects of Innovation
  - Parameter variability (e.g., new line of advertising) is part of uncertainty quantification.
  - New advertising campaigns, policies or policy responses – effects modeled in IBM.

- Case-by-case analyses of specific questions
  - Game Theory: Strategy options among entities (e.g., industry and other entities). “Interactions” between individuals and policies can be treated in a game-theoretic framework because the IBM explicitly accounts for individual decision-making strategies (as well as cognitive biases).
  - Other models/techniques: Evaluate feedbacks, significance of policies or components.

- Subsystem Diagram: Trace relevant impacts to other entities, expand analysis as necessary.
- Actualizing Solutions: Examine efficacy of policy implementations, revise and re-analyze based on new information

Notional timelines

2010...

2011...

2012 ...

2013...

Depth

2010...

2011...

2012 ...

2013...

Tobacco Products Summary
Our Question/Aspirations:
What policy options would be most effective for reducing tobacco-induced morbidity and mortality?
CASoS Analysis Process

Defining
- Define CASoS
- Define Aspirations
- Define Conceptual Model
- Test Aspirations

Designing & Testing Solutions
- Design Detailed Solutions
- Define Detailed Models
- Compare Solutions under Uncertainty
- Characterize Models
- Design Solutions

Actualizing
- Field Solution
- Monitor Attainment
Effort is Taking Shape

It's Alive!
Application of CASoS Process to Tobacco

Defining Phase

Aspirations:
Reduce tobacco-induced health problems

Possible Solutions/Interventions
1. Provide Information (e.g., advertise, educate)
2. Change Products (e.g., lower tar, add filters, change additive components)
3. Modify Barriers to Access (e.g., add taxes, age restrictions, availability)
4. Directly Intervene (e.g., provide nicotine replacement therapies, support groups, quit lines)

Individual-Based Model (micro-model)

Policies modify the environment, influencing individual behavior or susceptibility

Population Structure Model (macro-model)

Changes in behavior cascade through social networks

Changes in initiation, cessation, relapse rates change population profile

Other views, models, representations, analyses

Compare possible interventions in context of aspirations and uncertainty analysis
**Step 1: Modeling movement of opinions on interacting network**

### Policy Options

1. **Information**
   - Warnings
   - Advertising restrictions
   - Education on negative health impacts
   - Ingredient publication

2. **Changes to addictive properties**
   - Additives and product standards
   - Nicotine levels
   - Import quality controls

3. **New products, product changes**
   - Modified risk products
   - Flavorants

4. **Barriers to Access**
   - Packaging restrictions
   - Modify costs
   - Age restrictions

5. **Direct Assistance**
   - Cessation programs
   - Quit lines

6. **Other**
   - CTP expansion of authority

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- Measure changes in:
  - Prevalence
  - Morbidity
  - Mortality

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Instantiate network dynamics. Attitudes move through network using rule set based on opinion model.
Step 2: Build Out Population Structure Model (PSM)

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1. Information
   1. Warnings
   2. Advertising restrictions
   3. Education on negative health impacts
   4. Ingredient publication
2. Changes to addictive properties
   1. Additives and product standards
   2. Nicotine levels
   3. Import quality controls
3. New products, product changes
   1. Modified risk products
   2. Flavorants
4. Barriers to Access
   1. Packaging restrictions
   2. Modify costs
   3. Age restrictions
5. Direct Assistance
   1. Cessation programs
   2. Quit lines
6. Other
   1. CTP expansion of authority

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Incorporate age-dependent behavioral changes into dynamic stock and flow population model
Step 3: Implement Policies that Modify Propagation of Opinion on Network

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1. Information
   1. Warnings
   2. Advertising restrictions
   3. Education on negative health impacts
   4. Ingredient publication
2. Changes to addictive properties
   1. Additives and product standards
   2. Nicotine levels
   3. Import quality controls
3. New products, product changes
   1. Modified risk products
   2. Flavorants
4. Barriers to Access
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Step 4: Build out further policies, modifications, refinements

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   2. Advertising restrictions
   3. Education on negative health impacts
   4. Ingredient publication
2. Changes to addictive properties
   1. Additives and product standards
   2. Nicotine levels
   3. Import quality controls
3. New products, product changes
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   3. Age restrictions
5. Direct Assistance
   1. Cessation programs
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6. Other
   1. CTP expansion of authority

Policies modify the environment, influencing individual behavior or susceptibility

Changes in behavior cascade through social networks

Changes in initiation, cessation, relapse rates change population profile

Measure changes in
• Prevalence
• Morbidity
• Mortality

Add possible actions
Policy Options

1. Information
   - Warnings
   - Advertising restrictions
   - Education on negative health impacts
   - Ingredient publication

2. Changes to addictive properties
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   - Nicotine levels
   - Import quality controls

3. New products, product changes
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4. Barriers to Access
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5. Direct Assistance
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6. Other
   - CTP expansion of authority

Step 5: Evaluate Impacts of Different Combinations of Policies

Network Dynamics
Ranking of Individual and Combined Policy Options

• Baseline (no uncertainty)
  - Inputs: Best estimates of parameters based on most accurate information or expert opinion
  - Outputs: Values of measures, distributions for measures.
  - Ranking: Integrated measure (a combination of weighted measures) used for ranking policies and policy combinations. Different integrated measures may give different rankings. What are specific policy effects. What are best methods for integrating different types of measures?

• Incorporate Parameter Uncertainty
  - Inputs: Ranges for parameters
  - Outputs: Wider distributions for measures
  - Ranking: Integrated measure used for ranking policies and policy combinations.
    - Have rankings changed? What are specific policy effects?
    - Is there a clear policy choice, robust to uncertainty? Robust to different integrated measures?
    - If there is more overlap between reasonable courses of action, what data or model refinements would make choices more clear?
    - Are there critical enablers for system adaptation to changing environmental, social, and product development factors?

• Incorporate additional uncertainties and measures
  - How can we achieve parameter values that will be needed (e.g., how effective does education need to be).
  - Incorporate model uncertainty (uncertainties in model structure, assumptions, formulations, weights). Do measures’ values change? Does ranking change?
    - Results differ for different models
    - Results dependent upon different assumptions of basic behaviors (e.g., rational/irrational behaviors)
    - Results dependent upon social network interactions, initial networks
Don’t Let Up:
Feedback-Rich Societal Lifecycle of Smoking

Four “what-if” scenarios

Legend for Possible Futures:
- Lose focus
- Base run
- Reduce initiation
- Enhance focus
- Increase cessation

Use IBM Output as an exogenous change to initiation or cessation