Modeling the Healthcare Enterprise

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Overview

- Architecture of the Healthcare Enterprise
- Complex Adaptive Systems
  - Stakeholders & Interests
- Value-Driven Nature of Enterprises
- Hierarchical Network of Healthcare
- Levels of Modeling
- Network Representations
- Examples
  - Policy
  - Prevention
  - Vaccine Delivery
Knowledge and Skills for Enterprise Transformation

Clinical Practices (People)

Economic Model & Incentive Structure

System Structure (Organizations)

Human Productivity & Healthcare Costs

Competitive Positions & Economic Investments

Delivery Operations (Processes)

Economic Returns & Performance Information

Care Capabilities & Health Information

Clinical Practices (People)

Patient Care & Health Outcomes
Complex Adaptive Systems

- They are **nonlinear, dynamic** and do not inherently reach fixed equilibrium points. The resulting system behaviors may appear to be random or chaotic.
- They are composed of **independent agents** whose behavior can be described as based on physical, psychological, or social rules, rather than being completely dictated by the dynamics of the system.
- Agents' needs or desires, reflected in their rules, are not homogeneous and, therefore, their **goals and behaviors are likely to conflict** -- these conflicts or competitions tend to lead agents to adapt to each other's behaviors.
- Agents are **intelligent, learn** as they experiment and gain experience, and change behaviors accordingly. Thus, overall systems behavior inherently changes over time.
- Adaptation and learning tends to result in **self-organizing** and patterns of behavior that emerge rather than being designed into the system. The nature of such emergent behaviors may range from valuable innovations to unfortunate accidents.
- There is **no single point(s) of control** – systems behaviors are often unpredictable and uncontrollable, and no one is "in charge." Consequently, the behaviors of complex adaptive systems usually can be influenced more than they can be controlled.
<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Risk Mgt.</th>
<th>Prevention</th>
<th>Detection</th>
<th>Treatment</th>
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<tr>
<td>Public</td>
<td>e.g., Buy Insurance</td>
<td>e.g., Stop Smoking</td>
<td>e.g., Get Screened</td>
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<td>Delivery Sys</td>
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<td>Physicians</td>
<td>Physicians &amp; Hospitals</td>
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<td>Government</td>
<td>Medicare, Medicaid, Congress</td>
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<td>NIH, CDC, DoD, et al.</td>
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<td>Non-Profits</td>
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<td>American Cancer Society, American Heart Association, et al.</td>
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<tr>
<td>Academia</td>
<td>Business Schools</td>
<td>Basic Science Disciplines</td>
<td>Technology &amp; Medical Schools</td>
<td>Medical Schools</td>
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Value-Driven Nature of Enterprises

Delivered Via Value Streams
Enabled by Work Processes

Supported by Information
Enterprise Operations
Knowledge & Skills

Motivated by Incentives
Revenue & Profits
Investment & Returns

Designed Via Analytics
Complex System Models, System Architecture Frameworks, Organizational Simulations & Games, Network and Ecosystem Visualizations, and Statistical Methods for Data Mining and Enterprise Intelligence
Hierarchical Network

- **Healthcare Ecosystem (Society)**
- **System Structure (Organizations)**
- **Delivery Operations (Processes)**
- **Clinical Practices (People)**

*Intra-Level Information Flow & Incentives*

*Inter-Level Information Flow & Incentives*
## Levels of Modeling

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<th>Issues</th>
<th>Models</th>
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<td>GDP, Supply/Demand, Policy</td>
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<td>Economic Cycles</td>
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<td>Intra-Firm Relations, Competition</td>
<td>Network Models</td>
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<td>Organizations</td>
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<td>Competition</td>
<td>Game Theory</td>
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<td>Investment</td>
<td>DCF, Options</td>
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<td>Processes</td>
<td>Patient, Material Flow</td>
<td>Discrete-Event Models</td>
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<td>Process Efficiency</td>
<td>Learning Models</td>
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<td>Risk Aversion</td>
<td>Utility Models</td>
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<td>Disease Progression</td>
<td>Markov, Bayes Models</td>
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Network Representations

- **Transformations in Nodes**
  - Conversion of materials into products
  - Conversion of person into customer

- **Flows Between Network Nodes**
  - Components, assemblies, subsystems
  - Customers, patients

- **Controls of Transformation and Flows**
  - Information, e.g., work in process, inventory
  - Money, e.g., receivables, payables, assets

- **Forces of Social/Organizational Networks**
  - Reporting relationships
  - Who knows what, does what, and with whom
Queuing
Network
Markov
Model
Stochastic
Process
Block
Diagram
Differential
Equation
Bond
Graph
Model
Conservation & Continuity Principles (e.g., Little)
Modeling Primitives & Laws (e.g., Newton)
Physical Dynamic
Systems
Stochastic
Process
Logical
Relationships
Social
Relationships
Transformation
Flow
Control
Social/Org.
Example -- Policy

- **Understanding the System**
  - “Healthcare as a Complex Adaptive System: Implications for Design and Management”

- **Affordability of Healthcare**
  - “Engineering Perspectives on Healthcare Delivery: Can We Afford Technological Innovation in Healthcare?”

- **Impact of Government Price Controls**
  - “Impacts Of Healthcare Price Controls: Potential Unintended Consequences of Firms’ Responses to Price Policies”

- **Issues, Information, Incentives & Change**
  - “Engineering the System of Healthcare Delivery”
As the United States continues to debate reform of its healthcare system, this book argues that providing health insurance for all may only serve to worsen inherent problems.

The U.S. healthcare system has many excellent components: strong scientific input, extraordinary technology for diagnosis and treatment, skilled and staff, and top-notch facilities, among them. That the system has evolved haphazardly over time and although it has not failed entirely, the authors argue that the entire system where attention is paid to individual components at the expense of the system as a whole, it can never hope to succeed. Above all, they point out that the U.S. system does not provide value; healthcare is the highest costs in the world and yet many other countries have lower infant mortality rates and better life expectancy.

Together with a team of experienced experts, the authors of this publication advocate a complete re-think of healthcare from a systems perspective—a new engineering approach in healthcare—and they then describe how to set about it. Covering a wide range of subjects including: health care costs and economics, barriers to change, integrated health systems, electronic records and computer-based patient support, as well as patient safety and palliative care, this book will be of interest to all those involved in healthcare provision whose goal is affordable care to promote healthy, high quality lives.
Example -- Prevention

- **Costs of prevention include management of:**
  - Weight
  - Diet
  - Activity
  - Stress

- **Benefits of prevention include**
  - Lower healthcare costs later
  - Increased work productivity
  - Increased income (GDP)
  - Increased taxes paid

- **Net Present Value (Costs, Benefits) >> Zero!**
Population Data
- Age
- Gender
- Blood Glucose
- Cholesterol
- Body Mass Index
- Income

Disease Incidence Models
(e.g., Wilson, et al., 1998, 2007)

Disease Progression Models
(Prob. Decomposition by Year)

Patient Disease State by Year
(S1, S2, S3, …)

Disease State Consequences
- Work State by Year
- Health Costs by Year
- Prevention Costs by Year

Net Discounted Value Created
- Income Generated (GDP)
- Taxes Paid
- Employer Actuals
- National Averages

National Data
- Income by Age
- Taxes by Income
Component Models

- Population Data
  - Measurements of FGL, CHOL, BMI, etc. every 6 months
- Disease Incidence Models
  - Statistical rule-based models
- Disease Progression Models
  - Markov, Semi-Markov, Bayes Nets
- Disease State Models
  - Excel-based simulation model
- Disease Consequence Models
  - Statistical models
- Economic Value Models
  - Discounted cash flow models
  - Statistical models
Implications

- **Critical Issues**
  - Does the investor in prevention also gain the returns?
  - To what extent can people manage their own prevention?
  - What is the best role of other people?
    - Family members
    - Facebook friends
    - Health coaches

- **Many Approaches to Prevention**
  - Primary Care Physicians
  - Nurses & Physician Assistants
  - Health Coaches
  - Web-Based Tools & Games
  - Costs of Delivery Vary Widely
Example -- Vaccine Delivery

- **Supply Chain Can Be Lengthy**
  - Begins With Airplanes and Trucks
  - Ends With Bicycles and Backpacks
- **Vaccines Are Sensitive to Temperature**
  - Become Impotent At Extended High Temperatures
  - Become Impotent With Repeated Freezing
- **Simulation Provides Assessments of New Technology**
  - Discrete-event model of flow of containers
  - System dynamics model of state of vaccine
- **Economic Payoff Due in Two Ways**
  - Ship less vaccine for same number of potent vaccinations
  - Vaccinate more people for same amount of money
Vaccine Cold Chain
Four-Link Model

- The schematic to the right models the two transit links and two storage links.
- The first two links simulate truck transport of large containers from the state to the local government level, and a subsequent period of storage.
- The last two links simulate local transport of small containers from the local government to the point of vaccine administration, and a waiting period before use.
- These links represent a plausible scenario for container use.
Four-Link Model Baseline

- Modeling distribution of a vaccine with low heat tolerance
- First link has 48 hour duration at constant 35°C
- Second link has 120 hour duration at constant 5°C
- Third link has 8 hour duration at 35°C, with temperature increasing one degree per hour
- Fourth link has 6 hour duration at constant 25°C
Four-Link Model -- Variability

- Baseline scenario with added parameter variability
- Refrigerant mass randomized by 25% for both large and small containers
- First link has 36-60 hour duration at constant temperature between 25-45°C
- Second link unchanged
- Third link has 6-10 hour duration at temperature between 25-45°C, with temperature increasing one degree per hour
- Fourth link has 4.5-7.5 hour duration at constant temperature between 20-30°C
Four-Link Model -- Delay

- Variable four-link model with an added delay of 24 hours in the first link, resulting in duration of 60-84 hours for this link
- Other links as in variable model
- Storage at 5C in second link keeps temperature results in later links similar to those for the variable model, but delay has significant effects on loss probability
Projected Cost Savings

- Using loss probabilities (LP), the ratio of shipped vaccine needed to fulfill demand is $1/(1-LP)$
- In the average case for the four-link model with delayed delivery, 15% more vaccine must be purchased and shipped using the best-in-class competitor when compared to the proposed new container
- Using estimates presented earlier, the new container carries 25% more vaccine per unit weight and volume shipped, reducing shipping costs by approximately 30% when combined with reduced vaccine wastage
- The new container costs less than competitors, and should prove more durable, further enhancing value
- These factors make a compelling case for the product, which will be enhanced by incorporation of higher-order effects
Summary

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