Modeling & Managing Complex Systems
A Case Study of Healthcare Delivery

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Overview

• Complex Adaptive Systems
• Healthcare Delivery
• Complexity of Healthcare
• Case Study – Cost Control
• Healthcare Enterprise
• Summary
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.
Healthcare

- Stakeholders & Interests
- Example of Disease Detection
- Network of Networks
<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Risk Mgt.</th>
<th>Prevention</th>
<th>Detection</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>e.g., Buy Insurance</td>
<td>e.g., Stop Smoking</td>
<td>e.g., Get Screened</td>
<td></td>
</tr>
<tr>
<td>Delivery Sys</td>
<td></td>
<td>Physicians</td>
<td>Physicians &amp; Hospitals</td>
<td></td>
</tr>
<tr>
<td>Government</td>
<td>Medicare, Medicaid, Congress</td>
<td>NIH, CDC, DoD, et al.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Profits</td>
<td></td>
<td>American Cancer Society, American Heart Association, et al.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Academia</td>
<td>Business Schools</td>
<td>Basic Science Disciplines</td>
<td>Technology &amp; Medical Schools</td>
<td>Medical Schools</td>
</tr>
</tbody>
</table>
Disease Detection

Public Awareness → Public Readiness → Screening Available → Costs Covered → Screening Effective

Public Communication → Public Education → Physician Education

Consumer Advocacy → Medical Research

Public, Delivery System, Government, Non-Profits, Academia, Business

Public, Delivery System, Government, Non-Profits, Academia, Business

Knowledge and Skills for Enterprise Transformation.
Networks of Networks

Accreditation & Licensing
- American Board of Medical Specialties
- Accreditation Council for Graduate Medical Educ.
- Accreditation Council for Continuing Medical Educ.
- AOA Council on Postdoctoral Training
- Federation of State Medical Boards
- Joint Commission on Accreditation of Healthcare Org.
- Liaison Committee on Medical Education

Professional Associations
- American Academy of Family Physicians
- American Medical Association
- American Osteopathic Association (AOA)
- Council of Medical Specialty Societies
- Etc.

Examples of Other Stakeholders
- American Assoc of Retired Persons
- Leapfrog Purchasing Group
- National Business Group on Health
- Etc.
Complexity

- Market Complexity
- Studying Complexity
- Design Implications
- Management Implications
Market Complexity

• Retail
• Telecom
• Healthcare
• Complexity Model
  – Network Model
  – Calculating Complexity
  – Complexity Surface
• Complexity Assessment
Retail

Knowledge and Skills for Enterprise Transformation.
Healthcare
Network Model

\[ N_i \] = No. of 1\textsuperscript{st} tier suppliers to i\textsuperscript{th} product/service outlets
\[ N_{ij} \] = No. of 2\textsuperscript{nd} tier suppliers to ij\textsuperscript{th} Tier 1 supplier, e.g., OEM
\[ N_{ijk} \] = No. of 3\textsuperscript{rd} tier suppliers to ijk\textsuperscript{th} Tier 2 supplier
\[ N_{ijkl} \] = No. of 4\textsuperscript{th} tier suppliers to ijk\textsuperscript{lth} Tier 3 suppliers
Calculating Complexity

\[ C = \sum_{m=1}^{T} p t_m \left\{ \sum_{i=1}^{N_i} - p(n_i | t) \log [p(n_i | t_m)] + \sum_{j=1}^{N_{ij}} - p(n_j | n_i t) \log [p(n_j | n_i t_m)] + \sum_{k=1}^{N_{ijk}} - p(n_k | n_i n_j t) \log [p(n_k | n_i n_j t_m)] + \sum_{l=1}^{N_{ijkl}} - p(n_l | n_i n_j n_k t) \log [p(n_l | n_i n_j n_k t_m)] \right\} \]
Complexity Surface
Complexity Assessment

![Complexity Assessment Chart]

- **Aerospace**
- **Automotive**
- **Retail**
- **Healthcare**
- **Telecom**

Comparison of Consumer and Total Complexity across industries:
- **Aerospace**
- **Automotive**
- **Retail**
- **Healthcare**
- **Telecom**

Legend:
- **Consumer**
- **Total**

Bar Chart highlights the varying complexities across industries.
Design Implications

- Two Design Principles
- Designed Complexity
- Enterprise Agility
- Enterprise Architectures
Two Design Principles

- The nature and extent of B2C service value determines B2B service value, as well as the value of products and other value enablers.
- The magnitude of B2C complexity, relative to total market complexity, reflects market maturity
  - Both B2C and B2B complexity are expressed in terms of information theory binary digits (bits),
  - B2B complexity is often increased, in turn increasing total complexity, in order to reduce B2C complexity.

B2C = Business to Consumer
B2B = Business to Business
Designed Complexity

- The enterprise as a system includes all stakeholder organizations whether they are your partners, collaborators, channels, competitor, or regulators.
- Increase complexity where you can best manage it, in order to decrease complexity to end users, i.e., patients and physicians.
  - You can manage design, development, manufacturing, sustainment.
  - You cannot manage economies, markets, competitors, end users.
- Support managing complexity by providing means to monitor and influence system state, performance, and stakeholders – see Managing Complexity.
Enterprise Agility

- **Optimization Within Design Assumptions**
  - Objective is to balance performance and costs
  - Assure robust allocation of resources

- **Adaptation Beyond Design Assumptions**
  - Objective is to balance opportunities and risks
  - Assure ability to reallocate resources

- **Tradeoffs Between Optimization vs. Adaptation**
  - Options for contingencies enhance agility
  - Costs of options undermine optimality

- **Architectures That Enable Ongoing Tradeoffs**
Enterprise Architectures

- Strategic Processes
- Operational Processes
- Information Systems
- Information Technology
Management Implications

- Value Philosophy
- Organizational Behaviors
- Managing Complexity
Value Philosophy

• Value focuses on organizational outputs (or outcomes), rather than inputs.
  – Health states of patients vs. budgets of providers

• Value relates to benefits of outcomes, rather than outcomes themselves.
  – Productivity improvements due to wellness

• Value implies relevant, usable, and useful outcomes.
  – Stakeholders have to understand and appreciate
## Organizational Behaviors

<table>
<thead>
<tr>
<th></th>
<th>Traditional System</th>
<th>Complex Adaptive System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roles</td>
<td>Management</td>
<td>Leadership</td>
</tr>
<tr>
<td>Methods</td>
<td>Command &amp; Control</td>
<td>Incentives &amp; Inhibitions</td>
</tr>
<tr>
<td>Measurement</td>
<td>Activities</td>
<td>Outcomes</td>
</tr>
<tr>
<td>Focus</td>
<td>Efficiency</td>
<td>Agility</td>
</tr>
<tr>
<td>Relationships</td>
<td>Contractual</td>
<td>Personal Commitments</td>
</tr>
<tr>
<td>Network</td>
<td>Hierarchy</td>
<td>Heterarchy</td>
</tr>
<tr>
<td>Design</td>
<td>Organizational Design</td>
<td>Self Organization</td>
</tr>
</tbody>
</table>
Managing Complexity

- **System State**
  - Current and projected value flows
  - Current and projected problems

- **System Performance**
  - Current and projected value, costs & value/cost
  - Current and projected options for contingencies

- **System Stakeholders**
  - Involvement of each stakeholder group
  - Performance of each stakeholder group

- **Information Systems**
  - Measurement, modeling & display of system state
  - Agile “What If?” experimentation & adaptation
Case Study

• **Motivation**
  - Tripled %GDP for real healthcare costs for 1965-2005
  - 50% of cost growth attributable to technological innovation
  - “Running on Empty”

• **Approach**
  - Growth Model
  - Learning Model
  - Process Model

• **Conclusions**
Approach

- Overall Phenomenon
- Model No. 1 & Results
- Model No. 2 & Results
- Model No. 3 & Results
- Implications
Technology Innovation

- Increased Efficiency
- Increased Effectiveness
- Decreased Risk
- Decreased Cost/Use
- Increased Use
- Increased Expenditures
- Longer Life
- Improved Care
Model No. 1 -- Growth

Cost \((1 - \alpha)\) Use \((1 + \beta)\) = Total \((1 + \delta)\)

where

\[\alpha = \text{Annual rate of cost reduction}\]
\[\beta = \text{Annual rate of usage growth}\]
\[\delta = \text{Annual allowable total growth}\]

\[\alpha = (\beta - \delta)/(\beta + 1)\]
## Results No. 1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Annual Rate of Usage Growth</th>
<th>Minimum Annual Rate of Cost Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angiography</td>
<td>10%</td>
<td>9%</td>
</tr>
<tr>
<td>Angioplasty</td>
<td>15%</td>
<td>13%</td>
</tr>
<tr>
<td>Dialysis</td>
<td>12%</td>
<td>11%</td>
</tr>
<tr>
<td>Hip Replacement</td>
<td>10%</td>
<td>9%</td>
</tr>
<tr>
<td>Knee Replacement</td>
<td>11%</td>
<td>10%</td>
</tr>
</tbody>
</table>
Limitations

• Model Provides No Mechanism for Achieving Cost Reductions
• Model Does Not Differentiate Elements of Healthcare Delivery Process
## Model No. 2 -- Learning

Cost \( (t=T) = Cost \ (t=0) \ \text{No. Uses} \ (t=T) \cdot \text{Rate} \)

<table>
<thead>
<tr>
<th>Percent Cost Per Use for Each Doubling of Uses</th>
<th>Rate for Learning Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>0.515</td>
</tr>
<tr>
<td>80%</td>
<td>0.322</td>
</tr>
<tr>
<td>90%</td>
<td>0.152</td>
</tr>
</tbody>
</table>

*Note: This is a well-developed concept in a wide range of production processes.*
Cost Reductions @ 5% Growth

Cost Per Use for Three Learning Rates

Costs Per Use

- 100
- 80
- 60
- 40
- 20
- 0

Uses

100 110 122 134 148 163 180 198 218 241 265 293 323 356 392

- 70%
- 80%
- 90%
Expenditure Growth @ 5%

Growth of Expenditures @ 5%

Year

Total Costs

- 5,000
- 10,000
- 15,000
- 20,000
- 25,000

1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
Cost Reductions @ 10% Growth

Cost Per Use for Three Learning Rates

Costs Per Use

Uses
Expenditure Growth @ 10%

Growth of Expenditures @ 10%

Total Costs

Year
## Results No. 2

Results at 30 Years

<table>
<thead>
<tr>
<th>Rate</th>
<th>No. of Uses</th>
<th>Cost/Use</th>
<th>Total Expenditures</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>412</td>
<td>$48/use</td>
<td>$19,874</td>
</tr>
<tr>
<td>10%</td>
<td>1586</td>
<td>$24/use</td>
<td>$38,256</td>
</tr>
</tbody>
</table>

Note: Uses = 100, Cost/Use = $100, Total = $10,000 at Year = 1
Limitations

- Model Exhibits Impressive Cost Reductions Due to Production Learning, But It Does Not Suggest Where & How This Learning Happens
- Model Does Not Reflect the Process Whereby Healthcare Is Delivered
Model No. 3 -- Process

Detection → Diagnosis → Treatment → Recovery

Labor

Technology

←

←

←

←
Expanded Cost Model

Cost (t) = Cost of Labor (t) + Cost of Tech. (t)

\[ C_{TOT} (t) = CPU_L (t) \cdot NU (t) + CPU_T (t) \cdot NU (t) \]

\[ CPU_L (t) = CPU_L (1) \cdot NU (t)^{-Rate_L} \]

\[ CPU_T (t) = CPU_T (1) \cdot NU (t)^{-Rate_T} \]

\[ NU (t) = NU(1) \cdot (1+\beta)^{t-1} \]
Results No. 3

Required Efficiency (% Cost Per Use Per Doubling)

Labor Cost Per Use

Technology Use Growth Rate

- GDP = 0%
- GDP = 2%
- GDP = 4%
Implications

• In order to limit the growth of total healthcare spending to the growth of the GDP, some combination of three things is needed
  – Limiting the growth of technology use
  – Limiting the cost of technology use
  – Decreasing the cost of labor associated with use

• Overall, savings due to learning are the key to affordability
  – Learning rates of < 70% are very difficult to achieve
Sources of Learning

- Labor efficiency, changes in personnel mix, standardization, specialization, methods improvements, better use of equipment, changes in the resource mix, product and service redesign, and shared best practices.
  - **Less Labor Per Use**: Achievable via individual learning and productivity enhancements.
  - **Less Expensive Hours Per Use**: Achievable by, for example, substituting assistant physicians or nurse practitioners for physicians. In this case, the experts can be used as orchestrators of cadres of much less expensive clinicians.
  - **No Labor Per Use**: Often technology enabled. For example, web-based scheduling and account management can enable patients to substitute their labor for that of providers, as has been experienced in the airline, banking, and retail industries.
“Bending the Curve”

1. Producing and Using Better Information
   1. Promoting Health Information Technology
   2. Center for Medical Effectiveness & Health Care Decision Making
   3. Patient Shared Decision Making

2. Promoting Health and Disease Prevention
   1. Public Health: Reducing Tobacco
   2. Public Health: Reducing Obesity
   3. Positive Incentives for Health

3. Aligning Incentives with Quality and Efficiency
   1. Hospital Pay-for-Performance
   2. Episode-of-Care Payment
   3. Strengthening Primary Care and Care Coordination
   4. Limit Federal Tax Exemptions for Premium Contributions

4. Correcting Price Signals in the Health Care Market
   1. Reset Benchmark Rates for Medicare Advantage Plans
   2. Competitive Bidding
   3. Negotiated Prescription Drug prices
   4. All-Payer Provider Payment Methods and Rate
   5. Limit Payment Rate Updates in High-Cost Areas
Interpretation

• Seven of these recommendations would tend to reduce use rates
  – 1.2, 1.3, 2.1, 2.2, 2.3, 3.1, 3.2
• Nine of these recommendations focus on reducing costs by
  – Increased efficiency (1.1, 1.2, 3.3)
  – Increased market-based competition (3.4, 4.1-4.5)
Conclusions

• Successful Technology Innovation Leads to Growing Markets and Increased Revenues
  – Revenue to Innovator ➔ Cost to Payer

• Such Growth Is Viewed More Favorably When Individuals Pay, Rather Than Third Parties
  – Possible Market-Based Mechanisms?

• Increasing System Efficiency Is Needed to Assure the Affordability of Technology Innovation
  – Required Improvements Are Very Substantial
Healthcare Enterprise

- Entities & Context
- Enterprise Architecture
- Implications for Change
- Hierarchical Network
## Entities & Contexts

<table>
<thead>
<tr>
<th>Entities Interacting</th>
<th>Context of Interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>People</td>
<td>Processes</td>
</tr>
<tr>
<td>Processes</td>
<td>Organizations</td>
</tr>
<tr>
<td>Organizations</td>
<td>Society</td>
</tr>
</tbody>
</table>
Implications for Change

• Value can be increased in two ways
  – Increase the health outcomes
  – Decrease the cost of outcomes
• Increasing value provided by Clinical Practices
  – Constrained by the nature of Delivery Operations
• Increasing value provided by Delivery Operations
  – Constrained by System Structure
• Increased value provided by System Structure
  – Constrained by the Ecosystem
Summary

• Complex Adaptive Systems
• Healthcare Delivery
• Complexity of Healthcare
• Case Study – Cost Control
• Healthcare Enterprise