Massachusetts Institute of Technology

Engineering Approach to Healthcare Delivery

Predictive Modeling Team
Suhail Ahmad, Terry Hu, Kangse Kim, Jeongyeon Shim, Sungmin You

Seminar on Healthcare System Innovation
October 7, 2010
AGENDA

• Systems Engineering and Management
• Operations Research
• Engineering Healthcare as a Service System
• Process Engineering: A Necessary Step to a Better Public Health System
AGENDA

• Systems Engineering and Management

• Operations Research

• Engineering Healthcare as a Service System

• Process Engineering: A Necessary Step to a Better Public Health System
THE VALUE OF SYSTEMS ENGINEERING FOR HEALTHCARE

Healthcare as a non-system

Value proposition of systems engineering

NAE and IOM Findings

- Nontraditional system
- High organizational barriers
- Systems engineering has been proven in other industries
- Slow adoption of tools in healthcare
- Potential for improvement
- Inadequate attempt to use system engineering in healthcare
- Information systems will be critical
- Few incentives for change
- Active team effort necessary for adoption of system engineering tools
Definition of Requirements

Architecture of the System

NAE and IOM Recommendations

- Insurers, employers, and payers should provide incentives to use system tools
- Increase efforts to expand and integrate systems coordination
- NIH Library of Medicine should provide information and access to tools, Government entities should provide support to train people to use tools
- Do not wait in implementing single tools
- Increase support of research for application of systems engineering in healthcare
SYSTÉMS ENGINÉERING MÉTHODS AND TOOLS

Design
- Tradeoffs, Limits, Objectives
- Quality Function Deployment, Design Structure Matrices
- Plausibility
  - Failure Mode and Effects Analysis, Fault Tree Analysis

Analysis
- Modeling performance over time
  - Queuing theory, system dynamics
  - Mathematical programming – allocation of resources
  - Process engineering, supply chain management, risk management

Control
- Compare actual outcomes to desired outcomes, and adjust accordingly
- Statistical process controls and forecasting
  - Six Sigma, Toyota Production System
• Systems Engineering and Management

• Operations Research

• Engineering Healthcare as a Service System

• Process Engineering: A Necessary Step to a Better Public Health System
THERE ARE THREE KEY AREAS OF OPERATIONS RESEARCH IN HEALTHCARE DELIVERY

Operations management
- Reduce variability in the delivery processes
- Improve efficiency and effectiveness in the delivery of clinical, ancillary, and administrative services through process analyses

Medical management & biomedicine
- Assist in the structuring and support of medical decisions
- Improve the performance of diagnosis, testing, and treatment strategies

System design and planning
- Facilitate decision-making on services and technology to be provided
- Assist in planning for level of resources and capacity

Optimize across:
- Cost
- Technology
- Quality
- Access
Operations management can result in direct cost savings through better planning.

- Demand forecasting
- Workforce planning and scheduling
- Inpatient scheduling
- Outpatient scheduling

- An ARIMA model on patient demand by type of service and month of the year produced forecast with errors ranging from 3.3% to 21.5% in the UK.

- Use of optimization models and tools in managing home health workers has resulted in $30-45M annual savings in Sweden.
OPERATIONS RESEARCH METHOD CAN IMPROVE CLINICAL PRACTICE AS WELL AS BASIC RESEARCH

- Individual treatment choice
- Procedure performance
- Population-level disease screening
- Individual-level disease screening
- Computational biology

- Direct surgical costs of prostate cancer was reduced by $5,600 per patient through brachytherapy aided by nonlinear mathematical programming model and real-time imaging

- Operations research method was applied to HIV control in New Haven and NYC, including choice of method and cost implication
UK’s NICE using a cost-effectiveness model to determine whether to make a specific technology available to its population.

Mixed-integer programming was used to select optimal locations of traumatic brain injury units for VAMC in Florida.

Cincinnati Children’s Hospital Medical Center avoided construction of 102 additional beds through better capacity planning and demand forecasting.
DEMAND FORECASTING, FOLLOWED BY WORKFORCE PLANNING ARE AREAS WHERE MORE RESEARCH HAS TAKEN PLACE

<table>
<thead>
<tr>
<th>Demand forecasting</th>
<th>Workforce planning and scheduling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective</strong></td>
<td>• Develop capability to match staffing resources to a fluctuating demand</td>
</tr>
<tr>
<td></td>
<td>• Improve operating efficiency and quality of service</td>
</tr>
<tr>
<td></td>
<td>• Levels of decision:</td>
</tr>
<tr>
<td></td>
<td>• Corrective allocation: day</td>
</tr>
<tr>
<td></td>
<td>• Shift schedule: 1-2 months</td>
</tr>
<tr>
<td></td>
<td>• Workforce plan: quarter to year</td>
</tr>
<tr>
<td></td>
<td>• Typical practice: cyclic scheduling or self-scheduling for shifts</td>
</tr>
<tr>
<td><strong>Examples</strong></td>
<td>• Various regression methods incorporating exogenous and/or institutional variables</td>
</tr>
<tr>
<td></td>
<td>• Approach incorporating patient demand and higher level decision</td>
</tr>
<tr>
<td></td>
<td>• Multiple regression model based on ARIMA for workload forecasting</td>
</tr>
<tr>
<td></td>
<td>• Optimization through mathematical programming</td>
</tr>
</tbody>
</table>

**Objective**
- Enable revenue and resource planning
- Avoid shortfall, quality decrease, and cost hike

**Examples**
- Pre-hospital care and ambulance staffing
- Inpatient service by type and month
- Need for intermediate home nursing

**Method/Need**
- Various regression methods incorporating exogenous and/or institutional variables
AGENDA

• Systems Engineering and Management
• Operations Research

  • Engineering Healthcare as a Service System

• Process Engineering: A Necessary Step to a Better Public Health System
Essential components of Healthcare Services

- **Process**
- **Products**

**Value**

**Efficiency**
- Meeting demand with minimum cost

**Effectiveness**
- Producing the right service for the right patient at the right time and right place

**Robust**
- Insure reliability, quality and integrity

**Knowledge intensive agents**

**Create or coproduce**

**providers**

**consumers**
Complexity of Healthcare Services

Knowledge

Uncertainties

Information Technology

Complexity

Management

Emergence of electronic services based on IT
- Economies of knowledge and expertise
- Real-time adaptive decision making

Relationship with Manufacturing
- Interdependencies
- Similarities
- Complementarities
- Software algorithm-laden, self producing vs human resource-laden, co producing

Mass Customization
- Meeting the need of customer market that is partitioned into an appropriate number of segments, each with similar needs

Integrative
- Physical
- Temporal
- Organizational
- Functional

Adaptive
- Decision Making
- Decision Informatics
- Human Interface
Healthcare as an integrated system

Integration occurs over multiple dimensions

Physical
- natural, constructed or virtual environment?

Temporal
- strategic, tactical and operational perspectives

Organizational
- resources, economics, and management

Functional
- input, process and output function

People
- demanders
- suppliers

Processes
- procedural
- algorithmic

Products
- physical
- virtual
Co-producing systems MUST be adaptive by definition (example: personalized medicine)

Essential components of human centric adaptation:
- Decision making
- Decision informatics
- Human interface

Data || Information || Knowledge || Wisdom
Operational || Tactical || Strategic || Systemic

Adaptation dimensions

Monitoring
- Degree of sensed actions (sensors, patterns)

Feedback
- Degree of expected actions (standard operating procedures, Bayesian)

Cybernetic
- Degree of relative actions (deterministic, dynamic or adaptive actions)

Learning
- Degree of unstructured actions (cognition, evidence, improvisation, genetic or evolutionary algorithms)
Healthcare as a Complex System

Healthcare System Stages

Purpose
- Stakeholders, business models

Boundary
- Spatial, temporal

Design
- Robust, effective, efficient

Development
- Scalability, sustainability

Deployment
- Risk, unintended consequences

Operation
- Safe, secure

Life Cycle
- Predictable, controllable

Integrative Approaches

Adaptive Approaches

Complexity

Supply: Fixed - Demand Fixed
- Established Prices

Supply: Fixed - Demand: Flexible
- Dynamic pricing, target marketing

Supply: Flexible - Demand Fixed
- Inventory control, production scheduling

Supply: Flexible - Demand: Flexible
- Customized coproduction bundling

DCM

SCM

RTCM
• Systems Engineering and Management
• Operations Research
• Engineering Healthcare as a Service System

• Process Engineering: A Necessary Step to a Better Public Health System
<table>
<thead>
<tr>
<th>Public Health System</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Role: Intervention and prevention of disease and injury to protect entire population</td>
</tr>
<tr>
<td>• Complex, fragmented nature of public health system:</td>
</tr>
<tr>
<td>— No single point of control</td>
</tr>
<tr>
<td>— Function or program-specific silos of information</td>
</tr>
<tr>
<td>— Complex array of governing regulation (Federal, state and local)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Challenges and New Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Recognition of commonality: Increasing demand for interoperable, adaptive information system across U.S. health system</td>
</tr>
<tr>
<td>• New approach of process engineering: Need comprehensive analysis and understanding of the core business process</td>
</tr>
</tbody>
</table>
PROCESS ENGINEERING CONSISTS OF THREE PHASES: BUSINESS PROCESS ANALYSIS, BUSINESS PROCESS REDESIGN AND SYSTEM REQUIREMENT DEFINITION

Descriptions

- Analyze how organization's work is performed
- Produce documentation of core business process
- Use graphical tools such as context diagrams and task flows

- Redesign how the work should be performed
- Produce documentation of which processes can be restructured to improve efficiency

- Develop requirements based on the redesigned business process
- Describe how information system should be built to support the new process
APPENDIX
PATIENT SCHEDULING IS AN AREA WHERE MORE RESEARCH COULD TAKE PLACE

**Objective**
- Control demand while optimizing throughput and quality of outcome
- Reduce staffing costs and congestion

**Examples**
- Type of scheduling:
  - Scheduling of elective admissions
  - Daily scheduling of inpatients to appropriate care units
  - Discharge scheduling
- Typical practice of assigning slots or beds to specific specialty creating artificial variation

**Method/Need**
- Forecast based on estimation of length of stay
- Need to incorporate bottlenecks within the hospital system

**Inpatient scheduling**

**Outpatient scheduling**

- Typical practice includes:
  - Block scheduling
  - Modified block scheduling
  - Individual scheduling

- Queuing theory
- Truncated Poisson distribution for patient arrival
- Separate modeling of emergency and scheduled patients
OPERATIONAL RESEARCH CONTRIBUTES TO IMPROVEMENT IN PROVIDER...

**Objective**

- Facilitate complex decisions by identifying critical nodes influencing outcome

**Examples**

- Expected cost and QALY calculation in total hip arthroplasty vs. no surgery
- Choice of treatment for prostate cancer

**Method/Need**

- Decision trees
- Dynamic influence diagrams
- Sensitivity analysis
- Modeling ambiguous outcome

**Individual treatment choice**

**Procedure performance**

- Improve the quality and reduce costs of diagnosis and treatment procedures through real-time support and standardization
- Interpretation of mammograms
- Selection and sequencing of tests for HIV screening in blood donation
- Radiation treatment planning

- Bayesian network or decision model
- Optimization tools through MATLAB
...AS WELL AS PUBLIC HEALTH POLICIES AND BASIC RESEARCH

<table>
<thead>
<tr>
<th>Population-level disease screening</th>
<th>Individual-level disease screening</th>
<th>Computational biology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective</strong></td>
<td><strong>Objective</strong></td>
<td><strong>Objective</strong></td>
</tr>
<tr>
<td>• Minimize prevalence, given resource limit</td>
<td>• Minimize detection delay or maximize lead time, over individual lifetime</td>
<td>• Leverage operations research methodology to biology research</td>
</tr>
<tr>
<td>• Facilitate decision on cost, technology, test frequency, and compliance implication</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Examples</strong></td>
<td><strong>Examples</strong></td>
<td><strong>Examples</strong></td>
</tr>
<tr>
<td>• Epidemic control models of HIV and other infectious diseases</td>
<td>• Policy on screening interval for various cancer, taking into account variables such as age, sex, and history</td>
<td>• Sequence alignment algorithm of palindromes</td>
</tr>
<tr>
<td>• Mass-screening protocol for retinopathy or cancer</td>
<td></td>
<td>• Phylogenetic trees of virus</td>
</tr>
<tr>
<td>• Simulation models</td>
<td>• Bayesian network</td>
<td>• Protein folding simulation and structure prediction</td>
</tr>
<tr>
<td></td>
<td>• Comprehensive sensitivity analysis</td>
<td></td>
</tr>
<tr>
<td><strong>Method/Need</strong></td>
<td><strong>Method/Need</strong></td>
<td><strong>Method/Need</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Mathematical programs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Data mining</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Stochastic models</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Simulations</td>
</tr>
</tbody>
</table>
System-wide design or policy can also reap benefits from operations research such as optimization...

<table>
<thead>
<tr>
<th>Planning and strategy</th>
<th>Technology assessment and adoption</th>
<th>Regionalization of services and technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective</strong></td>
<td><strong>Objective</strong></td>
<td><strong>Objective</strong></td>
</tr>
<tr>
<td>• Facilitate healthcare system-wide design and planning on national level</td>
<td>• Assess the cost and benefit of new medical technology or drug</td>
<td>• Support decisions on regionalization, health districting, and the expansion and contraction of services</td>
</tr>
<tr>
<td><strong>Examples</strong></td>
<td><strong>Examples</strong></td>
<td><strong>Examples</strong></td>
</tr>
<tr>
<td>• Optimization of strategic choices (e.g., accessibility, copay, formularies)</td>
<td>• UK’s NICE assessing the cost effectiveness model in making decisions on whether to introduce a specific technology</td>
<td>• Reconfiguration model of US Military Health System</td>
</tr>
<tr>
<td>• Organizational performance analysis</td>
<td>• Cost effectiveness analysis</td>
<td>• Decision support system for HIV/AIDS services in UK (AIDSPLAN)</td>
</tr>
<tr>
<td><strong>Method/Need</strong></td>
<td><strong>Method/Need</strong></td>
<td><strong>Method/Need</strong></td>
</tr>
<tr>
<td>• Data envelopment analysis</td>
<td>• Cost benefit analysis</td>
<td>• Optimal clustering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Decision support system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• System dynamics model</td>
</tr>
</tbody>
</table>
...AS WELL AS PLANNING AT A REGIONAL SCALE

**Objective**
- Support decision on regionalization, opening or removal of a facility, or the location for specific services

**Examples**
- Computerized Ambulance Location Logic (CALL)
- Optimizing location for preventive services (GA, QB) or traumatic brain injury units (VAMC)
- Regionalization of CT scanners in Germany
- Supply chain management in blood and blood products in a region

**Method/Need**
- Hooke-Jeeves algorithm
- Location set covering model, maximal covering model, P-median model
- Various mathematical models

**Capacity planning and analysis**
- Plan addition, expansion, or contraction of services and facilities, taking into account the interdependence between services
- Estimation of the number of beds required given demand, occupancy, seasonality, organizational issues, and HR allocation
- Impact of obstetric service consolidation to hospital case load and profitability
- Various techniques such as demand forecasting, utilization optimization, throughput analysis
HEALTHCARE AS A COMPLEX SYSTEM

**Dynamic**
- No fixed equilibriums, chaotic by appearance

**Independent Agents**
- Individual behavior not dictated by the system
- Differing objectives lead to competition and conflict

**Adaptive**
- Individuals adapt their behaviors with learning, thereby changing the system over time
- Adaptations due to learning are not designed by the system
- Adaptive systems with unpredictable behaviors cannot be directly controlled, but rather influenced