Massachusetts Institute of Technology

Engineering Approach to Healthcare Delivery

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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

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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

REQUIREMENTS FOR ADOPTING SYSTEMS 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

SYSTEMS ENGINEERING METHODS 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

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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

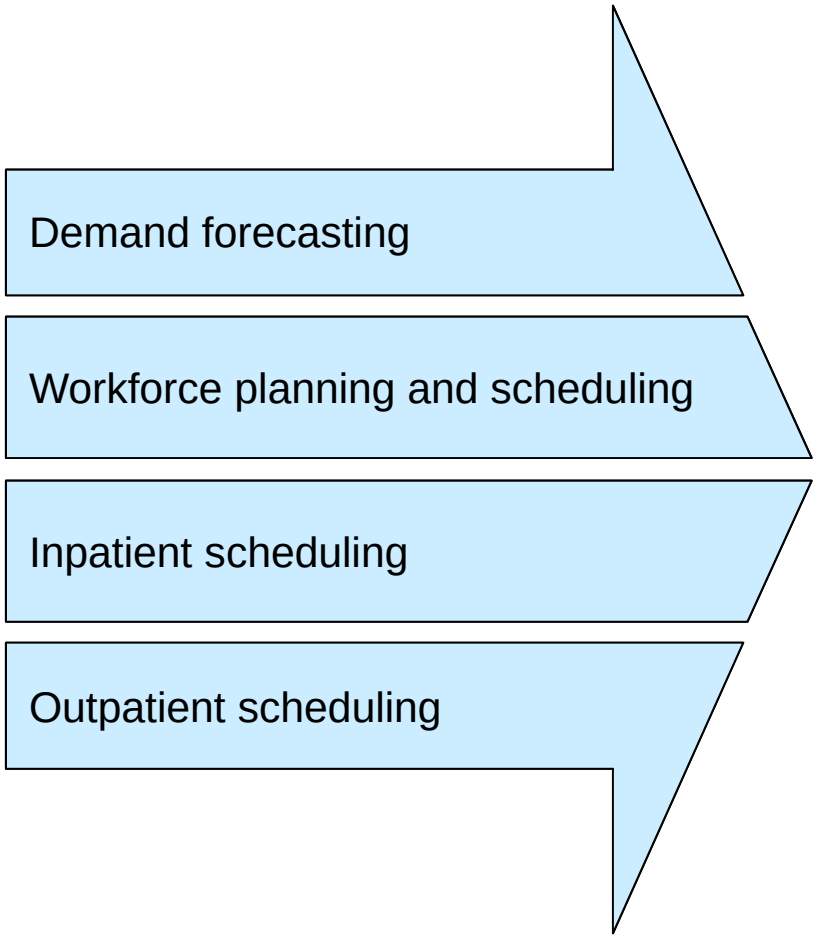
System design and planning

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

Optimize across:

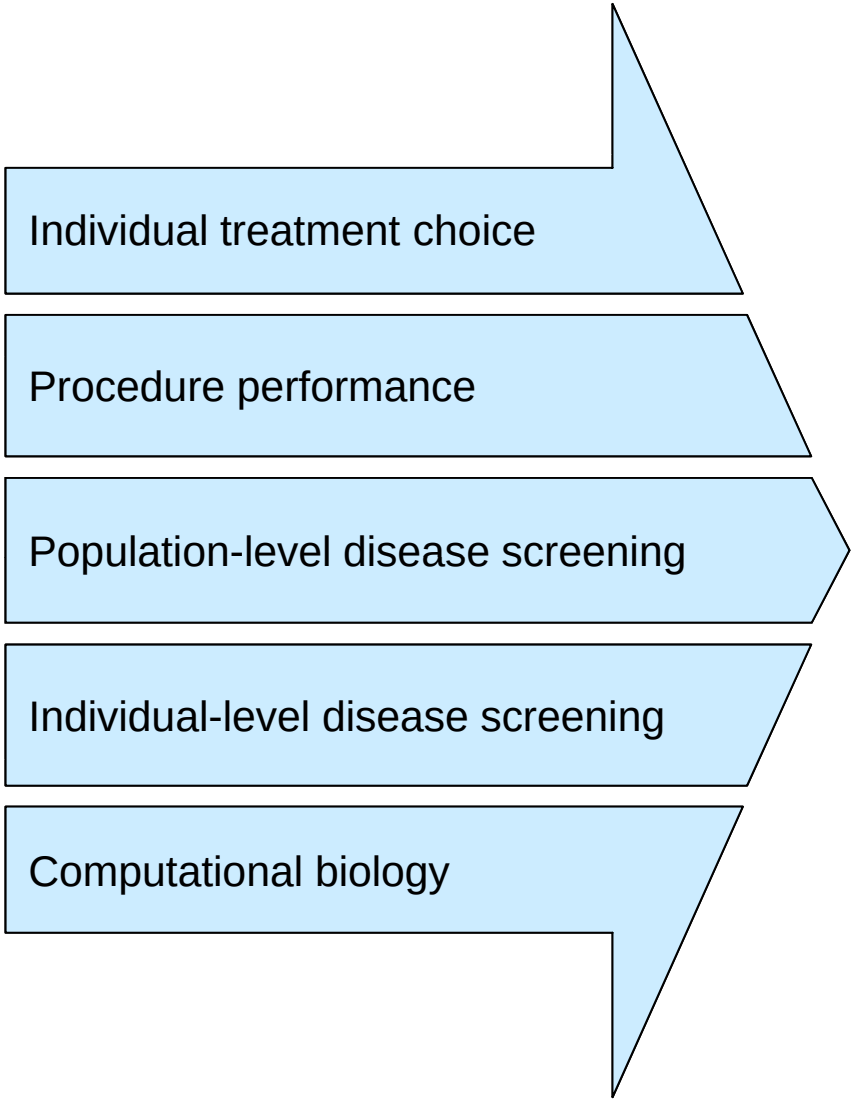
- Cost
- Technology
- Quality
- Access

OPERATIONS MANAGEMENT CAN RESULT IN DIRECT COST SAVINGS THROUGH BETTER PLANNING



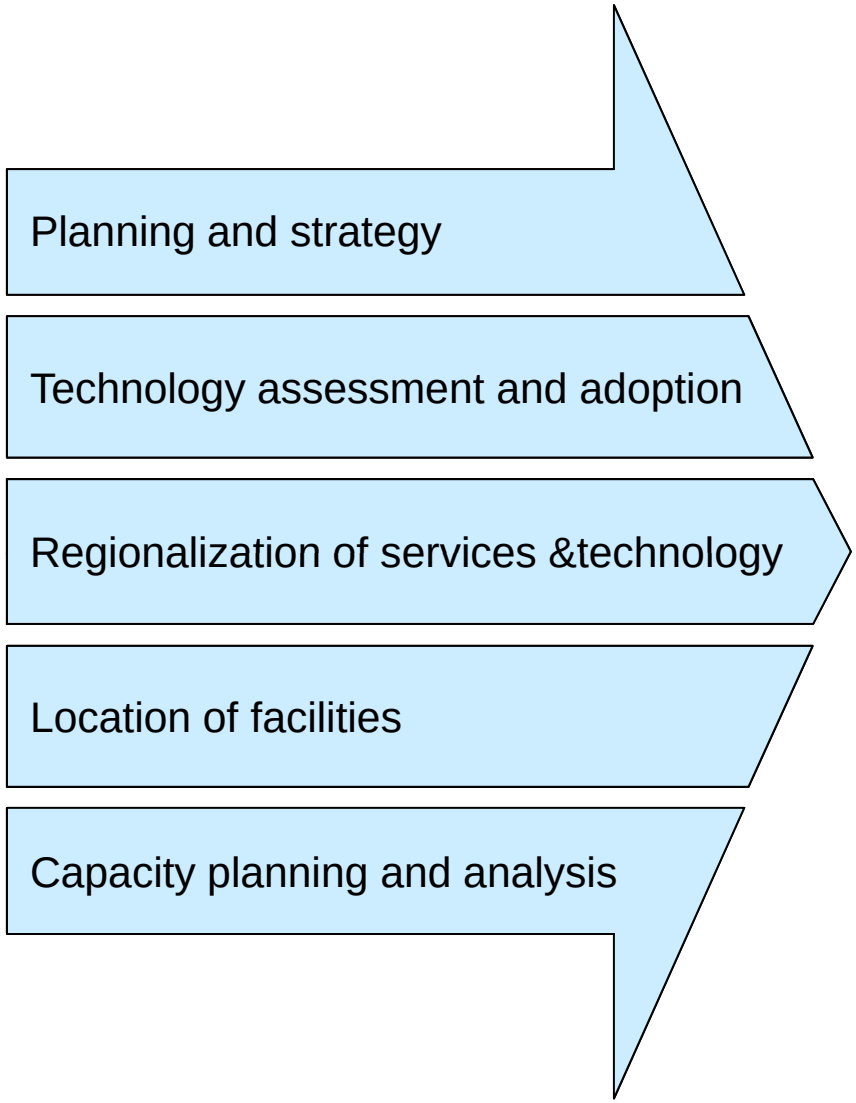
- An ARIMA model on patient demand by type of service and month of the year produced forecast with errors ranging from 3.3% to 21.5% in the UK
- Use of optimization models and tools in managing home health workers has resulted in $30-45M annual savings in Sweden

OPERATIONS RESEARCH METHOD CAN IMPROVE CLINICAL PRACTICE AS WELL AS BASIC RESEARCH



- 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

DECISION ON INFRASTRUCTURE INVESTMENT AND SERVICE PROVISION CAN BE FACILITATED THROUGH OPERATIONS METHOD



- 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

	Demand forecasting	Workforce planning and scheduling
Objective	• Enable revenue and resource planning • Avoid shortfall, quality decrease, and cost hike	• Develop capability to match staffing resources to a fluctuating demand • Improve operating efficiency and quality of service
Examples	• Pre-hospital care and ambulance staffing • Inpatient service by type and month • Need for intermediate home nursing	• Levels of decision: o Corrective allocation: day o Shift schedule: 1-2 months o Workforce plan: quarter to year • Typical practice: cyclic scheduling or self-scheduling for shifts
Method/ Need	• Various regression methods incorporating exogenous and/or institutional variables	• Approach incorporating patient demand and higher level decision • Multiple regression model based on ARIMA for workload forecasting • Optimization through mathematical programming

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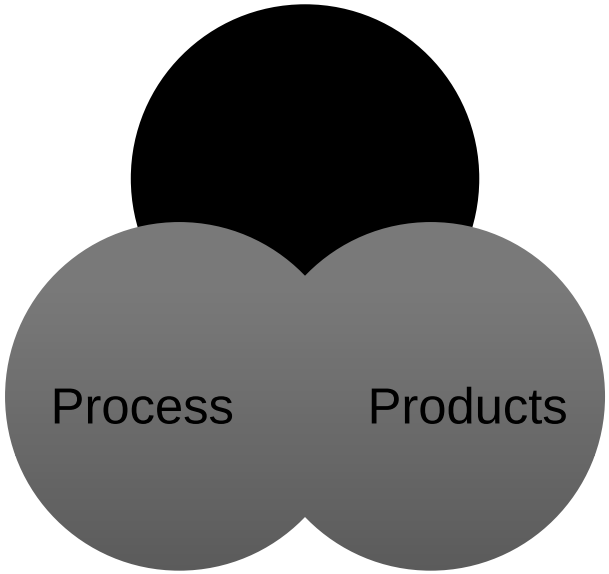
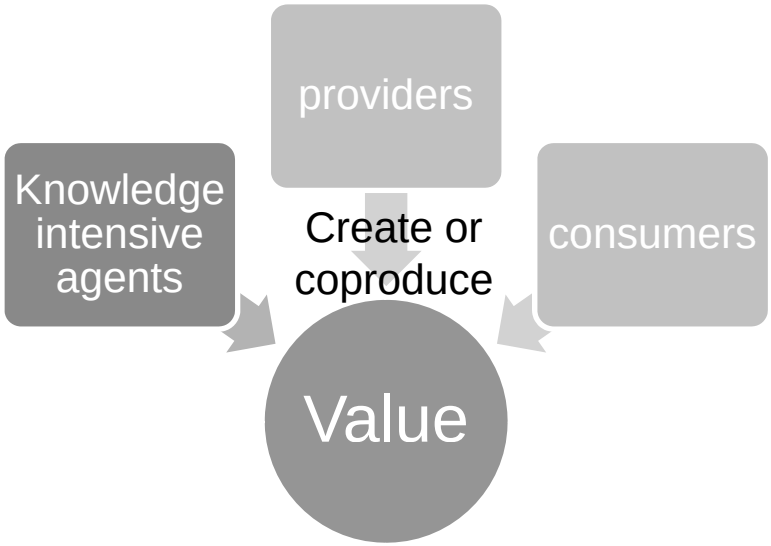
Healthcare Service System

Essential components of Healthcare Services





Efficiency

- Meeting demand with minimum cost

Effectiveness

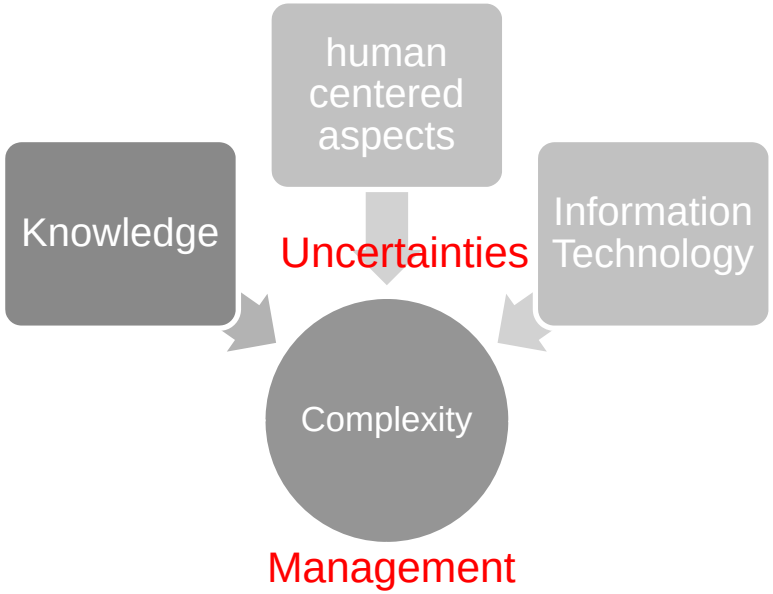
- Producing the right service for the right patient at at the right time and right place

Robust

- Insure reliability, quality and integrity

Healthcare Service System

Complexity of Healthcare Services



Integrative

- Physical
- Temporal
- Organizational
- Functional

Adaptive

- Decision Making
- Decision Informatics
- Human Interface

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

Healthcare as an integrated system

Healthcare as an integrated system

People
- demanders
- suppliers

Processes
- procedural
- algorithmic

Products
- physical
- virtual

Integration occurs over multiple dimensions

Physical
- natural, constructed or virtual environment?

Temporal
- strategic, tactical and operational perspectives

Organizational
- resources, economics, and management

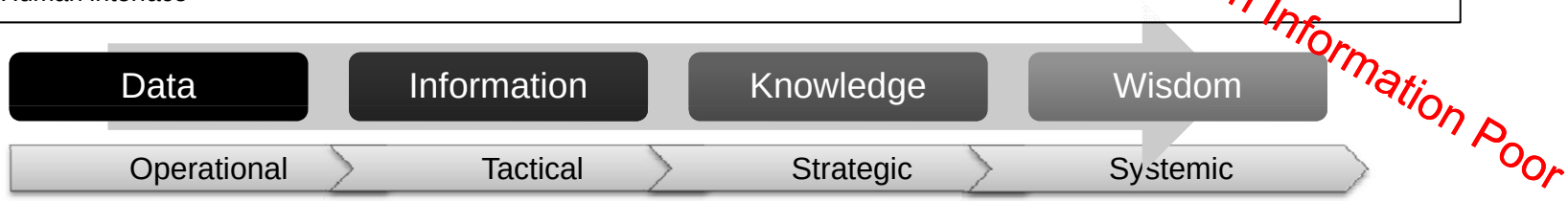
Functional
- input, process and output function

Healthcare as an adaptive system

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

Essential components of human centric adaptation:

- Decision making
- Decision informatics
- Human interface



Adaptation dimensions

Monitoring

- Degree of sensed actions (sensors, patterns)

Feedback

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

Cybernetic

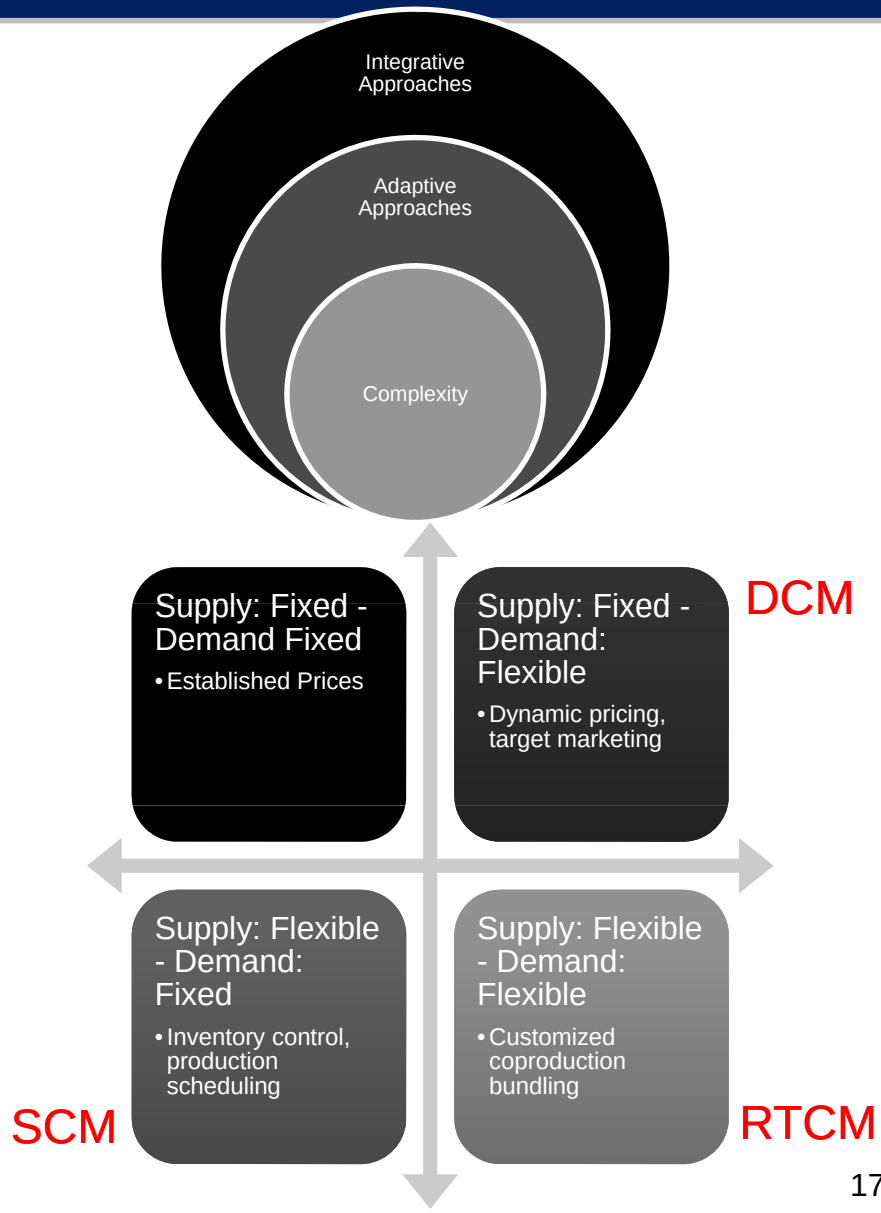
- Degree of relative actions (deterministic, dynamic or adaptive actions)

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



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DESPITE ITS COMPLEXITY, PUBLIC HEALTH SYSTEM ENCOUNTERS INCREASING NEEDS OF PROCESS ENGINEERING

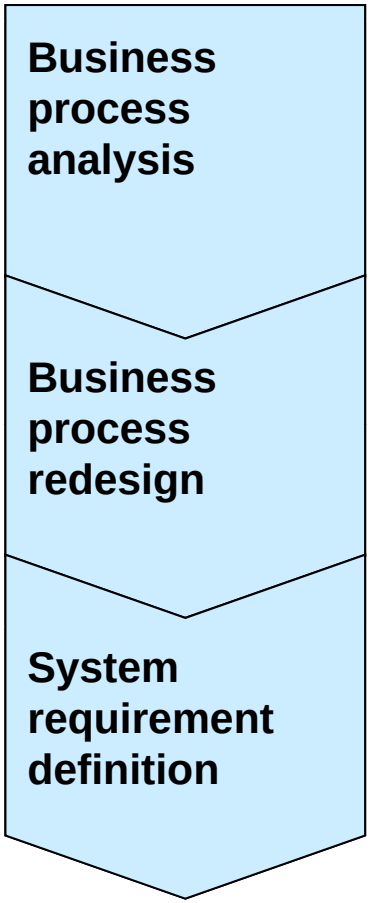
Public Health System

- Role: Intervention and prevention of disease and injury to protect entire population
- Complex, fragmented nature of public health system:
  - No single point of control
  - Function or program-specific silos of information
  - Complex array of governing regulation (Federal, state and local)

Challenges and New Approach

- Recognition of commonality: Increasing demand for interoperable, adaptive information system across U.S. health system
- New approach of process engineering: Need comprehensive analysis and understanding of the core business process

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

	Inpatient scheduling	Outpatient scheduling
Objective	• Control demand while optimizing throughput and quality of outcome • Reduce staffing costs and congestion	
Examples	• Type of scheduling: o Scheduling of elective admissions o Daily scheduling of inpatients to appropriate care units o Discharge scheduling • Typical practice of assigning slots or beds to specific specialty creating artificial variation	• Typical practice includes: o Block scheduling o Modified block scheduling o Individual scheduling
Method/ Need	• Forecast based on estimation of length of stay • Need to incorporate bottlenecks within the hospital system	• Queuing theory • Truncated Poisson distribution for patient arrival • Separate modeling of emergency and scheduled patients

OPERATIONAL RESEARCH CONTRIBUTES TO IMPROVEMENT IN PROVIDER…

	Individual treatment choice	Procedure performance
Objective	• Facilitate complex decisions by identifying critical nodes influencing outcome	• Improve the quality and reduce costs of diagnosis and treatment procedures through real-time support and standardization
Examples	• Expected cost and QALY calculation in total hip arthroplasty vs. no surgery • Choice of treatment for prostate cancer	• Interpretation of mammograms • Selection and sequencing of tests for HIV screening in blood donation • Radiation treatment planning
Method/ Need	• Decision trees • Dynamic influence diagrams • Sensitivity analysis • Modeling ambiguous outcome	• Bayesian network or decision model • Optimization tools through MATLAB

…AS WELL AS PUBLIC HEALTH POLICIES AND BASIC RESEARCH

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

SYSTEM-WIDE DESIGN OR POLICY CAN ALSO REAP BENEFITS FROM OPERATIONS RESEARCH SUCH AS OPTIMIZATION…

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

…AS WELL AS PLANNING AT A REGIONAL SCALE

	Location of facilities	Capacity planning and analysis
Objective	• Support decision on regionalization, opening or removal of a facility, or the location for specific services	• Plan addition, expansion, or contraction of services and facilities, taking into account the interdependence between 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	• 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
Method/ Need	• Hooke-Jeeves algorithm • Location set covering model, maximal covering model, P-median model • Various mathematical models	• 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

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