Hospital Acquired Infections and Intervention Strategies

Pinar Keskinocak

H. Milton Stewart School of Industrial & Systems Engineering
Georgia Institute of Technology

Research supported in part by the Health Systems Institute at Georgia Tech

My Research Interests in Health and Humanitarian Applications of OR/MS

- Disease spread modeling, intervention strategies, resource allocation
  - Flu pandemic
    - Food distribution (American Red Cross) and Vaccine Distribution (Centers for Disease Control and Prevention (CDC))
  - Measles
    - Optimizing vaccination strategies (CDC)
  - Modeling and optimizing patient flow
    - Children's Healthcare of Atlanta (CHOA), Dekalb Medical
    - Emergency department ambulance diversions
  - Hospital acquired (nosocomial) infection control
    - CHOA, Cook County Hospital
  - Childhood vaccination catch-up scheduling (CDC)
    - Available for free download from CDC website: http://www.cdc.gov/vaccines/recs/scheduler/catchup.htm
  - Health and humanitarian supply chains
    - Pre-positioning inventory for disaster response (CARE, Heart to Heart International)
    - Vaccine procurement (Pan American Health Organization)

http://www.scl.gatech.edu/research/humanitarian/
HAI Collaborators include

- Paul Griffin, Georgia Tech
- Ray Hagtvedt, University of Alberta
- Doug Scott, CDC
- John Stroger Hospital of Cook County
- Children’s Healthcare of Atlanta
  - Paul Ocon, Amber Cocks
- Georgia Tech MS students:
  - Jamie Beyer, Nishad Dravid, Karan Gandhi, Sarah Shacter, Anushree Verma
- Georgia Tech & Emory Ph.D. students
  - Taesu Cheong, Jennifer Grant
- University of Pittsburgh Medical Center
  - Bruce Lee

Hospital Acquired Infections (HAI)

- Infections that occur in hospitals where there was no evidence that the infection was present or incubating at the time of hospital admission
- A.k.a
  - Nosocomial or Healthcare Associated Infections
HAI Transmission

**Source**
- Patients
- Hospital personnel
- Visitors

**Transmission**
- Contact
- Common vehicles e.g., Examination tables, instruments
- Airborne
- Droplet e.g., coughing, sneezing
- Vector borne

**Susceptible host**
- Patients
- Hospital personnel
- Visitors

Impact of HAI's

- **Number of patients affected**
  - Two million infections per year (Levin, 2005)
  - 1 in 10 patients nationally
  - On a given day 90,000 patients in ICUs in the US, an average patient requires ~180 “actions” per day

- **Number of deaths**
  - 90,000 – 100,000 people a year (Levin, 2005)

- **Cost**
  - $15,000 – $25,000 per case (McCaughey, 2005; CDC)
  - Cost estimates from hospitals in PA
    - treating UTI patients: $450,000 per case
    - each patient who developed pneumonia while on a ventilator: $1.25 million
    - $1.4 million per patient with multiple infections
  - $5 billion to $11 billion total (Pronovost, 2008)
HAIs in the Future?

- Evolving antibiotics resistance in pathogens
- Increases use of outpatient treatment → sicker patients in hospitals
- Overcrowding in hospitals (emergency departments)

Government Actions

- Legislation by several states (CA, PA, MO, NY, etc.) requiring hospitals to report HAIs
- Medicare will no longer cover the additional cost of eight preventable complications
  - Catheter-associated urinary tract infections; Pressure ulcers (decubitus ulcers); Vascular catheter-associated infections; Mediastinitis after coronary artery bypass graft surgery; Fractures, dislocations, or other hospital-acquired injuries; Objects left in during surgery; Air embolisms; Blood incompatibilities
- The government may also stop covering ventilator-associated pneumonia in 2009
- Some hospital administrators expect Medicaid to follow suit
Literature

Specific types of NI
- Bloodstream infections (BSI) - (Tokars 1999, Kritchevsky 2001, Pronovost 2006,
- Others: Gram-negative bacteria: (Higgins 2001); Acinetobacter (Joshi 2006); Clostridium difficile (Pepin 2005); Zoonotics (Weber 2001)

Specific practices
- Ring-wearing (Trick 2003).
- Fingernails (Moolenaar 2000)

Literature

Surveillance
- Six states as of 2005 (Becker, 2005; Weinstein et al., 2005)
- Observability and incentives (Haley 1987)

Avoidance
- Equipment hygiene
  - Pronovost et al. (2006) on intubation
  - One third of HAI’s may be avoided through better equipment hygiene
- Hand-hygiene
  - Very low compliance (Vernon et al. 2003)
  - Number of sinks (Vernon2003)
  - Gloves and isolation (Trick2004)
  - Role models and adherence (Lankford2003)
  - CDC Guidelines for hand hygiene (MMWR 2002)
  - Training (Voss2005)
- Screening
  - MRSA in Israel (Shitrit et al. 2006) & US (Clancy et al. 2006)
- Isolation

Economics of HAI
- Graves et al. (2004, 2007) – insignificant
Research Agenda

- “Systems” perspective
- Multiple system-models for different levels of health care
  - Use simulation to model the spread of HAIs, in
    - a unit of a hospital, e.g., ICU
    - an entire hospital
    - a system of hospitals
  - Agent-based simulations of social networks of hospitals, communities, and long-term health facilities
- Study reason for low compliance in hand washing for health care workers
- Evaluate the effectiveness of different strategies to combat HAI’s
  - Combine results into an economic cost-benefit analysis

Two Projects

- Intensive Care Unit (ICU) at John Stroger Hospital

- Neonatal Intensive Care Unit (NICU) at Children’s Healthcare of Atlanta
Approach

- Discrete event simulation
  - Flow of patients, visitors, and pathogens through an ICU
  - Health Care Workers (HCW) colonized, and spread a general bug from location to location
  - Treatment times captured with a probability of discharge
- Use the models to estimate the effect of different strategies to combat HAI’s

Model Infection Flow

Visitors and patients may bring pathogens from outside.

Patients, visitors, HCWs can be colonized, but only patients are assumed to arrive with or develop infections
Cost

- Detailed cost data from both hospitals

\[
\text{CHOA: Cost}(\$) = 7947 + 5239 \text{ LOS} + 18387.5 \text{ HAI_LOS} \quad R^2=0.9035
\]
\[
\text{JSG: Cost}(\$) = 3028 + 1944 \text{ LOS} + 445.9 \text{ HAI_LOS} \quad R^2=0.88
\]

Data from John Stroger Hospital

- CARP (Chicago Antimicrobial Resistance Project) data
- 1,254 patients, 212 in ICU
  - age
  - surgeries
  - time in the ICU
  - confirmed or suspected HAI in their urinary tract, blood-stream, surgical site, lungs, or elsewhere
  - two severity of illness scores (Apache III, Charlson)
- 33 ICU patients died, 70 developed a confirmed HAI, 20 suspected
Network for patients, HCWs, and visitors

**Intervention Strategies**

- Different levels of hand-hygiene efficacy (HHE)
  - HHE = Probability of HCW colonization removed
    - Compliance
    - Probability of effective cleaning

- Two isolation models:
  - Carve-out model
    - Identical quantity of resources
    - 3 beds dedicated to screening (beds 8, 9, 10)
  - Plus Model:
    - Additional resources: area with three beds for screening
Illustration: nonlinear & counterintuitive relationships

- the number of discharged patients (total, with and without HAI) versus HHE
- LOS and average cost versus HHE
- proportion of time the ICU is full versus HHE

Previous statistical models used to assess the impact of HAIs on costs have been linear and uncoupled from LOS (Graves et al. 2007b).

Insights

- Both hand-hygiene and isolation policies impact on rates of HAIs, capacity, and costs
  - Effects vary depending on the capacity of the system
- Relatively the small difference in results between isolation-ward models and the base models
  - Since hand-hygiene is often poor, but may be improved through inexpensive alcohol-gels, while ICU isolation wards require significant capital expenditure, suggests the benefits to cost ratio is greater for hand-hygiene improvements
- The relationships between arrival rates (i.e. demand), physical structure, HHE, and LOS are complex, and unlikely to be adequately modeled with a single linear equation
New Initiatives at John Stroger Hospital

- 20+ additional alcohol-based hand gel dispensers in the emergency department
- Student observers throughout the hospital to observe staff hand hygiene compliance
- Post hand hygiene reminder signs and conduct annual training
- Enlist the help of patients and their families in the hand hygiene compliance reminder effort

Nosocomial Infection Control
Children’s Healthcare of Atlanta (CHOA)
**Problem**

The Neonatal Intensive Care Unit (NICU) at Scottish Rite has been experiencing a higher than expected rate of nosocomial infections. (2007 Statistics)

<table>
<thead>
<tr>
<th></th>
<th>No Infection</th>
<th>With Infection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average LOS</strong></td>
<td>23.19 Days</td>
<td>82.20 Days</td>
</tr>
<tr>
<td><strong>Average Cost</strong></td>
<td>$101,752.42</td>
<td>$387,828.71</td>
</tr>
<tr>
<td><strong># Patients</strong></td>
<td>406</td>
<td>44</td>
</tr>
</tbody>
</table>

**Project Goals**

- To understand how infections flow
- To uncover reasons for infection
- To model the current state with simulation
- Recommend process improvements and show potential benefits of intervention techniques

**Methods**

- Shadow and observe in the NICU
- Interview key employees
- Analyze administrative and clinical data
- Define assumptions and model parameters
- Build the simulation model
- Test interventions
Risk Factors For Infection

- Low birth weight
- Technology dependency
- Required touching
- Pacifiers and diapers
- Dark, warm environment
- Suboptimal visitor hand hygiene and cleaning compliance
- Many procedures performed in unit
- Patients not in separate rooms

<table>
<thead>
<tr>
<th>Patient Factor</th>
<th>p-value</th>
<th>Significant?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Birth Weight (LBW) &lt;1000g</td>
<td>0.684071</td>
<td>Not Significant</td>
</tr>
<tr>
<td>Number of Diagnoses</td>
<td>0.506719</td>
<td>Not Significant</td>
</tr>
<tr>
<td>Number of Procedures Performed</td>
<td>0.000105</td>
<td>Significant</td>
</tr>
</tbody>
</table>

Infection Chain

- More Procedures → Increased chance of Infection → Increased LOS → Increased Cost
- Poor Disinfection
Simulation Model

NICU Details

- 2 Patients per Nurse
- Nurse interacts with the patient every 4 hours
- 3 Day Doctors, 1 Night Doctor doing rounds
- About 60% of patients require a Respiratory Therapist
- Visitors allowed 22 hours a day
- Current Isolation Process - patient is isolated if:
  - MRSA upon admission (48 hour results delay)
  - Shows signs of infection
Admissions and Occupancy

91% Average Occupancy

Hand Hygiene Compliance*

<table>
<thead>
<tr>
<th>Health Care Worker</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doctors</td>
<td>82%</td>
</tr>
<tr>
<td>Nurses</td>
<td>98%</td>
</tr>
<tr>
<td>Respiratory Therapists</td>
<td>100%</td>
</tr>
</tbody>
</table>

*2007 data from CHOA infection control compliance reports
**Increased Visitor Hand Hygiene Model**

**Problem:** NICU visitors aren’t educated on proper hand hygiene procedures

**Recommendation**
Develop infection control education materials and training for patient families

**Modeled Benefits**
- Decrease Infections by 22%
- Decrease total cost per year by over $1.7M
- Increase of visitor hand hygiene efficacy by 30%

* Preliminary results based on initial simulation runs, they are currently being validated

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**Improved Disinfection Model**

**Problem:** Unclear role definition for disinfection processes

**Recommendation**
Clearly define cleaning roles and policies for nurses & Environmental Services

**Modeled Benefits**
- Decrease Infections by 13%
- Decrease total cost per year by just under $1M
- Increase the probability of disinfecting the location at each nurse-to-patient interaction by 40%

* Preliminary results based on initial simulation runs, they are currently being validated
Testing and Isolation

**Problem:** Patient is tested for MRSA and isolated 48 hours later if results are positive

**Possible Recommendations**
- Use MRSA quick results test (<1 hr)
- Run full panel infection tests upon admission
- Use sign designating “waiting for results”
- Decrease the probability of passing the colonization from patient to healthcare workers by 30%

**Modeled Benefits**
- Decrease Infections by 22%
- Decrease total cost per year by over $1.7M

*Preliminary results based on initial simulation runs, they are currently being validated

Next Steps with CHOA

- Multiple years of data & additional risk factors
  - Bed location, ventilator days
- Measuring the impact of some of the policies recently implemented by CHOA
  - No-ring policy
  - Increased number of gel dispensers
  - Supplies at the entrance of each isolation room
  - Red tape for isolated patient areas
- Additional Units
- Other Hospitals
Thank you!

pinar@isye.gatech.edu
Nosocomial Infection Control

Integrative Health Space with Technology Intervention

design, computing & physical environments
Toward a Smart Healing Environment

design, computation, and physical environments

Ellen Yi-Luen Do, College of Architecture & College of Computing Health Systems Institute, Georgia Institute of Technology
ellendo@gatech.edu
Things that Think, Spaces that Sense, and Places that Play
Making Creative Design Computing

Design, Arts, Science: Toward a Smart Living Environment
Toward a Smart **Healing** Environment -

Physically & Computationally Enhanced Environment
Toward a Smart Healing Environment -

Safe  People
Secure Places
Sound  Processes
Transforming Healthcare with Evidence-Based Design

- Transformational Leadership & Culture
- Research
- Re-engineered Clinical & Admin. Processes
- Shrinking Margins
- Performance-Based Building

The Prize: Healing Environment to Improve Outcomes: Patient, Staff & Resource
Nosocomial Infection

Presence of microorganisms in hospital environment

Immunocompromised patients

Transmission of pathogens between staff and patients and among patients

Bricks & Clicks
Solution Space

Behavioral

Environmental

Change the environment to modify behavior.
Nosocomial Infection Control

Integrative Space - design, computing & physical environment
Nosocomial Infection Control

**Behavioral Solutions**
- RFID monitoring
  - Records caregiver’s movements within room
  - Entering room triggers lighting, vibration reminders
  - Detects movement into patient or sink zone
  - Deactivates system when caregivers leaves room

**Environmental Solutions**
- Medical Records
  - Patient records displayed next to the sink for status checks while washing hands.
  - Activating sink starts on-screen timer to ensure caregiver washes for 15 seconds.
  - System logs off when caregiver leaves room.
- Lighting Cues
  - Track lighting illuminates path to sink
  - Undersink light draws eye to sink
  - If sink not activated within 15 seconds, lighting begins to blink
- Pocket Cleaners
  - Antiseptic gel bulb in waterproof pocket on jacket
  - Disinfectant solution always with caregiver
  - Disposable cartridge replaceable when empty
  - Vibrator on pocket reminds caregiver to use Clean Pocket or sink
Healthcare Environment of the Future
Patient Room of the Future
Pediatric Center of the Future
Field Observation

- Family waiting space
- Patient room
- Working surface
- Storage area
Care Cart
Patient Interactive Communication and Learning System
Patient Interactive Communication and Learning System
Interactive Waiting Room - learning & entertainment
Pervasive Asthma Monitoring System

Johny Huber
Age: 5 years 1 month
Sex: Male
Height: 72 cms
Weight: 96 lbs

Category
Severity: Persistent Severe
Control: Poor Control

SPirometry
FEV – 2.21 L
FEV₁ – 1.04 L
FEV₁ / FVC – 47%

PEAK EXPIRATORY FLOW RATE
140 L / Min
81% of Normal

ADVERSE EFFECTS
Shakiness

WHEEZE
Absent

Date: 08/02/07  Time: 11:00 am
Date: 12/03/07  Time: 3:00 pm
Date: 09/15/07  Time: 2:00 pm
Date: 12/04/07  Time: 8:00 am

Voice Analysis
Full Scale Working Prototype @ Open House
Smart Healing Environments of the Future

Ellen Yi-Luen Do, College of Architecture & College of Computing Health Systems Institute, Georgia Institute of Technology
ellendo@gatech.edu
Thanks

National Science Foundation
Steelcase Workspace Futures
Perkins + Will Architects
Health Systems Institute, Georgia Tech

hopefully, CDC...
Nosocomial infection

From Wikipedia, the free encyclopedia

Nosocomial infections are infections which are a result of treatment in a hospital or a healthcare service unit, but secondary to the patient’s original condition. Infections are considered nosocomial if they first appear 48 hours or more after hospital admission or within 30 days after discharge. Nosocomial comes from the Greek word nosokomeion (νοσοκομείον) meaning hospital (nosos = disease, komeo = to take care of). This type of infection is also known as a hospital-acquired infection (or more generically healthcare-associated infections).

Nosocomial infections are even more alarming in the 21st century:

- Hospitals house large numbers of people who are sick and whose immune systems are often in a weakened state;
- Increased use of outpatient treatment means that people who are in the hospital are sicker on average;
- Medical staff move from patient to patient, providing a way for pathogens to spread;
- Many medical procedures bypass the body’s natural protective barriers;
- Sanitation protocol regarding uniforms, equipment sterilization, washing, and other preventative measures may be either unheeded by hospital staff or too lax to sufficiently isolate patients from infectious agents;
- Patients are often prescribed antibiotics and other anti-microbial drugs to help treat illness; this may increase the selection pressure for the emergence of resistant strains.

Thorough hand washing and/or use of alcohol rubs by all medical personnel before each patient contact is one of the most effective ways to combat nosocomial infections. More careful use of anti-microbial agents, such as antibiotics, is also considered vital.

Epidemiology

In the United States, it has been estimated that as many as one hospital patient in ten acquires a nosocomial infection, or 2 million patients a year. Estimates of the annual cost range from $4.5 billion to $11 billion and up. Nosocomial infections contributed to 88,000 deaths in the U.S. in 1995. One third of nosocomial infections are considered preventable. Ms. magazine reports that as many as 92 percent of deaths from hospital infections could be prevented. The most common nosocomial infections are of the urinary tract, surgical site and various pneumonias.
Healthcare Infection Control Practices Advisory Committee (HICPAC)

About HICPAC
(Formerly the Hospital Infection Control Practices Advisory Committee)
The Healthcare Infection Control Practices Advisory Committee (HICPAC) is a federal advisory committee made up of 14 external infection control experts who provide advice and guidance to the Centers for Disease Control and Prevention (CDC) and the Secretary of the Department of Health and Human Services (HHS) regarding the practice of health care infection control, strategies for surveillance and prevention and control of health care associated infections in United States health care facilities.

One of the primary functions of the committee is to issue recommendations for preventing and controlling health care associated infections in the form of guidelines, resolutions and informal communications.

Other functions and activities include information exchange with CDC staff and formal and informal interactions with other CDC advisory committees such as the National Center for Infectious Diseases Board of Scientific Counselors, the Advisory Counsel on Elimination of Tuberculosis and the Advisory Committee on Immunization Practices.

The committee has liaison representatives from professional organizations and other federal agencies - including the Association for Professionals of Infection Control and Epidemiology Inc., the Society for Healthcare Epidemiology of America, the Association of Peri-Operative Registered Nurses, the Center for Medicaid and Medicare Services, the Food and Drug Administration; and such other non-voting liaison representatives as the Secretary deems necessary to effectively carry out the functions of the Committee.
Spring 2009 - CoA 8903, 8843; CS 8803-ED, 8803-DCH

- Design Computing for Healthy Quality Living
- Creativity and Design Cognition

ellendo@gatech.edu . http://www.cc.gatech.edu/~ellendo