An Integrated Agent-Based and Queueing Model for the Spread of Outpatient Infections

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Healthcare-Associated Infections

Inpatient

1. They’re common.
   - 1.7 million per year

2. They’re costly.
   - 99,000 deaths per year
   - $5B medical cost per year

3. It’s getting worse.
   - 36% increase over last 20 years

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### Outpatient

1. How bad is it?
   - 1.7 million per year

2. What factors contribute?

3. What policies are most effective?
Healthcare-Associated Infections at MGH Urgent Care Clinic

Sponsor Objectives:
- Investigate ways to reduce the spread of infection in outpatient clinics
- Develop generalizable knowledge in addition to specific solutions

AIM Statement

Test potential methods for reducing infection transmission with a focus on compartmentalization and hand sanitization measured in terms of system-wide exposure and performance.
Five Opportunities for Compartmentalization

In terms of

• Environment / Equipment
• Personnel

Patient Flow
Patient Population

- Incoming Infections
- Care Profiles

Staff Behavior

- Hand Sanitization
- Staff Interaction

Risk of Transmission

Patient

Staff

Location

Process Architecture

Patient Flow
Integrated Risk Model

Patient Population

Staff Behavior

Front Desk

Triage

Exam

Lab

Check Out

Risk of Transmission

Integrated Risk Model
## Model and Experimentation

### Experimental Variables
- Compartmentalization
- Hand Sanitization Rates
- Resource Reduction

### Sensitivity Variables
- Incoming Incidence Rates
- Cross Contamination Rates
- Initial Utilization Levels

### System Metrics
- Infection Exposures
- System Performance
- Feasibility

---
Experimental Results

Comparing Improvement Policies

Compartementalization
11 values
- types of compartmentalization

Hand Sanitization
$3^4$ values
- low, med, high for 4 staff types

891 Combinations
- Newly Exposed Patients
- Patient Wait Time
- Difficulty
Experimental Results

All Improvement Scenarios

Difficulty

Newly Exposed Patient Rate

Wait Time (hours)

Pareto Optimal Points

Non-Optimal Points
Experimental Results

Pareto Optimal Improvement Scenarios

- Newly Exposed Patient Rate
- Wait Time (hours)
- Low Difficulty
- High Difficulty

Scenarios:
1. Low Difficulty
2. Medium Difficulty
3. High Difficulty
Experimental Results

Pareto Optimal Improvement Scenarios

Newly Exposed Patient Rate

Wait Time (hours)

Patient Sorting
- None
- Random
- Risk-Based

Scenarios:
1. None
2. Random
3. Risk-Based
Experimental Results

Sorting Algorithm Parameterization

- Newly Exposed Patients
- Specificity
- Sensitivity
Experimental Results

Sorting Algorithm Parameterization

Patient Wait Time

Specificity

Sensitivity
# Recommended Policies

<table>
<thead>
<tr>
<th>Patient Sorting Type</th>
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<th>Random</th>
<th>Risk-Based</th>
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<td>Early Medium</td>
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<td>Staff +5%, MD +10%</td>
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## Newly Exposed Patients Change (%)

| Change (%) | -7 | -12 | -20 |

## Wait Time Increase (Hours)

| Increase (Hours) | 0.14 | 0.3 |

## Implementation Difficulty

| Difficulty | 4 | 9 | 20 |
## Triple Aim Impact

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### Cost Savings
- **None**
  - Additional Treatment Avoided ($56,300)
- **Random**
  - Additional Treatment Avoided ($96,400)
- **Risk**
  - Additional Treatment Avoided ($160,700)

### Quality
- **None**
  - Increased Waiting Time (None)
- **Random**
  - Increased Waiting Time (5,100 Hours)
- **Risk**
  - Increased Waiting Time (10,500 Hours)

### Health
- **None**
  - 21% Reduction in Exposure
- **Random**
  - 36% Reduction in Exposure
- **Risk**
  - 61% Reduction in Exposure
Conclusions and Extensions

Generalized Findings

• Proof of concept: queueing and agent-based infection spread model
Conclusions and Extensions

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- Diminishing returns of the same intervention

Before:

After:
Conclusions and Extensions

Generalized Findings

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  • Tradeoff between efficiency and risk
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• Diminishing returns of the same intervention
  • Need for multiple cross-functional interventions
Conclusions and Extensions

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• Diminishing returns of the same intervention
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• Risk based sorting only worthwhile for extensive compartmentalization
• Compartmentalize where resources are least constrained
Conclusions and Extensions

Further Questions

• What opportunities do clinics actually have for “compartmentalization”?
Conclusions and Extensions

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- How to best model different kinds of infections/risk?
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• At what level is it best to conduct this analysis?
Conclusions and Extensions

Further Questions

Health Network

System Dynamics

Agent-Based

Queueing

Patient Flow

Front Desk  Triage  Exam  Lab  Check Out
Conclusions and Extensions

Further Questions

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- How to best model different kinds of infections/risk?
- How will models be validated, improvements measured?
- At what level is it best to conduct this analysis?
  - Where data, model, and action can align...
Thank you.
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### Triple Aim Impact

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<th>Compartmentalization Advantages</th>
<th>Compartmentalization Disadvantages</th>
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<td>Fewer exposures, fewer infections</td>
<td>Dividing resources can limit throughput, revenue</td>
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<td>Compartments may improve care coordination</td>
<td>Compartments may require additional staff</td>
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<td>Fewer infections introduced into the population</td>
<td>Compartments may increase waiting times</td>
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**Cost**
- HAIs require additional treatment/admission
- Providers out sick reduce throughput, revenue

**Quality**
- Fewer infections
- Compartments may improve care coordination

**Health**
- Fewer infections introduced into the population

**Advantages**
- Compartmentalization

**Disadvantages**
- [No disadvantages identified]