Modeling Influenza Pandemic and Strategies for Food Distribution

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Pandemic Flu – Historical Information

<table>
<thead>
<tr>
<th>Pandemic cases in history</th>
<th>Excess Mortality</th>
<th>Populations Affected</th>
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</thead>
<tbody>
<tr>
<td>1918-19 (Spanish flu) (A/H1N1)</td>
<td>40-50 million (2.2-2.8%)</td>
<td>Persons &lt;65 years</td>
</tr>
<tr>
<td>1957-58 (Asian flu) (A/H2N2)</td>
<td>2 million (0.069%)</td>
<td>Infants, elderly</td>
</tr>
<tr>
<td>1968-69 (Hong Kong flu) (A/H3N2)</td>
<td>1 million (0.028%)</td>
<td>Infants, elderly</td>
</tr>
</tbody>
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Middle-ground estimate: 25% of entire population will be infected (Gibbs and Soares 2005)
Potential Impact of Pandemic Flu

- $71.3-165.5 billion economic impact in the U.S. (CDC)
- U.S. Department of Health & Human Services and U.S. Department of Commerce estimates
  - 20% of working adults will become ill
  - 40% workforce loss during peak outbreak periods

Response Plans

- Preparation efforts
  - Local governments
  - Federal government
  - NGOs
  - Companies
- Response plans focus on
  - How to treat ill people
  - Food, vaccine and medicine distribution
Focus of Analysis

- Modeling and understanding the disease spread geographically and over time
- Constructing a food distribution network
  - Number of facilities and their locations (over time)
  - Allocation of resources among the facilities

In collaboration with

Disease Spread Model

- An individual-based stochastic model
- Natural history for pandemic flu (Wu et al. 2006):

![Diagram of disease spread model]

- Similar to S-E-I-R models
- 5 age groups (0-5, 6-11, 12-18, 19-64, 65+)

Sus.: Susceptible
E: Exposed
P: Presymptomatic
A: Asymptomatic
S: Symptomatic
R: Recovered
H: Hospitalized
D: Dead
Disease Contact Network
- Households
- Peer groups (work place and schools)
- Community: Census Tract-based
  - Population ~ (1500-8000)
- Test case: State of Georgia
  - Household statistics, work flow data, classroom sizes, age statistics

Disease Spread in Georgia
- Base case: $R_0 = 1.5$ (Dublin and Lotka 1925)
- Simulation results for Georgia:
  - Infection Attack Rate ≈ 49.76%
  - Peak time ≈ day 70 (10 weeks)
  - Peak value ≈ 2.58% of the population

How does the disease spread geographically over time?
Day 30
Initial Seed – Fulton

Day 40
Initial Seed – Fulton
Day 50
Initial Seed – Fulton

Day 60
Initial Seed – Fulton
Day 70
Initial Seed – Fulton

Day 80
Initial Seed – Fulton
Day 90
Initial Seed – Fulton

Day 100
Initial Seed – Fulton
Day 150
Initial Seed – Fulton

Day 160
Initial Seed – Fulton
Day 170
Initial Seed – Fulton

Day 180
Initial Seed – Fulton
Day 10
Initial Seed – Atkinson

Day 20
Initial Seed – Atkinson
Day 30
Initial Seed – Atkinson

Day 40
Initial Seed – Atkinson
Day 50
Initial Seed – Atkinson

Day 60
Initial Seed – Atkinson
Day 70
Initial Seed – Atkinson

Day 80
Initial Seed – Atkinson
Day 110
Initial Seed – Atkinson

Day 120
Initial Seed – Atkinson
Day 170
Initial Seed – Atkinson

Day 180
Initial Seed – Atkinson
- Peak infection rate is similar regardless of starting location
- Time of peak depends on the starting locations
  - Similar for densely populated areas
  - Different for less dense areas

Infections over Time
Estimating the food need (Metropolitan Atlanta Area)

Daily Number of Meals for HHs with an Infected Individual

Day 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Below Poverty Income Below 25,000 All

Cumulative Number of Meals for HHs with an Infected Individual

Day 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Below Poverty Income Below 25,000 All

Daily Number of Meals for HHs with an Infected Adult

Day 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Below Poverty Income Below 25,000 All

Cumulative Number of Meals for HHs with an Infected Adult

Day 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Below Poverty Income Below 25,000 All

Daily Number of Meals for HHs with an Infected Adult

Day 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Below Poverty Income Below 25,000 All

Cumulative Number of Meals for HHs with All Adults Infected

Day 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Below Poverty Income Below 25,000 All

Cumulative Number of Meals for HHs with All Adults Infected

Day 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Below Poverty Income Below 25,000 All
Estimated food need over time (for all HHs with an infected individual) (Day 20)

Estimated the food need over time (for all HHs with an infected individual) (Day 30)
Estimated the food need over time (for all HHs with an infected individual) (Day 40)

Estimated the food need over time (for all HHs with an infected individual) (Day 50)
Estimated the food need over time (for all HHs with an infected individual) (Day 60)

Estimated the food need over time (for all HHs with an infected individual) (Day 70)
Estimated the food need over time (for all HHs with an infected individual) (Day 80)

Estimated the food need over time (for all HHs with an infected individual) (Day 90)
Estimated the food need over time (for all HHs with an infected individual) (Day 100)

Estimated the food need over time (for all HHs with an infected individual) (Day 110)
Estimated the food need over time (for all HHs with an infected individual) (Day 120)

Estimated the food need over time (for all HHs with an infected individual) (Day 130)
Intervention strategies: Quarantine

- Quarantine leads to two peaks

When to start the quarantine?

- To minimize the maximum peak, or maximum “food distribution capacity” needed
  - Start sometime during weeks 7-9
  - If shorter quarantine → start later
When to start the quarantine?

- To minimize the total % of infected population, i.e., the total “food distribution”
  - Start quarantine between weeks 8-11

![Graph showing Infection Attack Rate]

How long to impose quarantine?

- A longer quarantine
  - delays the timing and reduces the magnitude of the second peak
  - does not significantly impact the first peak
  - reduces the percentage affected at the maximum peak

![Graph showing Percentage Infected at the Peak]
Effect of Compliance Rate on the Attack Rate

- Base case: 50%

**Infection Attack Rate**

![Infection Attack Rate Graph]

Effect of Compliance Rate on the Peak Value

![Peak Value Graph]
Decisions (in each time period)

- Which facilities to open/close
- How much food to send:
  - from the suppliers to each of the major facilities
  - from the major facilities to each of the PODs
- Subject to
  - Capacity constraints
  - Potential locations
- To minimize
  - Opening/closing, operating, and distribution costs
Computational Results: Georgia Case

- 1615 census tracts in Georgia (for disease spread model)
- 603 census tracts (15 counties) in Metropolitan Atlanta Area
  - Distances between census tracts
- Estimated data
  - Cost figures
  - Supply amount
  - Potential facility locations and capacities

Models

- **Dynamic model**
  - Decisions made and updated in each time period
    - 5 scenarios are generated in each time period for the remaining time horizon and the average is used as an estimate
- **Static model**
  - Decisions about opening the facilities is done at the beginning of the planning horizon
  - Resource allocation decisions are made in each time period
Dynamic Model Computational Results

Opening Closing PODs over Time (Week 4)
Opening Closing PODs over Time (Week 6)

Opening Closing PODs over Time (Week 8)
Opening Closing PODs over Time (Week 10)

Opening Closing PODs over Time (Week 12)
Opening Closing PODs over Time (Week 14)

Opening Closing PODs over Time (Week 16)
Preliminary Computational Results: Georgia Case

- Static: ~10% higher cost than dynamic
- Cost under dynamic updates vs. the “perfect hindsight” solution
  - 32.71% (compared to the lower bound)
  - 7.87% (compared to best integer solution)
- Service level
  - Under dynamic updates
    - 63.21% of the demand served from a POD within 10 miles
  - Best integer solution
    - 69.95% of the demand served from a POD within 10 miles

Conclusions and Next steps

- Dynamic facility location and resource allocation decisions for food distribution during a pandemic
- Next steps
  - Optimization with a fixed budget
    - Maximize number of people served subject to a budget
  - Heuristics for obtaining solutions efficiently
  - Effect of other intervention strategies for the disease spread and optimizing their decisions
  - Effect of temperature on the disease spread
  - Sensitivity analysis on $R_0$

Acknowledgement: Special thanks to Joseph T. Wu for sharing his C++ code for the disease spread model
**MISSION:** Positive humanitarian “impact” worldwide

To improve humanitarian logistics and ultimately the human condition by system transformation and organization effectiveness through education, outreach, and solutions.

**Education**  **Outreach**  **Research/Applications**

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**Questions/Discussions?**

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