University of Pittsburgh

FRED: Overview & Case Studies

David Sinclair

Public Health Dynamics Laboratory

Pitt Public Health

Outline

- Why model?
- FRED – A Framework for Reconstructing Epidemiological Dynamics
- Case studies

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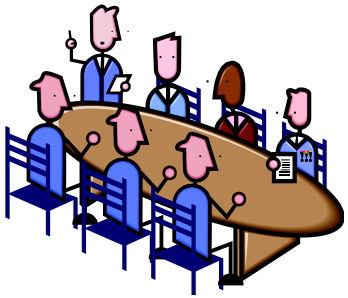
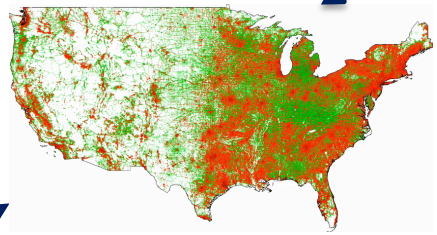
Modeling in Public Health Policy

Scientific Literature

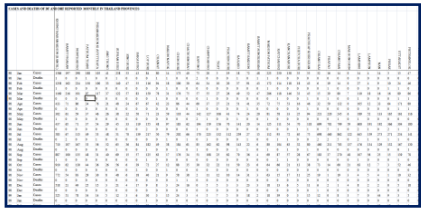


Expert Opinion

Decision Maker



Modeling & Simulation



Public Health Data

Simulations Enable a New Level of "What-if" Analysis

- Preparedness Planning
- Vaccine Policy
- Paid Sick Leave Policy
- Risk Communication
- Chronic Disease Planning
- School closures

Types of Modeling

- Mathematical Modeling
  - Differential Equation
- Statistical Modeling
  - Regression
  - Clustering
- Network Modeling
- Agent-Based Modeling
- Etc.

Agent-based Models

- Study the effects of **heterogeneous** populations on **spatiotemporal** epidemic **dynamics**
- Include **each person** in the model, along with social contacts and **interactions** with the environment
- Include **individual** responses and **behaviors** in the model
- Investigate interactions between agents and spatially distributed resources such as school and hospitals

Agent-based Models

Purposes

- Study how interactions among *individuals and their environment* can result in patterns of *population behavior*
- Study the *impact of policy and programs* on public health

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What is FRED?

- **FRED** is a **F**ramework for **R**econstructing **E**pidemiological **D**ynamics
- **Framework:** FRED is not a model. FRED is a tool for building models
- **Epidemiology:** the study and analysis of the patterns, causes, and effects of health and disease conditions in defined populations (Wikipedia)
  - Infectious and noninfectious diseases
  - Health-related conditions such as obesity, drug use, violence, vaccine acceptance, etc
- **Dynamics:** FRED is designed to study how patterns of health conditions in defined populations *vary over time and space*

FRED is designed to build agent-based (individual-based) models

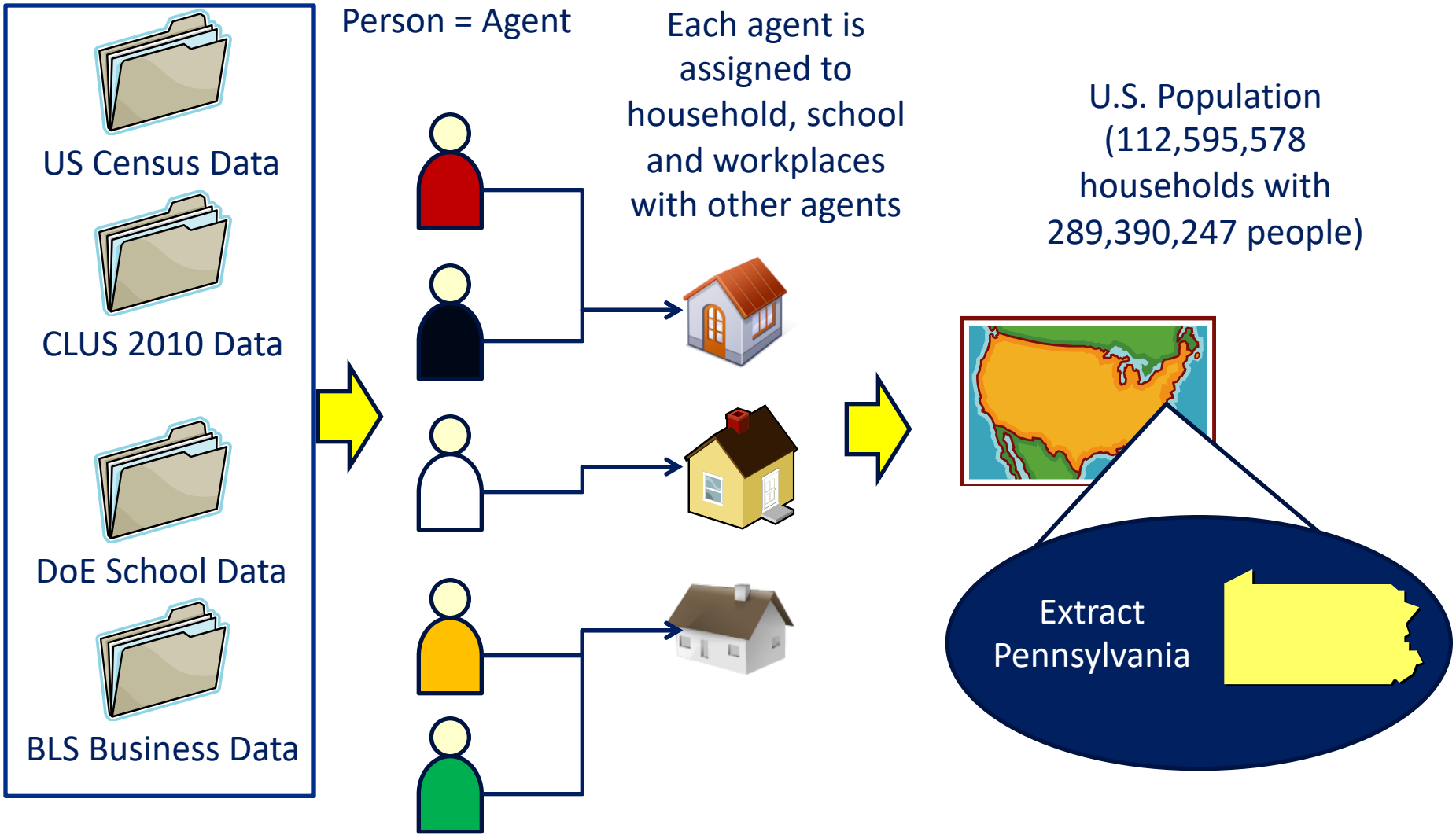
Foundational Concepts in FRED

- Space
  - Three-dimensional geography based on actual locations
- Time
  - Time step = 1 day (agents have multiple serial activities per day, encoded by hour)
  - Duration = 1 day to 100 years
- Agent = individual person
- Places (mixing groups for agents)
  - Households, neighborhoods, workplaces, schools
  - Flexibly create places and assign agents
- Population
  - Based on census data and other sources
  - Agents are associated with specific places

FRED Key Features

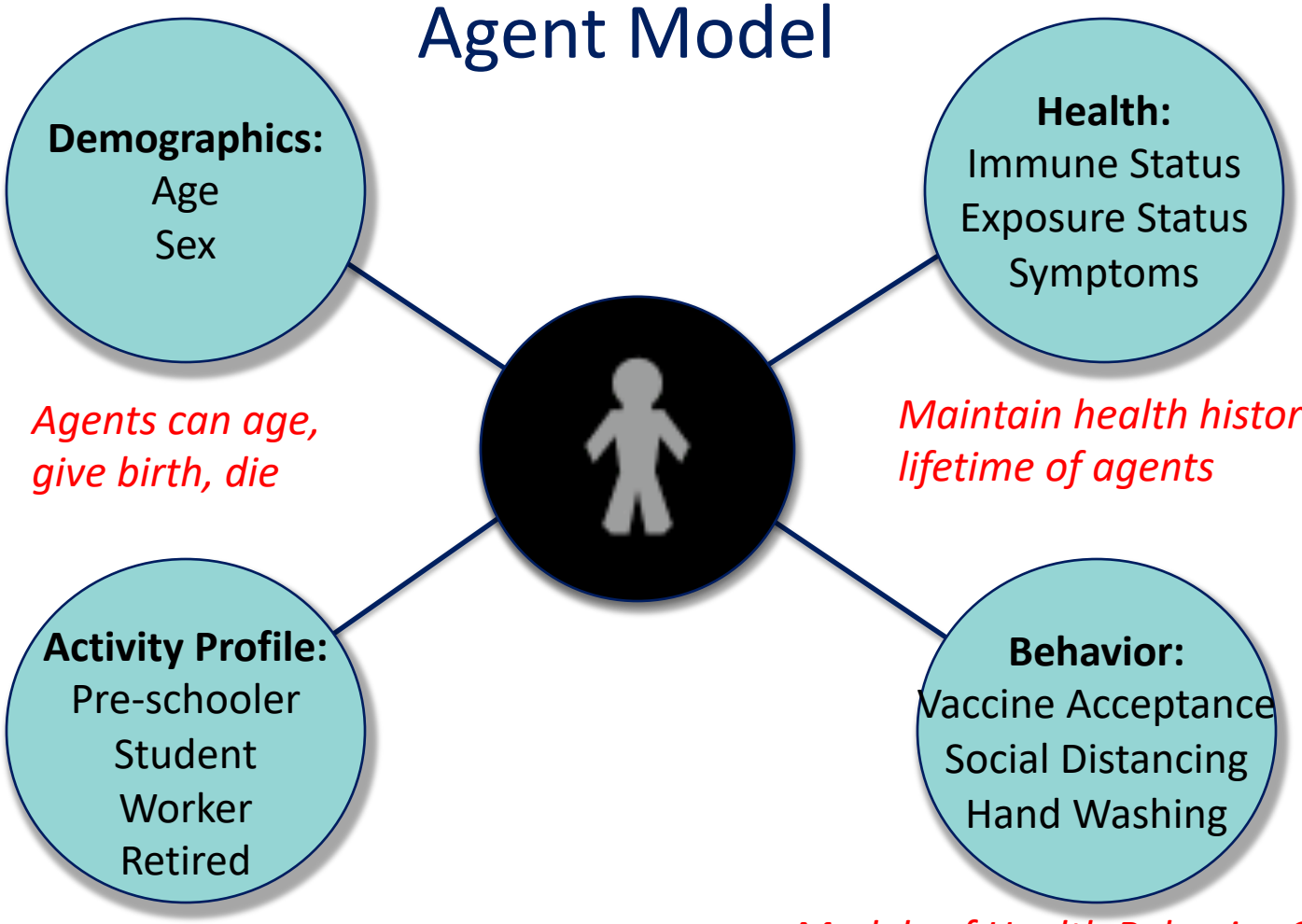
- Synthetic population for selected countries
  - Group quarters: college dorms, prisons, military bases, nursing homes
- Simulates daily activities of individual:
  - Household, neighborhood, school, workplaces, healthcare facilities
- Intercity Travel
- Flexible Disease Models:
  - Natural History
  - Transmission Models
  - Importation schedule
  - Daily tracking: counts by location, who infects whom, etc.
- Intervention Models
  - Vaccines, Antivirals
  - Social Distancing

Census-matched Synthetic Population



FRED: Key Features

Agent Model



Agents can age, give birth, die

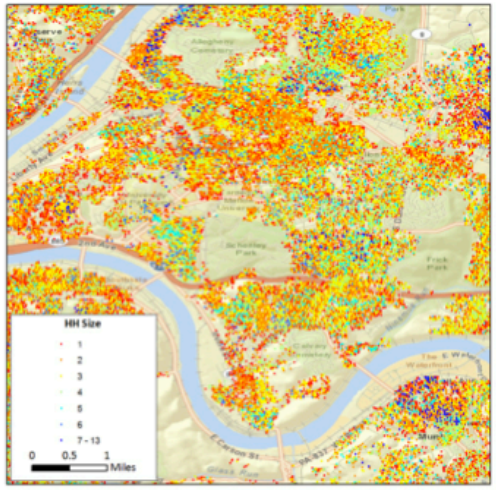
Maintain health history over lifetime of agents

Activity Profiles can change over lifetime of agents

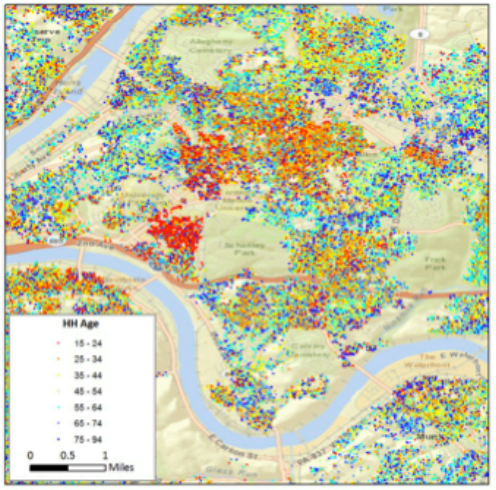
Models of Health Behavior Change:

- *Stochastic*
- *Social norms / influence*
- *Health Belief Model*
- *Segmented populations*

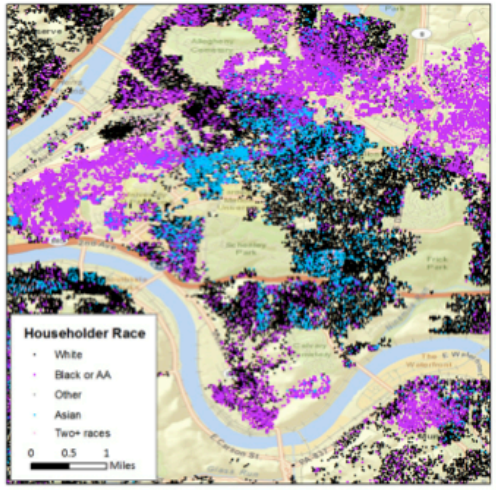
Synthetic Population Matches Real Demographics



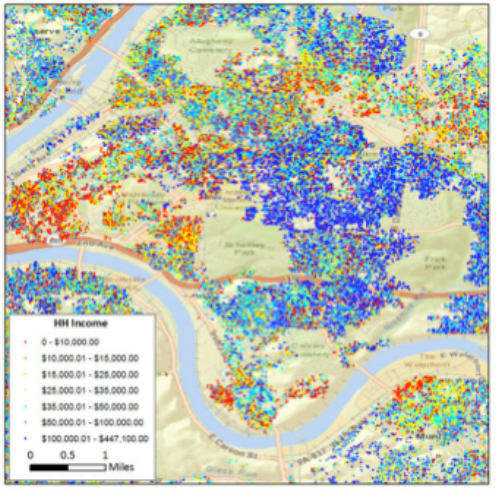
Household Size



Age



Race

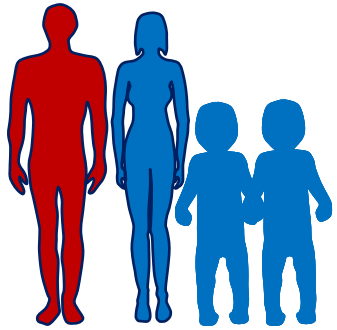


Income

Pittsburgh, PA

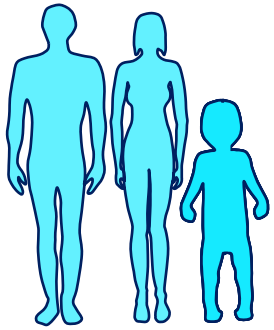
FRED Daily Dynamics

Location and size of each school



Household size, ethnicity, ages, income

Location and size of each workplace



FRED Daily Dynamics

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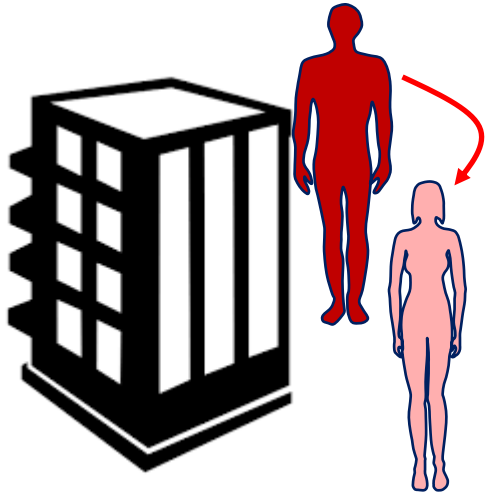
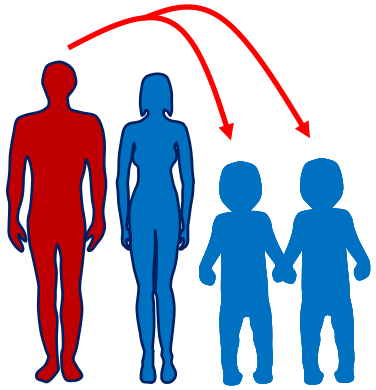


Location and size of each workplace

FRED Daily Dynamics

Location and size of each school



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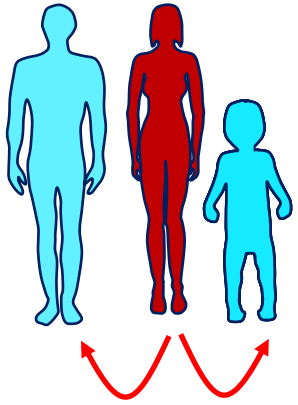
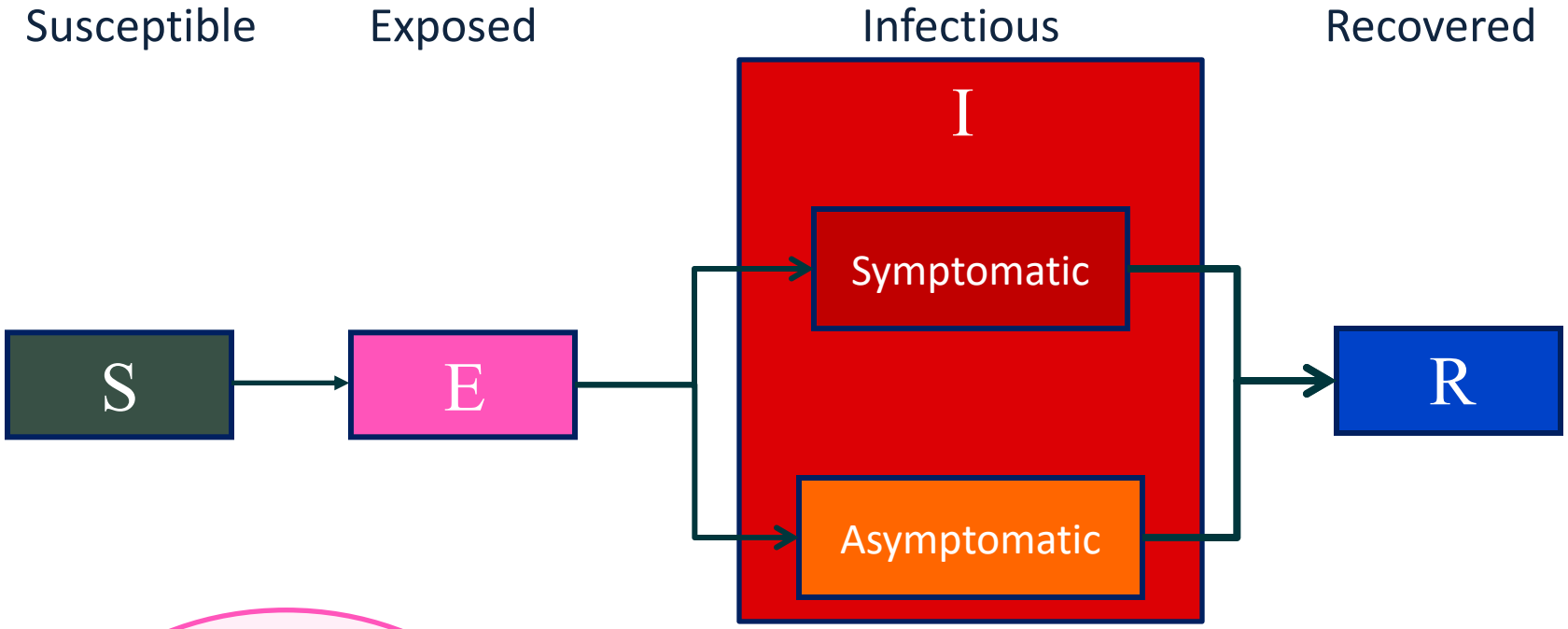
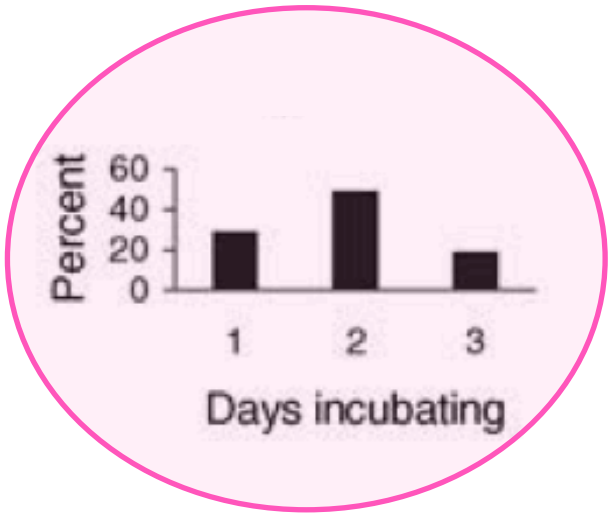
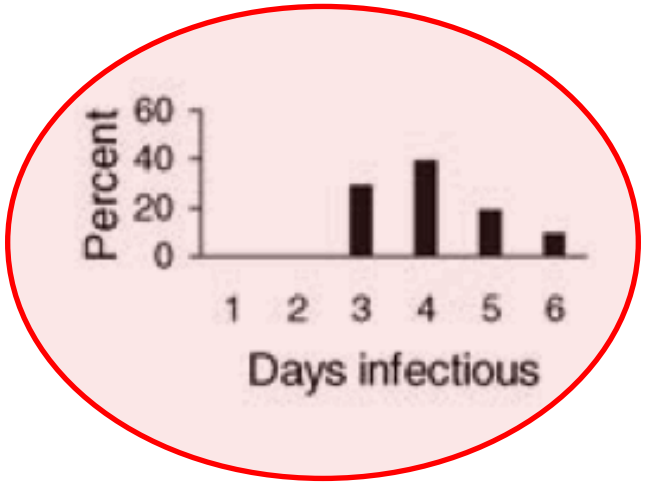


FRED: Key Features

Individual Disease Model







Distributions for influenza:
Longini et al, Science 2005

FRED: Key Features

FRED Outputs

Daily Summary Statistics of Population Health Status

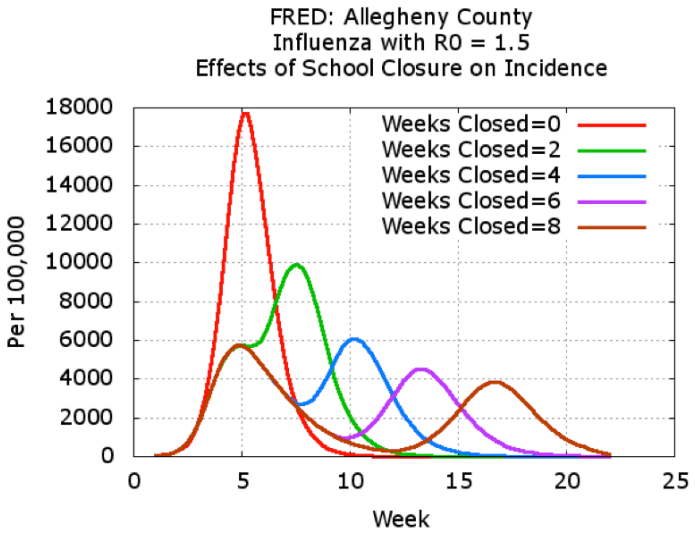
- Incidence
- Prevalance, etc

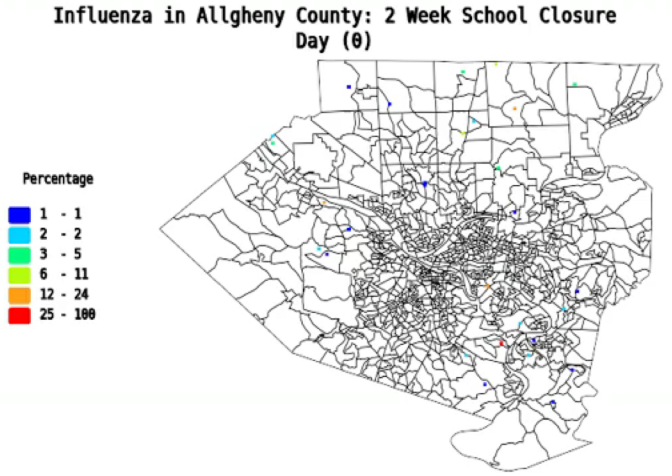
Individual transmission events

- Who infects whom, and where infection occurs

Plots of user-selectable variables

Data for producing maps and movies





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Measles vaccinations

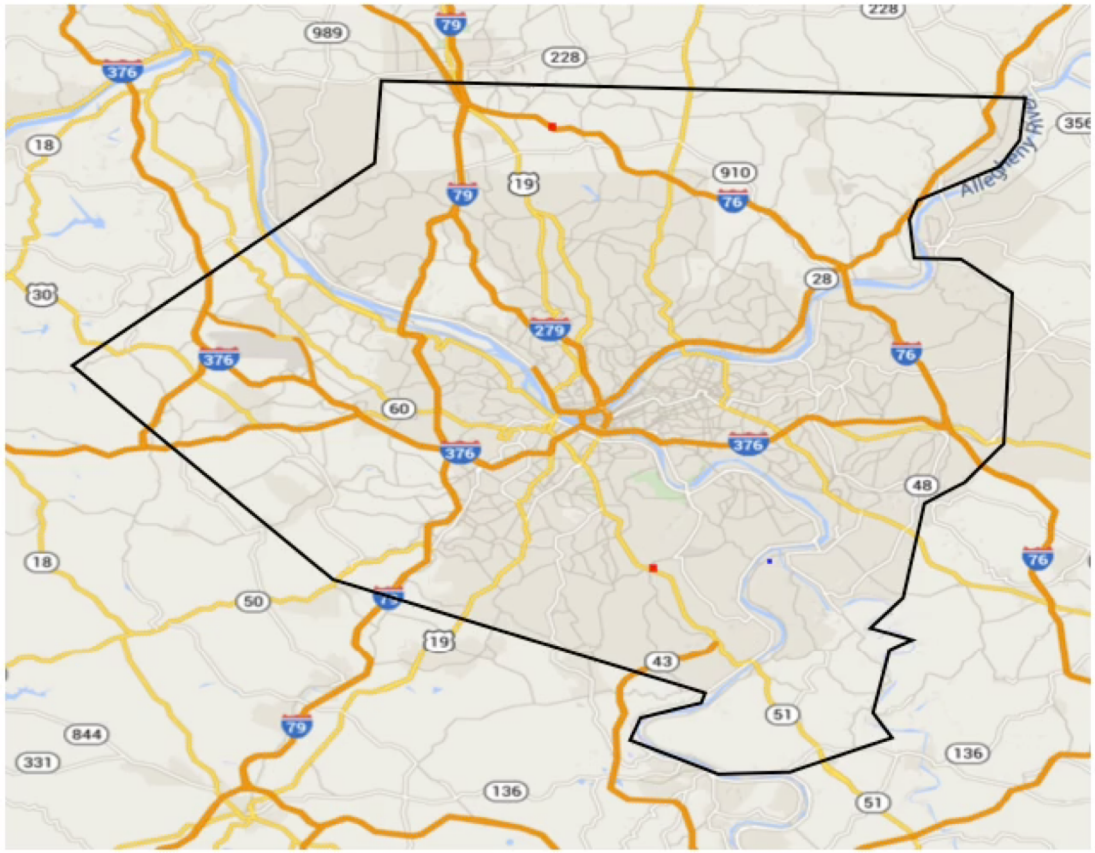
- 47 US states allow religious and/or personal exemptions to allow unvaccinated children to attend schools.
- In some states, vaccination exemptions are increasing
- Some argue that exemptions should not be allowed

FRED Measles Model

- Two simulations of measles outbreaks
- Scenarios:
  - **95%** of children 6 months to 15 years old are **immunized** against measles
  - **80%** of children 6 months to 15 years old are **immunized** against measles

FRED Measles Model

Measles in Allegheny County, PA
Coverage = 95%
Day 30

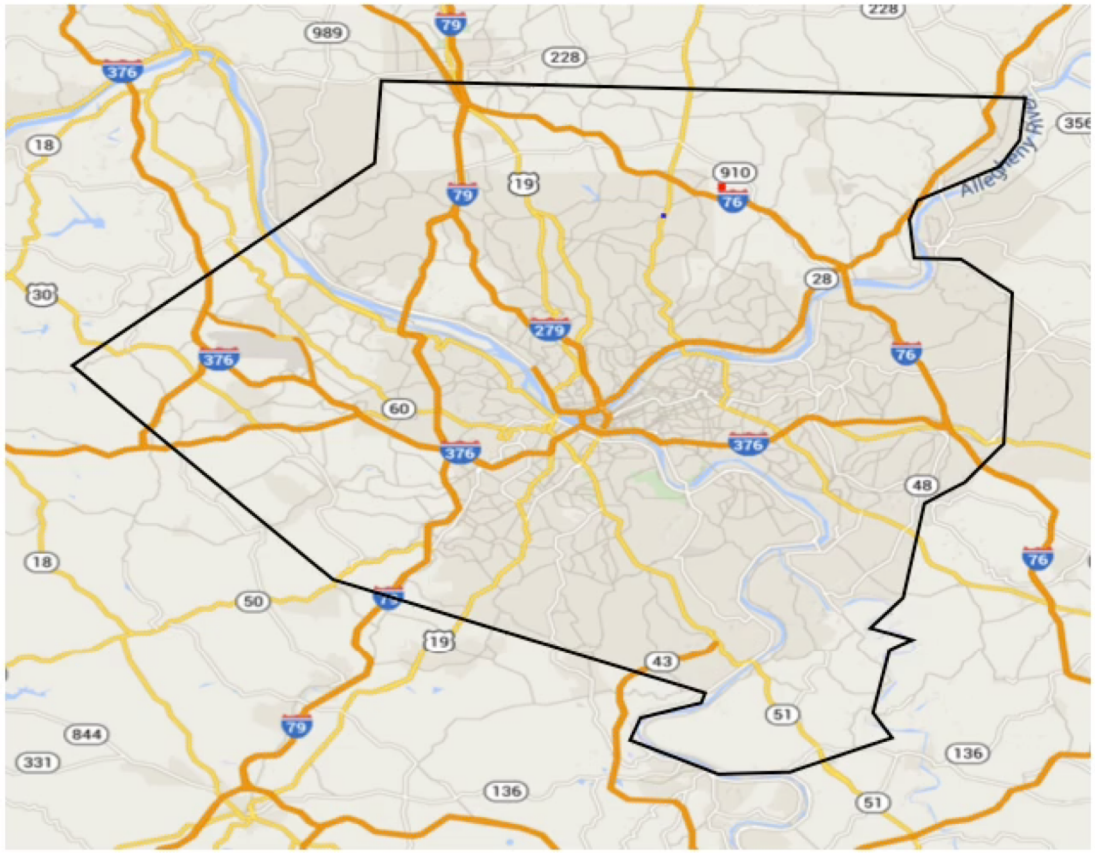


Red Dot = Infectious Case

Blue Dot = Recovered Case

FRED Measles Model

Measles in Allegheny County, PA
Coverage = 80%
Day 30



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FRED Measles Model

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California, 11 other states introduce vaccine bills

By Andis Robeznieks | April 22, 2015

Health officials have declared California's measles outbreak over, but the legislative response is just getting rolling.

The outbreak started at the Disneyland theme park and sickened 131 Californians and another 16 people from other states.

AP

"... Sen. Marty Block, a San Diego Democrat, said he was convinced to vote “yes” after Pan showed him a computer modeling program [Link to FRED] from the University of Pittsburgh that simulates how quickly a measles outbreak could spread depending on a community's vaccination rate."

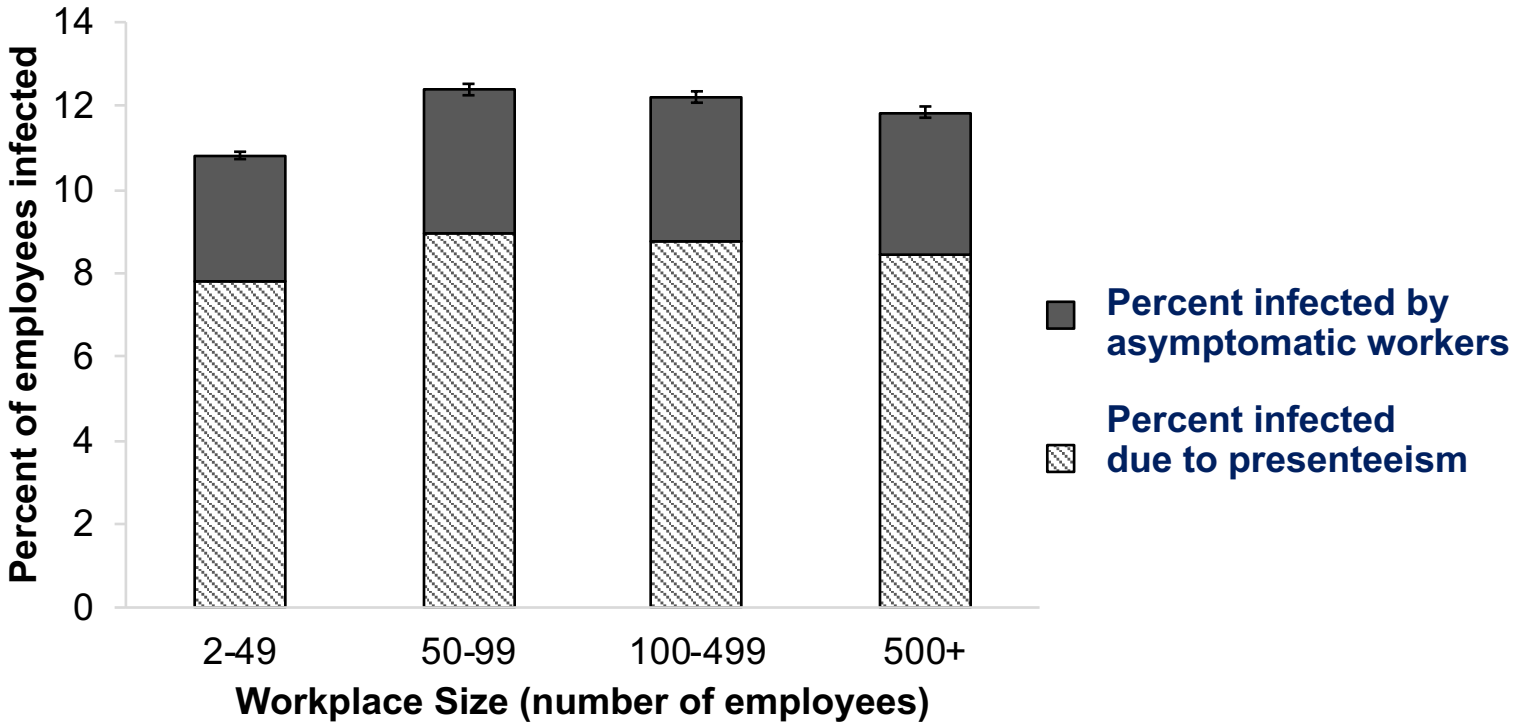
Paid sick leave

- US is the only industrialized country without universal access to paid sick leave (Heymann et al. 2009)
- Employees sometimes turn up at work when sick and infect others
- Would paid sick leave help?

Paid sick leave

Baseline Attack Rate among employed adults due to workplace transmission : 11.5%

Simulated epidemic: R_0=1.4



Conclusion: ~71% of infections at work occur due to presenteeism

Policies to reduce influenza in the workplace: Impact assessments using an agent-based model. Kumar et al. *Am J Public Health* (2013)

Lessons Learned

- Universal access to paid sick days reduces influenza infections due to workplace transmission by about 6%

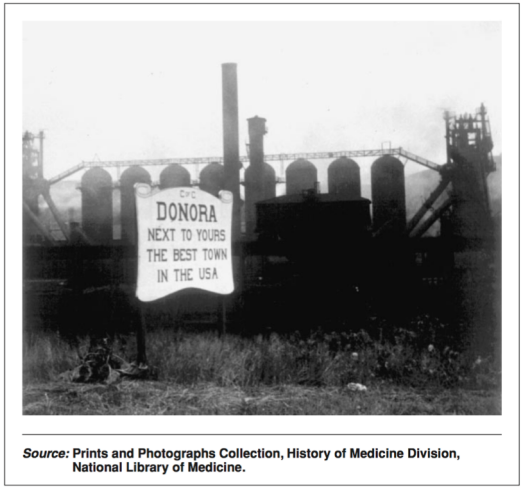
- Flu Days have a larger impact on infection reduction:
  - 25% (1 Flu day)
  - 39% (2 Flu days)

- Combination of universal paid sick days and interventions to increase the number of days spent at home may have a large as well as an equitable impact

Policies to reduce influenza in the workplace: Impact assessments using an agent-based model. Kumar et al. *Am J Public Health* (2013)

Background: Donora Smog 1948

- Donora PA
  - 24 miles SE of Pittsburgh
  - 14,000 residents in 1948
- Temperature inversion Oct. 27-31, 1948
- Combined with heavy emission of air pollution from nearby mills
- More than one-third of population affected with respiratory distress
  - 15.5% mild symptoms
  - 16.8% moderate symptoms
  - 10.4% severe symptoms
- 70 excess deaths within 1 month
  - Elevated mortality for 10 years after



Source: Prints and Photographs Collection, History of Medicine Division, National Library of Medicine.

Am J Public Health Nations Health. 1950 Feb; 40(2): 183–189. PMCID: PMC1528640
Investigation of the Smog Incident in Donora, Pa., and Vicinity James G. Townsend

Health Emergency Scenario

Scenario

- Developed with City of Pittsburgh under the 100 Resilient Cities Project (Rockefeller Foundation)
- Pittsburgh experiences a severe heat wave
- At the same time, an air pollution event occurs
- An air temperature inversion occurs, trapping dense smog at lower elevations

Focus

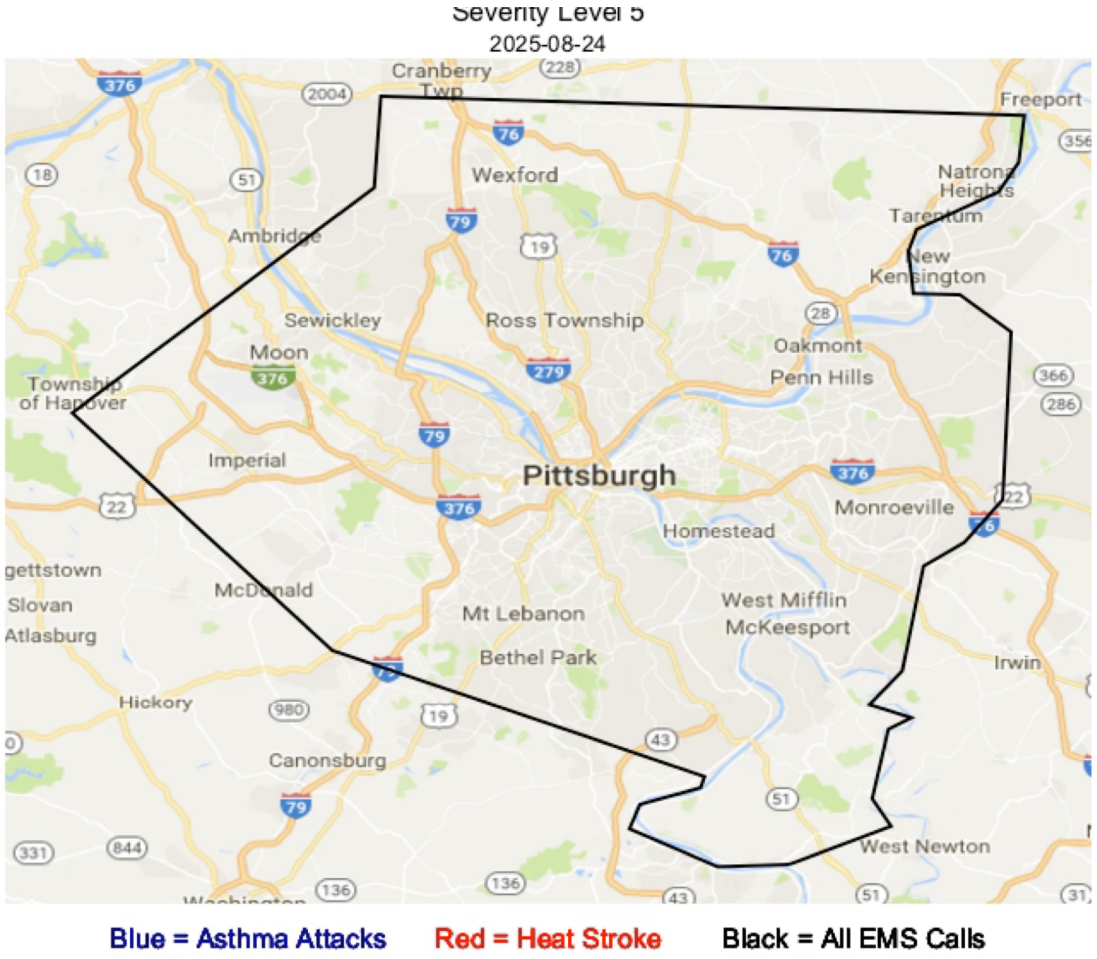
- How well does the City's emergency response system deal with the crisis?

Health Emergency Scenario

FRED Simulation of EMS Requests

FRED assigned asthma and heat stroke risks to individuals in the Pittsburgh synthetic population to match known prevalence based on age, gender and race

Simulated air pollution at lower elevations, and heat wave throughout area



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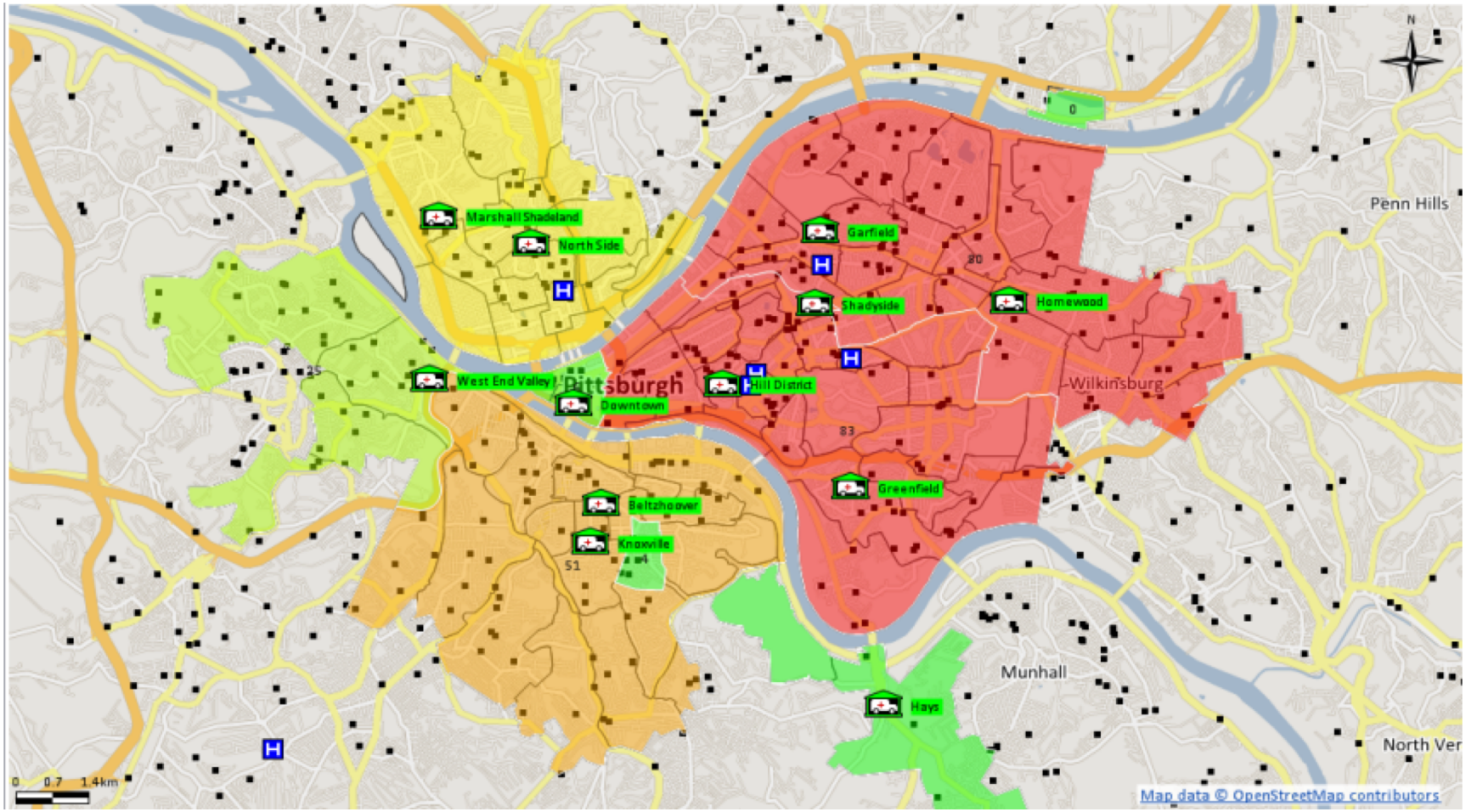
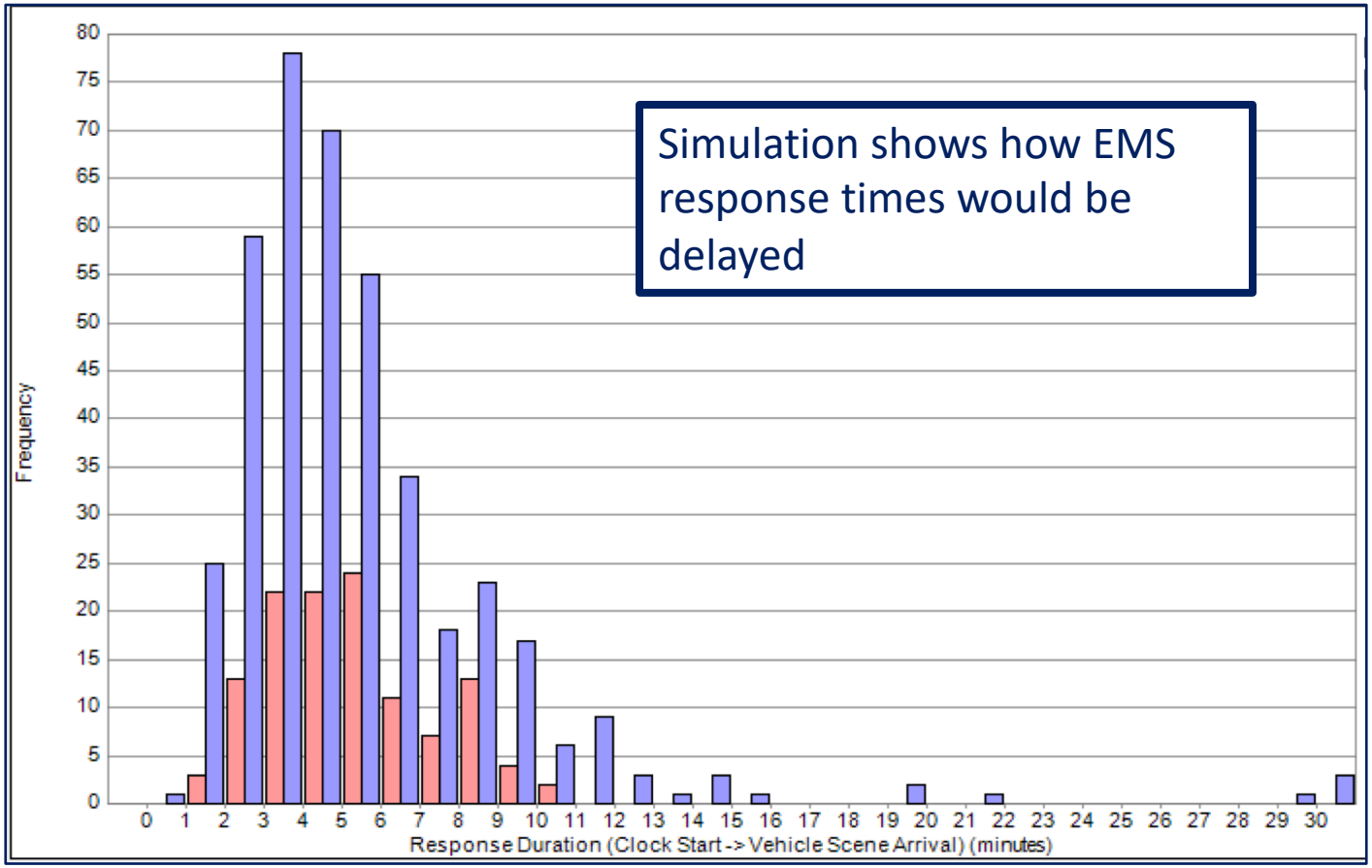
Health Emergency Scenario



Health Emergency Scenario

Data Distribution Response Duration (Clock Start -> Vehicle Scene Arrival)



	Count	Average	50th Percentile	90th Percentile	Minimum	Maximum	Std Deviation
Baseline Event Time ...	121	5.24	5.02	8.35	1.33	10.55	2.10
Level 3 Impact (Base...	410	5.59	4.55	9.23	0.98	54.32	4.77

Summary

- FRED is a flexible model framework
- Large-scale, realistic synthetic populations
- Investigation of epidemic scenarios
- Evaluate health behavior effects
- Can be used to inform policy and planning

Acknowledgments

FRED Team

- Don Burke, Bob Frankeny, David Galloway, John Grefenstette, Mary Krauland, Mark Roberts,

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- Benter Foundation