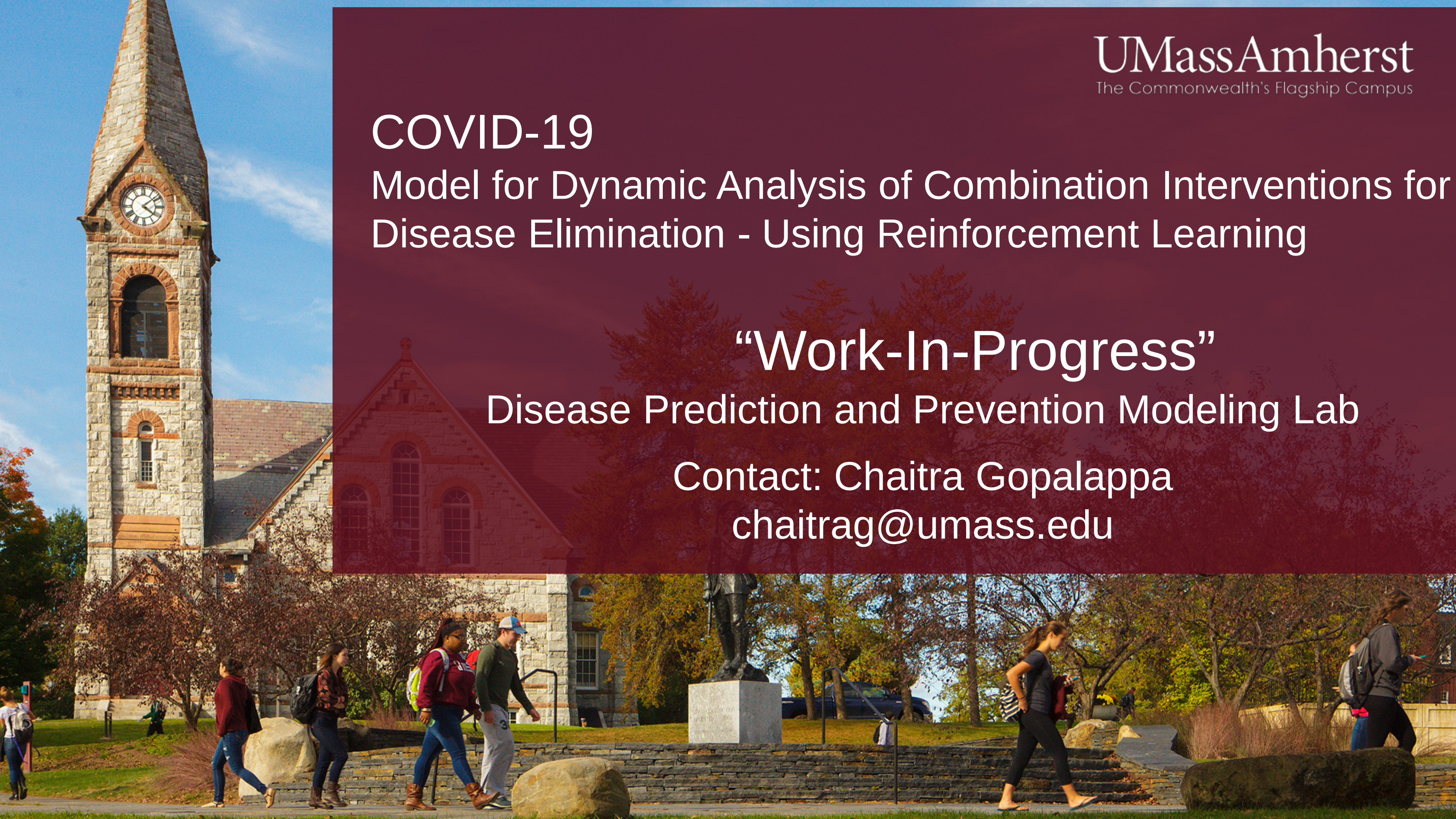

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COVID-19

Model for Dynamic Analysis of Combination Interventions for Disease Elimination - Using Reinforcement Learning

“Work-In-Progress”

Disease Prediction and Prevention Modeling Lab

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Collaborators

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Disease Prediction and Prevention Modeling Lab

Current Simulation Modeling Overview

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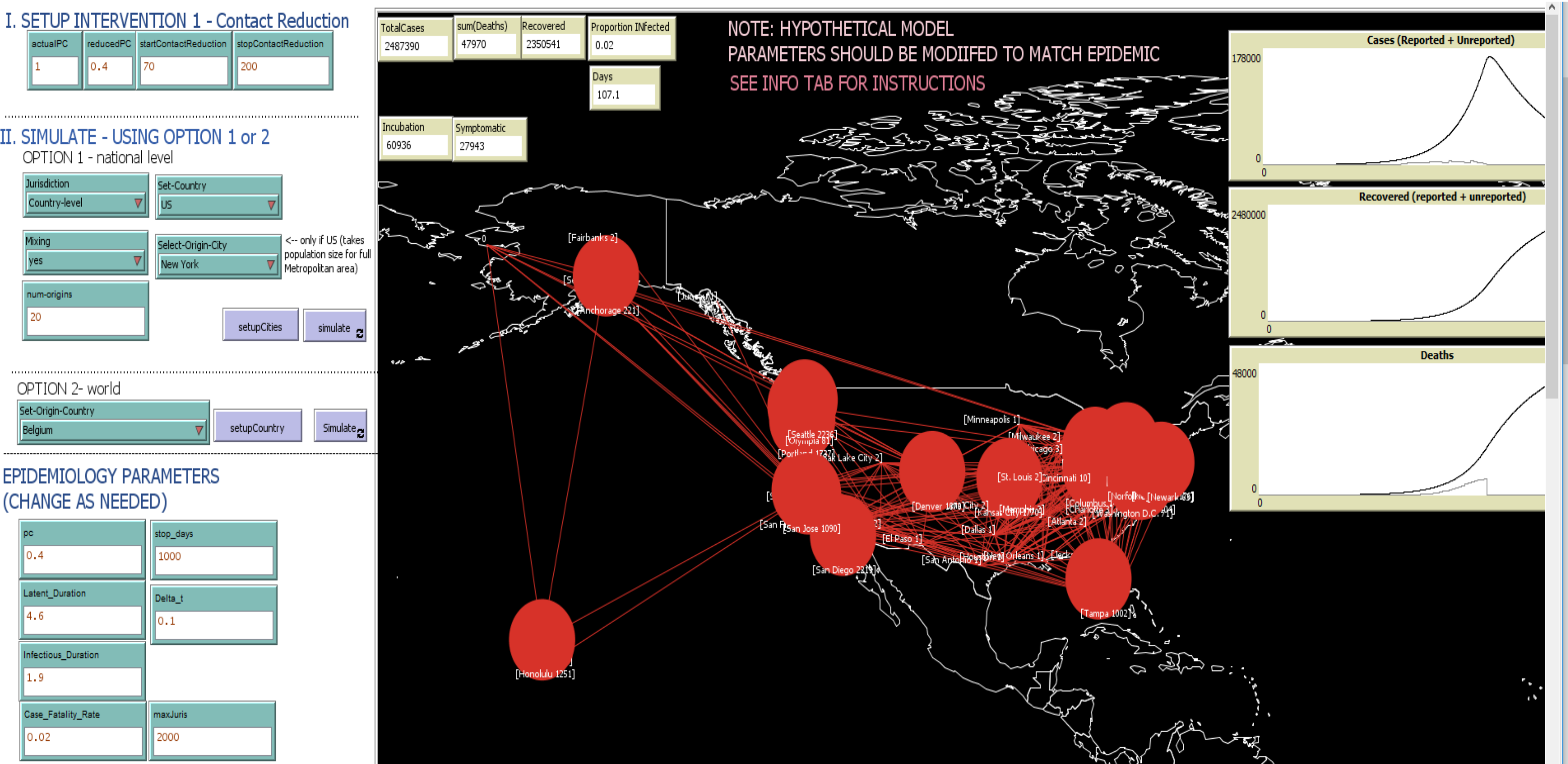
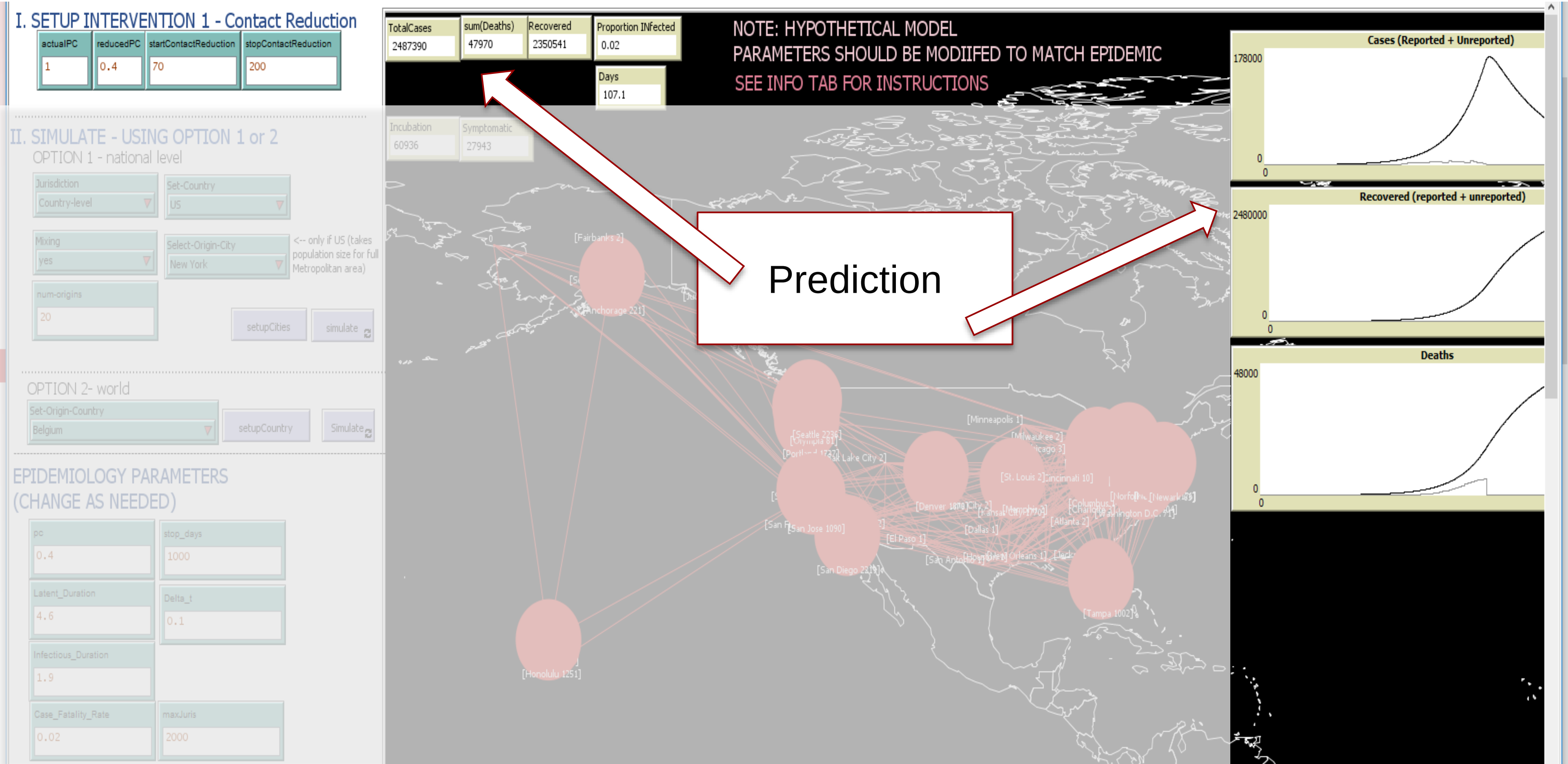
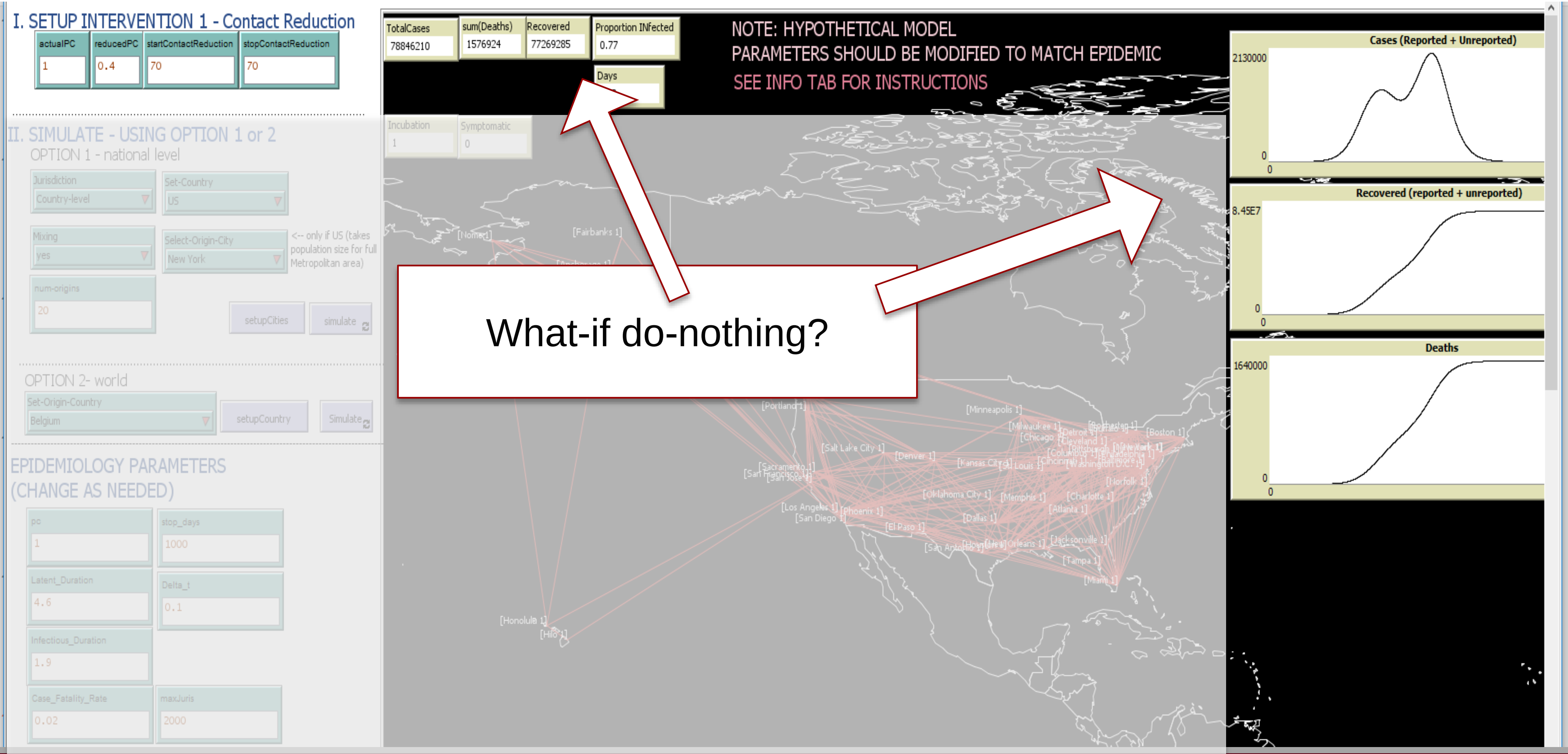


Current Simulation Modeling- Prediction



Current Simulation Modeling- What-if analysis



Current Simulation Modeling- What-if

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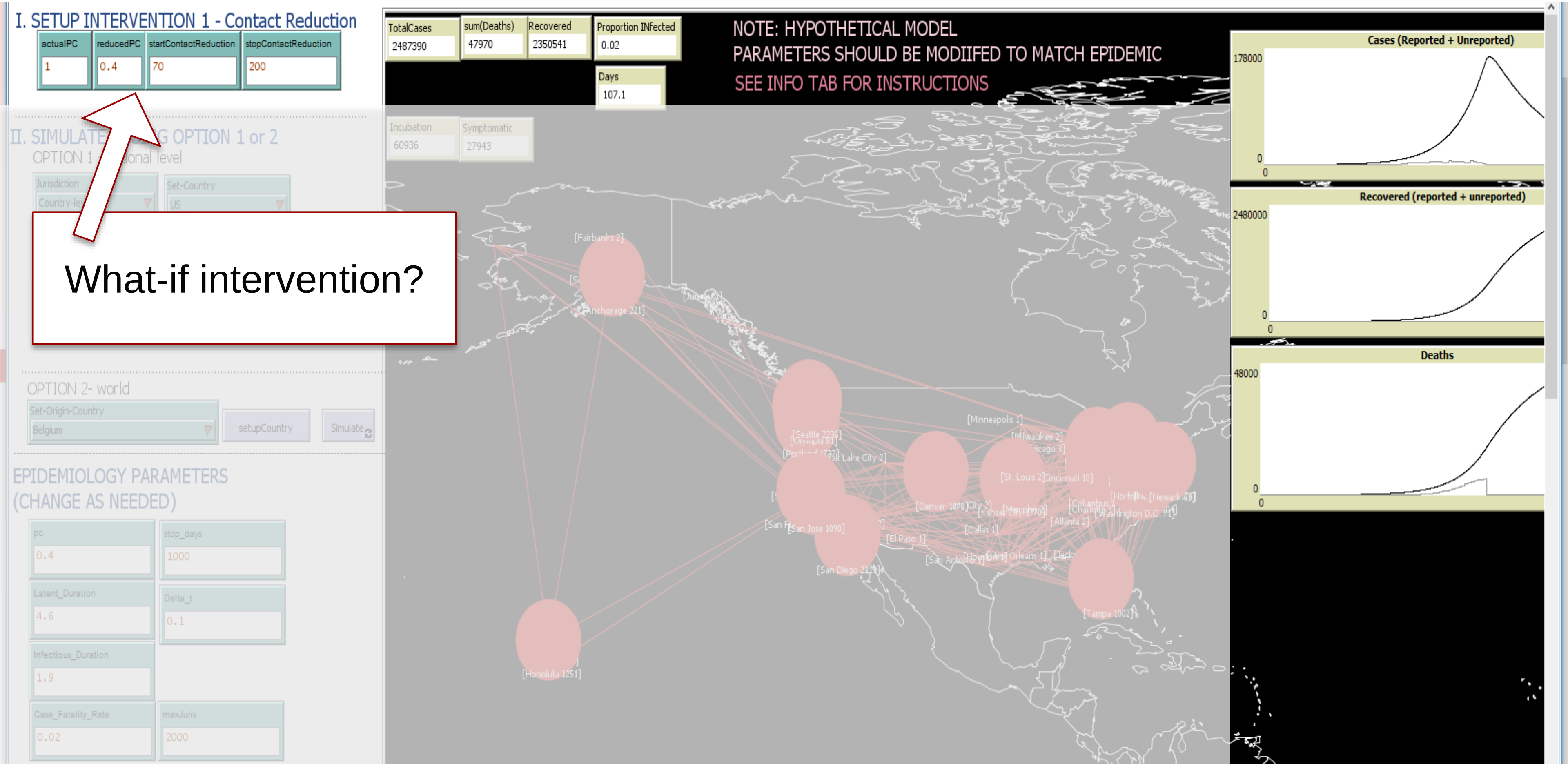

What-if intervention?

Current Simulation Modeling- What-if

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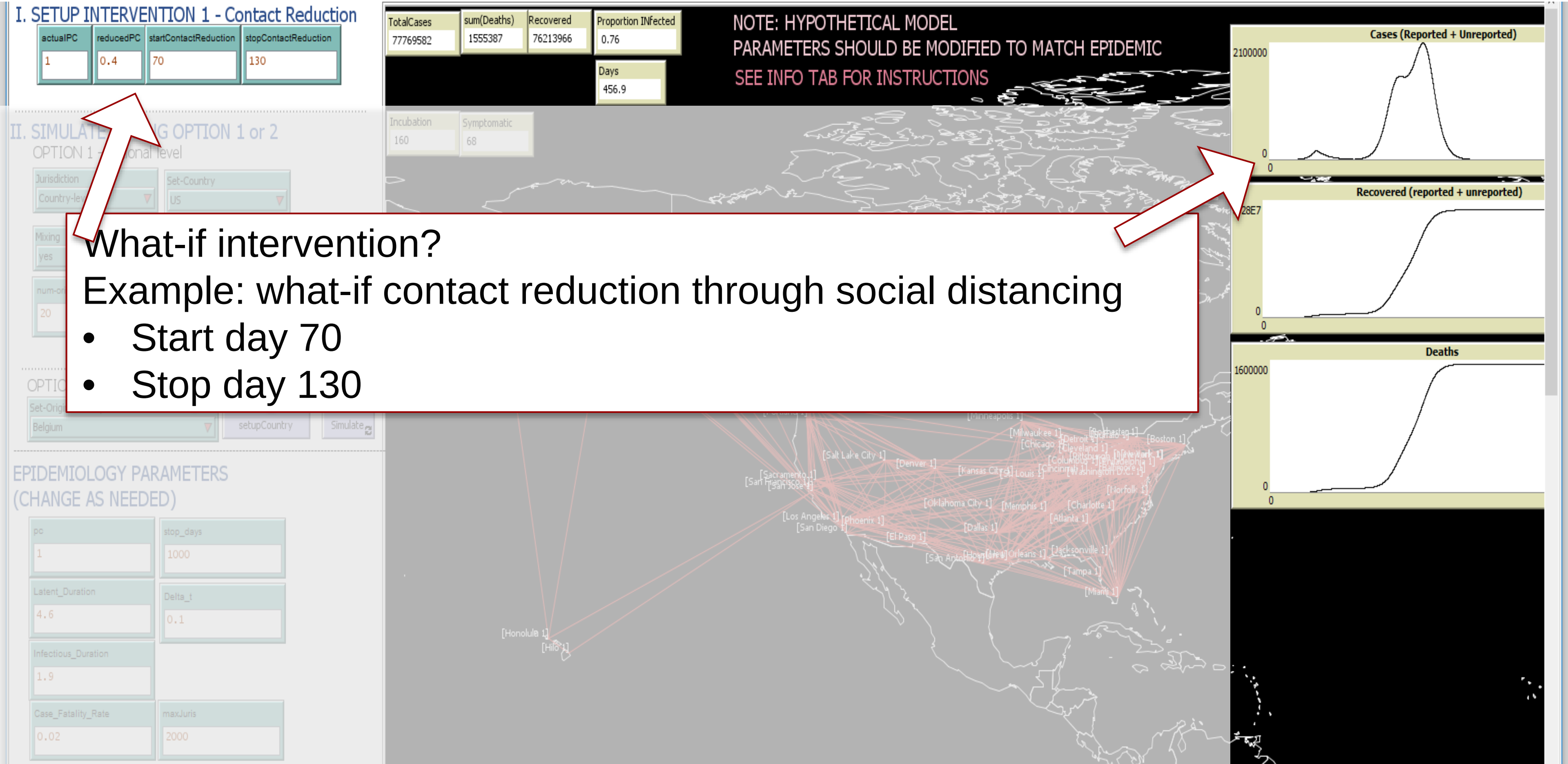

What-if intervention?

Example: what-if contact reduction through social distancing

- Start day 70
- Stop day 130

Current Simulation Modeling- What-if

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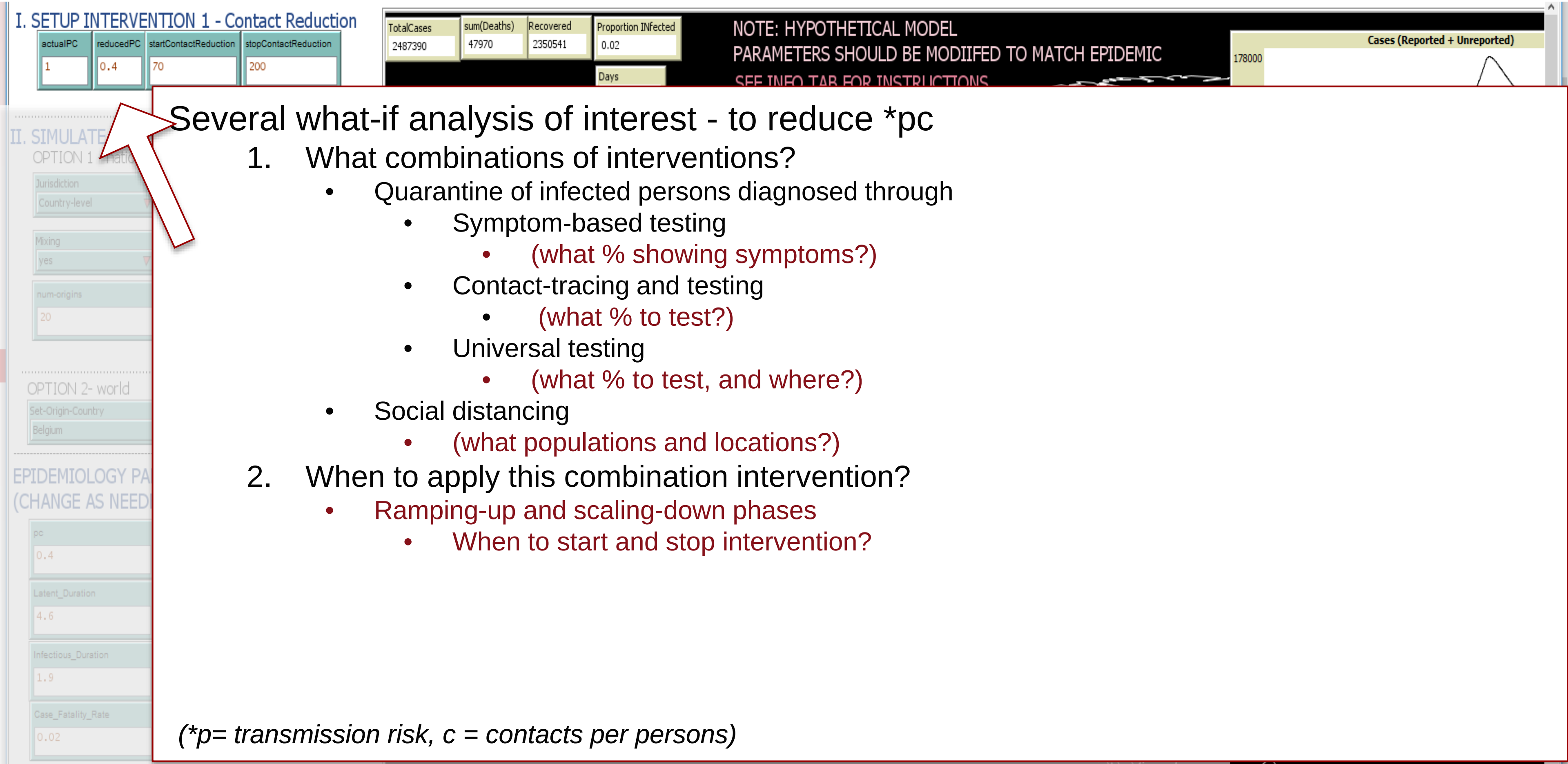

Several what-if analysis of interest - to reduce *pc

1. What combinations of interventions?
   - Quarantine of infected persons diagnosed through
     - Symptom-based testing
       - (what % showing symptoms?)
     - Contact-tracing and testing
       - (what % to test?)
     - Universal testing
       - (what % to test, and where?)
   - Social distancing
     - (what populations and locations?)
2. When to apply this combination intervention?
   - Ramping-up and scaling-down phases
     - When to start and stop intervention?

*(*p= transmission risk, c = contacts per persons)*

Current Simulation Modeling- What-if

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Influenced by dynamics of disease and past decisions

A disease elimination strategy should thus be a planned "sequence" of decisions

*(*p= transmission risk, c = contacts per persons)*

Current Simulation Modeling- What-if

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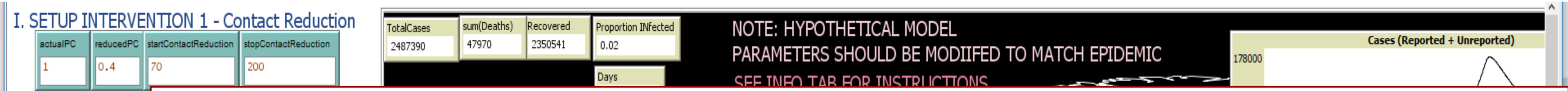

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Influenced by dynamics of disease and past decisions

An elimination strategy should thus be a “planned” “sequence” of decisions

Challenging: too many combinations to exhaustively explore

Simplest: $20^{3^{52}}$ (3 types of interventions each at 20 possible levels for a 52 week period)

*(*p= transmission risk, c = contacts per persons)*

Research Focus

- Develop a model to identify best disease elimination strategies
  - combination of interventions
  - sequence /phases

Formulation of Decision Question

- At time t
- Given "*observable*" system state = $[Q_I, Q_E, H, R, D]_t$ *
  - Q_I = % infectious (symptomatic and diagnosed)
  - Q_E = % exposed (asymptomatic and diagnosed)
  - H = % hospitalized
  - R = % recovered
  - D = % dead
- What is optimal policy sequence = $\{[s, u, c]_t,\ [s, u, c]_{t+1}, [s, u, c]_{t+2}, \ldots \ldots\}$ *
  - s = % social distancing
  - u = % universal testing
  - c = % testing reached through contact tracing
- to "optimally" lead to zero infections or disease elimination?

*denominators- total population; assume closed system

Formulation of Optimality (objective function)

Optimal trade-off in Total Costs, Benefits, and Consequences

- Maximize QALYs (quality-adjusted life-years lived)
  - Value per person per year
    - 1 healthy
    - (0,1] sick
    - 0 death
- Maximize productivity
  - Economic value per person per year
    - 0 Unemployed
    - (0,1] partial
    - 1 Employed
- Minimize cost
  - Unit costs
    - Contact tracing and testing
    - Universal testing
    - Hospitalization
- Subject to: Constraints (supply constraints)
  - Strict v what-if
    - Hospital capacity (number who can receive care)
    - Testing (=number with test outcome)

Methods

- Prediction model
- Decision analytic model

Prediction Model
System dynamics modeling (differential equations modeling)

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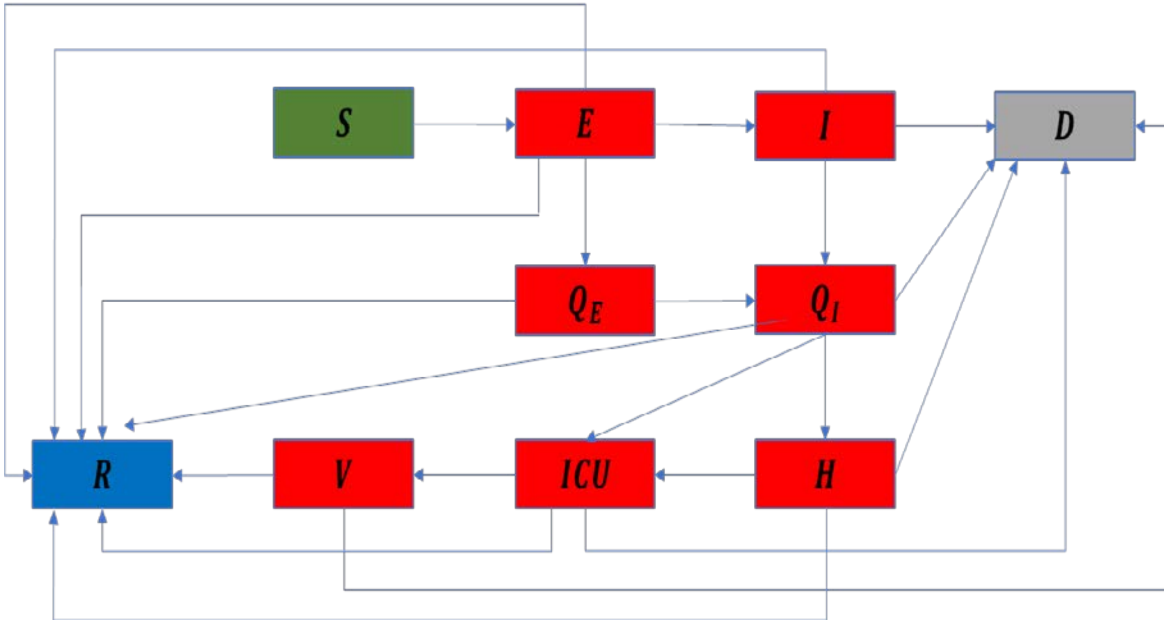
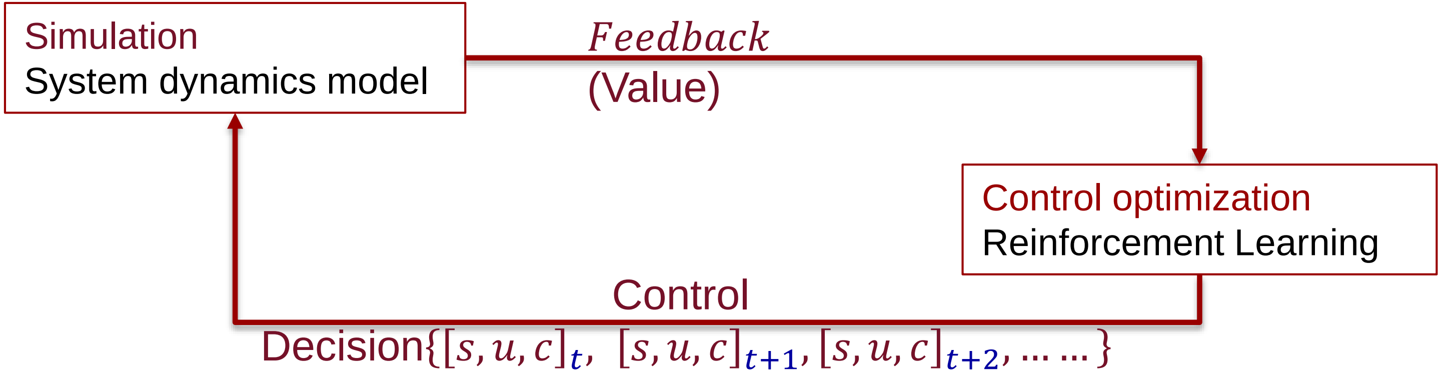


- S = the number of **susceptible** persons,
- E = the number of **exposed (asymptomatic or presymptomatic)** persons,
- I = the number of **infected (symptomatic)** persons,
- Q_I = the number of **tested and diagnosed** who are infected and symptomatic,
- Q_E = the number of **tested and diagnosed** who are infected and asymptomatic,
- H = the number of **hospitalized** persons,
- ICU = the number of persons in **ICU**,
- V = the number of persons on **ventilation**,
- R = the number of persons **recovered**,
- D = the number of **deaths**,

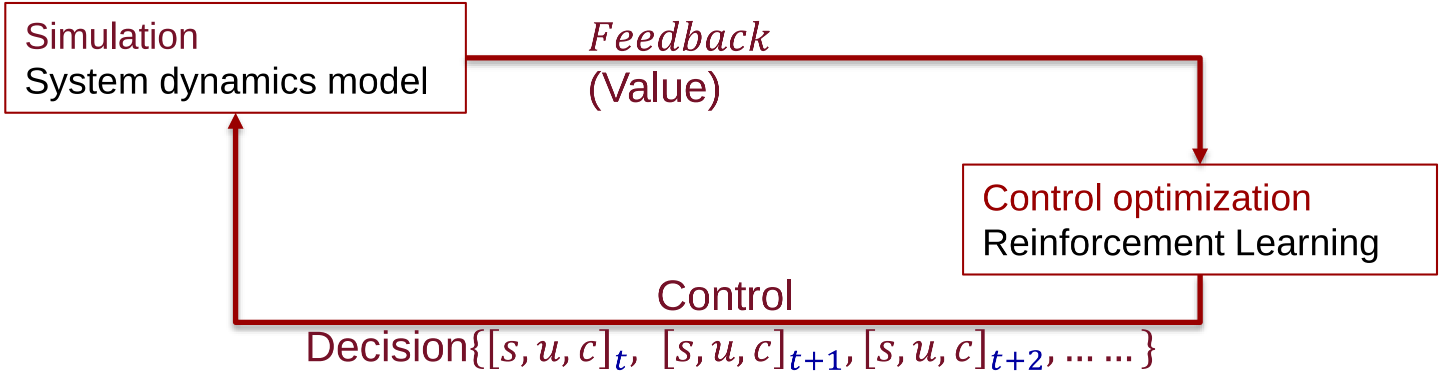
Decision Analytic Method
- Reinforcement Learning
(simulation based control optimization)



Identify optimal policy-

A sequence of decisions that optimally leads to disease elimination

Decision Analytic Method
- Reinforcement Learning
(simulation based control optimization)



Identify optimal policy-

A **sequence** of **(combination controls**) decisions that optimally lead to disease elimination (**completion of task**)

Analogous to autonomous helicopter control

-Identify **sequence** of **combination controls** (main**-**rotor's blade tilt, tail rotor pitch, rotor plane/ cyclic pitch) for successful **completion of task**

Expected output

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Model output: $Optimal\ policy = a\ sequence\ of\ decisions =$
$\{[s,u,c]_t, [s,u,c]_{t+1}, [s,u,c]_{t+2}, \ldots\ldots [s,u,c]_{t+N}\} \mid [Q_I, Q_E, H, R, D]_t$

- Helps in planning response strategies and resource allocation decisions
- Helps eliminate bad decisions

$[Q_I, Q_E, H, R, D]_t$ = **observed state of system at time t** (reported cases of disease)
Q_I = the number of **tested and diagnosed** who are infected and symptomatic,
Q_E = the number of **tested and diagnosed** who are infected and asymptomatic,
H = the number of **hospitalized** persons,
ICU = the number of persons in **ICU**,
V = the number of persons on **ventilation**,
R = the number of persons **recovered**,
D = the number of **deaths**,

Expected output

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Model output: $Optimal\ policy = a\ sequence\ of\ decisions =$

$\{[s,u,c]_{t=0}, [s,u,c]_{t=1}, [s,u,c]_{t=2}, \ldots..[s,u,c]_{t=N}\} \mid [Q_I, Q_E, H, R, D]_{t=0}$

Implementation: update based on observation

$t = 0\ (now)$

Observe: $[Q_I, Q_E, H, R, D]_t$

Implement $[s,u,c]_{t=0} \mid [Q_I, Q_E, H, R, D]_{t=0}$

$t = 1$

Observe: $[Q_I, Q_E, H, R, D]_{t=1}$

Implement $[s,u,c]_{t=1} \mid [Q_I, Q_E, H, R, D]_{t=1}$

$t = 2$

Observe: $[Q_I, Q_E, H, R, D]_{t=2}$

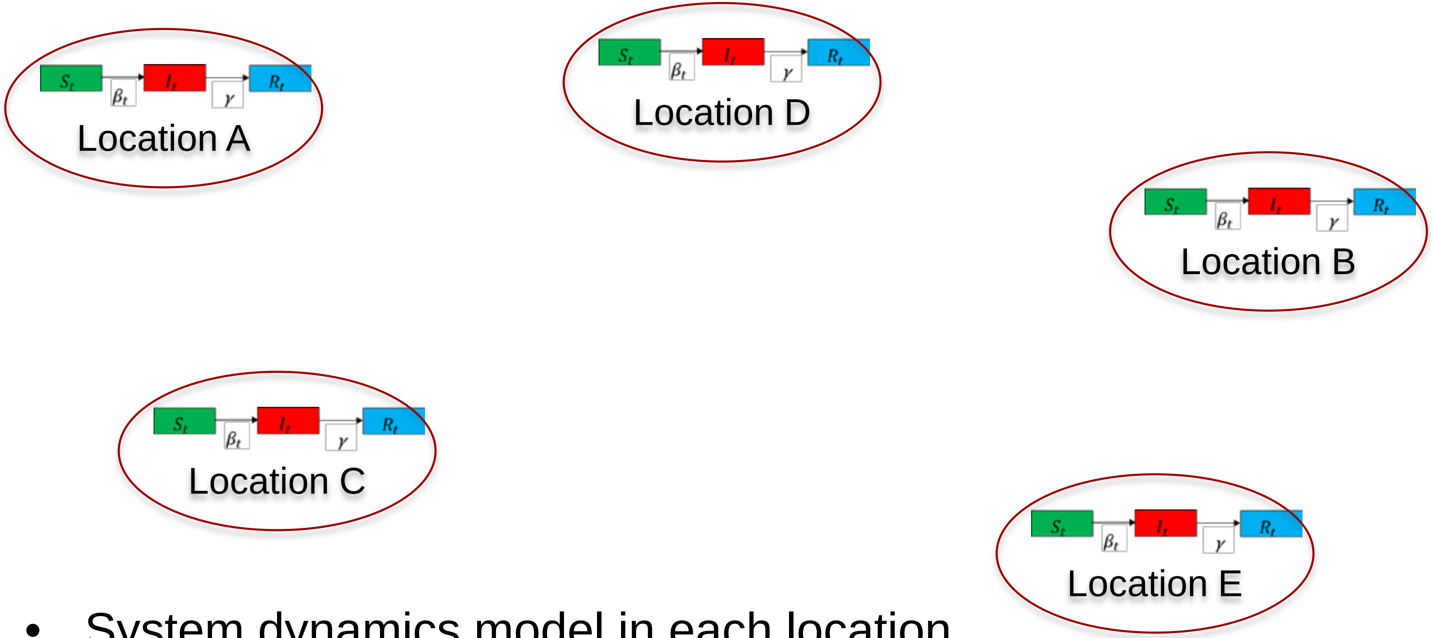
Implement $[s,u,c]_{t=2} \mid [Q_I, Q_E, H, R, D]_{t=2}$

$t = 3$

$\ldots\ldots. [Q_I, Q_E, H, R, D]_{t=3}$

Phase I

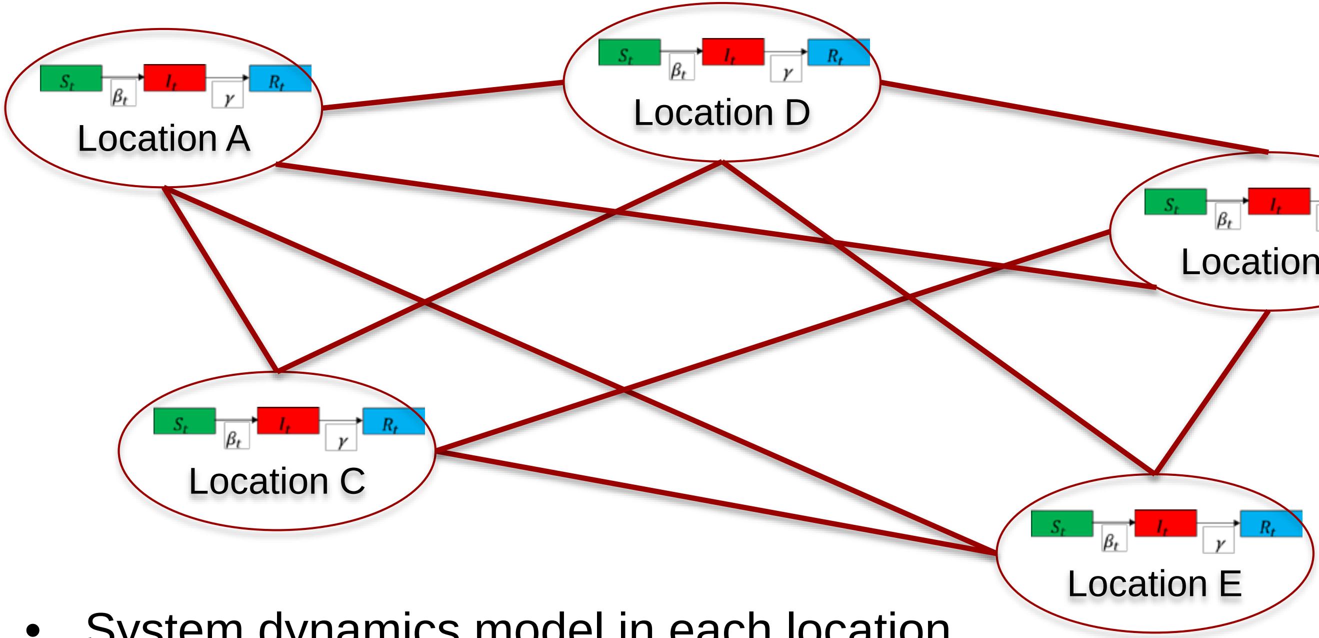
- Independent jurisdiction models



- System dynamics model in each location

Phase II

- Interactions between jurisdictions



- System dynamics model in each location
- Locations connected through network

Persons Interested in Collaborating Contact

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Research lab
Disease Modeling Lab

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Objective: Develop new mathematical and computational methods necessary to analyze complex decisions related to public policy

Collaborators

- CDC - U.S. Centers for Disease Control and Prevention
- WHO- World Health Organization
- IARC- International Agency for Research on Cancer
- PAHO- Pan-American Health Organization
- UNAIDS – Joint United Nations Agencies Programmed on HIV/AIDS
- UNICEF - United Nations International Children's Emergency Fund

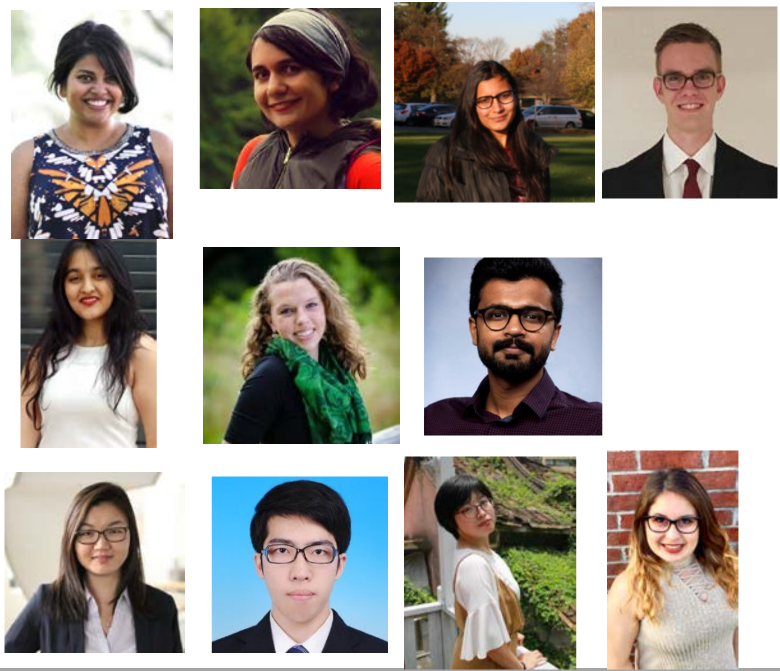
Funded By

- National Institutes of Health
- National Science Foundation
- World Health Organization

NSF

NIH
National Institutes of Health

Graduate and undergraduate students



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