Modeling Intervention Strategies for United States TB Control

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Introduction

Epidemiological models offer insight into the structure of disease outbreaks and the merits of various interventions. The most common epidemiological models are compartmental differential equation models, such as the SIR system, illustrated in figures 1 and 2.

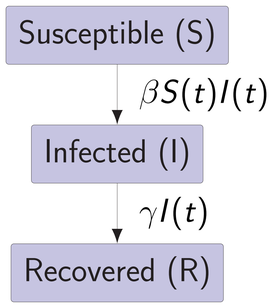

Figure: This flowchart depicts the standard SIR epidemiological model. It is accompanied by the system of differential equations 2.

$$\frac{dS}{dt} = -\beta S(t)I(t)$$
$$\frac{dI}{dt} = \beta S(t)I(t) - \gamma I(t)$$
$$\frac{dR}{dt} = \gamma I(t)$$
$$N = S(t) + I(t) + R(t)$$

Figure: The system of differential equations governing the SIR model.

The Basic Hill Model

In order to model tuberculosis (TB) in the United States (US), Hill, Becerra, and Castro designed a complex compartmental model called the hill model.

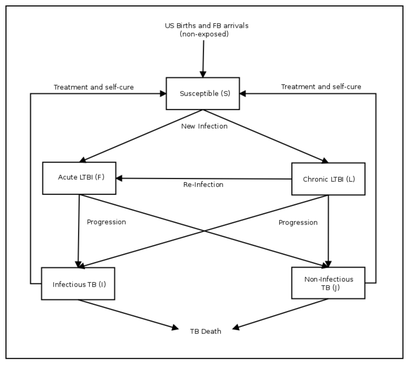

Figure: A flow chart representing the compartments of the Hill Model.

Populations:

- US Born Individuals (USB)
- Foreign Born Individuals (FB)

Individuals also leave the model due to natural death.

Analyzing US TB Reduction Strategies

- Implemented in R, with various numerical DE solvers.
- Tracks US Health Care System (HCS) cost.
- Tracks statistics about various health states.

Basic Hill Behaviour

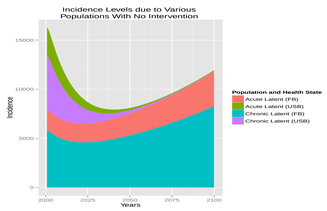

Figure: The source population of US TB incindecence

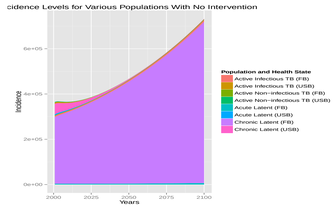

Figure: New cases per year of various types of TB in the US.

Intervention Analysis

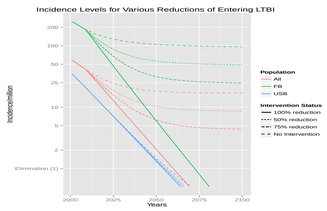

Figure: Incidence/million in USB, FB, and total populations, given 0%, 50%, 75%, or 100% treatment of incoming LTBI.

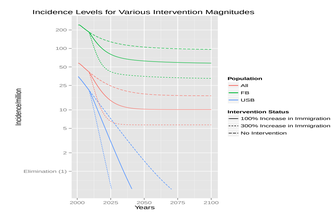

Figure: Incidence/million in USB, FB, and total populations, given 0%, 100%, or 300% LTBI treatment increase.

Economic Modeling

- Tracks treatment costs for various disease states
- Estimates implementation cost of intervention

Figure: Cumulative implementation costs, US HCS savings, and net US costs of LTBI arrival cure rates. Cost/case cured was \$600, \$800, and \$1000 for 50%, 75%, and 100% cured.

Base HCS Costs:

Active TB: \$14,014.90

LTBI: \$403.45

An Agent Based Implementation

Agent based models capture disease dynamics on the individual level, and reflect stochasticity and granularity lost in compartmental models. Agent based counterparts to the Hill model were implemented in Netlogo and c++.

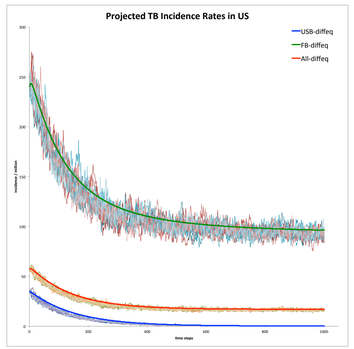

Figure: Incidence/million for R and NetLogo models (12 runs, $\Delta t = 0.1$, popConst $= 100$)

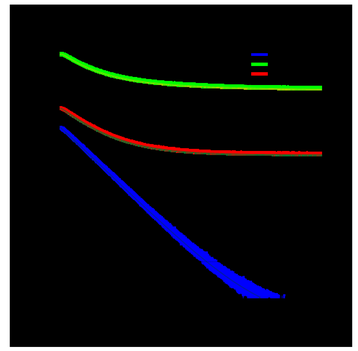

Figure: Incidence/million for R and c++ models (2100 runs, $\Delta t = 0.01$, popConst $= 1$)

Stochastic Models as a Measure of Variability

The stochastic model provides data on the variability of the results of the deterministic model.

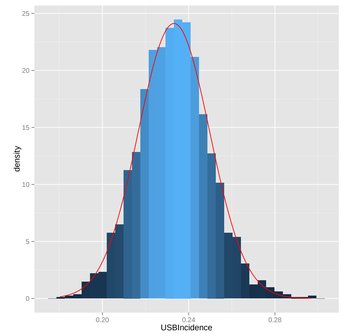

Figure: USB Incidence (c++) with fitted Normal curve ($\mu = 0.233196, \sigma = 0.016534$)

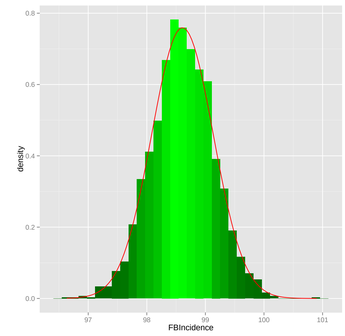

Figure: FB Incidence (c++) with fitted Normal curve ($\mu = 98.6087, \sigma = 0.525294$)

Future Extensions

- Including contact structure
- Multi-drug resistant TB
- HIV

https://www.github.com/mmcdermott/disease-modeling