**SMDM ID Modeling Short Course**

**Notes on Stanford course materials/possible outline for course**

**Next Steps**

* Kyu create GitHub
* Tess R session #1 and SIR w/ births and deaths and SIR w/ low- and high-risk group
* Kyu rest of R session #2 and all of R session #3
* Come up with accompanying slides focused on the R part – snapshot/equations
  + Placeholders in slides for sensitivity analysis
* Later: rest of the slides

**PRESENTATION**

**Background/motivation:**

* Infectious diseases and how they’re different from chronic/non-communicable diseases
* ID modeling use cases
  + Mention a few - understanding dynamics, estimating impact of potential interventions, predicting future dynamics under different scenarios
  + Focus more on 1 motivational example(s) that we can keep returning too/embellishing (as we cover new concepts, go through code together, etc.)
    - Can use this disease to potentially explain the terminology too
* Goals for the course
  + Learn how to structure and code dynamics of infectious diseases in R
  + Learn how to implement potential interventions for infectious diseases in R
  + [something on appropriate structure/assumptions for your use case]
* Agenda
  + Course format
    - Key concepts and simple models
    - Implement in R – understand how basic parameters affect disease dynamics
    - Embellishments to models/when to make them
    - Implement in R – understand how these embellishments influence disease dx
    - Interventions
    - Implement in R
    - Calibration – maybe won’t get to in much detail, but can provide code

**Model structures part 1: Basics and SIR**

* Why do we need a special set of modeling methods for infectious diseases?
* Start with Markov model example and reasons why it might not always be a good fit for ID modeling
* Transmission rate depends on # ppl infected – in a Markov model it would have to change every second to account for this -> better to use ODEs
* Explain ODEs – allows for use of continuous time scale/continuous transition rates between different states (don’t have to keep updating transition matrix as we would in a Markov model)
  + Discrete vs. continuous time
  + Rates vs. probabilities
* Show comparison (Markov model structure and results vs. ODE)
* Focusing today on dynamic compartmental models like SIR and variations of SIR that use ODEs
  + Return to this later (when might you want to use a different type of model?)
* SIR – simplest model, core model structure for today that we’ll build on, used for lots of ID modeling
  + Draw from Stanford course (lecture 2 slides 23-47)
    - R and R0
    - Force of infection and effective contact rate
      * Effective contact rate can be derived from R0 and other info about the disease (duration of infectiousness? Check!)
    - Can cover density-dependence vs. frequency-dependence here maybe (I feel like I never have a strong grasp of this concept!)
  + Transition into R lab
    - Show differential equations and parameters
    - Interpretation of parameters

**R session #1: SIR**

* **Differential equations and parameters**
* **Generate and calculate and visualize outcomes** 
  + **S(t), I(t), R(t) over time**
  + **R\_t, incidence rate,**
  + **Epidemic always burns out**
* **Show how the dynamic changes as we vary each parameter (e.g. low/high transmissibility - beta, slower/faster recovery - gamma)**

**BREAK**

**Model structures part 2: embellishments to SIR**

* Add-ons to SIR (draw from Stanford course lecture 3)
  + SIR with births and deaths
    - Births = new inflows of S’s, allows for endemicity (whereas in SIR above, infection always burns out because not enough susceptibles)
    - Deaths balance births out
    - Show in slide how the R code changes
  + Chronic infections (SI)
    - HIV, HCV (diseases that aren’t cured naturally)
    - Show in slide how the R code changes
  + Infections without immunity (SIS)
    - [bacterial infections?]
    - Show in slide how the R code changes
  + Waning immunity (SIRS)
    - Flu, COVID, etc.
    - Additional parameter: rate of waning immunity (1/avg. duration of immunity)
    - Show in slide how the R code changes
  + Latent period (SEIR; draw from Stanford course lecture 4)
    - Talk about latent/incubation/infectious/symptomatic periods here
    - When/why does this latent period matter?
    - Show in slide how the R code changes
  + Stratifying by age, other characteristics
    - Discuss contact matrix and mixing patterns here?
      * Draw from Stanford course lecture 5

**R session #2: Embellishments to SIR**

* SIR with births and deaths
  + - Focusing on endemicity
    - Show how higher birth/death rate affects disease dynamics
* SIRS (without births/deaths)
  + - Still have endemicity because our pool of S’s is replenished from R (waning immunity)
    - Show how varying waning immunity affects disease dynamics
* SEIR
  + - Show how timing of peak varies with duration of latent period
* SIR with 1 stratification (high-risk and low-risk group)
  + - With assortative mixing

**Modelling interventions**

* Vaccination
  + Simplest: send S -> R - assumes vaccine completely protective & waning immunity same as from infection
  + Create vaccinated compartment
  + Vaccine effectiveness data usually is from protection from symptoms/hospitalizations – the way we’ve discussed modeling this it assume vaccine is also protective against infection/infectiousness
    - Can incorporate this through additional embellishments to model
* Quarantine and Testing/Screening
  + Q compartment – flow from I compartment determined by testing rate/test characteristics
  + Q doesn’t infect others because no interaction with S

**R session #3: Interventions**

* Vaccination
  + How it affects disease dynamics
* Quarantine and Testing/Screening
  + How it affects disease dynamics

**Things we may not have time for that we can add if extra time/briefly talk about at the end**

Calibrating and validating ID models

* Motivation for calibration is that data for model parameters are not always available
* Common types of data/targets used to validate ID models?
* Uses and abuses of models (talking about model validity, draw from lecture 14)

Seasonality

* Set initial distribution of population (such as immunity) where it was left at end of last season to repeat multiple season & seed new epidemic if last season’s epidemic dies
* Seasonal forcing with beta/environmental factors
* Can happen naturally under very specific conditions (waning immunity and replenishment of susceptibles)
* Pathogen evolution maybe

**Added complexities** (mention, but don’t really have time to cover)

* Additions to dynamic compartmental models
  + Zoonotic or water-borne – add animal/reservoir compartments
  + Add stratification to capture heterogeneities – can capture more than just age - spatial components, risk factors, stage of disease, etc.
  + Seasonality
    - Sometimes occurs naturally (by modeling immunity and evolution of new strains)
    - Sometimes can be forced
* When might you want to use something other than dynamic compartmental?
  + Markov model or decision tree – if you aren’t interested in modeling changes in transmission (for example, you’re modeling a small enough subset of the population that you don’t expect them to impact overall transmission patterns, or your intervention is unlikely to affect transmission)
    - “catalytic model” in Stanford class basically falls under this
  + Gravity models (when you want to model spatially but don’t have enough evidence to generate a mixing matrix/geography-specific parameters?)
  + Individual-level stochastic models
    - Microsimulation
    - Agent-based models
    - Network models
    - Use cases
  + Statistical models – for nowcasting or projections with a very short timeframe
    - Unlikely to be useful for projecting longer-term disease trajectories or modeling the impact of interventions
      * Can discuss the example of IHME’s COVID model here potentially?
  + Branching model
    - Not sure if worth discussing, but this basically is an SI model (is it?)
  + Evolutionary models

**CODE/LABS**

* **Implementing interventions on the SEIR model**
  + **Vaccination**
  + **Quarantine**
* **Model calibration**
  + **Calibrating a constant beta against the observed incidence rate**
* **Modeling seasonality**
  + **Time-varying betas**

**ADVANCE MATERIALS**

* Try to share a pre-read in advance that includes some of the “key concepts” terms, or just share a glossary that ppl can reference?
  + **Key concepts** (in ID epi that will come in handy for the class) – might include
    - Basic reproductive number and reproductive number
    - ~~Herd immunity~~
    - ~~Equilibria and thresholds~~
    - Force of infection and effective contact rate
    - Contact/mixing patterns (draws from course lecture 5)
    - Seasonality
    - Immunity
    - Periods: latent, incubation, infectious, symptomatic
    - Generation interval and serial interval
    - Doubling time
* Couple seminal papers?
* Any readings from Keeling & Rohani?

**PREREQUISITES**

* R coding experience
* Calculus/differential equations?
* Modeling experience helpful but not required?