Simulation Based What-If Analysis of COVID-19 Spread in Universities

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Application

This project was based off the article *"Simulation-based what if-analysis for controlling the spread of COVID-19 in universities"* (Ghaffarzadegan, 2021).

Our project uses a SEIR-model framework to look at the transmission of COVID-19 among both students and faculty among Ivy League universities. SEIR (Susceptible, Exposed, Infected, Recovered) models are often used for diseases, and can help with understanding disease dynamics.

- S: susceptible individuals (those who able to contract the disease)
- E: exposed individuals (those who have been exposed/infected)
- I: infectious individuals (those who can transmit the disease)
- R: recovered individuals (those who have recovered from the disease)

Variables

Name in UI	Name in simfunc	Default value in App	Unit	Name in App	Definition
students	A	100	Person/day	Arrival rate of students	Arrival rate of students
cmax	C_max	13	Person/day	Constant contact rate	constant contact rate absent any exogenous or endogenous changes in social behaviour
h	h	100	scaler	Student Sensitivity to COVID	coefficient representing the sensitivity of a college to the number of daily cases; h=0 means students don't care at all about COVID transmission and keep at maximum contact rate
i_n	i_N	0.037	Person/day	Infection Probability	infection probability in the absence of mask
phi	phi	1	scaler	University closure decision	1 or 0, university closure decision, 0 open, 1 closed
	alpha	0.2 * y	scaler		relative infectivity of documented to undocumented cases
	N	A *tao_arrival	person		initial population
	L_E	phi*E0/T	Person/day		Leaving rate of students with status exposed
	L_I	phi*I0/T	Person/day		Leaving rate of students with status infected
	L_R	phi*R0/T	Person/day		Leaving rate of students with status recovered
	L_S	phi*S0/T	Person/day		Leaving rate of students with status susceptible
	A_E	0.003*A	Person/day		Daily arrival rate of students with status exposed
	A_S	0.97*A	Person/day		Daily arrival rate of students with status susceptible
	E0	10	person		initial exposure
	I0	1	person		initial infection
	len	120	day		# of days simulated
	mu	0.66	scaler		relative infectivity of exposed to undocumented cases
	R0	0	person		initial recovered
	T	14	day		Average time to evacuate college town after school closure
	tao_1	6	day		exposure period: average time to move from early to late stage of the disease
	tao_2	10	day		infection post-exposure period
	tao_arrival	14	day		Arrival duration
	y	1	scaler		scaler

Simulation

Main Functions

- `simfunc` : Run simulation and create a record table that keeps the daily cases numbers.
- `func_getcum` : Take in the daily case table and create a cumulative case table.
- `analysis_behaviour` : Analyze relationship between student sensitivity, university closure policy and COIVD cases. Generate a dataframe that records statistics (mean, maximum, and standard deviation) of daily cases under different policy and students' sensitivities.
- Detailed documentation are in the docstring of the function.

Equations

The equations used were based on Equations 3,4,6, and 8 from the article (the equations are simplified), and represent the transmission dynamics

- $\frac{dS}{dt} = -i_N C \frac{S}{N}(\mu E + \alpha I) + A_s - L_s$ (Equation 3)
- $\frac{dE}{dt} = -i_N C \frac{S}{N}(\mu E + \alpha I) - \frac{E}{\tau_1} + A_E - L_E$ (Equation 4)
- $\frac{dI}{dt} = \frac{E}{\tau_1} - \frac{I}{\tau_2} - L_I$ (Equation 6)
- $\frac{dR}{dt} = \frac{I}{\tau_2} - L_R$ (Equation 8)
- dS/dt represents the rate of change in susceptible population. It is calculated as the incoming susceptible student population (A_s) minus the leaving susceptible students (L_x) minus the population that is already exposed to the disease (first component in the equation). mu*E + alpha* I is the effective population that could transmit the disease. The transmission rate is affected by the infection probability (i_N) and contact rate C.
    - Contact Rate C is subject to change over time. It is related to students' sensitivity to the disease and rolling average of COVID cases. Defined as:
        - $C = C_{max} W_n$
        - $W_n = exp(-h(\frac{RollingAvg}{N}))$ (Equation 17)
    - L_x is the leaving rate of students with status x. When university closure = 0, all leaving rate is equal to zero. When university closure = 1, L_x = X/(Average time to leave the university), where x could be S, E, I, or R.
- dE/dt represents the rate of change in exposed population. It takes in the exposed population and arrival exposed students (A_E) and subtracts the leaving exposed students (L_E) and population that is already infected (E/tau_1).
- dI/dt represents the rate of change in infected population. It is calculated as incoming infected population minus the leaving infected students (L_I) and recovered population (I/tau_2).
- dR/dt represents the rate of change in recovered population. It is the newly recovered population (I/tau_2) minus the leaving recovered students (L_R).

Parameter Descriptions

- **Arrival rate of students:**
    - Changes initial population of susceptible. When users select an Ivy League from the drop-down, the arrival rate is changed to that specific university
- **Constant contact rate:**
    - The maximum contact rate (person/day) possible.
- **Infection probability:**
    - Affect rate of transmission/infection
- **Student Sensitivity to COVID:**
    - Students' sensitivity to the disease and rolling average of COVID cases. It affects the Contact Rate, which is subject to change over time.
- **University Closure Decision:**
    - 1: University starts to evacuate students. 0: University operates as normal. It affects the leaving rate of students. e.g. When set to 1, students leave campus at certain rate.

Shiny App

Link to app

When the app is first run, it shows a single run of this model using default parameters. Users can look at the transmission of COVID-19 among students and faculty for different universities, by selecting an Ivy League school and changing the model parameters. When users select an Ivy League, the arrival rate is changed to that specific university. Users can learn more about the inputs by clicking on the `Information about Inputs` button on the App.

School Data

- Fall 2020 student to faculty ratios were used.
- All data came from Common Data Sets(CDS)
- Only using full-time equivalent students and full-time instructional faculty (no TAs)

The tab `Daily cases` shows the daily cases of COVID-19 for exposed and infected individuals, with min, max and average contact rate listed below.

The tab `Cumulative cases` shows the cumulative cases of COVID-19 over time.

The tab `SEIR Curve` shows the daily number of all S,E,I,R status.

The tab `Behaviour and Policy Analysis` shows how daily cases would change according to different behaviour and policy. Users can choose from the bottom to show either Daily Average or Daily Maximum. The graphs show that students' sensitivity to COVID and university closure decision have a large impact on daily cases.

The `Summary` table shows the statistics for contact rate for specific variables.

Sources

- Ghaffarzadegan N (2021) Simulation-based what-if analysis for controlling the spread of Covid-19 in universities. PLoS ONE 16(2): e0246323. https://doi.org/10.1371/journal.pone.0246323
- https://sites.me.ucsb.edu/~moehlis/APC514/tutorials/tutorial_seasonal/node4.html