Covid simulator

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1 About

Covid simulator is an online tool designed for generating various possible pandemic scenarios. This is based upon age stratified infection epidemic model guided by the social mixing pattern. For background on infection epidemic model that is implemented in the current framework, see the paper by Khalaie and Mitra et al. The state of the art study on social contact patterns is the POLYMOD study, a survey based on self-reported contacts, is the first large scale study with 7290 participants across eight European countries. For detailed information on age-specific mixing matrices and what data inform them, see the paper on POLYMOD by Mossong et al.

2 User input panel

2.1 Getting right contact matrix

2.1.1 Country

In order to simulate the outbreak scenarios for a country, user has to first select the country from the dropdown menu. Based upon the user specification, a quarry will be generated to extract the relevant contact matrix from the ”socialmixr” R package. In this current framework, Polymod countries and few other countries were included. Integrating other countries and associated contact matrices is under development. Integrating pandemic specific contact matrix (CoMix) is ongoing.

2.1.2 Custom city

Sometimes it is useful to the public health authorities to generate city specific scenarios, but city specific contact matrix is very difficult to derive. Therefore, in the current framework national contact matrix is used as a proxy assuming homogeneous mixing pattern across all the cities.

In order to simulate custom city, custom city box needs to be checked and user will be asked to pass additional information about the demographic structure of the society. This will override the national demographic information and all other relevant model information will be collected as % except daily vaccination and therefore scaled.

2.1.3 Age breaks

0-18, 18-40, 40-60 and 60+ is considered.

2.1.4 Type of day

During the contact survey of POLYMOD study, participants were asked to provide the contact day. For the pandemic simulation, selecting all contacts is recommended. For any other selection, for example, selecting Monday-Friday will discard all the weekend contacts and the model simulation will be based on only weekdays contacts.

2.1.5 Contact duration

In the POLYMOD study, participants were asked to mention the duration of a contact. In general, contacts that lasts less than 15 min, may not be sufficient for successful transmission. Therefore selecting either all or more than 15 min is recommended here.

2.1.6 Contact intensity

In the POLYMOD study, participants were asked to classify contacts as physical or non-physical. For the pandemic simulation, selecting all is recommended.

2.1.7 Gender

Selecting all is recommended here unless gender specific contact matrix and the respective transmission is not under investigation.

2.1.8 Tabpanel: General

Reciprocity

The total number of contacts made by one age group members with another age group members should be the same as vice versa. This relationship is usually not fulfilled for several reasons. Mathematically, if C_{ij} is the mean number of contacts made by one age group i with another age group j, and the total number of people in age group i (j) is $N_i(N_j)$, then

$$C_{ij}N_i = C_{ji}N_j$$

To obtain a symmetric contact matrix, following normalization can be applied,

$$C'_{ij} = \frac{1}{2N_i}(C_{ij}N_i + C_{ji}N_j)$$

To get this normalization done, Reciprocity box need to be checked.

Weigh by age

Whether to weigh by the age of the participants (vs. the populations' age distribution). The age brackets used in contact survey and in demographic data might differ. On that case age groups will be adjusted by interpolating, in case they don't match between demographic and survey data. For more information, see socialmixr package.

Weigh by week/weekend

Whether to weigh the day of the week (weight (5/7 / N_{week}/N) for weekdays and (2/7 / $N_{weekend}/N$) for weekends. For more information, see socialmixr package.

Include all locations

Participants of the survey were asked to specify the location of contacts as 'Home', 'Work', 'School', 'Transport', 'Leisure', 'Otherplace'. In order to consider contacts of all locations Include all locations box needs to be checked.

2.2 Setting up epidemic model

2.2.1 Description of the model

In infectious disease transmission, contact patterns between age groups can have quite a profound impact on the disease transmission and therefore model estimate. This also have implications for designing optimal disease intervention strategies (like age-targeted vaccination, social distancing, or closing schools). For a simple SIR model, the system of ordinary differential equations with contact matrix looks like this:

$$\begin{aligned}
\frac{dS_i}{dt} &= -\beta S_i \sum_j C_{ij} I_j / N_j \\
\frac{dI_i}{dt} &= \beta S_i \sum_j C_{ij} I_j / N_j - \gamma I_i \\
\frac{dR_i}{dt} &= \gamma I_i
\end{aligned}$$

where i and j are the indices of the age classes, and N_j is the population in age group j. β is the transmission probability on contact. γ is the recovery rate.

After setting up contact matrix, it is important to set up model parameters in order to get realistic model prediction. In this current framework we used a COVID-19 specific infection epidemic model and the model schematic is represented in the middle panel *Model* tab. Briefly, the model is composed of healthy individuals without immune memory of COVID-19 (susceptible, S), infected individuals without symptoms but not yet infectious (exposed, E) and infected individuals without symptoms who are infectious (carrier, C_{I}, C_{R}). The carriers are distinguished into asymptomatic (C_{R}) and pre-symptomatic infected (C_{I}), determined as α and $(1-\alpha)$ portion of the exposed, respectively. The pre-symptomatic infected are categorized into detected symptomatic (I) and undetected mild-symptomatic (I_X). Out of I, CFR fraction will die (I_D) and $(1-CFR)$ fraction will recover (I_R). The recovered compartment (R) consists of recovered patients from different states of the infection.

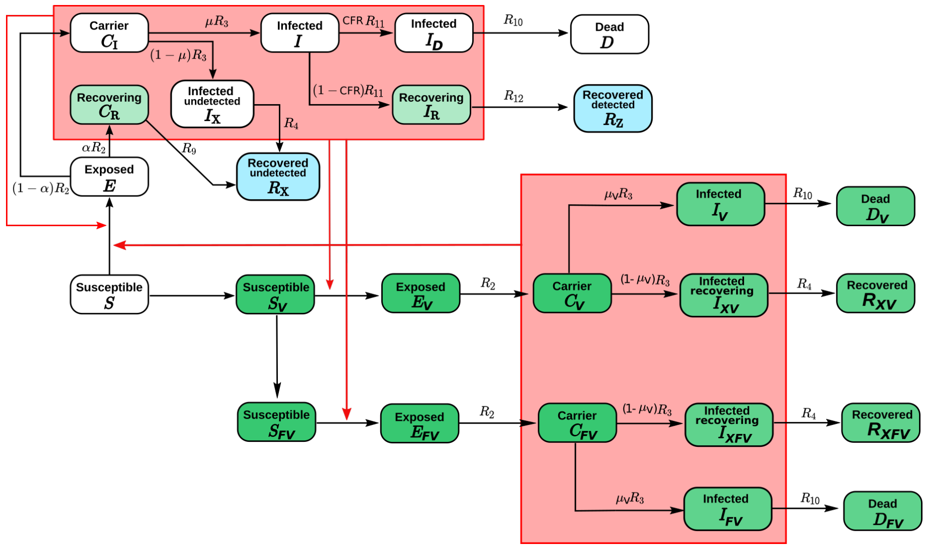

Figure 1: Schematic representation of the model used in the framework. Parameter range used is specified in the middle panel *Parameter* tab

If vaccination is on, depending upon daily vaccination, susceptible (S) and recovered (R) people will be single vaccinated and become S_V. The daily vaccination will continue until it reached up to the vaccination willingness limit of that age group. Upon contact with either vaccinated (first or second) or non-vaccinated infected cases, S_V will become exposed (E_V). The risk of catching an infection for the single vaccinated cases is considered 50% lower compared to the non-vaccinated cases. Following the same route as above, the outcome of exposed (E_V) cases can either be recovered (R_{XV}) or dead (D_V). Probability of death for single vaccinated people is considered 90% lower compared to the non-vaccinated cases.

The minimal gap between first and second dose is considered 30 days. Depending upon daily second vaccination, susceptible (S_V) people will be full vaccinated and become S_{FV}. We do not consider providing second dose to the single vaccinated but infected and recovered later (R_{XV}). Upon contact with either vaccinated (first or second) or non-vaccinated infected cases, S_{FV} will become exposed (E_{FV}). The risk of catching an infection for the full vaccinated cases is considered 90% lower compared to the non-vaccinated cases. As before, the outcome of E_{FV} can either be recovered (R_{XFV}) or dead (D_FV). Probability of death for full vaccinated people is considered 90% lower compared to the non-vaccinated cases.

2.2.2 Tab panel: Model parameters

Period

User need to specify the simulation period. End date should be higher than the start date.

Reproduction number

User need to specify the best guess of the Reproduction number (R_t). R_t and the largest eigenvalue of the matrix M will be used to calculate the transmission probability, where M has elements $M_{ij} = C_{ij}\frac{f_i}{f_j}$, f_i represent the demographic fraction of age group i.

Seasonality

Seasonal variation is a key factor for many respiratory viral infections, and some studies have suggested associations between temperature, humidity, and COVID-19 incidences.

Seasonal variation in transmission will be taken into account according to Gavenčiak et al. 2021. The peak of transmission is considered 01 Jan. and trough in July. According to the Gavenčiak et al. 2021, seasonality is modeled as a sinusoidal multiplicative factor $\Gamma(t)$ to R_t:

$$\Gamma(t) = 1 + \gamma \sin\left(2\pi \frac{t + d_0 - d_\gamma}{365} + \frac{\pi}{2}\right)$$

where γ is the intensity (amplitude) of the seasonal effect, d_γ is the day of the year of the highest seasonal effect (1 Jan) on R_t, and d_0 is the first day of the simulation period. Seasonal reproduction number is represented as:

$$R'_t = R_t \frac{\Gamma(t)}{\Gamma(0)}$$

Source: doi:10.1101/2021.06.10.21258647.

In order to take seasonality into account, user needs to check the box and is advised to select the amplitude within 0.25.

Agreed for vaccination: 18-40, 40-60, 60+

100% vaccination may not be achieved by several reasons, particularly it depends upon medical conditions of individuals. Specify here the % of people that are willing to take the vaccine. This will be used as upper boundary for vaccination of relevant age group.

Pre-existing immune memory/vaccinated population

In order to consider pre-existing immune memory or currently achieved vaccination, user needs to select the box and provide the immunized fraction (at least single vaccinated) of population of relevant age group in %. This will split the susceptible population into non-vaccinated susceptible (S) and single vaccinated susceptible (S_V) (see model schematic).

Do not select higher than the vaccinated willingness percentage of relevant age group.

2.2.3 Tab panel: Vaccination

First vaccination

In case user is interested to run vaccination in parallel to understand the impact of vaccination upon epidemic spread or for epidemic planning, user needs to provide the daily vaccination plan for relevant age group. Vaccination will take effect after 14 days by transferring the desired amount each day from non-vaccinated susceptible (S) population to single vaccinated susceptible population (S_V) (see model schematic).

Vaccination interval

Interval between first and second vaccination is considered 30 days by default.

Second Vaccination

User needs to provide the daily second vaccination plan for relevant age group. Vaccination will take effect after 44 (30 days interval + 14 days) days by transferring the desired amount each day from single vaccinated susceptible (S_V) population to full vaccinated susceptible population (S_FV) (see model schematic).

2.2.4 Tab panel: Measures

In order to apply measures with the settings previously selected (e.g. per day vaccination or pre-existing memory, etc.) user needs to check *Include physical distancing* and *Apply Measures* box. This is particularly important to investigate the impact of closing one or more establishments (e.g. school/work/leisure etc.) upon pandemic development.

Apply measures after

Desired contact reduction will commence after the selected months.

Reduce 'home' contacts (%)

In the Polymod study, participants were asked to specify the contact place. If increased, desired percentage will be reduced from the contacts that are classified as 'home' contacts in Polymod data and the resultant contact matrix will replace the previous contact matrix after the desired month, selected before.

Reduce 'work' contacts (%)

As before, if increased, desired percentage will be reduced from the 'work' contacts in Polymod data and the resultant contact matrix will replace the previous contact matrix.

Reduce 'school', 'transport', 'leisure', 'otherplace' contacts (%)

As before, if increased, desired percentage will be reduced from the respective contacts, classified in the Polymod data and the resultant contact matrix will replace the previous contact matrix.

3 Output panel

Output panel consists of three rows. First row represents contact matrix, total incidences per day and total deaths per day. Second row represents total incidences per day for four age groups. Third row represents total deaths per day for four age groups.

Depending upon the user selection and upon pressing the *Simulate* button, contact matrix will be updated. Numeric value of contact matrix represents average number of contacts per day and the color scale is represented in side. Row and column of contact matrix represents age of contact and age of participants, respectively. For example, first element of lowest row represent average contacts per day made by the 0-18 age group with themselves. Similarly, second element of lowest row represent contacts per day made by the 18-40 age group with 0-18 age group. Contact matrix, demography and the survey period is printed under the 'All results' section. Total contacts made per day by each age group is represented in 'Contact rates' tab.

When applying measures, contact matrix plot will represent the reduced form of previous matrix.

Schematic diagram of the model is represented in the 'Model' section.