ODD

Purpose

The purpose of this model is to explore and understand the spread of COVID-19 in a population. Specifically, how different policy interventions can affect the rate of spread (R0), as well as the impact on the economy.

The model was tested and evaluated with respect to it's different stages of development, and how they in turn affected the R0 value. More information on these patterns can be found in the analysis section.

Entities, State Variables and Scales

The following entities are included in the model: agents representing persons susceptible to catching the virus, and the global environment representing a typical city with houses, shops, workplaces, and a CBD area, all configurable in the UI.

Observer State Variables:

Variable name	Variable meaning	Variable type	Variable range (if applicable)
infected-persons	Number of persons infected within a day, reset to 0 at every new day, used for R0 calculation	Number (count)	
currently-infected	Total number of people infected as of the beginning of the day, used for R0 calculation	Number (count)	
r-zero	Calculated R0 value, computed by dividing infected-persons by currently-infected at the end of every day	Number	
tick-counter	Used to keep track of when to calculate R0	Number (count)	
positional-xcor-list	List of all possible x-coordinate values in range 0, max-xcor	List	0 to max-xcor
positional-ycor-list	List of all possible y-coordinate values in range 0, max-ycor	List	0 to max-ycor
cbd-xcor-list	x-coordinate values for the CBD	List	cbd-min-x to cbd-max-x
cbd-ycor-list	y-coordinate values for the CBD	List	cbd-min-y to cbd-max-y
int-cbd-xcor-list	cbd-xcor-list values converted to int	List	Same as cbd-xcor-list
int-cbd-ycor-list	cbd-ycor-list values converted to int	List	Same as cbd-ycor-list
house-xcor	x-coordinate of a house, used several times to take random values from outside the CBD	Number (coordinate)	

house-ycor	y-coordinate of a house, used several times to take random values from outside the CBD	Number (coordinate)	
shops-xcor	x-coordinate of a shop, used several times to take random values from both inside and outside the CBD	Number (coordinate)	
shops-ycor	y-coordinate of a shop, used several times to take random values from both inside and outside the CBD	Number (coordinate)	
cbd-min-x	Minimum x-coordinate for the CBD	Number (coordinate)	
cbd-max-x	Maximum x-coordinate for the CBD	Number (coordinate)	
cbd-min-y	Minimum y-coordinate for the CBD	Number (coordinate)	
cbd-max-y	Maximum y-coordinate for the CBD	Number (coordinate)	
shops-roll	Variable that decides whether a shop will be inside the CBD or outside, if 0 it's inside the CBD, if 1 it's outside	Number	0 or 1
total-dead	Count of total fatalities	Number (count)	
total-recovered	Count of total people recovered from virus	Number (count)	
num-days	Count of the days	Number (count)	
economy	Economy variable, calculated as the number of daily trips divided by the total number of people	Number	

Agents State Variables:

Variable Name	**Variable Meaning**	**Variable type**	**Variable range (if applicable)**
infected?	True or False variable indicating whether or not the person is infected	Boolean	True or False
persons-house	The house that each person is linked with (only 1)	Breed: house	

persons-workplace	The workplace that each person is linked with (only 1)	Breed: workplace	
persons-shop	The shop that each person is linked with (only 1 on a given day, but changes everyday)	Breed: shop	
shops-or-work	Sets a random value to determine whether the person will go to shops or work, 1/3rds of the time they go the shops, 2/3rds of the time they go to work	Number	0 to 2
incubation-period	Number of days the incubation period is for each person	Number	Normally distributed with mean = 7 and standard deviation = 2.3
total-days-with-covid	Total number of days a person has had covid	Number (count)	
infectious-days	Number of days before the symptomatic period starts that the virus becomes infectious for a person	Number	1 to 3
infectious-period	The day on which the infectious period begins for each person, calculated by subtracting infectious-days from incubation-period	Number	
am-i-going-to-die	A random floating-point number picked in the range 1 to 100, people with values smaller than the mortality rate will die, values greater will stay alive	Floating-point number	1 to 100
will-i-stay-at-home	A random floating-point number picked in the range 1 to 100, people with values smaller than the percentage-staying-home will stay at home when symptomatic, values greater will go to work or to the shops	Floating-point number	1 to 100
immune?	True or False variable indicating whether or not the person is immune to the virus	Boolean	True or False
depart-wave	A random number picked in the range 1 to 100, people with values smaller than percentage-daily-travel will go to work or shops, others will stay home	Number	1 to 100

leave-home-time	A random number, picked in the range 1 to 100, that dictates at which tick a person will live their home	Number	1 to 100
leave-shops-time	A random number, picked in the range 100 to 400, that dictates at which tick a person will leave the shops (if they go to shops that day)	Number	100 to 400
leave-work-time	A random number, picked in the range 400 to 100, that dictates at which tick a person will the work (if they go to work that day)	Number	400 to 1000

Scales

The model's spatial extent is custom and can be defined by the user in the UI. Furthermore, the CBD size can also be defined by the user and represents a square at the center of the world. The model runs at a rate of 1 tick = 1 minute, therefore 1440 ticks = 1 day.

Processes Overview and Scheduling

Processes: The model is developed to cover the interactions of people in a metropolitan city, and covers a time period from when the virus COVID-19 is introduced, to when everyone either becomes immune or when nobody is infected anymore.

1. The model checks if all persons are immune or if no one is infected. If so, it stops.
2. The model executes "calculate-r-zero"
    a. If the *tick-counter* is 1, the counter has been reset and it is the beginning of a new day. The mode sets *infected-persons* to 0, and sets *currently-infected* to the number of all people who are currently infected
    b. If the *tick-counter* is 1440, it is the end of the day. R0 is calculated as *infected-persons* / *currently-infected*. The *tick-counter* is reset to 0.
    c. The *tick-counter* is incremented by 1
3. The model executes "spread-infection"
    a. The model asks all people who are currently *infected?*, if they are in their infectiou period*,* and if so, to ask the people in the same patch to get infected.
    b. People in the same patch have their *infected?* value set to true, their *total-days-with-covid* gets set to 0, they draw a value for their *incubation-period*, *infectious-days*, *am-i-going-to-die* and *will-i-stay-at-home*. Their *infectious-period* is calculated.
4. The model executes "recover-or-die"
    a. The model asks all people who are currently *infected?*, if their *total-days-with-covid* is greater than their *incubation-period* + a random value from 1 to 10 (this allows people to die at random in their symptomatic period), and if their *am-i-going-to-die* value is lesser than the mortality-rate and if *fatalities* is on. If so, *total-dead* is incremented by 1, and the agent is asked to die.
    b. If instead, the *total-days-with-covid* is greater than or equal to the *incubation-period* + 10 (because that's the value chosen for the symptomatic period to last), then it sets *infected?* to false, sets *immune?* To true, incremented *total-recovered* and sets the person's color to green. It also ensures that if *fatalities?* Is true, then the person's *am-i-going-to-die* is greater than or equal to the *mortality-rate*

5. The model executes “recolor”, which changes the person’s color based on a set of conditions
    a. If the person is *infected?* and in their symptomatic period, their color is set to red
    b. If the person is *infected?* and in their infectious period but not symptomatic, their color is set to orange
    c. If the person is *infected?* and in their incubation period as well as not in their infectious period, their color is set to yellow
    d. If the person is not *infected?*, their color is set to gray
6. If *policy-intervention?* Is false, the model executes “calculate-economy” and “move”
    a. “calculate-economy” checks if the number of ticks are equal to 1440, which means we are at the end of the day, and if so, checks if *staying-home-when-sick?* is false, and if so sets *economy* to the number of people, which is also the number of daily trips in this case. If *staying-home-when-sick?* is true, it sets *economy* to the number of people minus the number of people who are symptomatic and staying at home at the time.
    b. “move” asks all persons,
        i. If the number of ticks is less than their own *leave-home-time*, for them to stay put at home
        ii. If the number of ticks is greater than or equal to their own *leave-home-time*, and lesser than their *leave-shops-time*
            1. Check if *staying-home-when-sick?* is true and if they are symptomatic and infected, and if so, to stay home
            2. If not, to move to either work or the shops, depending on their *shops-or-work*
        iii. If the number of ticks is greater than or equal to their *leave-shops-time* but less than their *leave-work-time*,
            1. Check if *staying-home-when-sick?* is true and if they are symptomatic and infected, and if so, to stay home
            2. If not, to move to either work or home, depending on their *shops-or-work*
        iv. If the number of ticks is greater than or equal to their *leave-work-time* and less than 1440, they are asked to move home
        v. If the number of ticks is greater than or equal to 1440, to ask all persons to set their *persons-shop* to a new shop, set their *shops-or-work* to a new value, and if their *infected?* is true, to increment their *total-days-with-covid*. Finally the global variable *num-days* is incremented
7. If *policy-intervention?* Is true, the model executes “calculate-economy-with-intervention” and “move-with-policy-intervention”
    a. “calculate-economy-with-intervention” basically checks if the ticks are equal to 1440, which means we are at the end of the day, and if so sets the economy value by calculating the number of daily trips
    b. “move-with-policy-intervention” only asks those turtles whose *depart-wave* value is less than their *percentage-daily-travel* or if they’re *immune? =* true to carry out the same procedure as “move”, else they stay home. Also, each person’s *depart-wave* is reset to a new value.
8. Tick forward

Rationale for Processes

At each tick, since each tick corresponds to a minute, we need to systematically check how the world changes and how it affects each person with regards to their movement and infection related attributes. Thus, if no one is infected or everyone is immune, we can stop the model. We also need to calculate R0 if the ticks are at the end of the day. At every tick, we need to check if the infection is going to spread amongst the people in case they are on the same patch, as well as check if the persons can recover from the virus, or if fatalities is on, if they are to die from it. Recoloring of the persons with regards to the infection spread or recovery is also important for a more visual perspective on what is going on in the world. Finally, like R0, if we are at the end of the day, we calculate the economy, and at every tick, based on the criteria mentioned above, we move the persons to simulate and continue the world.

Rationale for Order

Firstly, the model has to check at the beginning if all persons are immune or if no one is infected, so it can stop immediately if so, and doesn't run any extra processes than what's required. After this, it checks if it has to calculate R0 (if ticks = 1440), which has to be before more infections are spread, to maintain accuracy. Then the model spreads the infection among other persons, and then for each person checks if they need to recover from the infection or they are to die. The agents are then recolored, depending on whether they were newly infected, if they recovered or if their number of days with the virus signify a color change. Finally, the economy is calculated, just as with calculating R0, it is done right as before they move around the world.

Design Concepts

Basic Principles

The model simulates the spread of the COVID-19 virus in a population, while addressing the problem of maintaining an accurate R0 value that reflects COVID-19, as well as policy interventions that can curb the spread of the virus and lower the R0 value, as well as maintain the economy.

Emergence

The key outcomes of the model are the R0 values and the economy – how they differ with policy interventions, and change the spread of the virus and how the persons in the world react to this.

Adaptation

The persons have the adaptive behaviour of moving around the city at certain times, depending on their own values for their respective depart times, such as *leave-home-time*, *leave-work-time* and *leave-shops-time*. Furthermore, they make go either to shops or to work, and if they are symptomatic, they may have to stay at home, depending on *staying-home-when-sick?* More information on these variables can be found in the Agent State Variables table.

They also have the adaptive behaviour of spreading or catching the virus from another agent if they are on the same patch.

Sensing

Each person knows if there are any other persons on the same patch as them through NetLogo's *persons-here*. Furthermore, each person knows the location (x and y coordinates) of their house, shop and workplace. They can also access all global variables

Interaction

There is one primary form of direct interaction in this model, which is the spread of the virus. A person who is infected will infect others who are in the same patch as them.

Stochasticity

Stochasticity is used in various ways in this model.

- Firstly, the locations of houses, workplaces and shops are all randomly placed.
- With regards to persons, random persons are chosen to be infected depending on the number of infected persons at initialization.
- The allocation of person to different houses, shops and workplaces is stochastic.
- The time to depart home, depart shops and depart work is stochastic for each person
- Whether or not the person will die is stochastic, probabilistically determined by the *mortality-rate*
- Whether or not a symptomatic person will stay home is stochastic, probabilistically determined by the *percentage-staying-home*
- Whether or not persons will leave home at all (if the policy intervention is in place) is stochastic, probabilistically determined by *percentage-daily-travel.*

Initialization

1. Firstly, the world is initialized with the supplied *max-xcor* and *max-ycor*.
2. Then supporting variables like *positional-xcor-list*, *positional-ycor-list*, *tick-counter*, *int-cbd-xcor-list*, *int-cbd-ycor-list* are all initialized (more information on them in the observer state variables).
3. The patch size is set based on the supplied *patch-sizer*.
4. The mode executes “setup-cbd”
    a. Calculates *cbd-min-x, cbd-max-x, cbd-min-y, cbd-max-y* as the corner coordinates within which the CBD will be built
    b. Creates *cbd-xcor-list* and *cbd-ycor-list* in these corner ranges
    c. Populates *int-cbd-xcor-list* and *int-cbd-ycor-list* with the integer versions of these values
    d. Colors the patches bordering the CBD so it can be visualized
5. The model executes “make-workplaces”
    a. Creates as many workplaces as the supplied input
    b. Sets the shape to “factory”
    c. Places the item at random in a coordinate that’s within the CBD
    d. Sets the size to 3
    e. Sets the color to blue
6. The mode executes “make-houses”
    a. Creates as many houses as the supplied input
    b. Sets the *house-xcor* and the *house-ycor* to random values from *positional-xcor-list* and *positional-ycor-list*
    c. Makes the *house-xcor* and *house-ycor* values be re-initialized until both are not in the CBD
    d. Does a bit of padding to ensure the houses aren’t on the border patches of the CBD
    e. Sets the shape to “house”
    f. Places the item on it’s *house-xcor* and *house-ycor*
    g. Sets the size to 2
    h. Sets the color to 35
7. The model executes “make-shops”
    a. Creates as many shops as the supplied input
    b. Rolls a random value between 0 and 1 for *shops-roll*
    c. If *shops-roll* is 0, places the shop in the CBD
    d. If *shops-roll* is 1, places the shop outside the CBD, executed the same way as was for houses
    e. Sets the shape to “building store”
    f. Sets the size to 1.75
    g. Sets the color to 125
8. The model executes “make-persons”
    a. Sets the default shape to “person”
    b. Creates as many persons as the supplied input

c. Sets *infected?* to false for all
d. Sets *immune?* to false for all
e. Sets the global variable *infected-persons* to 0
f. Assigns each person a house
g. Sets the coordinates of each person around the house
h. Assigns each person a workplace
i. Assigns each person a shop
j. Sets the *shops-or-work* variable for each person
k. Sets the *depart-wave* for each person
l. Sets the *leave-home-time*, *leave-shops-time* and *leave-work-time* for each person

9. The model executes “infect”
    a. Asks a random *num-infected* set of persons to set their *infected?* to true
    b. Sets their *total-days-with-covid* to 0
    c. Picks a random value for *incubation-period* based on the normal distribution
    d. Picks a random value for the *infectious-days (*between 1 and 3)
    e. Calculates the *infectious-period*
    f. Sets *am-i-going-to-die*
    g. Sets *will-i-stay-at-home*
9. The model executes “recolor”, which changes the person’s color based on a set of conditions
    a. If the person is *infected?* and in their symptomatic period, their color is set to red
    b. If the person is *infected?* and in their infectious period but not symptomatic, their color is set to orange
    c. If the person is *infected?* and in their incubation period as well as not in their infectious period, their color is set to yellow
    d. If the person is not *infected?*, their color is set to gray
10. If *policy-intervention?* Is true, the model sets the economy value by calculating the number of daily trips, based on the number of people whose *depart-wave* is less than or equal to their *percentage-daily-travel*
11. If *policy-intervention?* Is false, the model sets *economy* to the number of people, which is also the number of daily trips in this case.
12. Sets the number of days to 0
13. Sets the total number of dead people to 0
14. Sets the total number of recovered people to 0
15. Resets the ticks

Submodels

The submodels here are adequately described in the Initialization and Process Overview and Scheduling subsections.